Appendix C

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

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Overview

In Appendix B, we focused on independently collecting all the required climate parameters from the National Climatic Data Center (NCDC) - Summary of the Day and Surface Airways CD's, and computed ET_o (using the ASCE Reference ET equation), crop ET, net irrigation, net diversion, and depletion. In this Appendix, we focus on obtaining a grid-estimate of the climate data from climate models such as PRISM (Parameter-elevation Regressions on Independent Slopes Model; DiLuzio et al., 2008) and Maurer et al., 2002, and used this data set to recalculate ET_o, crop ET, net irrigation, and net diversion requirement, and net depletion.

In using the gridded meteorological approach described herein, the standard ASCE-PM equation (as described Appendix B) is used for a monthly time-step as opposed to the daily time-step considered in Appendix B. For a monthly time-step, ET_o is calculated at the J^{th} day of each month for a given year. Here, J represents a day number for a given year. The equation for J is shown below (ASCE, 2005):

$$J_{month} = Int(30.4M - 15) \quad (1)$$

where, M is the number of the month (1 to 12) and *Int* is a function which rounds its argument to the nearest integer less than or equal to the argument. ET_o calculated at the J^{th} day of each month is then multiplied by the number of days in a particular month to get the monthly ET_o.

Because grid-estimate of climate data for the net solar radiation estimation is not available from the climate models (i.e, PRISM or Maurer et al., 2002), a Hargreaves-Samani style of radiation prediction equation (ASCE, 2005) is used. This equation is shown below:

$$Rs = K_{RS} Ra \sqrt{(T\max - T\min)} \quad (2)$$

where, K_{RS} is an adjustment coefficient (0.16 to 0.19 $^{o}C^{-0.5}$), *Ra* is the extraterrestrial radiation (MJ m^{-2} day^{-1}), *Rs* is the net shortwave radiation (MJ m^{-2} day^{-1}), and Tmax and Tmin are maximum and minimum daily temperature in ^{o}C. A K_{RS} value equals to 0.16 is used by following the ASCE, 2005, guidelines in the net radiation calculations for this step.

When considering a monthly time-step, it is important to consider the soil heat flux density (*G*). For STEP 3 ET_o calculations, following equation is used to estimate *G* (ASCE, 2005):

$$G_{month,i} = 0.14(T_{month,i} - T_{month,i-1}) \quad (3)$$

where, $T_{month,i}$ is the mean daily air temperature for the i^{th} month. In equation (3), the unit of *G* is (MJ m^{-2} day^{-1}).

For ET_o calculation with the monthly time step for the period of record from July-1948, to December-2004, T_{mean} for June-1948 is used in order to estimate *G* for July-1948.

Climate data

Climate data from the climate models PRISM (DiLuzio et al., 2008) and Maurer et al., 2002, are downloaded by providing the latitude and longitude of the centroid of each agricultural unit. The centroid of each agricultural unit is calculated using the centroid of each small individual polygon. The centroid of each individual small polygon is, in turn, calculated by using the GIS shape files (source: NRCE, 2008), and then the centroid of the whole agricultural unit is calculated by area-weightage average of the X- and Y-coordinates of each individual polygon. Figure 1 shows the location of each agricultural unit along with its centroid, and Table 1 lists latitude, longitude, and elevation of the centroid for each unit. The elevation of the centroid of each agricultural unit is estimated using the Digital Elevation Model (DEM) for New Mexico State West (NAD-1983).

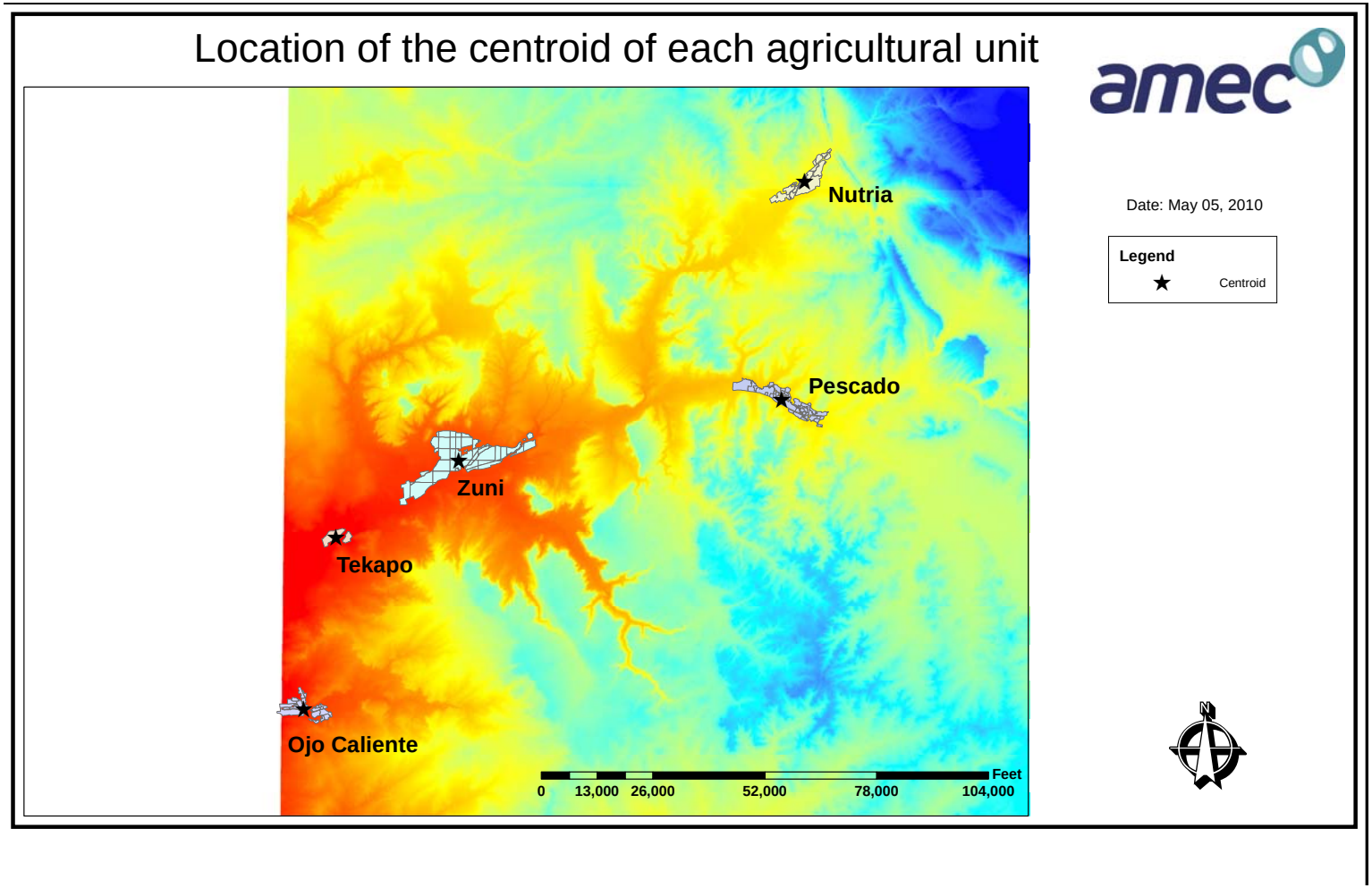

Figure 1. Location of each agricultural unit along with its centroid.

Table 1. Latitude, longitude, and elevation of each agricultural unit along with the PRISM grid cell elevation.

Agricultural unit	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)	Elevation of the centroid, feet	PRISM grid cell elevation, feet
Nutria	35.25577176	108.5865305	6766.08	6840.55
Pescado	35.11615445	108.6031697	6725.68	6873.36
Ojo Caliente	34.91572098	108.9720439	6423.64	6387.80
Tekapo	35.02565613	108.9484246	6193.33	6233.60
Zuni	35.07567666	108.8537718	6300.66	6348.43

The latitude and longitude of the centroid of each agricultural unit is used to download climate parameters from the PRISM model. Because PRISM provides climate data with a 4 km resolution, the parameters are not exactly at the centroid of each unit, but they are averaged for a 4 km surrounding region, and represent a grid cell-estimated value. Note that the grid cells whose climate parameters are downloaded from the PRISM model are at a different elevation with respect to the elevation of the centroid of each agricultural unit (see Table 1). As pointed out in the NRCE report, Tmax, Tmin, Tdew, and Precp are strongly correlated to the elevation of the measurement site. Elevation adjustment of Tmax, Tmin, Precp, and Tdew is carried out as described in Appendix B. The next subsections provide a brief description of each climate parameter along with its source.

Tmax

PRISM provides the monthly time series of this parameter. Using the latitude and longitude of the centroid of each agricultural unit (listed in Table 1), a monthly time-series from July-1948 to December-2004 is downloaded form the official PRISM website (URL: http://www.prism.oregonstate.edu/). Figure 2 shows the monthly pattern of this parameter for the full period of record considered for this exercise.

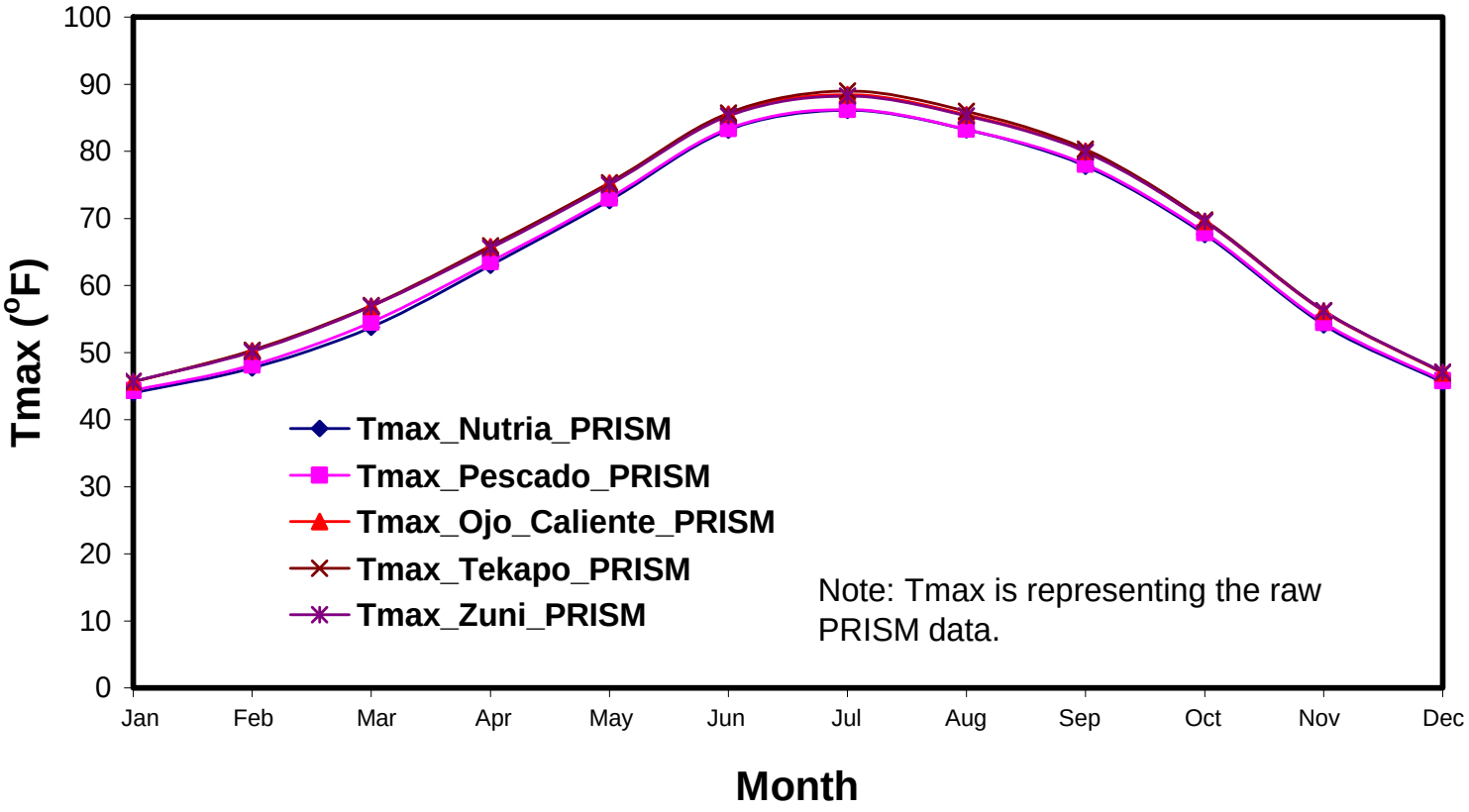

Figure 2. Monthly pattern of Tmax for all the agricultural units.

Tmin , Tdew, and Precp

PRISM provides a monthly time-series of all these parameters. To download a monthly time series for Tmin, Tdew, and Precp, a procedure similar to the procedure for Tmax is followed. Figure 3, 4, and 5 show the monthly pattern of Tmin, Tdew, and Precp for the full period of record (from July-1948 to December-2004).

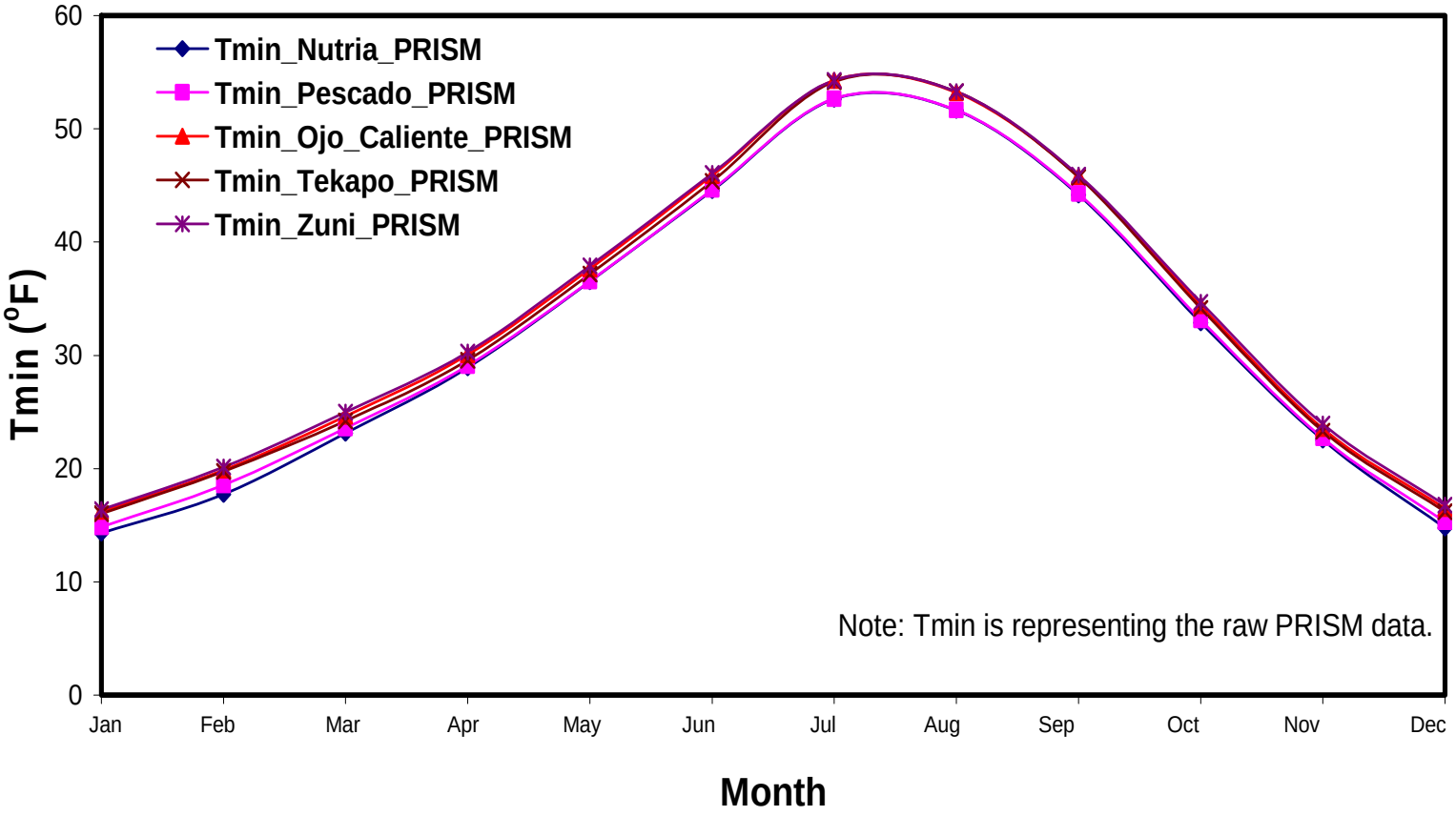

Figure 3. Monthly pattern of Tmin for all the agricultural units.

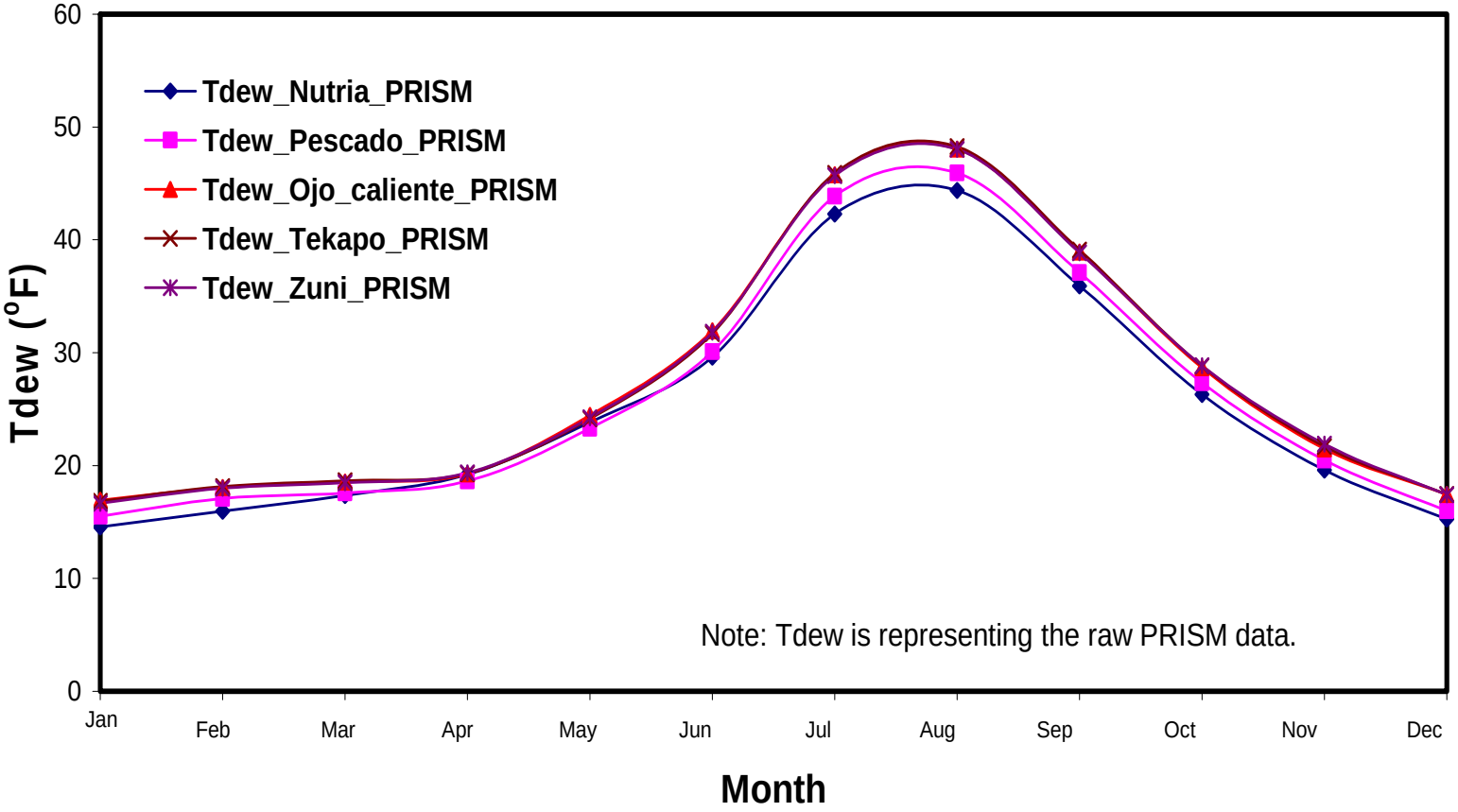

Figure 4. Monthly pattern of Tdew for all the agricultural units.

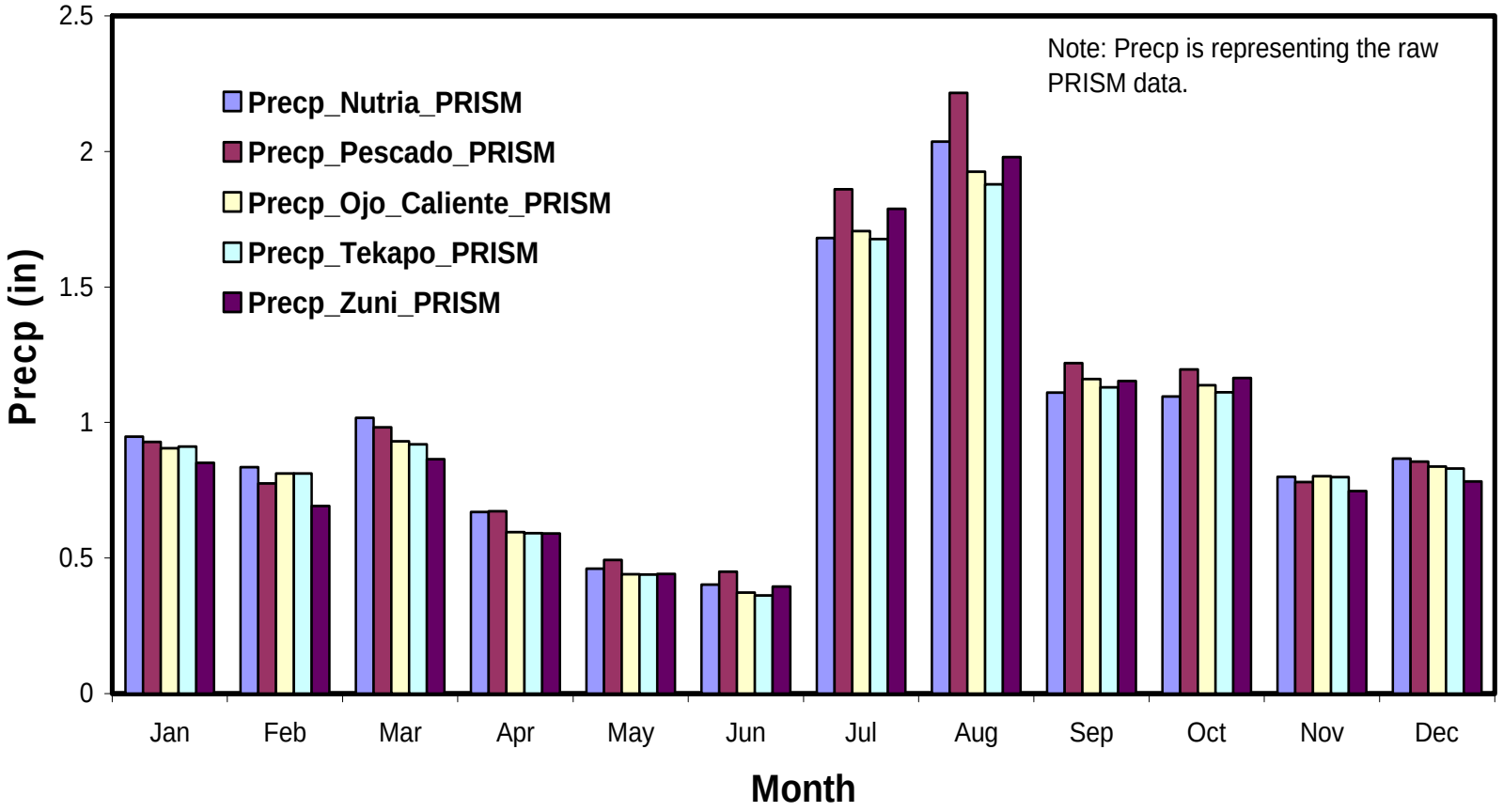

Figure 5. Monthly pattern of Precp for all the agricultural units.

Wind

Because the PRISM model does not provide wind speed data for any agricultural unit, Maurer et al., 2002, climate model is used to get the monthly time series for wind. The resolution of climate data from this model is 12 km, and official data only exist from the year 1949 to 1999. The data for the year 1949 is not as reliable as the data for the subsequent years. However, the 1949 climate data is used to provide an initial condition to the model to get climate data for the later years (Maurer et al., 2002). For years from 2000 to 2004, an extended dataset by Andrew Wood (personal communication, Harding, 2010) is used. With this extended dataset, a complete time series of wind data can be formed from the year 1950 to 2004. In order to get the monthly wind data from July-1948 to December-1949, a monthly average of the available wind data from 1950-2004 is used. Figure 6 shows the monthly pattern of the wind data for each agricultural unit. NCDC, 2002, suggests that wind does not strongly correlation with the elevation of a measurement site, so no elevation adjustment is performed for wind data obtained from the Maurer et al., 2002, climate model.

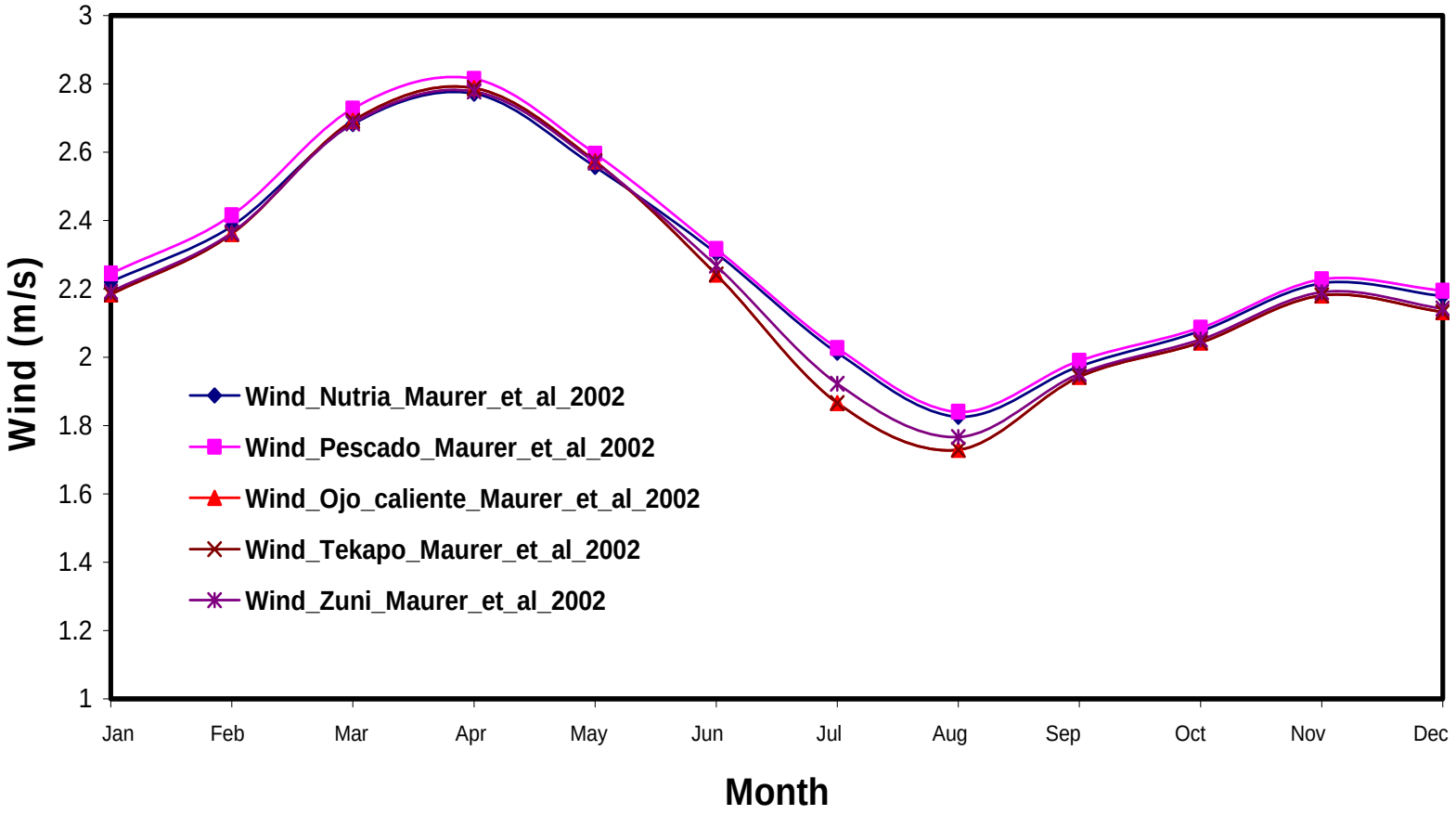

Figure 6. Monthly pattern of wind speed for all the agricultural units.

Aside: As pointed out in Appendix B, local wind measurements are not available for any of the agricultural unit. To deal with this issue, NRCE, 2008, has used the Gallup municipal airport wind data for each agricultural unit to calculate the daily ET_o. However, when the monthly pattern of ET_o, as computed with the Gallup wind data for a period of 11 years from 1980 to 1990, is compared with the monthly ET_o pattern computed using the Maurer et al., 2002, wind data, it is found that the former provides annual ET_o which is 7.96% higher than the latter. Monthly pattern of ET_o's computed using two separate wind data sets is shown in Figure 7.

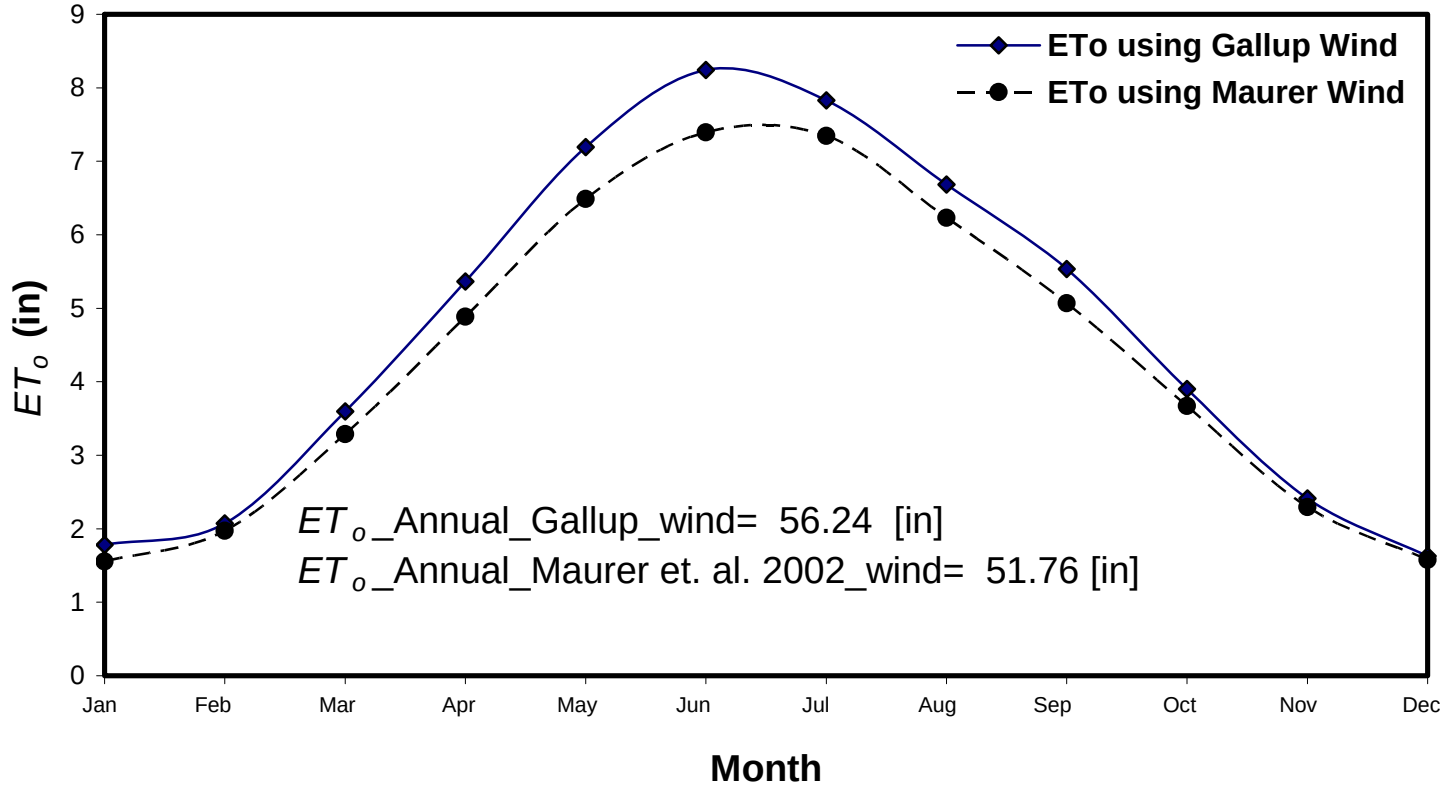

Figure 7. Comparison of monthly pattern of ET_o (once calculated using Gallup municipal airport station wind data, and the second time calculated using Maurer et al., 2002, wind data).

Arid climate adjustment of the climate data

Allen et al., 1998, states that when ET_o estimates are carried out at a non-reference site (e.g., in arid climatic condition), where the difference between Tmin and Tdew is "systematically" higher than 2°C, corrections to Tmax, Tmin, and Tdew should be performed. The following logic is used to correct the observed data for Tmax, Tmin, and Tdew for arid climatic conditions:

Let $\Delta T = Tmin - Tdes$ [°C]

If $\Delta T > 2$°C for any month then

$(Tmax)_{corr} = (Tmax)_{obs} - 0.5*(\Delta T - Ko)$

$(Tmin)_{corr} = (Tmin)_{obs} - 0.5*(\Delta T - Ko)$

$(Tdew)_{corr} = (Tdew)_{obs} - 0.5*(\Delta T - Ko)$

else

$(Tmax)_{corr} = (Tmax)_{obs}$

$(Tmin)_{corr} = (Tmin)_{obs}$

$(Tdew)_{corr} = (Tdew)_{obs}$

where, corr and obs subscript refer to the corrected and observed value of a parameter, and Ko equals to 2 is used by following the guidelines from Allen et al., 1998. Details are contained in Allen et al., 1998.

No arid climate correction is suggested by Allen et al., 1998, for Precp and Wind, therefore no such arid climate correction is performed for the two parameters. Figures 8, 9, 10, and 11 shows the final Tmax, Tmin, Tdew, and Precp after elevation and arid climate corrections, if required.

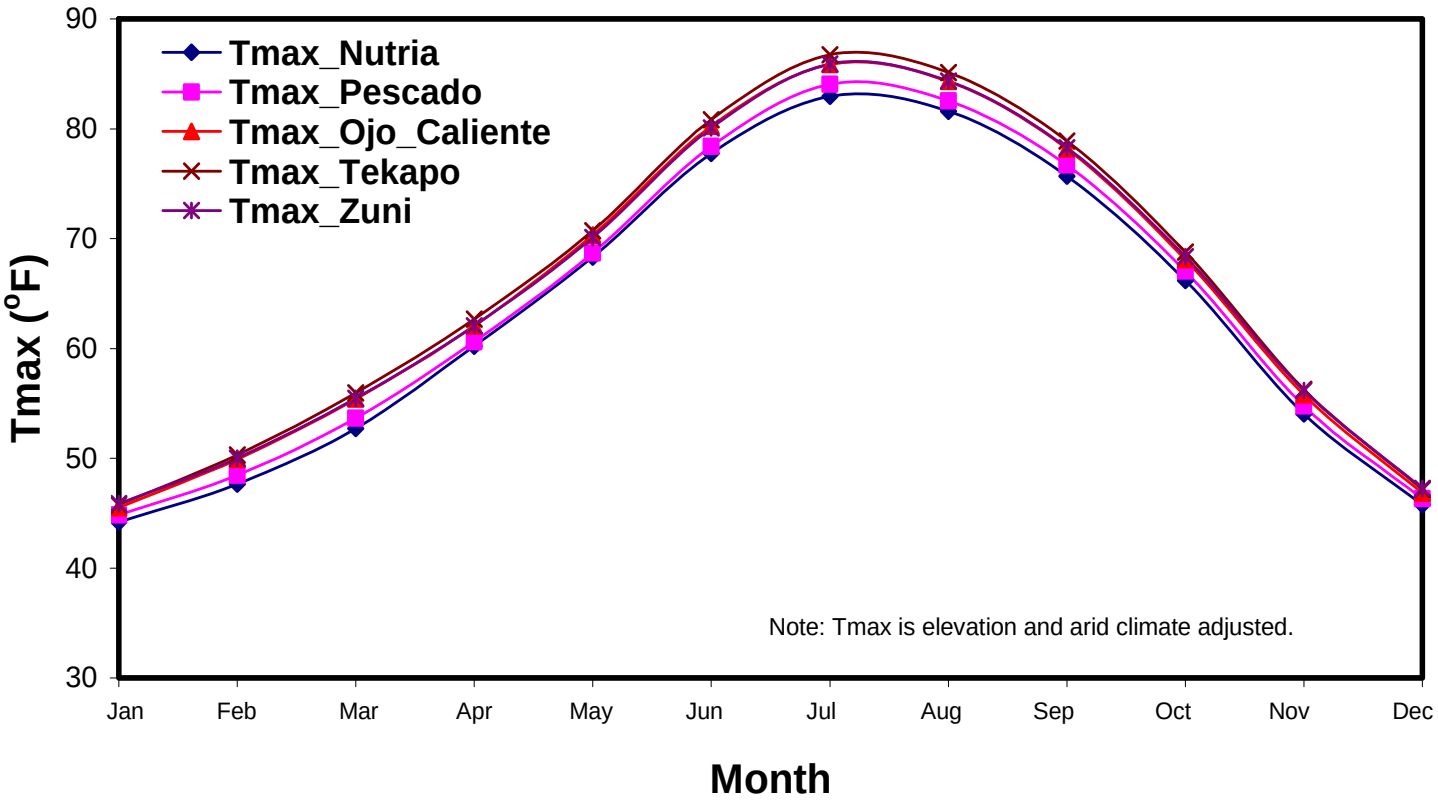

Figure 8. Monthly pattern of elevation and arid climate adjusted Tmax for all the agricultural units.

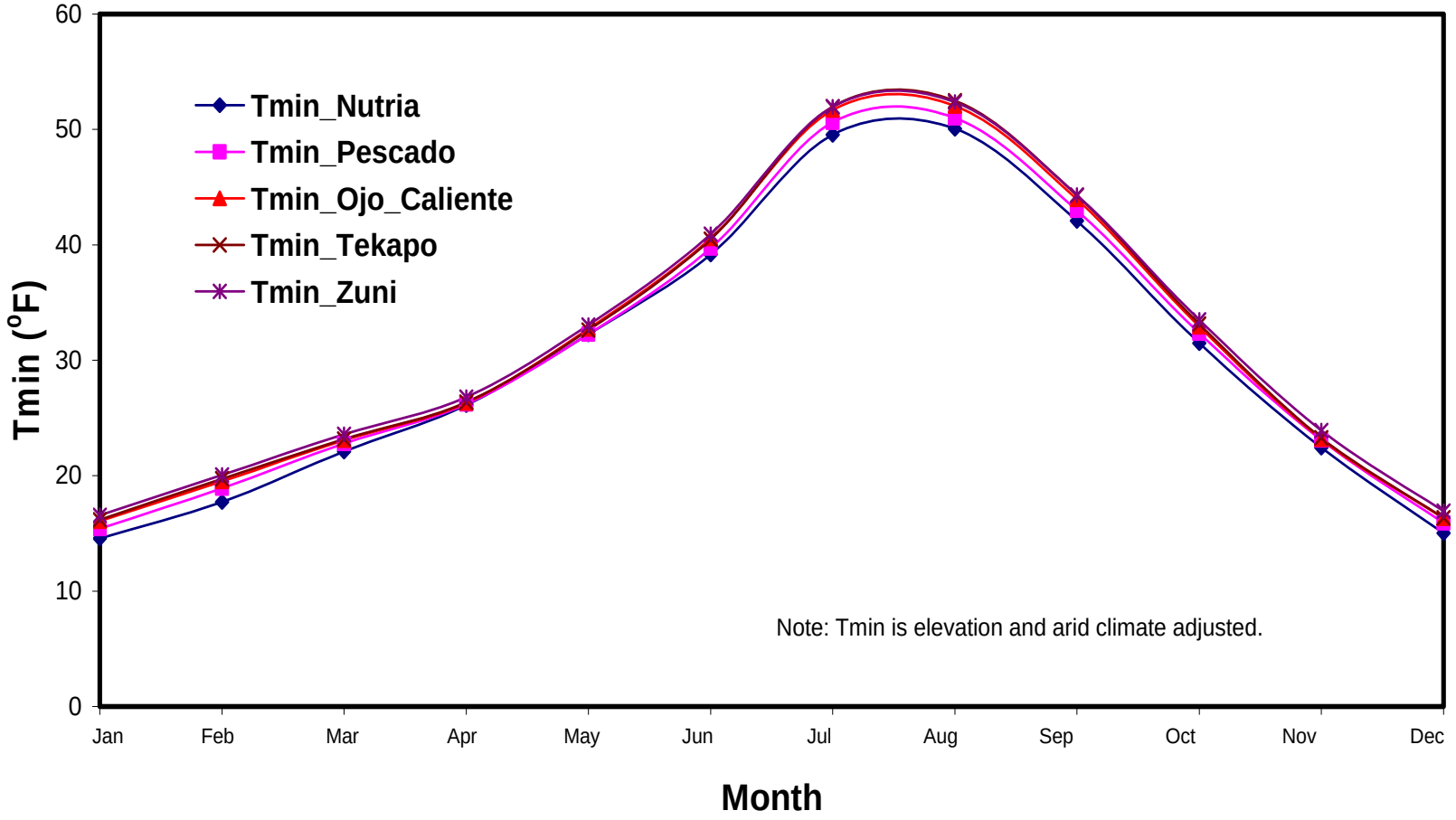

Figure 9. Monthly pattern of elevation and arid climate adjusted Tmin for all the agricultural units.

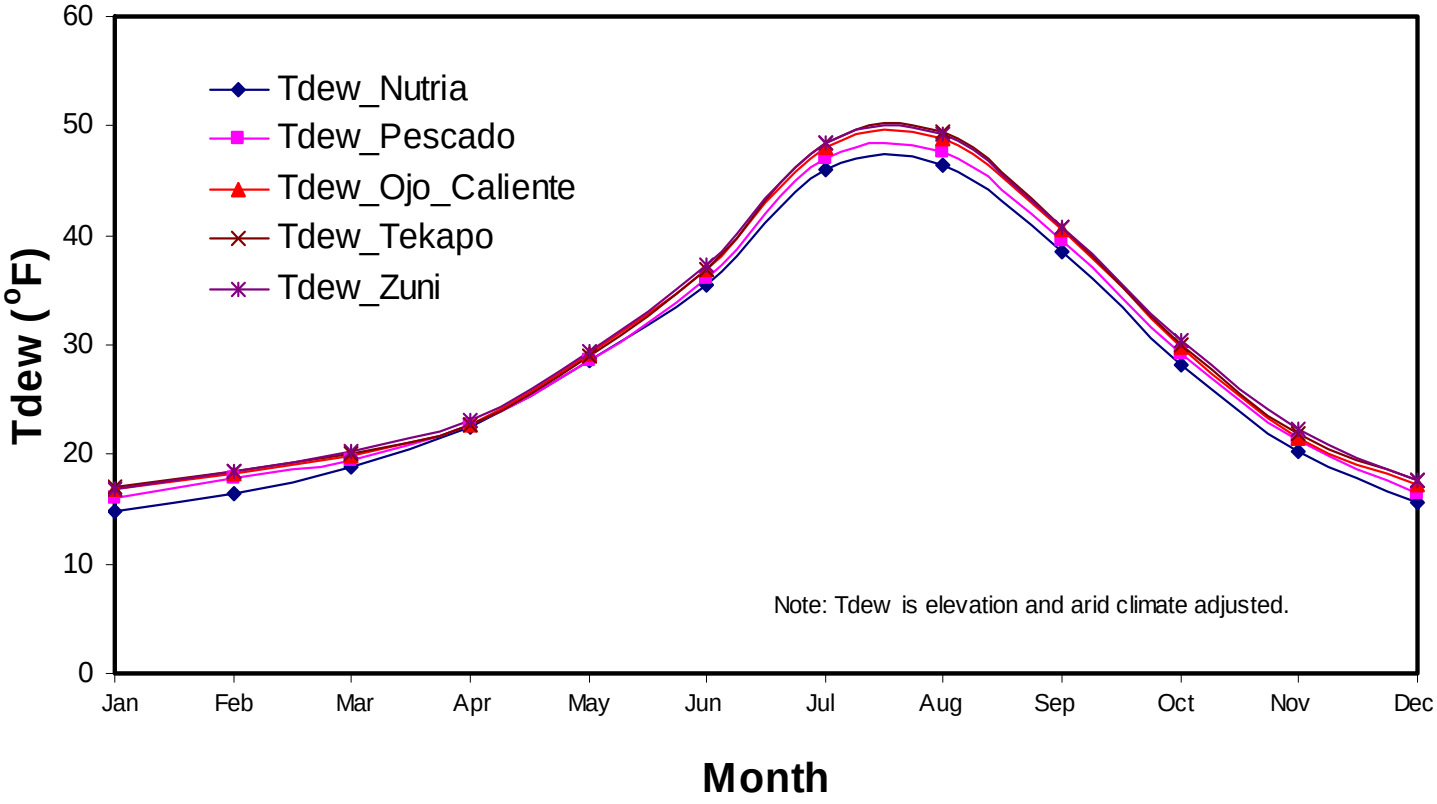

Figure 10. Monthly pattern of elevation and arid climate adjusted Tdew for all the agricultural unit.

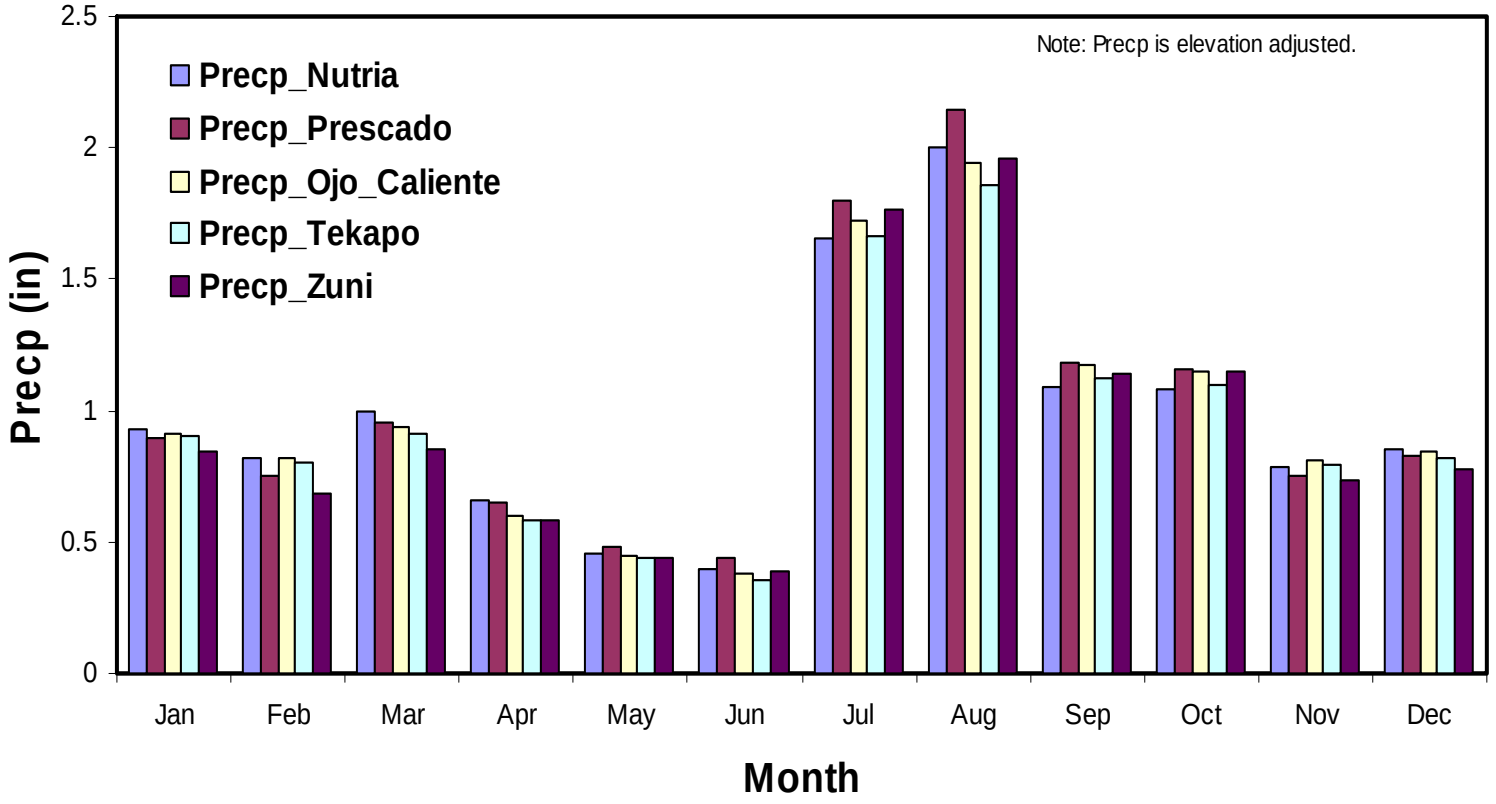

Figure 11. Monthly pattern of elevation adjusted Precp for all the agricultural units.

Crop coefficients (Kc)

Crop coefficients for various types of crops grown in each agricultural unit were estimated in Appendix B, along with their growing seasons. In this step, the same crop coefficients are used as listed in the Appendix B report to get the crop ET.

Precipitation estimation with 80% exceedence probability

To get the monthly Precp with 80% exceedence probability a procedure similar to the procedure described in the Appendix B report is used, and is not revisited here.

Effective Precipitation

In order to obtain the effective precipitation for each crop for each month**,** a procedure same as the procedure described in the Appendix B report is used, and is not revisited here.

Irrigation requirement

In order to get the net irrigation requirement and the monthly weighting factor for each crop, a procedure same as the procedure described in the Appendix B is used, and, therefore, is not revisited here. Table 3, 4, 5, 6, and 7 list the computed values of the monthly and annual ET_o, crop ET, precipitation, effective precipitation for each crop category, the net irrigation requirement for each crop, along with the unit diversion requirement, for the following agricultural units: Nutria, Pescado, Ojo Caliente, Tekapo, and Zuni, respectively. Tables 3 to 7 also compare the parameter values (mentioned earlier) as reported by NRCE, 2008, and as obtained in AMEC Appendix B calculations, along with their % differences. In Tables 3 to 7, there are two separate rows for unit diversion requirement. In these tables, the unit diversion requirement (with a * on it), is calculated using the NRCE, 2008, suggested overall efficiency (see Table 2). The unit diversion requirement with a ** on it, is computed using the Franzoy, 2010, overall efficiency (see Table 2). In Table 3, two additional columns are included to compare AMEC's gridded data approach with Stetson Engineers Inc. (Stetson, 2009) reported ET_o for the Nutria agricultural unit.

Table 2: 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

Total annual diversion requirement and the net annual depletion

For the total annual diversion requirement and depletion calculation, a procedure similar to the procedure described in the Appendix B report is followed. Table 8 provides the final values of the net diversion requirement and net depletion from STEP 3 calculations and shows a comparison of parameters' value with AMEC Appendix B and NRCE, 2008, estimations. As in the Appendix B calculations, two different sets of acreages and of the net annual diversion requirement and the net annual depletion are calculated, once using the NRCE, 2008, suggested overall efficiency and the next time using the Franzoy, 2010, suggested overall efficiency.

Table 3. ET_o, crop ET, Effective precipitation, net irrigation requirement, and the 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	STEP 2 estimation	% diff. wrt STEP 2	Stetson estimation	% diff. wrt Stetson
ETo (in)	1.5789	1.9859	3.2547	4.4683	5.8537	6.7195	6.8045	6.1063	4.9541	3.6437	2.2478	1.596	49.21	48.56	-1.35	49.13	-0.17	50.76	3.05
80% exceedence monthly precipitation (in)	0.70	0.62	0.75	0.50	0.34	0.30	1.25	1.51	0.82	0.81	0.59	0.64	8.84	10.95	19.23	11.19	20.98		
Crop ET																			
Small grains, Grain	0.00	0.00	0.00	1.74	6.73	7.73	5.44	2.38	0.00	0.00	0.00	0.00	24.03	21.41	-12.22	24.46	1.78		
Small Grains, Hay	0.00	0.00	0.00	3.98	6.44	7.39	7.35	0.00	0.00	0.00	0.00	0.00	25.16	19.70	-27.70	25.60	1.72		
Alfalfa	0.00	0.00	0.00	2.28	2.99	7.73	3.47	7.02	2.53	4.19	0.00	0.00	30.20	31.26	3.39	30.57	1.22		
Garden crops	0.00	0.00	0.00	0.00	2.28	3.76	7.14	6.41	4.26	0.00	0.00	0.00	23.86	21.42	-11.40	24.31	1.82		
Corn	0.00	0.00	0.00	0.00	2.28	4.10	7.83	7.02	3.42	0.00	0.00	0.00	24.65	21.79	-13.11	25.10	1.82		
Irrigated Pasture and non-crop	0.00	0.00	0.00	1.92	4.51	6.11	6.19	5.56	4.51	3.32	0.00	0.00	32.12	29.40	-9.24	32.59	1.44		
calculated Effective precipitation																			
Small grains, Grain	0.00	0.00	0.00	0.31	0.26	0.22	1.00	1.01	0.00	0.00	0.00	0.00	2.80	2.14	-30.79	3.36	16.59		
Small Grains, Hay	0.00	0.00	0.00	0.35	0.25	0.22	1.11	0.00	0.00	0.00	0.00	0.00	1.94	1.17	-65.58	2.44	20.64		
Alfalfa	0.00	0.00	0.00	0.32	0.21	0.22	0.89	1.30	0.56	0.61	0.00	0.00	4.13	4.22	2.21	4.84	14.68		
Garden crops	0.00	0.00	0.00	0.00	0.20	0.18	1.10	1.26	0.62	0.00	0.00	0.00	3.36	2.96	-13.49	3.91	14.04		
Corn	0.00	0.00	0.00	0.00	0.20	0.18	1.14	1.30	0.59	0.00	0.00	0.00	3.42	3.32	-3.02	3.98	14.00		
Irrigated Pasture and non-crop	0.00	0.00	0.00	0.32	0.23	0.21	1.04	1.20	0.63	0.58	0.00	0.00	4.20	4.29	2.08	4.93	14.87		
Calculated Net Irrigation Requirement																			
Small grains, Grain	0.00	0.00	0.00	1.43	6.47	7.50	4.45	1.37	0.00	0.00	0.00	0.00	21.23	19.27	-10.16	21.11	-0.58		
Small Grains, Hay	0.00	0.00	0.00	3.62	6.18	7.17	6.24	0.00	0.00	0.00	0.00	0.00	23.22	18.53	-25.30	23.15	-0.28		
Alfalfa	0.00	0.00	0.00	1.96	2.78	7.50	2.58	5.72	1.96	3.58	0.00	0.00	26.07	27.04	3.57	25.74	-1.31		
Garden crops	0.00	0.00	0.00	0.00	2.08	3.58	6.05	5.15	3.64	0.00	0.00	0.00	20.50	18.46	-11.07	20.40	-0.52		
Corn	0.00	0.00	0.00	0.00	2.08	3.92	6.69	5.72	2.83	0.00	0.00	0.00	21.23	18.47	-14.93	21.13	-0.48		
Irrigated Pasture and non-crop	0.00	0.00	0.00	1.61	4.28	5.91	5.15	4.35	3.88	2.73	0.00	0.00	27.92	25.11	-11.17	27.65	-0.95		
Cropping Pattern	**Monthly weighting factors for each crop**																		
Small grains, Grain (10%)	0.00	0.00	0.00	0.14	0.65	0.75	0.44	0.14	0.00	0.00	0.00	0.00	2.12	1.73	-22.70	2.11	-0.58		
Small Grains, Hay (6%)	0.00	0.00	0.00	0.22	0.37	0.43	0.37	0.00	0.00	0.00	0.00	0.00	1.39	0.74	-88.26	1.39	-0.28		
Alfalfa (39%)	0.00	0.00	0.00	0.76	1.08	2.93	1.01	2.23	0.77	1.40	0.00	0.00	10.17	8.38	-21.35	10.04	-1.31		
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	0.62	0.37	-66.24	0.61	-0.52		
Corn (38%)	0.00	0.00	0.00	0.00	0.79	1.49	2.54	2.17	1.07	0.00	0.00	0.00	8.07	5.54	-45.60	8.03	-0.48		
Irrigated Pasture and non-crop (4%)	0.00	0.00	0.00	0.06	0.17	0.24	0.21	0.17	0.16	0.11	0.00	0.00	1.12	6.03	81.48	1.11	-0.95		
Weightage Average Monthly NIR (in)	0.00	0.00	0.00	1.19	3.13	5.94	4.75	4.87	2.10	1.51	0.00	0.00	23.48	22.79	-3.04	23.28	-0.86		
Unit Diversion Requirement* (in)	0.00	0.00	0.00	2.83	7.44	14.14	11.32	11.59	5.01	3.58	0.00	0.00	55.91	54.27	-3.03	55.44	-0.86		
Unit Diversion Requirement (in)**	0.00	0.00	0.00	2.76	7.27	13.81	11.05	11.32	4.89	3.50	0.00	0.00	54.61	54.27	-0.63	54.15	-0.86		

Table 4. ET_o, crop ET, Effective precipitation, net irrigation requirement, and the 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	STEP 2 estimation	% diff. wrt STEP 2
ETo (in)	1.5978	2.0182	3.35	4.539	5.9195	6.7773	6.8924	6.1833	5.0365	3.7018	2.2838	1.6167	49.92	50.54	1.23	50.98	2.09
80% exceedence monthly precipitation	0.70	0.59	0.74	0.51	0.37	0.34	1.41	1.68	0.92	0.91	0.59	0.65	9.41	9.60	1.96	9.66	2.57
Crop ET																	
Small grains, Grain	0.00	0.00	1.31	3.45	6.81	7.79	2.83	0.00	0.00	0.00	0.00	0.00	22.18	20.27	-9.44	23.29	4.76
Small Grains, Hay	0.00	0.00	2.98	4.45	6.51	7.46	0.00	0.00	0.00	0.00	0.00	0.00	21.40	17.48	-22.40	22.53	5.02
Alfalfa	0.00	0.00	0.00	0.00	3.02	7.79	7.93	7.11	2.57	4.26	0.00	0.00	32.68	30.44	-7.34	33.54	2.58
Garden crops	0.00	0.00	0.00	0.00	2.31	4.00	7.24	6.43	0.00	0.00	0.00	0.00	19.97	22.07	9.49	20.59	3.01
Corn	0.00	0.00	0.00	0.00	2.31	4.27	7.93	7.11	3.93	0.00	0.00	0.00	25.54	22.47	-13.68	26.28	2.82
Irrigated Pasture and non-crop	0.00	0.00	0.00	1.95	3.37	6.17	6.27	5.63	4.58	3.37	0.00	0.00	31.34	29.28	-7.05	32.26	2.84
calculated Effective precipitation																	
Small grains, Grain	0.00	0.00	0.47	0.35	0.29	0.27	0.97	0.00	0.00	0.00	0.00	0.00	2.36	1.52	-55.17	2.39	1.22
Small Grains, Hay	0.00	0.00	0.52	0.37	0.29	0.27	0.00	0.00	0.00	0.00	0.00	0.00	1.45	0.91	-59.21	1.41	-2.59
Alfalfa	0.00	0.00	0.00	0.00	0.24	0.27	1.29	1.45	0.63	0.68	0.00	0.00	4.56	4.31	-5.71	4.76	4.27
Garden crops	0.00	0.00	0.00	0.00	0.23	0.22	1.24	1.39	0.00	0.00	0.00	0.00	3.08	3.03	-1.52	3.19	3.69
Corn	0.00	0.00	0.00	0.00	0.23	0.22	1.29	1.45	0.68	0.00	0.00	0.00	3.87	3.42	-13.03	4.03	4.19
Irrigated Pasture and non-crop	0.00	0.00	0.00	0.32	0.24	0.25	1.17	1.33	0.71	0.65	0.00	0.00	4.68	4.45	-5.08	4.85	3.49
Calculated Net Irrigation Requirement																	
Small grains, Grain	0.00	0.00	0.83	3.10	6.52	7.52	1.86	0.00	0.00	0.00	0.00	0.00	19.82	18.75	-5.73	20.91	5.17
Small Grains, Hay	0.00	0.00	2.46	4.07	6.22	7.19	0.00	0.00	0.00	0.00	0.00	0.00	19.95	16.57	-20.38	21.12	5.53
Alfalfa	0.00	0.00	0.00	0.00	2.78	7.52	6.64	5.67	1.94	3.57	0.00	0.00	28.12	26.13	-7.61	28.78	2.30
Garden crops	0.00	0.00	0.00	0.00	2.08	3.78	6.00	5.04	0.00	0.00	0.00	0.00	16.90	19.04	11.25	17.40	2.88
Corn	0.00	0.00	0.00	0.00	2.08	4.05	6.64	5.67	3.24	0.00	0.00	0.00	21.68	19.05	-13.80	22.25	2.57
Irrigated Pasture and non-crop	0.00	0.00	0.00	1.63	3.13	5.92	5.10	4.30	3.87	2.72	0.00	0.00	26.67	24.83	-7.40	27.41	2.72
Cropping Pattern	**Monthly weighting factors for each crop**																
Small grains, Grain (10%)	0.00	0.00	0.08	0.31	0.65	0.75	0.19	0.00	0.00	0.00	0.00	0.00	1.98	1.69	-17.31	2.09	5.17
Small Grains, Hay (6%)	0.00	0.00	0.15	0.24	0.37	0.43	0.00	0.00	0.00	0.00	0.00	0.00	1.20	0.66	-81.34	1.27	5.53
Alfalfa (39%)	0.00	0.00	0.00	0.00	1.09	2.93	2.59	2.21	0.75	1.39	0.00	0.00	10.97	8.10	-35.39	11.22	2.30
Garden crops (3%)	0.00	0.00	0.00	0.00	0.06	0.11	0.18	0.15	0.00	0.00	0.00	0.00	0.51	0.38	-33.41	0.52	2.88
Corn (38%)	0.00	0.00	0.00	0.00	0.79	1.54	2.52	2.15	1.23	0.00	0.00	0.00	8.24	5.72	-44.02	8.46	2.57
Irrigated Pasture and non-crop (4%)	0.00	0.00	0.00	0.07	0.13	0.24	0.20	0.17	0.15	0.11	0.00	0.00	1.07	5.96	82.10	1.10	2.72
Weightage Average Monthly NIR (in)	0.00	0.00	0.23	0.62	3.09	6.00	5.68	4.69	2.14	1.50	0.00	0.00	23.96	22.51	-6.43	24.66	2.83
Unit Diversion Requirement* (in)	0.00	0.00	0.48	1.29	6.44	12.51	11.84	9.76	4.46	3.13	0.00	0.00	49.91	46.89	-6.44	51.37	2.83
Unit Diversion Requirement (in)**	0.00	0.00	0.66	1.77	8.83	17.15	16.24	13.39	6.12	4.29	0.00	0.00	68.45	46.89	-45.98	70.44	2.83

Table 5. 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	STEP 2 estimation	% diff. wrt STEP 2
ETo (in)	1.601	2.0932	3.5	4.6964	6.1033	6.9363	6.9704	6.2774	5.1382	3.7689	2.3316	1.6116	51.03	51.55	1.01	51.95	1.77
80% exceedence monthly precipitation	0.71	0.64	0.73	0.47	0.35	0.29	1.34	1.51	0.91	0.89	0.63	0.66	9.11	8.93	-1.96	8.82	-3.26
Crop ET																	
Small grains, Grain	0.00	0.00	1.37	4.41	7.02	6.94	3.49	0.00	0.00	0.00	0.00	0.00	23.22	20.58	-12.83	24.16	3.89
Small Grains, Hay	0.00	0.00	3.12	4.88	6.71	7.35	0.00	0.00	0.00	0.00	0.00	0.00	22.07	17.07	-29.26	22.97	3.93
Alfalfa	0.00	0.00	0.00	2.40	3.11	7.98	3.55	7.22	5.91	4.33	0.00	0.00	34.50	34.63	0.37	35.29	2.22
Garden crops	0.00	0.00	0.00	0.00	2.38	4.65	7.32	6.21	0.00	0.00	0.00	0.00	20.56	22.51	8.66	21.14	2.72
Corn	0.00	0.00	0.00	0.00	2.38	5.13	8.02	7.09	3.85	0.00	0.00	0.00	26.48	23.02	-15.01	27.16	2.52
Irrigated Pasture and non-crop	0.00	0.00	0.00	2.02	5.43	6.31	6.34	5.71	4.68	3.43	2.12	0.00	36.05	32.16	-12.08	36.80	2.05
calculated Effective precipitation																	
Small grains, Grain	0.00	0.00	0.47	0.34	0.27	0.21	0.95	0.00	0.00	0.00	0.00	0.00	2.23	1.30	-71.59	2.20	-1.22
Small Grains, Hay	0.00	0.00	0.51	0.35	0.26	0.21	0.00	0.00	0.00	0.00	0.00	0.00	1.33	0.86	-55.06	1.27	-4.79
Alfalfa	0.00	0.00	0.00	0.30	0.21	0.22	0.96	1.32	0.75	0.67	0.00	0.00	4.44	4.28	-3.64	4.48	1.00
Garden crops	0.00	0.00	0.00	0.00	0.21	0.18	1.18	1.24	0.00	0.00	0.00	0.00	2.82	2.67	-5.47	2.91	3.37
Corn	0.00	0.00	0.00	0.00	0.21	0.19	1.23	1.31	0.67	0.00	0.00	0.00	3.60	3.13	-15.03	3.70	2.60
Irrigated Pasture and non-crop	0.00	0.00	0.00	0.29	0.24	0.20	1.12	1.21	0.70	0.64	0.41	0.00	4.83	4.27	-13.03	4.82	-0.08
Calculated Net Irrigation Requirement																	
Small grains, Grain	0.00	0.00	0.90	4.08	6.75	6.73	2.53	0.00	0.00	0.00	0.00	0.00	20.99	19.29	-8.81	21.96	4.41
Small Grains, Hay	0.00	0.00	2.60	4.54	6.45	7.14	0.00	0.00	0.00	0.00	0.00	0.00	20.73	16.21	-27.90	21.70	4.44
Alfalfa	0.00	0.00	0.00	2.09	2.90	7.76	2.60	5.90	5.16	3.66	0.00	0.00	30.07	30.36	0.97	30.81	2.40
Garden crops	0.00	0.00	0.00	0.00	2.18	4.46	6.14	4.97	0.00	0.00	0.00	0.00	17.75	19.84	10.56	18.22	2.62
Corn	0.00	0.00	0.00	0.00	2.18	4.94	6.79	5.79	3.18	0.00	0.00	0.00	22.88	19.89	-15.01	23.46	2.51
Irrigated Pasture and non-crop	0.00	0.00	0.00	1.73	5.19	6.11	5.22	4.50	3.97	2.79	1.71	0.00	31.22	27.88	-11.98	31.98	2.37
Cropping Pattern	**Monthly weighting factors for each crop**																
Small grains, Grain (10%)	0.00	0.00	0.09	0.41	0.68	0.67	0.25	0.00	0.00	0.00	0.00	0.00	2.10	1.54	-36.29	2.20	4.41
Small Grains, Hay (6%)	0.00	0.00	0.16	0.27	0.39	0.43	0.00	0.00	0.00	0.00	0.00	0.00	1.24	0.65	-91.37	1.30	4.44
Alfalfa (39%)	0.00	0.00	0.00	0.82	1.13	3.02	1.01	2.30	2.01	1.43	0.00	0.00	11.73	9.41	-24.61	12.01	2.40
Garden crops (3%)	0.00	0.00	0.00	0.00	0.07	0.13	0.18	0.15	0.00	0.00	0.00	0.00	0.53	0.40	-33.09	0.55	2.62
Corn (38%)	0.00	0.00	0.00	0.00	0.83	1.88	2.58	2.20	1.21	0.00	0.00	0.00	8.69	6.16	-41.12	8.92	2.51
Irrigated Pasture and non-crop (4%)	0.00	0.00	0.00	0.07	0.21	0.24	0.21	0.18	0.16	0.11	0.07	0.00	1.25	6.69	81.33	1.28	2.37
Weightage Average Monthly NIR (in)	0.00	0.00	0.25	1.57	3.29	6.38	4.24	4.83	3.38	1.54	0.07	0.00	25.54	24.86	-2.75	26.25	2.71
Unit Diversion Requirement* (in)	0.00	0.00	0.46	2.90	6.10	11.82	7.85	8.94	6.26	2.85	0.13	0.00	47.30	46.03	-2.76	48.62	2.71
Unit Diversion Requirement (in)**	0.00	0.00	0.51	3.26	6.86	13.30	8.83	10.06	7.04	3.21	0.14	0.00	53.21	46.03	-15.61	54.70	2.71

Table 6. 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	STEP 2 estimation	% diff. wrt STEP 2
ETo (in)	1.5978	2.0924	3.5268	4.746	6.1396	7.0044	7.0575	6.3417	5.1808	3.7984	2.3341	1.6071	51.43	51.55	0.24	51.95	1.00
80% exceedence monthly precipitation	0.69	0.62	0.70	0.45	0.33	0.28	1.28	1.43	0.86	0.85	0.61	0.63	8.74	8.93	2.13	8.82	0.88
Crop ET																	
Small grains, Grain	0.00	0.00	1.38	4.46	7.06	7.00	3.53	0.00	0.00	0.00	0.00	0.00	23.43	20.58	-13.85	24.14	2.95
Small Grains, Hay	0.00	0.00	3.14	4.94	6.75	7.42	0.00	0.00	0.00	0.00	0.00	0.00	22.25	17.07	-30.36	22.47	0.97
Alfalfa	0.00	0.00	0.00	2.42	3.13	8.06	3.60	7.29	5.96	4.37	0.00	0.00	34.83	34.63	-0.56	35.30	1.36
Garden crops	0.00	0.00	0.00	0.00	2.39	4.69	7.41	6.28	0.00	0.00	0.00	0.00	20.78	22.51	7.70	23.66	12.18
Corn	0.00	0.00	0.00	0.00	2.39	5.18	8.12	7.17	3.89	0.00	0.00	0.00	26.75	23.02	-16.18	27.11	1.34
Irrigated Pasture and non-crop	0.00	0.00	0.00	2.04	5.46	6.37	6.42	5.77	4.71	3.46	2.12	0.00	36.37	32.16	-13.08	36.90	1.45
calculated Effective precipitation																	
Small grains, Grain	0.00	0.00	0.45	0.32	0.26	0.19	0.92	0.00	0.00	0.00	0.00	0.00	2.14	1.30	-64.38	2.20	3.00
Small Grains, Hay	0.00	0.00	0.49	0.33	0.25	0.20	0.00	0.00	0.00	0.00	0.00	0.00	1.27	0.86	-48.23	1.27	-0.43
Alfalfa	0.00	0.00	0.00	0.29	0.21	0.20	0.92	1.26	0.71	0.64	0.00	0.00	4.24	4.28	0.99	4.48	5.43
Garden crops	0.00	0.00	0.00	0.00	0.20	0.17	1.14	1.19	0.00	0.00	0.00	0.00	2.70	2.67	-0.99	2.94	8.22
Corn	0.00	0.00	0.00	0.00	0.20	0.17	1.19	1.25	0.64	0.00	0.00	0.00	3.44	3.13	-10.03	3.70	6.81
Irrigated Pasture and non-crop	0.00	0.00	0.00	0.28	0.23	0.19	1.08	1.16	0.67	0.61	0.40	0.00	4.62	4.27	-8.13	4.82	4.15
Calculated Net Irrigation Requirement																	
Small grains, Grain	0.00	0.00	0.93	4.14	6.80	6.81	2.61	0.00	0.00	0.00	0.00	0.00	21.29	19.29	-10.39	21.94	2.94
Small Grains, Hay	0.00	0.00	2.65	4.60	6.50	7.23	0.00	0.00	0.00	0.00	0.00	0.00	20.98	16.21	-29.41	21.20	1.05
Alfalfa	0.00	0.00	0.00	2.13	2.93	7.85	2.68	6.03	5.24	3.73	0.00	0.00	30.59	30.36	-0.75	30.82	0.77
Garden crops	0.00	0.00	0.00	0.00	2.20	4.52	6.27	5.09	0.00	0.00	0.00	0.00	18.08	19.84	8.87	20.72	12.75
Corn	0.00	0.00	0.00	0.00	2.20	5.01	6.93	5.91	3.25	0.00	0.00	0.00	23.30	19.89	-17.15	23.41	0.48
Irrigated Pasture and non-crop	0.00	0.00	0.00	1.76	5.23	6.19	5.34	4.61	4.05	2.85	1.72	0.00	31.75	27.88	-13.88	32.09	1.04
Cropping Pattern	**Monthly weighting factors for each crop**																
Small grains, Grain (10%)	0.00	0.00	0.09	0.41	0.68	0.68	0.26	0.00	0.00	0.00	0.00	0.00	2.13	1.54	-38.27	2.19	2.94
Small Grains, Hay (6%)	0.00	0.00	0.16	0.28	0.39	0.43	0.00	0.00	0.00	0.00	0.00	0.00	1.26	0.65	-93.64	1.27	1.05
Alfalfa (39%)	0.00	0.00	0.00	0.83	1.14	3.06	1.04	2.35	2.04	1.45	0.00	0.00	11.93	9.41	-26.77	12.02	0.77
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	0.54	0.40	-35.60	0.62	12.75
Corn (38%)	0.00	0.00	0.00	0.00	0.83	1.90	2.63	2.25	1.23	0.00	0.00	0.00	8.85	6.16	-43.74	8.90	0.48
Irrigated Pasture and non-crop (4%)	0.00	0.00	0.00	0.07	0.21	0.25	0.21	0.18	0.16	0.11	0.07	0.00	1.27	6.69	81.02	1.28	1.04
Weightage Average Monthly NIR (in)	0.00	0.00	0.25	1.59	3.32	6.46	4.34	4.94	3.44	1.57	0.07	0.00	25.98	24.86	-4.52	26.29	1.16
Unit Diversion Requirement* (in)	0.00	0.00	0.52	3.31	6.92	13.47	9.04	10.29	7.17	3.26	0.14	0.00	54.13	51.77	-4.57	54.77	1.16
Unit Diversion Requirement (in)**	0.00	0.00	0.59	3.70	7.73	15.03	10.10	11.48	8.00	3.64	0.16	0.00	60.43	51.77	-16.72	61.14	1.16

Table 7. 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	STEP 2 estimation	% diff. wrt STEP 2
ETo (in)	1.6222	2.0899	3.4835	4.6678	6.052	6.906	6.989	6.2795	5.1268	3.7609	2.3307	1.6266	50.93	51.55	1.19	51.95	1.95
80% exceedence monthly precipitation	0.65	0.53	0.66	0.45	0.34	0.30	1.36	1.50	0.88	0.89	0.57	0.59	8.70	8.93	2.53	8.82	1.29
Crop ET																	
Small grains, Grain	0.00	0.00	1.36	4.39	6.96	6.91	3.49	0.00	0.00	0.00	0.00	0.00	23.11	20.58	-12.28	24.14	4.29
Small Grains, Hay	0.00	0.00	3.10	4.85	6.66	7.32	0.00	0.00	0.00	0.00	0.00	0.00	21.93	17.07	-28.48	22.47	2.39
Alfalfa	0.00	0.00	0.00	2.38	3.09	7.94	3.56	7.22	5.90	4.33	0.00	0.00	34.42	34.63	0.62	35.30	2.52
Garden crops	0.00	0.00	0.00	0.00	2.36	4.63	7.34	6.22	0.00	0.00	0.00	0.00	20.54	22.51	8.74	23.66	13.17
Corn	0.00	0.00	0.00	0.00	2.36	5.11	8.04	7.10	3.85	0.00	0.00	0.00	26.45	23.02	-14.90	27.11	2.43
Irrigated Pasture and non-crop	0.00	0.00	0.00	2.01	5.39	6.28	6.36	5.71	4.67	3.42	2.12	0.00	35.96	32.16	-11.82	36.90	2.55
calculated Effective precipitation																	
Small grains, Grain	0.00	0.00	0.42	0.32	0.25	0.22	0.97	0.00	0.00	0.00	0.00	0.00	2.18	1.30	-67.71	2.20	1.04
Small Grains, Hay	0.00	0.00	0.46	0.33	0.25	0.22	0.00	0.00	0.00	0.00	0.00	0.00	1.26	0.86	-46.70	1.27	0.61
Alfalfa	0.00	0.00	0.00	0.29	0.21	0.23	0.97	1.31	0.72	0.67	0.00	0.00	4.41	4.28	-2.93	4.48	1.70
Garden crops	0.00	0.00	0.00	0.00	0.20	0.19	1.20	1.24	0.00	0.00	0.00	0.00	2.83	2.67	-6.12	2.94	3.56
Corn	0.00	0.00	0.00	0.00	0.20	0.20	1.25	1.31	0.65	0.00	0.00	0.00	3.60	3.13	-14.87	3.70	2.71
Irrigated Pasture and non-crop	0.00	0.00	0.00	0.28	0.23	0.21	1.14	1.21	0.68	0.64	0.37	0.00	4.76	4.27	-11.37	4.82	1.28
Calculated Net Irrigation Requirement																	
Small grains, Grain	0.00	0.00	0.94	4.07	6.70	6.69	2.52	0.00	0.00	0.00	0.00	0.00	20.93	19.29	-8.48	21.94	4.62
Small Grains, Hay	0.00	0.00	2.64	4.53	6.41	7.10	0.00	0.00	0.00	0.00	0.00	0.00	20.67	16.21	-27.52	21.20	2.50
Alfalfa	0.00	0.00	0.00	2.09	2.88	7.71	2.59	5.91	5.17	3.65	0.00	0.00	30.01	30.36	1.15	30.82	2.64
Garden crops	0.00	0.00	0.00	0.00	2.16	4.44	6.14	4.97	0.00	0.00	0.00	0.00	17.71	19.84	10.74	20.72	14.53
Corn	0.00	0.00	0.00	0.00	2.16	4.91	6.79	5.79	3.20	0.00	0.00	0.00	22.85	19.89	-14.90	23.41	2.39
Irrigated Pasture and non-crop	0.00	0.00	0.00	1.73	5.15	6.07	5.22	4.51	3.99	2.79	1.75	0.00	31.21	27.88	-11.93	32.09	2.74
Cropping Pattern	**Monthly weighting factors for each crop**																
Small grains, Grain (10%)	0.00	0.00	0.09	0.41	0.67	0.67	0.25	0.00	0.00	0.00	0.00	0.00	2.09	1.54	-35.89	2.19	4.62
Small Grains, Hay (6%)	0.00	0.00	0.16	0.27	0.38	0.43	0.00	0.00	0.00	0.00	0.00	0.00	1.24	0.65	-90.81	1.27	2.50
Alfalfa (39%)	0.00	0.00	0.00	0.82	1.12	3.01	1.01	2.30	2.02	1.43	0.00	0.00	11.70	9.41	-24.38	12.02	2.64
Garden crops (3%)	0.00	0.00	0.00	0.00	0.06	0.13	0.18	0.15	0.00	0.00	0.00	0.00	0.53	0.40	-32.82	0.62	14.53
Corn (38%)	0.00	0.00	0.00	0.00	0.82	1.87	2.58	2.20	1.22	0.00	0.00	0.00	8.68	6.16	-40.98	8.90	2.39
Irrigated Pasture and non-crop (4%)	0.00	0.00	0.00	0.07	0.21	0.24	0.21	0.18	0.16	0.11	0.07	0.00	1.25	6.69	81.34	1.28	2.74
Weightage Average Monthly NIR (in)	0.00	0.00	0.25	1.56	3.27	6.35	4.23	4.83	3.39	1.54	0.07	0.00	25.50	24.86	-2.58	26.29	3.00
Unit Diversion Requirement* (in)	0.00	0.00	0.60	3.72	7.79	15.11	10.08	11.51	8.08	3.66	0.17	0.00	60.72	59.18	-2.60	62.59	3.00
Unit Diversion Requirement (in)**	0.00	0.00	0.63	3.91	8.18	15.86	10.59	12.08	8.48	3.84	0.18	0.00	63.75	59.18	-7.73	65.72	3.00

Table 8: Comparison of irrigation diversion requirement and depletion from NRCE and AMEC calculations

						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

Tables 3 to 7 show that the AMEC estimated values for the following parameters: crop *ET*, effective precipitation, NIR, and unit diversion requirement from calculations using the gridded climatic data as inputs, are generally higher than NRCE, 2008 estimates and are slightly lower than the AMEC estimates from Appendix B calculations. Some of the main contributing factors for the former are:

- AMEC estimated crop pattern is different from the NRCE, 2008 estimates for the same

- NRCE has stated in its report (NRCE, 2008, page H-1) that "… *In the original claims, the crop coefficients were calculated as the basal crop coefficients and did not include the soil water evaporation factor. The soil water evaporation factor was included in the revised crop coefficients and the crop ET calculations were revised*". It also stated that "… *The effect of applying the soil water evaporation factor was to increase the crop ET results relative to the claim values. The overall effect, seen in comparing the net irrigation requirement values for the claim and modified values, was very little."* Therefore, it retained the old crop *ET* values. On the contrary, from the AMEC Appendix B estimations for the crop ET, crop ET is found non-negligibly higher when the wet soil evaporation is considered along with the basal crop coefficient. A relatively higher crop ET resulted in a higher value of the net irrigation requirement.

Two of the main contributing factors for the differences between AMEC estimates from the direct use of weather station data (Appendix B) versus gridded meteorological data for various parameters as listed in Tables 2-6 are:

1. Following NRCE procedure, AMEC Appendix B considers the Gallup Municipal airport weather stations to obtain wind data for each agricultural unit. Figure 7 shows that ET_o's are relatively higher when the Gallup station wind data is used as compared to the Maurer et al., 2002, wind data.

2. In Appendix B, climate data from various near by and far away stations is used. The climate data as used in AMEC gridded data calculations described in this Appendix is more reliable than climate data as used in the AMEC Appendix B calculations, because data for the former take a more objective consistent approach to obtain needed climate values at locations near the spatial centroid of the PPIW units.

AMEC gridded data ET_o for Pescado, Zuni, Tekapo, and Ojo Caliente agricultural units are low compared to the corresponding values from either NRCE, 2008, or AMEC Appendix B calculations for the same units. This is because in NRCE, 2008 and AMEC Appendix B, wind data from Gallup station is used for each agricultural unit. The wind data from Gallup station results in relatively higher ET_o (see Figure 7) in comparison to the case when Maurer et al., 2002 wind data is used.

ET_o as estimated using a grid-estimate of the climate data for the Nutria agricultural unit is low in comparison to the Stetson, 2009 reported ET_o for the same agricultural unit, and relatively high in comparison to the NRCE, 2008 and AMEC Appendix B estimate. The same is true for the weightage-average monthly NIR and the unit diversion requirement. A probable reason for the former is the procedure used by the Stetson to fill/extend the missing climate data. A probable reason for the latter is that for Nutria agricultural unit, temperature data from the McGaffey 5 SE weather station is used. McGaffey station is located at relatively higher elevation with respect to the Nutria agricultural unit. From the lapse rate exercise for AMEC Appendix B, it is noted that temperature has inverse relationship with elevation of a measurement site. Thus, using the temperature data from the McGaffey station results in relatively low ET_o in comparison to the case when local temperature data (from gridded data) is used.

Estimate of the total annual diversion requirement and the net annual depletion from AMEC gridded climate data calculations is generally low as compared to AMEC Appendix B estimate, and is relatively high in comparison to the NRCE, 2008, estimate, except for the Nutria agricultural unit. The opposite behavior for the Nutria agricultural unit is caused by its relatively higher ET_o in comparison to the NRCE, 2008, or AMEC

Appendix B calculation. The main reason for a higher estimate (in comparison to NRCE, 2008) of the net annual diversion requirement and/or the net annual depletion from AMEC (both Appendix B and C) calculations lies in the fact that AMEC determined crop coefficients includes the wet soil evaporation factor along with the basal crop coefficient, while NRCE's does not.

In summary, crop water requirement as computed here using gridded climate data are more reliable than AMEC Appendix B or NRCE, 2008, estimate, because the gridded climate data is relatively more "local" than the climate data used in either AMEC Appendix B or NRCE, 2008, estimation. ***Allen et al, 1998, states that ET_o estimation using ASCE-PM method is as good as the input climate data.***

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