Evaluation of Crop Consumptive Use and Irrigated Acreage Associated With Past and Present Irrigation from Permanent Works for the Zuni Indian Tribe, Subproceeding 1 of the Zuni River Basin Adjudication, Case No. 07-00681-BB

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1. INTRODUCTION

This report documents the evaluation AMEC Earth & Environmental (AMEC) on behalf of the Navajo Nation of the crop consumptive use and irrigated acreage associated with Past and Present Irrigation from Permanent Works (PPIW) claimed by the Zuni Indian Tribe and the United States on behalf of the Zuni Tribe under Subproceeding 1 of the Zuni River Basin adjudication, Case No. 07-00681-BB. This overarching evaluation focuses on three separate aspects of the claim, including quantification of the acreage associated with PPIW, the cropping patterns on that acreage, and water depletion due to evapotranspiration from those crops. As part of our evaluation, expert reports prepared by consultants to the US and the Zuni tribe (Allen 2008, Hart 2008), as well as expert reports by the State of New Mexico and their consultants (Longworth et al., 2010; Samani, 2010; Brengosz, 2010; Hordes, 2010; Petronis, 2010; Franzoy, 2010; and Wear, 2010) were reviewed.

AMEC's evaluation documented herein was performed by Dr. Jim McCord, P.E. and staff under his direct supervision.

1.1 Organization of Report

This report is organized into separate sections as described below.

- A summary of AMEC's overall opinions are provided in Section 2,
- detailed summaries of the various components of our evaluation in Section 3,
- Section 3.1 describes our review the US's evaluation of acreage associated with PPIW,
- Section 3.2 provides our summary of cropping patterns and irrigation practices,
- Section 3.3 covers our analysis of crop evapotranspiration (ET), and
- Section 3.4 describes the availability of surface water supplies that can be used to provide irrigation to the PPIW lands,
- Section 4 presents a summary and conclusions from our evaluations.

Before presenting these aspects of our evaluation, the remainder of Section 1 provides background information on the study area and the history of irrigation from permanent works by the Zuni Tribe in the study area.

1.2 Description of Study Area

The study area includes all lands within the Zuni Indian Reservation that are or have been served from permanent irrigation works. As shown in **Figure 1**, the Reservation consists of about 640 square miles in west-central New Mexico, along the Arizona border. There are five areas, or agricultural units, within the Zuni Reservation that are irrigated through permanent works; these units are Nutria, Pescado, Zuni, Tekapo, and Ojo Caliente as shown of **Figure 2.**

1.3 History of Zuni Tribe Permanent Irrigation Works

As described by Allen (2008) and Hart (2006), agriculture has been practiced by the Zuni people for centuries. The first western accounts of the Zuni come from the Spaniards, who reported extensive farming of corn and other crops in the area in the 16th century. Zuni agricultural methods in the past have mainly consisted of three types: floodwater irrigation, surface diversions and canal systems, and waffle gardens. Zuni floodwater irrigation involved planting crops in channels that received occasional water flows. Diversions were utilized to control water levels and velocities. Zuni canal systems were largely used to grow wheat and corn. The canals and ditches were used to convey water from natural springs to the fields. Waffle gardens have traditionally been used to grow specialty crops in the immediate vicinity of their settlements, and were reported to be hand watered by the Zuni women. When the Zuni Indian Reservation was established in 1877, these methods for agriculture were still being used. This report focuses on agriculture irrigated by permanent diversions structures feeding water supply canals.

More permanent diversions / dams and associated canals and ditches were built on the Zuni Indian Reservation in the 20th century. Between 1906 and 1909, Blackrock Dam and its associated canals were constructed near the village of Zuni. Shortly after construction (September 1909), the dam failed. The reconstruction of Blackrock Dam was completed in 1913. The Nutria Diversion Dam (1929-1931), Pescado (1931), Nutria No. 2 (1932), Nutria No. 3 (1934), Ojo Caliente (1934), Tekapo (1937), and Nutria No. 4 (1938), were all built in the 1930s.

2. SUMMARY OF OPINIONS

Based on our data and information review, and our hydrologic data analysis, including detailed analysis of climate data and calculation of evapotranspiration by crops in the study area based upon a reasonable degree of scientific certainty, Dr. McCord has developed the following opinions:

1. Up to 7,018.55 acres have been historically irrigated from permanent works on the Zuni Reservation, although not that much in any single year.
2. Of that acreage that has at some time in the past been subject to irrigation from permanent works, available data and information from BIA crop reports indicates that the maximum amount irrigated in a single year was 2,759.5 acres in 1949.
3. Based on BIA crop reports, the period between 1947 and 1950 experienced an average annual irrigated cropping of 2,572.6 acres.
4. Historical water depletions estimated using the Blaney – Criddle methods and adjustments to account for reported historical alfalfa yields are on the order of 1.1 acre-ft/acre.
5. Using estimated on-farm and conveyance system efficiencies, historical water diversions would have been on the order of 6,600 acre-ft per annum to meet CIR demand estimated using Blaney – Criddle methods.
6. Using estimated on-farm and conveyance system efficiencies, water diversions would be on the order of 12,400 acre-ft per annum to meet CIR demand estimated using Penman – Monteith reference ET methods.
7. If the historically irrigated acreage were cropped in a pattern representative of that observed in the past, and available water supplies

were successfully diverted to the cropped fields, one would expect up to depletions on the order of 5,300 acre-ft per annum and diversions on the order of 12,400 acre-ft per annum.

These opinions are based on data and information reviewed to date, including expert reports and associated data provided by experts of the US and the State of New Mexico in this matter. If additional data or information becomes available, Dr. McCord reserves the right to acquire and review that data, and if necessary update his opinions.

2.1 Qualification of Expert

Dr. James T. McCord is a registered Professional Engineer in New Mexico (License Number 15568) and Colorado (Registration No. 42958). He works for AMEC Earth & Environmental, a full service consulting engineering company with offices worldwide. He has worked for AMEC since 2007, when his previous employer, Hydrosphere Resource Consultants, Inc. was acquired by AMEC.

Prior to joining Hydrosphere in 1999, he was an Assistant Professor of Civil Engineering and Geology at Washington State University (Pullman, WA, 1989-1990) teaching courses in hydrology, a Senior Member of the Technical Staff at Sandia National Laboratories (Albuquerque, NM, 1990-1997) working on radioactive and hazardous waste containment problems, and the Hydrology Group Leader and Senior Hydrologist with D.B. Stephens & Associates (Albuquerque, NM, 1997-1999) working on water resource and environmental contamination problems. Dr. McCord earned a B.S. Degree in Civil Engineering from the Virginia Tech in 1981, and an M.S. in Hydrology and a Ph.D. in Geoscience with a Dissertation in Groundwater Hydrology from New Mexico Tech in 1986 and 1989, respectively.

He has over 25 years of professional experience in groundwater hydrology, water resources management, and water quality investigations, has published numerous articles in groundwater hydrology, co-authored the graduate-level textbook Vadose Zone Processes (1999, Lewis Publishers / CRC Press), and was the lead author on Transport Phenomena and Vulnerability of the Unsaturated Zone, the overarching vadose zone hydrology article for the on-line Encyclopedia of Life Support Systems (2003, UNESCO, www.eolss.net). His curriculum vitae, which sets forth his expertise and professional qualifications is attached to this report as Appendix A.

Dr. McCord has been accepted as an expert in groundwater hydrology by the Superior Court of the State of California, County of Sacramento (Case No.: 97AS06295); the Superior Court of the State of California, County of San Bernardino, (Consolidated Case No. RCV 31496); State of New Mexico, State Engineer Administrative Hearing Unit (Case No. HU 07-059); and Federal District Court of Colorado (Civil Action 01-PC-2163). He has been deposed on numerous occasions. Dr. McCord's resume in Appendix A includes a listing of his deposition and testimony experience.

3. EVALUATION OF WATER REQUIREMENTS FOR PAST AND PRESENT IRRIGATED LANDS SERVED BY PERMANENT WORKS FOR THE ZUNI INDIAN TRIBE

This section provides a description of our technical evaluation of water requirements for past and present irrigated lands from permanent works on the Zuni reservation. To perform our evaluation, we focused on three aspects to the problem:

1. What acreage historically and currently have been irrigated by permanent works?
2. What were the cropping patterns on the land irrigated from permanent works?

3. What has crop irrigation requirement (on an acre-foot per irrigated acre basis) could be applied to the lands and crops identified above?

The following subsections of this report provide our evaluations for each of these three questions.

3.1 Acreage Irrigated by Permanent Irrigation Works

As defined by Allen (2008), permanent irrigation works include diversion structures, ditches and canals, pipeline, reservoirs, and wells. For this aspect of our evaluation, we reviewed historical cropping reports by the BIA. These reports provide valuable site-specific data on historical cropped acreages as well as on crop mix on those irrigated lands (the crop mix is covered in detail in Section 3.2). In addition to considering these reports, we reviewed BIA historical maps as well as aerial photography with delineated fields prepared by consultants to the US (Allen, 2008; Appendix A). Finally, we also joined the US consultant Dr. Niel Allen. in the field on the Zuni Reservation in July 2009 to review and assess methods employed by him and his staff from Natural Resource Consulting Engineers, Inc. (NRCE) for on-the-ground verification of field delineations, point-of-diversion locations, and supply conveyance canal locations from aerial photography.

3.1.1 BIA Crop Reports

Cited Allen (2008) as well as by State of NM experts Hordes (2010) and Wear (2010), crop reports by the BIA are available that date back to the 1920s. As noted by both Hordes and Wear, these reports provide an incomplete and inconclusive record of cropped acreage on the Zuni Reservation over time. For example, Hordes (2010) and Wear (2010) note that the earliest reports (from the 1920s) do not clearly distinguish between crops produced on irrigated lands and crops produced by native dryland farming methods. Furthermore, BIA crop reports do not exist at all for some years. Both Hordes (2010) and Wear (2010) provide a narrative summary and chronology of the BIA crop reports from the early 1900s through 2004. For our independent analysis, we obtained the crop reports for 1934, 1952, and 1981 through 2004 (with 1992, 1994-1996, and 2000 missing) from the Zuni Basin adjudication web site. Figure 3 presents the chronology of cropped irrigated acreages for the entire Zuni Reservation by year compiled from the BIA crop reports[1].

As noted by both Longworth et al (2010) and Wear (2010), the crop reports from the period between 1947 and 1950 provide some of the most complete cropping data, showing cropped and irrigated acreage for all five Zuni agricultural units, as well as a summary sheet for the entire reservation. Wear (2010) also notes that the 1949 BIA crop report indicates a total irrigated acreage of 2,904 acres, the most irrigated acreage reported in any single year. As can be seen in **Figure 3**, since the cropped irrigated acreage peaked around 1950, the amount of cropped land has dropped precipitously, particularly after 1980.

3.1.2 BIA Historical Maps

Historical maps from the BIA provide snapshots of irrigated and irrigable lands in each of the Zuni project areas in 1956 and 1966. The BIA maps consist of Irrigated and Irrigable Lands maps from 1956 and Engineering maps from 1966. Allen (2008) includes copies of these maps in Appendix B of his report.

3.1.3 Aerial Photography

One of the primary sources of irrigated acreage compiled by Allen (2008) is aerial photography taken between 1934 and 2005. Table 2-2 of Allen (2008) provides a summary of the aerial photography that he utilized for delineating irrigated fields; for convenience that table is reproduced here as **Table 1**.

[1] Figs. 3-7 includes crop report data from 1947 through 1950 as summarized by Longworth et al. (2010); crop reports for those years were not available

Table 1: Summary of aerial photography used in irrigated lands delineation (reproduced from Allen, 2008).

Year (s)	Photo Type	Scale	Source
1934-1936	Black & White Aerial Image	1:31,680	BIA-Albuquerque
1953-1954	Black & White Aerial Image	1:60,000	BIA-Albuquerque
1981	Black & White Aerial Image	1:15,840	BIA-Albuquerque
1996-1998	Black & White Ortho-rectified Aerial Image	1:12,000	USGS
2001	Color Ortho-rectified Aerial Image	1:12,000	New Mexico Aerial Surveys, Inc
2005	Color Ortho-rectified Aerial Image	1:12,000	USGS

As noted by Allen (2008), the cropped fields and their corresponding irrigation works can be seen in the aerial photography. From each of the air photo set, one can outline or delineate the boundaries of irrigated fields, and comparing one set to the next one can see that irrigated fields and their associated works change over time. Combining all of the delineations from each of the sets results in a composite delineation. Once these images are appropriately georegistered in a GIS, acreages can be computed. Table 2-1 of Allen (2008) summarizes the composite irrigated acreage for each of the project areas; that table is reproduced here as **Table 2**. Allen (2008) specifically notes (Sec 2.5, page 2-3) that the acreages computed in this manner represent a composite of all lands determined to have been irrigated at some time in the past, as opposed to the total acreage in any one year.

Table 2: Summary of Allen's composite delineation of historically irrigated acreage on the Zuni Reservation served by permanent works (reproduced from Allen, 2008).

Project Area	**Acreage**	**Primary Water Source(s)**
Nutria	976.86	Rio Nutria, Springs, and three Reservoirs
Pescado	1317.86	Springs, Zuni River. Rio Pescado, Cebolla Creek, Pescado Reservior
Zuni	3629.78	Zuni River and Black Rock Reservoir
Tekapo	320.57	Zuni River and Tekapo Reservoir
Ojo Caliente	773.73	Springs and Ojo Caliente Reservoir
Total	7018.55	

3.1.4 Evaluation of Irrigated Acreage

Comparing the irrigated field delineations (Section 3.1.3) to the BIA project area maps (Section 3.1.2) shows general agreement between the two, but with some minor deviations. While the outermost boundaries of the irrigated fields delineated on aerial photography generally coincide with outer edges of the lands mapped as irrigated or irrigable on the BIA project maps, there are notable localized discrepancies. For example, for the Nutria Agricultural unit, Allen's (2008) air photo delineations indicate fields as being historically irrigated in the western portion of the area (extending into Section 27) that extend beyond the outer boundaries of the areas marked as irrigated on the BIA maps for that portion of the Nutria unit. Wear (2010) also notes that the irrigated field delineations from aerial photography appeared generally to agree with the historical BIA maps, "although they are expanded in some areas."

In addition, Wear (2010) reports that his office (Office of State Engineer, Hydrographic Survey and Mapping Bureau, or (HSMB) digitally overlaid and georeferenced the historical BIA maps for quantitative comparison to the air photo delineations and calculation of acreages. From this analysis, the HSMB found that the 1956 BIA maps indicated a total irrigated and irrigable acreage under permanent works to be 7,699 acres, and the 1966 BIA maps depicted 6,827 irrigated acres. These two values bracket the historically irrigated acreage of 7,018.55 determined by Allen (2008) from his composite air photo delineations. Finally, it is worth noting that that the maximum acreage irrigated in a single year based on available cropping data is on the order of 3,000 acres, far less than the total historical irrigated acreage of 7,018.55 delineated by Allen from aerial photography.

3.2 Cropping Patterns and Irrigation Practices

Again, BIA crop reports described above help shed light on historical cropping patterns and irrigation practices on the Zuni Reservation. As noted above, the earliest reports do not clearly distinguish between crops produced on irrigated lands and crops produced by native dryland farming methods. Given that this study is focused on irrigated agriculture, ambiguity on irrigation practices renders the earlier BIA reports of limited value. From those BIA reports that do report irrigated lands separately, one can piece together a picture of cropping patterns and irrigation practices on the Zuni Reservation, and their evolution over time.

One notable observation is that the mix of crops grown on Zuni irrigated lands has evolved over time. As shown in **Table 3**[2], in the early part of the 20^{th} century wheat and other small grains were the predominant crops, and over the course of the century alfalfa has steadily grown as a percentage of acreage planted. These changes, however, have been quite variable by crop and agricultural unit as illustrated by **Figure 3** through **Figure 7**. These figures show the relative acreages by crop for each of the five Zuni PPIW units between 1981 and 2004, along with the reservation-wide and unit long-term averages. The Zuni reservation-wide averages from the BIA crop report data that we obtained are summarized in

Table 3: Cropping pattern by percent of total cropped acreage by year from available BIA cropping report data. Note that the data for the period between 1947 and 1950 was taken from Longworth et al. (2010).

	1934	1947	1948	1949	1950	1952	1981-1993	1997-2001	2003-2004
Corn	4.9%	23.0%	24.0%	24.0%	23.0%	34.8%	43.9%	15.4%	13.2%
Small Grains, Hay	59.9%	34.0%	36.0%	36.0%	37.0%	34.2%	16.4%	10.6%	12.2%
Alfalfa	21.5%	27.0%	24.0%	23.0%	24.0%	17.0%	30.2%	74.0%	74.7%
Garden Crops	5.7%	14.0%	14.0%	15.0%	14.0%	14.0%	5.8%	0.0%	0.0%
Irrigated Pasture +Noncrop	8.0%	2.0%	2.0%	2.0%	2.0%	0.0%	3.7%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

[2] This table was developed by combining data from BIA crop reports included by Allen (2008) together with 1947-1950 summary data from Longworth et al. (2010). The mix of crops in the categories of small grains, garden crops, and irrigated pasture deviate slightly between Allen (2008) and Longworth et al. (2010). We did not receive the 1947-1950 crop reports until May 20 (day this report was due), and have not undertaken a detailed review of this data as of report date.

Table 4: Overall reservation-wide average cropping pattern by percent of total irrigated acreage compiled from available BIA report data from 1934 through 2002

Corn	22.90%
Small Grains, Hay+ Grain	30.70%
Alfalfa	35.00%
Garden Crops	9.20%
Irrigated Pasture + Noncrops	2.20%
Total	100.00%

Of particular import for this study are the BIA reports from the period between 1947 and 1950, because the State of New Mexico experts rely on the average values from those particular reports as the basis for their water depletion and diversion analyses. **Table 5** below presents that data extracted from the report by Longworth et al. (2010).

Table 5: Overall reservation-wide cropping pattern by acreage and percent of total irrigated acreage compiled from available BIA report data from 1947 through 1950 (reproduced from Longworth et al, 2010).

Year	1947		1948		1949		1958		1947-50 Average	
Crop	Crop%	Acres	Crop%	Acres	Crop%	Acres	Crop%	Acres	Crop%	Acres
Corn	23%	526	24%	614	24%	667	24%	635	24%	610.5
Small Grains	34%	761	36%	937	36%	996.5	37%	986	36%	920.1
Alfalfa	27%	613	24%	623	23%	638	24%	633	25%	626.8
Garden	14%	317	15%	376	15%	415	14%	371	14%	369.8
Pasture	2%	55	2%	41	2%	43	2%	43	2%	45.5
Total	100%	2272	100%	2591	100%	2759.5	100%	2668	100%	2572.6

3.3 Evapotranspiration

The third component of our evaluation of water requirements for Zuni PPIW lands is the estimation of crop water use on a per unit-area basis. Allen (2008) employed the American Society of Civil Engineers (ASCE) Penman – Monteith (P-M) method to calculate the reference evapotranspiration (ET) for the study area based on regional and local climatic conditions. As a cross-check on his P-M analysis, Allen (2008, Appendix F) also employed the Hargreaves (1985) and Hargreaves – Samani (1982) methods to estimate the reference ET. For the

State of New Mexico, Longworth et al (2010), Brengosz (2010), and Samani (2010) employ the Original Blaney – Criddle (OBC), Modified Blaney-Criddle (MBC), the Hargreaves – Samani (H-S), and ASCE Reference methods to estimate crop ET with adjustments based on reported crop yields.

Before presenting and discussing the results of the US and State of New Mexico experts, we first review ET estimation methodologies, and then we independently evaluate crop water use using the ASCE Reference ET method parameterized in two distinct ways: directly using local weather station data with data filling as needed from regional weather stations, and using gridded weather data for Tmin, Tmax, Tdew, and Precp in conjunction with local and filled weather station data for wind speed.

3.3.1 Background on Methods to Estimate Crop ET

As described by Allen et al. (1989, ASCE Manual No.70), consumptive use of water, or evapotranspiration, includes evaporation of water from land and water surfaces and transpiration by vegetation, and quantification of ET is of foremost importance in water resources planning and management, particularly in arid and semiarid irrigated areas of the world. Allen et al. (1989) specifically mention the need to understand ET in the adjudication of water rights in river basins, which is the goal of this study.

Allen et al. (1989) note that numerous formulas have been developed that relate ET to climatological measures based on experimental data. Extensive plot and field studies were conducted in the first decades of the 20th century to assess seasonal ET by crops (ASCE, 1930). Moving beyond empirical relationships, Penman (1948) combined energy balance and aerodynamic equations into what is commonly known as the “combination equation” for estimating ET for meteorological data. Penman’s combination equation, and subsequent refinements and improvements to it, has been (and continues to be) used throughout the world.

Documents prepared to describe the current “state-of-the-science” in consumptive use and ET include ASCE’s (American Society of Civil Engineers) “Consumptive Use of Water and Irrigation Water Requirements” published in 1974, and its update, ASCE Manual No. 70 “Evapotranspiration and Irrigation Water Requirements” (Jensen et al., 1990). These documents incorporate many years of user experience and advances in the physics of evaporation from plant and soil surfaces. ASCE Manual No. 70 includes separate chapters on comparative evaluation of various ET estimating methods and utilization of ET in the context of practical engineering and water management venues.

The ASCE Manual No. 70 chapter on evaluation of methods (Jensen et al., 1990, Chapter 7) compared 19 methods for computing ET on a monthly basis and 13 for computing ET on a daily basis. In all cases the computed ET was compared to ET measured using weighing lysimeters (which measure ET directly). Methods evaluated included the SCS Blaney-Criddle and the FAO-24 Blaney-Criddle, and the Hargreaves – Samani method, all of which are classified by Jensen et al. (1990) as temperature-based methods, as well as the Penman – Monteith method which is a refinement to Penman’s original combination equation. I specifically mention those methods here because the US expert in the Zuni Tribe PPIW matter (Allen, 2008) employed the Penman – Monteith method, and the State of New Mexico experts (Longworth et al., 2010; Brengosz, 2010) applied two forms of the Blaney – Criddle method (Original and Modified), the Hargreaves – Samani method, and the ASCE reference Penman – Monteith method. Of the 19 monthly methods tested, the Penman – Monteith method was ranked in ASCE Manual No. 70 *as the best method for monthly ET in both humid and arid climates*. Given the overall climatic condition of the Zuni Reservation, we are most interested in how the various methods perform in arid and semi-arid conditions. For arid climates, the Hargreaves – Samani method was ranked 13th, and the FAO-24 Blaney – Criddle and the SCS Blaney – Criddle were ranked 9th, and 15th respectively. Both the Hargreaves – Samani and the SCS Blaney – Criddle were found to underestimate actual ET in arid climates, and while the FAO-24 Blaney – Criddle did not exhibit a bias (in underestimating or overestimating ET), its standard error of the estimates was significantly larger than that of the Penman – Monteith method.

The ASCE Manual No. 70 chapter on applications of ET estimation to real-world water resource problems (Jensen et al., 1990, Chapter 8) lists and briefly describes various venues where ET calculation has played an important role, including water rights litigation and river basin adjudications. In that chapter, the authors of ASCE Manual No. 70 do not indicate a preference of one ET method over another for particular applications.

Since the publication of ASCE Manual No. 70, research into ET methods has proceeded and the Penman – Monteith method has continued to be recognized as a robust, accurate tool for quantification of crop water requirements. For example, Ventura et al. (1999) compared the Penman – Monteith method to the Pruitt and Doorenbos version of the hourly Penman equation, and found both the hourly and the 24-hr Penman – Monteith equation to provide better agreement with lysimeter measurements. Another example of Penman – Monteith equation testing is the work of Evett et al. (2000), who found the Penman – Monteith method accurately calculated the actual ET from alfalfa determined from high precision weighing lysimeters at a windy, semi-arid site near Bushland, Texas. In an extensive report for the United Nations Food and Agriculture Organization referred to as the FAO-56 paper, Allen et al. (1998) assumed some constant parameters and simplified functions for air density and vapor aerodynamic resistance, and provided recommended procedures for estimating all the input parameters for the ASCE Manual No. 70 Penman – Monteith equation for a short clipped grass reference crop.

Finally, to provide a standardized basis for the calculation of reference ET and to improve the transferability of crop coefficients, the ASCE Task Committee on Standardization of Reference Evapotranspiration developed the ASCE Standardized Reference Evapotranspiration Equation along with prescriptive approaches for calculating vapor pressure terms, net radiation, and soil heat flux (ASCE, 2005). In addition, ASCE (2005) presents guidelines on assessing weather data integrity and estimating values for missing data. The basis for the standardized reference ET equation is the ASCE Penman – Monteith (ASCE – PM) method of ASCE Manual No. 70. For the Zuni PPIW evaluation, the US and State of New Mexico experts both applied the ASCE – PM method. The following subsections describe our application of the ASCE – PM method for this matter.

3.3.2 AMEC's Application of ASCE – PM Method to Evaluate Expected Water Use for Zuni Reservation PPIW Lands

To provide an independent check on the ET estimates provided by the US expert (Allen, 2008) and the State of New Mexico experts (Longworth et al., 2010; Brengosz, 2010; Samani, 2010), we performed our own analysis using the ASCE Standardized Reference Penman – Monteith equation. As mentioned previously, our independent analysis employed the standardized ASCE Reference ET method parameterized in two distinct ways: (i) directly using local weather station data with data filling as needed from regional weather stations, and (ii) using gridded weather data for Tmin, Tmax, Tdew, and Precp in conjunction with local and filled weather station data for wind speed. In approach (i), we followed the methods described by NRCE (Allen 2008) for implementing the equation and filling missing climatic data; NRCE generally followed ASCE (2005) recommended procedures, although in some cases there are slight deviations. In approach (ii), we explicitly adopted all recommended procedures from ASCE (2005).

For application to the Zuni case, we used the same climate data set as NRCE, using the same techniques to fill/extend the missing climate as used in the NRCE, 2008 report. For this exercise, the raw climate data from January 1, 1948, to December 31, 2004, for each pertinent weather station is downloaded from the National Climatic Data Center (NCDC) Summary of the Day (SD) and Surface Airways (SA) CD's. The raw climate data is then filled/extended by AMEC using the procedure specified in the ASCE FAO reference. The data set is then adjusted first for elevation and then for arid climatic conditions to suit each agricultural unit on the Zuni Reservation (namely, Nutria, Pescado, Tekapo, Ojo Caliente, and Zuni). The complete data set for the period from July 1, 1948, to December 31, 2004, is then used to calculate ETo with a daily time-step. The daily ETo's are summed to get the monthly ETo's. Once the ETo reference ET is computed, we estimated the crop coefficients for each major category of crops grown in each agricultural unit following the FAO-56 methods. The final part of the exercise calculates the effective precipitation, the net diversion requirement, and the net depletion for an annual period. Our independently created estimates are then compared to estimates by other experts in the case (e.g., Allen, 2008; Longworth et al., 2010). Appendix A provides a detailed summary of both our implementations of the ASCE – PM equation, including climate data processing and filling, crop coefficient calculation, and determination of diversion requirements.

Reference Evapotranspiration

Following the procedures described in Appendix A, we developed estimates of the standardized ASCE – PM Reference ETo for each of the Zuni ag units, and our final results are presented in **Table 6**. The results show that the gridded meteorological data leads to slight smaller ETo, but the differences are generally less than 2%

Crop Coefficients

To determine expected consumptive demand by the various crops grown on the Zuni Reservation, the reference ETo must be multiplied by a crop coefficient. The reference ET (ETo) calculated using the standard ASCE-PM equation is based on a number of assumptions that are not met under actual field conditions. Therefore, it is essential to modify ETo to account for non-standard conditions using a term known as the crop coefficient, Kc (Allen, 1998, ASCE, 2005, and NEH, 1993). Appendix A provides details on how we derived crop coefficients, and **Table 7** summarizes our values.

Table 6: ASCE Reference ETo computed by AMEC for each of the Zuni ag units using (i) local and regional weather station data, and (ii) gridded climatic data.

Ag Unit / Method	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Nutria / Weather Station	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
Nutria / Gridded	1.58	1.99	3.25	4.47	5.85	6.72	6.80	6.11	4.95	3.64	2.25	1.60	49.21
Pescado / Weather Station	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
Pescado / Gridded	1.60	2.02	3.35	4.54	5.92	6.78	6.89	6.18	5.04	3.70	2.28	1.62	49.92
Zuni / Weather Station	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
Zuni / Gridded	1.62	2.09	3.48	4.67	6.05	6.91	6.99	6.28	5.13	3.76	2.33	1.63	50.93
Tekapo / Weather Station	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
Tekapo / Gridded	1.60	2.09	3.53	4.75	6.14	7.00	7.06	6.34	5.18	3.80	2.33	1.61	51.43
Ojo Caliente/ Weather Station	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
Ojo Caliente/ Gridded	1.60	2.09	3.50	4.70	6.10	6.94	6.97	6.28	5.14	3.77	2.33	1.61	51.03

Table 7: Crop coefficients computed by AMEC for each of the Zuni ag units for application to ASCE Reference ETo.

Ag Unit / crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Nutria / Kc_grain	0	0	0	0.39	1.15	1.15	0.8	0.39	0	0	0	0
Nutria / Kc_hay	0	0	0	0.89	1.1	1.1	1.08	0	0	0	0	0
Nutria / Kc_alfalfa	0	0	0	0.51	0.51	1.15	0.51	1.15	0.51	1.15	0	0
Nutria / Kc_Graden_crop	0	0	0	0	0.39	0.56	1.05	1.05	0.86	0	0	0
Nutria / Kc_Corn	0	0	0	0	0.39	0.61	1.15	1.15	0.69	0	0	0
Nutria / Kc_Irrigated_Pasture_ar	0	0	0	0.43	0.77	0.91	0.91	0.91	0.91	0.91	0	0
Pescado / Kc_grain	0	0	0.39	0.76	1.15	1.15	0.41	0	0	0	0	0
Pescado / Kc_hay	0	0	0.89	0.98	1.1	1.1	0	0	0	0	0	0
Pescado / Kc_alfalfa	0	0	0	0	0.51	1.15	1.15	1.15	0.51	1.15	0	0
Pescado / Kc_Graden_crop	0	0	0	0	0.39	0.59	1.05	1.04	0	0	0	0
Pescado / Kc_Corn	0	0	0	0	0.39	0.63	1.15	1.15	0.78	0	0	0
Pescado / Kc_Irrigated_Pasture_	0	0	0	0.43	0.57	0.91	0.91	0.91	0.91	0.91	0	0
Zuni / Kc_grain	0	0	0.39	0.94	1.15	1	0.5	0	0	0	0	0
Zuni / Kc_hay	0	0	0.89	1.04	1.1	1.06	0	0	0	0	0	0
Zuni / Kc_alfalfa	0	0	0	0.51	0.51	1.15	0.51	1.15	1.15	1.15	0	0
Zuni / Kc_Graden_crop	0	0	0	0	0.39	0.67	1.05	0.99	0	0	0	0
Zuni / Kc_Corn	0	0	0	0	0.39	0.74	1.15	1.13	0.75	0	0	0
Zuni / Kc_Irrigated_Pasture_and	0	0	0	0.43	0.89	0.91	0.91	0.91	0.91	0.91	0.91	0
Tekapo / Kc_grain	0	0	0.39	0.94	1.15	1	0.5	0	0	0	0	0
Tekapo / Kc_hay	0	0	0.89	1.04	1.1	1.06	0	0	0	0	0	0
Tekapo / Kc_alfalfa	0	0	0	0.51	0.51	1.15	0.51	1.15	1.15	1.15	0	0
Tekapo / Kc_Graden_crop	0	0	0	0	0.39	0.67	1.05	0.99	0	0	0	0
Tekapo / Kc_Corn	0	0	0	0	0.39	0.74	1.15	1.13	0.75	0	0	0
Tekapo / Kc_Irrigated_Pasture_a	0	0	0	0.43	0.89	0.91	0.91	0.91	0.91	0.91	0.91	0
Ojo Caliente / Kc_grain	0	0	0.39	0.94	1.15	1	0.5	0	0	0	0	0
Ojo Caliente / Kc_hay	0	0	0.89	1.04	1.1	1.06	0	0	0	0	0	0
Ojo Caliente / Kc_alfalfa	0	0	0	0.51	0.51	1.15	0.51	1.15	1.15	1.15	0	0
Ojo Caliente / Kc_Graden_crop	0	0	0	0	0.39	0.67	1.05	0.99	0	0	0	0
Ojo Caliente / Kc_Corn	0	0	0	0	0.39	0.74	1.15	1.13	0.75	0	0	0
Ojo Caliente / Kc_Irrigated_Past	0	0	0	0.43	0.89	0.91	0.91	0.91	0.91	0.91	0.91	0

Effective Precipitation

Recognizing that part of the annual crop consumptive use demand is met via precipitation, the crop irrigation requirement (CIR) is computed as the total consumptive use minus the effective precipitation. The effective precipitation for the Zuni agricultural units crop categories is developed following equations presented in NEH (1993). **Table 8** summarizes the effective precipitation for each Zuni irrigated agricultural unit and crop category. A detailed summary of our methods employed to estimate the effective precipitation can be found in Appendix A.

Annual Diversion Requirements

Multiplying the reference ETo times a crop coefficient provides an estimate of the amount of water that would be depleted in the field by the crop, known as the crop consumptive use demand (CU). Subtracting the effective precipitation (**Table 8**) from the CU yield the crop irrigation requirement (CIR) or net irrigation requirement (NIR). To understand how much water must be diverted from a stream or well to meet the crop NIR, this water depletion must be scaled up by both on-farm and conveyance system efficiencies. Both Allen (2008) and Franzoy (2010) estimated on-farm and system efficiencies, but we do not provide an independent estimate of efficiencies. To get an estimate of the diversion requirement for each of the Zuni irrigated agricultural units, we first computed the NIR for each unit (using the ETo, crop coefficients, and effective precipitation values presented in **Table 6** through **Table 8**), and then divided the NIR by both Allen (2008) and Franzoy (2010) system efficiencies as summarized in **Table 9**.

Table 8: Effective precipitation computed by AMEC for each Zuni irrigated agricultural unit by crop type.

Ag Unit / crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total (inches)
Nutria / Precp_grain	-	-	-	3.75	-	-	-	-	-	-	-	-	3.75
Nutria / Precp_hay	-	-	-	3.65	-	-	-	-	-	-	-	-	3.65
Nutria / Precp_alfalfa	-	-	-	3.65	-	-	-	-	-	-	-	-	3.65
Nutria / Precp_Garden_crop	-	-	-	-	-	-	-	-	-	-	-	-	-
Nutria / Precp_Corn	-	-	-	-	-	-	-	-	-	-	-	-	-
Nutria / Precp_Irrigated_Pasture_	-	-	-	3.65	-	-	-	-	-	-	-	-	3.65
Pescado / Precp_grain	-	-	0.47	0.33	0.28	0.27	1.03	-	-	-	-	-	2.39
Pescado / Precp_hay	-	-	0.52	0.35	0.27	0.26	-	-	-	-	-	-	1.41
Pescado / Precp_alfalfa	-	-	-	-	0.22	0.27	1.39	1.49	0.67	0.72	-	-	4.76
Pescado / Precp_Garden_crop	-	-	-	-	0.21	0.21	1.33	1.43	-	-	-	-	3.19
Pescado / Precp_Corn	-	-	-	-	0.21	0.22	1.39	1.49	0.73	-	-	-	4.03
Pescado / Precp_Irrigated_Pastu	-	-	-	0.30	0.23	0.24	1.26	1.37	0.75	0.69	-	-	4.85
Zuni / Precp_grain	-	-	0.43	0.31	0.25	0.22	0.99	-	-	-	-	-	2.20
Zuni / Precp_hay	-	-	0.48	0.32	0.24	0.22	-	-	-	-	-	-	1.27
Zuni / Precp_alfalfa	-	-	-	0.28	0.20	0.24	0.99	1.37	0.74	0.66	-	-	4.48
Zuni / Precp_Garden_crop	-	-	-	-	0.21	0.21	1.23	1.29	-	-	-	-	2.94
Zuni / Precp_Corn	-	-	-	-	0.19	0.20	1.28	1.36	0.66	-	-	-	3.70
Zuni / Precp_Irrigated_Pasture_a	-	-	-	0.28	0.23	0.21	1.16	1.26	0.69	0.63	0.36	-	4.82
Tekapo / Precp_grain	-	-	0.43	0.31	0.25	0.22	0.99	-	-	-	-	-	2.20
Tekapo / Precp_hay	-	-	0.48	0.32	0.24	0.22	-	-	-	-	-	-	1.27
Tekapo / Precp_alfalfa	-	-	-	0.28	0.20	0.24	0.99	1.37	0.74	0.66	-	-	4.48
Tekapo / Precp_Garden_crop	-	-	-	-	0.21	0.21	1.23	1.29	-	-	-	-	2.94
Tekapo / Precp_Corn	-	-	-	-	0.19	0.20	1.28	1.36	0.66	-	-	-	3.70
Tekapo / Precp_Irrigated_Pastur	-	-	-	0.28	0.23	0.21	1.16	1.26	0.69	0.63	0.36	-	4.82
Ojo Caliente / Precp_grain	-	-	0.43	0.31	0.25	0.22	0.99	-	-	-	-	-	2.20
Ojo Caliente / Precp_hay	-	-	0.48	0.32	0.24	0.23	-	-	-	-	-	-	1.27
Ojo Caliente / Precp_alfalfa	-	-	-	0.28	0.20	0.24	0.99	1.37	0.74	0.66	-	-	4.48
Ojo Caliente / Precp_Garden_cr	-	-	-	-	0.19	0.20	1.23	1.30	-	-	-	-	2.91
Ojo Caliente / Precp_Corn	-	-	-	-	0.19	0.20	1.28	1.36	0.66	-	-	-	3.70
Ojo Caliente / Precp_Irrigated_P	-	-	-	0.27	0.23	0.22	1.16	1.26	0.69	0.63	0.36	-	4.82

Table 9: Net Irrigation Requirement (NIR) and system diversion requirments for each of the Zuni irrigated agricultural units computed using ETo, Kc, and Precp for Table 6 through Table 8, and diversion requirement computed from NIR using system efficiencies provided by Allen (2008) and Franzoy (2010). Results presented here utilize the ETo in Table 6 derived from the weather station data; results from the gridded climatic data can be found in Appendix A.

Ag Unit / NIR or Diversion Requirement	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Nutria NIR (in/mo)	-	-	-	1.11	3.09	6.00	4.75	4.80	2.07	1.47	-	-	23.28
Diversion Req, Franzoy	-	-	-	2.63	7.36	14.28	11.30	11.43	4.94	3.49	-	-	55.44
Diversion Requir, Allen	-	-	-	2.57	7.19	13.95	11.04	11.16	4.82	3.41	-	-	54.15
Pescado NIR (in/mo)	-	-	0.25	0.67	3.29	6.29	5.81	4.72	2.16	1.47	-	-	24.66
Diversion Req, Franzoy	-	-	0.51	1.39	6.86	13.10	12.11	9.83	4.51	3.06	-	-	51.37
Diversion Requir, Allen	-	-	0.70	1.91	9.41	17.96	16.61	13.48	6.18	4.19	-	-	70.44
Zuni NIR (in/mo)	-	-	0.28	1.68	3.49	6.60	4.37	4.83	3.45	1.53	0.06	-	26.29
Diversion Req, Franzoy	-	-	0.66	4.00	8.31	15.71	10.41	11.50	8.21	3.64	0.15	-	62.59
Diversion Requir, Allen	-	-	0.69	4.20	8.73	16.50	10.93	12.08	8.62	3.82	0.16	-	65.72
Tekapo NIR (in/mo)	-	-	0.28	1.68	3.49	6.60	4.37	4.83	3.45	1.53	0.06	-	26.29
Diversion Req, Franzoy	-	-	0.58	3.50	7.27	13.75	9.11	10.07	7.18	3.18	0.13	-	54.77
Diversion Requir, Allen	-	-	0.64	3.90	8.12	15.35	10.17	11.24	8.02	3.55	0.15	-	61.14
Ojo Caliente NIR (in/mo)	-	-	0.26	1.67	3.47	6.61	4.37	4.84	3.45	1.53	0.07	-	26.25
Diversion Req, Franzoy	-	-	0.48	3.08	6.42	12.24	8.10	8.96	6.39	2.83	0.12	-	48.62
Diversion Requir, Allen	-	-	0.54	3.47	7.22	13.76	9.11	10.07	7.19	3.18	0.14	-	54.70

3.3.3 Comparison and Discussion of AMEC's Evaluation of Expected Water Use to the Estimates of US and State of New Mexico Experts

Experts for both the US (Allen, 2008) and the State of New Mexico (Longworth et al., 2010; Brengosz, 2010; Samani, 2010) also computed a reference ETo, crop CU, and CIR for the ASCE – PM equation. In addition, both Allen and the State of New Mexico computed those quantities for the Hargreaves – Samani method, and the State of NM calculated them for the Original Blaney – Criddle and Modified Blaney – Criddle methods. **Table 10** summarizes values for these quantities as reported by Allen (2008), Longworth et al. (2010), and Brengosz (2010) along with the estimates developed by AMEC and presented above. In some cases (ETo for Blaney – Criddle methods, and CU for the State's implementation of the Hargreaves – Samani), the values don't exist because they are not employed in the method (i.e., Blaney Criddle), or were not presented by the authors.

Reviewing **Table 10**, it appears that all of the reference ET methods (Penman - Monteith and Hargreaves – Samani) yield similar values for ETo and especially for the CIR. The ETo results of AMEC presented herein and Allen (2008) are within a couple percent of each other, while the ETo of Brengosz (2010) appears to be roughly 10% to 15% higher than the AMEC's and Allen's findings (Brengosz' CIR estimates, however, are within 5% of those found by AMEC and Allen). One contributing factor to the difference is that Brengosz did not make an aridity adjustment as recommended in FAO-56, Annex 6 (Allen et al., 2998); application of the aridity adjustment would also lower the ETo slightly. We also reviewed the period-of-record ("POR") of the meteorological data that was used by the Brengosz, Allen, and ourselves to determine whether differences in the period-of-record utilized by the various researchers may contribute to the ETo difference observed in **Table 10**. To help illustrate our findings, **Figure 8** presents a plot of the Palmer Hydrologic Drought Index (PHDI; Palmer, 1965; Gutman, 1991; Heim, 2000) for New Mexico, the average yearly temperature at the Zuni and Blackrock stations since 1948, along with an indicators of the PORs used by each of analysts. This figure clearly shows that the POR used by AMEC and Allen (2008) includes a representative sampling of both dry and wet periods (e.g., the droughts of the 1950s and between 1996 and 2006, as well as the very wet 1980s), whereas the POR used by Brengosz includes the very moist 1992-1994 followed by the drier late 1996 through 2006.

Table 10: Compilation of estimates of ETo, CU, and CIR estimated by AMEC herein and presented by US expert (Allen (2008) and State of New Mexico experts (Longworth et al, 2010; Brengosz, 2010).

Analyst / Method	ETo	CU	CIR
AMEC / ASCE - PM w/ Weather Station	51.95	28.71	26.29
AMEC / ASCE - PM w/ Gridded data	50.93	27.69	24.86
Allen / ASCE - PM	51.55	30.02	24.85
Longworth - Brengosz / Original BC*	NA	21.34	16.16
Longworth - Brengosz / Modified BC*	NA	21.17	17.23
Longworth - Brengosz / Hargreaves - Samani*	56.41	NA	24.00
Brengosz / ASCE - PM Zuni Station**	57.39	NA	24.98

* from Tables 3, 5, and 7 from Longworth et al., and using Zuni station results from Brengosz
** subtract ETo - NIR difference from Brengosz ASCE-PM Eto for Zuni station

The average annual temperature is also somewhat higher in Brengosz's POR. This finding suggests that the shorter climate trace employed by Brengosz likely contributed to the higher ETo resulting from her analysis. Accounting for these differences suggests that the Brengosz ETo would be even closer to those of AMEC (this report) and Allen, 2008). This close agreement between the various approaches to implement the reference ET methods suggests that the CIR from derived these methods is a robust estimate of crop irrigation requirements for the Zuni Reservation agricultural units under modern irrigation methods.

While the reference ET methods yield similar results, both Blaney – Criddle methods, however, suggest far less CU and CIR demand than the ETo methods, 25% to more than 30% less. In their discussion of the various methods, Longworth et al. (2010) note that the Blaney – Criddle methods have historically been used in New Mexico and across the western US for determining CIRs in adjudications, interstate compacts, and other water allocation assessments.

Longworth et al. also computed and present an adjusted CIR based on a correlation between CU and crop yield as developed by Smeal et al. (1995) for alfalfa in northwest New Mexico. The adjusted CIR derived from reported alfalfa yields from 1947 – 1950 is even less than the Blaney – Criddle derived estimates. This result indicates that the Zuni alfalfa crop was raised under deficit irrigation conditions and historical crop water depletions from that time period were far less than one would expect for a crop grown under idealized full water-supply conditions (as is assumed for the ASCE – PM approach).

Given the evidence that historical depletions from 1947 through 1950 were far less than the idealized ASCE – PM method would suggest, Longworth et al. (2010, Chapter 9) conclude that a CIR of 1.1 acre-ft/acre (13.2 inches) is a good estimate of historical water use during the 1947-1950 period; multiplying this CIR to the average cropped acreage during that period indicates a historical depletion on the order of 2,700 acr-ft per annum. Using on-farm and conveyance efficiencies as compiled by Franzoy (2010), Longworth et al also compute project delivery requirements (PDRs) on the that range between 2.2 acre-ft/acre and 3.02 acre-ft/acre for the Zuni irrigated agricultural units. Multiplying an average PDR of 2.56 acre-ft/acre by the average cropped acreage during that period (2,573 acres) yields an estimated historical diversion of 6,596 acre-ft per annum between 1947 and 1950.

Looking into the future, if the historical single-year irrigated acreage of 2,573 acres is cropped by the historical average cropping pattern as we present above in

	1934	1947	1948	1949	1950	1952	1981-1993	1997-2001	2003-2004
Corn	4.9%	23.0%	24.0%	24.0%	23.0%	34.8%	43.9%	15.4%	13.2%
Small Grains, Hay	59.9%	34.0%	36.0%	36.0%	37.0%	34.2%	16.4%	10.6%	12.2%
Alfalfa	21.5%	27.0%	24.0%	23.0%	24.0%	17.0%	30.2%	74.0%	74.7%
Garden Crops	5.7%	14.0%	14.0%	15.0%	14.0%	14.0%	5.8%	0.0%	0.0%
Irrigated Pasture +Noncrop	8.0%	2.0%	2.0%	2.0%	2.0%	0.0%	3.7%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 4, and system efficiencies as estimated by Franzoy (2010) and Allen (2008) remain applicable, and irrigated crops are raised in conditions close to the idealized reference conditions, then one would expect higher water depletions and PDRs than found by Longworth et al. (2010). **Table 11** compares to Longworth's 2010 historical estimates to the expected future depletions (from the ASCE reference PM equation) and PDRs, which would be 5,330 and 12,403 af.

Table 11: Historical and idealized future net depletion and diversion for 2,572.6 irrigated acres.

	CIR (acre-ft /acre)	Net Depletion (acre-ft)	PDR (acre-ft /acre)	Net Diversion Requirment (acre-ft)
Longworth et al (2010) Historical 1947-1950 Estimate	1.1	2,830	2.56	6,586
AMEC / ASCE - PM w/ Gridded data	2.07	5,330	4.82	12,403

3.4 Surface Water Availability / Shortage

Synthesizing the data and information presented in Sections 3.1 through 3.3 above permits one to estimate CU demand and diversion requirements for each of the Zuni PPIW units. For example, the acreage from Section 3.1 can be multiplied by the cropping pattern (Section 3.2) and CIR demand (Section 3.3) to get the total annual depletion, and that depletion can be divided by on-farm and conveyance system efficiencies (Section 3.2) to obtain the diversion requirement.

The surface water supply expert from the State of New Mexico (Petronis, 2010) utilized the acreage, CIR demand, and efficiencies provided by Allen (2008) to compute the diversion demand. Petronis (2010) then compared that diversion demand to the historical record of surface water supplies (from USGS streamflow gaging records) to derive estimates of supply shortages. Based on this data and analysis (and if the input acreages and demands are accurate), Petronis (2010) found that the Zuni PPIW units would always experience a surface water supply shortage, often severe. Recall that the PPIW acreages reported by Allen (2008) represent a composite of all lands in the Zuni agricultural units that have ever been irrigated, and in fact are more than double the maximum single-year irrigated acreages from available BIA crop reports.   To gain an understanding of surface water availability / shortages under more realistic single-year acreages, we felt is necessary to perform calculations similar to Petronis using representative single-year acres.

Reviewing the BIA crop reports, we identified the maximum single-year acreages for each of the three units analyzed by Petronis (2010), and repeated her analyses for the Nutria unit. **Tables 12** and **13** reproduce Petronis (2010) Tables C-1 and C-2 for the monthly water availability and demand for the Nutria unit with and without reservoir storage. In our tables, we used the maximum single year irrigated acreage for computing the monthly total demand. **Table 14** compares our water availability / shortage estimates for Nutria to those of Petronis (2010), and illustrates that when using more res\presentative single-year acreage values, surface water supply shortages would be much less severe than characterized by Petronis. One can reasonably extrapolate from these results to the other units analyzed by Petronis (2010).

Table 12: Estimated surface water supply shortage for the Nutria unit using maximum single-year irrigated acreage of 488 acres, assuming Franzoy efficiencies, and no reservoir storage; adapted from Petronis (2010; Table C-1). Last column presents surface water supply availability as percent of water diversion demand.

		April					May				
year	monthly Nutria Springflow (ac-ft)	monthly discharge (ac-ft)	monthly discharge plus springflow (ac-ft)	monthly irrigation unit diversion req'ments (in)	demand (ac-ft)	shortage (ac-ft)	monthly discharge (ac-ft)	monthly discharge plus springflow (ac-ft)	monthly irrigation unit diversion req'ments (in)	demand (ac-ft)	shortage (ac-ft)
1970	12.0	119.0	131.0	2.8	112.2	-	11.0	23.0	7.3	295.6	272.6
1971	12.0	8.0	20.0	2.8	112.2	92.2	6.0	18.0	7.3	295.6	277.6
1972	12.0	8.0	20.0	2.8	112.2	92.2	6.0	18.0	7.3	295.6	277.6
1973	12.0	11,127.0	11,139.0	2.8	112.2	-	2,078.0	2,090.0	7.3	295.6	-
1974	12.0	26.0	38.0	2.8	112.2	74.2	13.0	25.0	7.3	295.6	270.6
1975	12.0	1,827.0	1,839.0	2.8	112.2	-	64.0	76.0	7.3	295.6	219.6
1976	12.0	7.0	19.0	2.8	112.2	93.2	5.0	17.0	7.3	295.6	278.6
1977	12.0	18.0	30.0	2.8	112.2	82.2	9.0	21.0	7.3	295.6	274.6
1978	12.0	449.0	461.0	2.8	112.2	-	32.0	44.0	7.3	295.6	251.6
1979	12.0	8,634.0	8,646.0	2.8	112.2	-	561.0	573.0	7.3	295.6	-
1980	12.0	9,467.0	9,479.0	2.8	112.2	-	621.0	633.0	7.3	295.6	-
1981	12.0	173.0	185.0	2.8	112.2	-	6.0	18.0	7.3	295.6	277.6
1982	12.0	708.0	720.0	2.8	112.2	-	72.0	84.0	7.3	295.6	211.6
1983	12.0	8,164.0	8,176.0	2.8	112.2	-	543.0	555.0	7.3	295.6	-
1984	12.0	2,083.0	2,095.0	2.8	112.2	-	39.0	51.0	7.3	295.6	244.6
1985	12.0	1,857.0	1,869.0	2.8	112.2	-	873.0	885.0	7.3	295.6	-
1986	12.0	71.0	83.0	2.8	112.2	29.2	9.0	21.0	7.3	295.6	274.6
1987	12.0	4,790.0	4,802.0	2.8	112.2	-	370.0	382.0	7.3	295.6	-
1988	12.0	684.0	696.0	2.8	112.2	-	87.0	99.0	7.3	295.6	196.6
1989	12.0	15.0	27.0	2.8	112.2	85.2	9.0	21.0	7.3	295.6	274.6
1990	12.0	11.0	23.0	2.8	112.2	89.2	25.0	37.0	7.3	295.6	258.6
1991	12.0	2,344.0	2,356.0	2.8	112.2	-	24.0	36.0	7.3	295.6	259.6
1992	12.0	402.0	414.0	2.8	112.2	-	73.0	85.0	7.3	295.6	210.6
1993	12.0	1,434.0	1,446.0	2.8	112.2	-	336.0	348.0	7.3	295.6	-
1994	12.0	51.0	63.0	2.8	112.2	49.2	17.0	29.0	7.3	295.6	266.6
1995	12.0	857.0	869.0	2.8	112.2	-	215.0	227.0	7.3	295.6	68.6
1996	12.0	25.0	37.0	2.8	112.2	75.2	53.0	65.0	7.3	295.6	230.6
1997	12.0	445.0	457.0	2.8	112.2	-	21.0	33.0	7.3	295.6	262.6
1998	12.0	2,529.0	2,541.0	2.8	112.2	-	38.0	50.0	7.3	295.6	245.6
1999	12.0	65.0	77.0	2.8	112.2	35.2	187.0	199.0	7.3	295.6	96.6
2000	12.0	68.0	80.0	2.8	112.2	32.2	4.0	16.0	7.3	295.6	279.6
2001	12.0	28.0	40.0	2.8	112.2	72.2	2.0	14.0	7.3	295.6	281.6
2002	12.0	2.0	14.0	2.8	112.2	98.2	6.0	18.0	7.3	295.6	277.6
2003	12.0	43.0	55.0	2.8	112.2	57.2	40.0	52.0	7.3	295.6	243.6
2004	12.0	444.0	456.0	2.8	112.2	-	3.0	15.0	7.3	295.6	280.6
2005	12.0	195.0	207.0	2.8	112.2	-	14.0	26.0	7.3	295.6	269.6
2006	12.0	1.0	13.0	2.8	112.2	99.2	-	12.0	7.3	295.6	283.6
2007	12.0	104.0	116.0	2.8	112.2	-	1.0	13.0	7.3	295.6	282.6

	June					July				
year	monthly discharge (ac-ft)	monthly discharge plus springflow (ac-ft)	monthly irrigation unit diversion req'ments (in)	demand (ac-ft)	shortage (ac-ft)	monthly discharge (ac-ft)	monthly discharge plus springflow (ac-ft)	monthly irrigation unit diversion req'ments (in)	demand (ac-ft)	shortage (ac-ft)
1970	4.0	16.0	13.8	561.6	545.6	10.0	22.0	11.1	449.4	427.4
1971	5.0	17.0	13.8	561.6	544.6	3.0	15.0	11.1	449.4	434.4
1972	4.0	16.0	13.8	561.6	545.6	5.0	17.0	11.1	449.4	432.4
1973	79.0	91.0	13.8	561.6	470.6	11.0	23.0	11.1	449.4	426.4
1974	6.0	18.0	13.8	561.6	543.6	181.0	193.0	11.1	449.4	256.4
1975	7.0	19.0	13.8	561.6	542.6	31.0	43.0	11.1	449.4	406.4
1976	3.0	15.0	13.8	561.6	546.6	5.0	17.0	11.1	449.4	432.4
1977	7.0	19.0	13.8	561.6	542.6	19.0	31.0	11.1	449.4	418.4
1978	4.0	16.0	13.8	561.6	545.6	3.0	15.0	11.1	449.4	434.4
1979	64.0	76.0	13.8	561.6	485.6	4.0	16.0	11.1	449.4	433.4
1980	32.0	44.0	13.8	561.6	517.6	3.0	15.0	11.1	449.4	434.4
1981	6.0	18.0	13.8	561.6	543.6	18.0	30.0	11.1	449.4	419.4
1982	19.0	31.0	13.8	561.6	530.6	216.0	228.0	11.1	449.4	221.4
1983	67.0	79.0	13.8	561.6	482.6	82.0	94.0	11.1	449.4	355.4
1984	2.0	14.0	13.8	561.6	547.6	4.0	16.0	11.1	449.4	433.4
1985	70.0	82.0	13.8	561.6	479.6	25.0	37.0	11.1	449.4	412.4
1986	9.0	21.0	13.8	561.6	540.6	9.0	21.0	11.1	449.4	428.4
1987	23.0	35.0	13.8	561.6	526.6	21.0	33.0	11.1	449.4	416.4
1988	23.0	35.0	13.8	561.6	526.6	17.0	29.0	11.1	449.4	420.4
1989	12.0	24.0	13.8	561.6	537.6	185.0	197.0	11.1	449.4	252.4
1990	21.0	33.0	13.8	561.6	528.6	81.0	93.0	11.1	449.4	356.4
1991	5.0	17.0	13.8	561.6	544.6	5.0	17.0	11.1	449.4	432.4
1992	10.0	22.0	13.8	561.6	539.6	2.0	14.0	11.1	449.4	435.4
1993	29.0	41.0	13.8	561.6	520.6	1.0	13.0	11.1	449.4	436.4
1994	9.0	21.0	13.8	561.6	540.6	2.0	14.0	11.1	449.4	435.4
1995	10.0	22.0	13.8	561.6	539.6	3.0	15.0	11.1	449.4	434.4
1996	11.0	23.0	13.8	561.6	538.6	15.0	27.0	11.1	449.4	422.4
1997	33.0	45.0	13.8	561.6	516.6	116.0	128.0	11.1	449.4	321.4
1998	6.0	18.0	13.8	561.6	543.6	30.0	42.0	11.1	449.4	407.4
1999	8.0	20.0	13.8	561.6	541.6	61.0	73.0	11.1	449.4	376.4
2000	11.0	23.0	13.8	561.6	538.6	4.0	16.0	11.1	449.4	433.4
2001	3.0	15.0	13.8	561.6	546.6	4.0	16.0	11.1	449.4	433.4
2002	5.0	17.0	13.8	561.6	544.6	5.0	17.0	11.1	449.4	432.4
2003	4.0	16.0	13.8	561.6	545.6	4.0	16.0	11.1	449.4	433.4
2004	2.0	14.0	13.8	561.6	547.6	16.0	28.0	11.1	449.4	421.4
2005	-	12.0	13.8	561.6	549.6	-	12.0	11.1	449.4	437.4
2006	-	12.0	13.8	561.6	549.6	-	12.0	11.1	449.4	437.4
2007	-	12.0	13.8	561.6	549.6	8.0	20.0	11.1	449.4	429.4

	August					September				
year	monthly discharge (ac-ft)	monthly discharge plus springflow (ac-ft)	monthly irrigation unit diversion req'ments (in)	demand (ac-ft)	shortage (ac-ft)	monthly discharge (ac-ft)	monthly discharge plus springflow (ac-ft)	monthly irrigation unit diversion req'ments (in)	demand (ac-ft)	shortage (ac-ft)
1970	93.0	105.0	11.3	460.3	355.3	7.0	19.0	4.9	198.9	179.9
1971	2.0	14.0	11.3	460.3	446.3	73.0	85.0	4.9	198.9	113.9
1972	4.0	16.0	11.3	460.3	444.3	3.0	15.0	4.9	198.9	183.9
1973	23.0	35.0	11.3	460.3	425.3	6.0	18.0	4.9	198.9	180.9
1974	76.0	88.0	11.3	460.3	372.3	10.0	22.0	4.9	198.9	176.9
1975	6.0	18.0	11.3	460.3	442.3	7.0	19.0	4.9	198.9	179.9
1976	29.0	41.0	11.3	460.3	419.3	10.0	22.0	4.9	198.9	176.9
1977	39.0	51.0	11.3	460.3	409.3	7.0	19.0	4.9	198.9	179.9
1978	4.0	16.0	11.3	460.3	444.3	4.0	16.0	4.9	198.9	182.9
1979	82.0	94.0	11.3	460.3	366.3	2.0	14.0	4.9	198.9	184.9
1980	4.0	16.0	11.3	460.3	444.3	6.0	18.0	4.9	198.9	180.9
1981	144.0	156.0	11.3	460.3	304.3	25.0	37.0	4.9	198.9	161.9
1982	182.0	194.0	11.3	460.3	266.3	24.0	36.0	4.9	198.9	162.9
1983	138.0	150.0	11.3	460.3	310.3	2.0	14.0	4.9	198.9	184.9
1984	8.0	20.0	11.3	460.3	440.3	114.0	126.0	4.9	198.9	72.9
1985	18.0	30.0	11.3	460.3	430.3	12.0	24.0	4.9	198.9	174.9
1986	60.0	72.0	11.3	460.3	388.3	9.0	21.0	4.9	198.9	177.9
1987	295.0	307.0	11.3	460.3	153.3	49.0	61.0	4.9	198.9	137.9
1988	39.0	51.0	11.3	460.3	409.3	8.0	20.0	4.9	198.9	178.9
1989	16.0	28.0	11.3	460.3	432.3	48.0	60.0	4.9	198.9	138.9
1990	83.0	95.0	11.3	460.3	365.3	27.0	39.0	4.9	198.9	159.9
1991	5.0	17.0	11.3	460.3	443.3	107.0	119.0	4.9	198.9	79.9
1992	440.0	452.0	11.3	460.3	8.3	6.0	18.0	4.9	198.9	180.9
1993	12.0	24.0	11.3	460.3	436.3	5.0	17.0	4.9	198.9	181.9
1994	3.0	15.0	11.3	460.3	445.3	7.0	19.0	4.9	198.9	179.9
1995	207.0	219.0	11.3	460.3	241.3	12.0	24.0	4.9	198.9	174.9
1996	149.0	161.0	11.3	460.3	299.3	198.0	210.0	4.9	198.9	-
1997	861.0	873.0	11.3	460.3	-	359.0	371.0	4.9	198.9	-
1998	21.0	33.0	11.3	460.3	427.3	6.0	18.0	4.9	198.9	180.9
1999	144.0	156.0	11.3	460.3	304.3	18.0	30.0	4.9	198.9	168.9
2000	11.0	23.0	11.3	460.3	437.3	18.0	30.0	4.9	198.9	168.9
2001	259.0	271.0	11.3	460.3	189.3	5.0	17.0	4.9	198.9	181.9
2002	5.0	17.0	11.3	460.3	443.3	30.0	42.0	4.9	198.9	156.9
2003	11.0	23.0	11.3	460.3	437.3	5.0	17.0	4.9	198.9	181.9
2004	3.0	15.0	11.3	460.3	445.3	3.0	15.0	4.9	198.9	183.9
2005	65.0	77.0	11.3	460.3	383.3	-	12.0	4.9	198.9	186.9
2006	179.0	191.0	11.3	460.3	269.3	43.0	55.0	4.9	198.9	143.9
2007	17.0	29.0	11.3	460.3	431.3	3.0	15.0	4.9	198.9	183.9

	October					Annual Totals		
year	monthly discharge (ac-ft)	monthly discharge plus springflow (ac-ft)	monthly irrigation unit diversion req'ments (in)	demand (ac-ft)	shortage (ac-ft)	Demand (ac-ft)	Shortage (ac-ft)	Percent Supply
1970	6.0	18.0	3.5	142.3	124.3	2,220.4	1,905.2	14.0
1971	21.0	33.0	3.5	142.3	109.3	2,220.4	2,018.4	9.0
1972	149.0	161.0	3.5	142.3	-	2,220.4	1,976.1	11.0
1973	2.0	14.0	3.5	142.3	128.3	2,220.4	1,631.5	27.0
1974	36.0	48.0	3.5	142.3	94.3	2,220.4	1,788.4	19.0
1975	4.0	16.0	3.5	142.3	126.3	2,220.4	1,917.2	14.0
1976	4.0	16.0	3.5	142.3	126.3	2,220.4	2,073.4	7.0
1977	2.0	14.0	3.5	142.3	128.3	2,220.4	2,035.4	8.0
1978	4.0	16.0	3.5	142.3	126.3	2,220.4	1,985.2	11.0
1979	4.0	16.0	3.5	142.3	126.3	2,220.4	1,596.5	28.0
1980	9.0	21.0	3.5	142.3	121.3	2,220.4	1,698.5	24.0
1981	26.0	38.0	3.5	142.3	104.3	2,220.4	1,811.2	18.0
1982	7.0	19.0	3.5	142.3	123.3	2,220.4	1,516.2	32.0
1983	145.0	157.0	3.5	142.3	-	2,220.4	1,333.2	40.0
1984	65.0	77.0	3.5	142.3	65.3	2,220.4	1,804.2	19.0
1985	12.0	24.0	3.5	142.3	118.3	2,220.4	1,615.5	27.0
1986	65.0	77.0	3.5	142.3	65.3	2,220.4	1,904.4	14.0
1987	17.0	29.0	3.5	142.3	113.3	2,220.4	1,347.5	39.0
1988	10.0	22.0	3.5	142.3	120.3	2,220.4	1,852.2	17.0
1989	9.0	21.0	3.5	142.3	121.3	2,220.4	1,842.4	17.0
1990	7.0	19.0	3.5	142.3	123.3	2,220.4	1,881.4	15.0
1991	12.0	24.0	3.5	142.3	118.3	2,220.4	1,878.2	15.0
1992	11.0	23.0	3.5	142.3	119.3	2,220.4	1,494.2	33.0
1993	2.0	14.0	3.5	142.3	128.3	2,220.4	1,703.5	23.0
1994	7.0	19.0	3.5	142.3	123.3	2,220.4	2,040.4	8.0
1995	11.0	23.0	3.5	142.3	119.3	2,220.4	1,578.2	29.0
1996	28.0	40.0	3.5	142.3	102.3	2,220.4	1,668.5	25.0
1997	11.0	23.0	3.5	142.3	119.3	2,220.4	1,220.0	45.0
1998	232.0	244.0	3.5	142.3	-	2,220.4	1,804.8	19.0
1999	8.0	20.0	3.5	142.3	122.3	2,220.4	1,645.4	26.0
2000	15.0	27.0	3.5	142.3	115.3	2,220.4	2,005.4	10.0
2001	8.0	20.0	3.5	142.3	122.3	2,220.4	1,827.4	18.0
2002	6.0	18.0	3.5	142.3	124.3	2,220.4	2,077.4	6.0
2003	14.0	26.0	3.5	142.3	116.3	2,220.4	2,015.4	9.0
2004	5.0	17.0	3.5	142.3	125.3	2,220.4	2,004.2	10.0
2005	-	12.0	3.5	142.3	130.3	2,220.4	1,957.2	12.0
2006	-	12.0	3.5	142.3	130.3	2,220.4	1,913.4	14.0
2007	-	12.0	3.5	142.3	130.3	2,220.4	2,007.2	10.0
							Average (%)	19
							Maximum (%)	45
							Minimum (%)	6

Table 13: Estimated surface water supply shortage for the Nutria unit using maximum single-year irrigated acreage of 488 acres, assuming Franzoy efficiencies, and with reservoir storage; adapted from Petronis (2010; Table C-2).

				April							May							June							July						
year	Reservoir capacity (ac-ft)	starting reservoir storage (ac-ft) $	monthly Nutria Springflow (ac-ft)	monthly discharge (ac-ft)	monthly supply with springflow and reservoir storage (ac-ft)	monthly irrigation unit diversion req'ments (in)	demand (ac-ft)	shortage (ac-ft)	surplus (ac-ft)	Ending reservoir storage (ac-ft)	monthly discharge (ac-ft)	monthly supply with springflow and reservoir storage (ac-ft)	monthly irrigation unit diversion req'ments (in)	demand (ac-ft)	shortage (ac-ft)	surplus (ac-ft)	Ending reservoir storage (ac-ft)	monthly discharge (ac-ft)	monthly supply with springflow and reservoir storage (ac-ft)	monthly irrigation unit diversion req'ments (in)	demand (ac-ft)	shortage (ac-ft)	surplus (ac-ft)	Ending reservoir storage (ac-ft)	monthly discharge (ac-ft)	monthly supply with springflow and reservoir storage (ac-ft)	monthly irrigation unit diversion req'ments (in)	demand (ac-ft)	shortage (ac-ft)	surplus (ac-ft)	Ending reservoir storage (ac-ft)
1970	120	120	12.0	119.0	251.0	2.8	112.2	-	138.8	120.0	11.0	143.0	7.3	295.6	152.6	-	-	4.0	16.0	13.8	561.6	545.6	-	-	10.0	22.0	11.1	449.4	427.4	-	-
1971	120	120	12.0	8.0	140.0	2.8	112.2	-	27.8	27.8	6.0	45.8	7.3	295.6	249.9	-	-	5.0	17.0	13.8	561.6	544.6	-	-	3.0	15.0	11.1	449.4	434.4	-	-
1972	120	120	12.0	8.0	140.0	2.8	112.2	-	27.8	27.8	6.0	45.8	7.3	295.6	249.9	-	-	4.0	16.0	13.8	561.6	545.6	-	-	5.0	17.0	11.1	449.4	432.4	-	-
1973	120	120	12.0	11,127.0	11,259.0	2.8	112.2	-	#######	120.0	2,078.0	2,210.0	7.3	295.6	-	1,914.4	120.0	79.0	211.0	13.8	561.6	350.6	-	-	11.0	23.0	11.1	449.4	426.4	-	-
1974	120	120	12.0	26.0	158.0	2.8	112.2	-	45.8	45.8	13.0	70.8	7.3	295.6	224.9	-	-	6.0	18.0	13.8	561.6	543.6	-	-	181.0	193.0	11.1	449.4	256.4	-	-
1975	120	120	12.0	1,827.0	1,959.0	2.8	112.2	-	1,846.8	120.0	64.0	196.0	7.3	295.6	99.6	-	-	7.0	19.0	13.8	561.6	542.6	-	-	31.0	43.0	11.1	449.4	406.4	-	-
1976	120	93	12.0	7.0	112.0	2.8	112.2	0.2	-	-	5.0	17.0	7.3	295.6	278.6	-	-	3.0	15.0	13.8	561.6	546.6	-	-	5.0	17.0	11.1	449.4	432.4	-	-
1977	120	120	12.0	18.0	150.0	2.8	112.2	-	37.8	37.8	9.0	58.8	7.3	295.6	236.9	-	-	7.0	19.0	13.8	561.6	542.6	-	-	19.0	31.0	11.1	449.4	418.4	-	-
1978	120	120	12.0	449.0	581.0	2.8	112.2	-	468.8	120.0	32.0	164.0	7.3	295.6	131.6	-	-	4.0	16.0	13.8	561.6	545.6	-	-	3.0	15.0	11.1	449.4	434.4	-	-
1979	120	120	12.0	8,634.0	8,766.0	2.8	112.2	-	8,653.8	120.0	561.0	693.0	7.3	295.6	-	397.4	120.0	64.0	196.0	13.8	561.6	365.6	-	-	4.0	16.0	11.1	449.4	433.4	-	-
1980	120	120	12.0	9,467.0	9,599.0	2.8	112.2	-	9,486.8	120.0	621.0	753.0	7.3	295.6	-	457.4	120.0	32.0	164.0	13.8	561.6	397.6	-	-	3.0	15.0	11.1	449.4	434.4	-	-
1981	120	120	12.0	173.0	305.0	2.8	112.2	-	192.8	120.0	6.0	138.0	7.3	295.6	157.6	-	-	6.0	18.0	13.8	561.6	543.6	-	-	18.0	30.0	11.1	449.4	419.4	-	-
1982	120	120	12.0	708.0	840.0	2.8	112.2	-	727.8	120.0	72.0	204.0	7.3	295.6	91.6	-	-	19.0	31.0	13.8	561.6	530.6	-	-	216.0	228.0	11.1	449.4	221.4	-	-
1983	120	120	12.0	8,164.0	8,296.0	2.8	112.2	-	8,183.8	120.0	543.0	675.0	7.3	295.6	-	379.4	120.0	67.0	199.0	13.8	561.6	362.6	-	-	82.0	94.0	11.1	449.4	355.4	-	-
1984	120	120	12.0	2,083.0	2,215.0	2.8	112.2	-	2,102.8	120.0	39.0	171.0	7.3	295.6	124.6	-	-	2.0	14.0	13.8	561.6	547.6	-	-	4.0	16.0	11.1	449.4	433.4	-	-
1985	120	120	12.0	1,857.0	1,989.0	2.8	112.2	-	1,876.8	120.0	873.0	1,005.0	7.3	295.6	-	709.4	120.0	70.0	202.0	13.8	561.6	359.6	-	-	25.0	37.0	11.1	449.4	412.4	-	-
1986	120	120	12.0	71.0	203.0	2.8	112.2	-	90.8	90.8	9.0	111.8	7.3	295.6	183.9	-	-	9.0	21.0	13.8	561.6	540.6	-	-	9.0	21.0	11.1	449.4	428.4	-	-
1987	120	120	12.0	4,790.0	4,922.0	2.8	112.2	-	4,809.8	120.0	370.0	502.0	7.3	295.6	-	206.4	120.0	23.0	155.0	13.8	561.6	406.6	-	-	21.0	33.0	11.1	449.4	416.4	-	-
1988	120	120	12.0	684.0	816.0	2.8	112.2	-	703.8	120.0	87.0	219.0	7.3	295.6	76.6	-	-	23.0	35.0	13.8	561.6	526.6	-	-	17.0	29.0	11.1	449.4	420.4	-	-
1989	120	120	12.0	15.0	147.0	2.8	112.2	-	34.8	34.8	9.0	55.8	7.3	295.6	239.9	-	-	12.0	24.0	13.8	561.6	537.6	-	-	185.0	197.0	11.1	449.4	252.4	-	-
1990	120	117	12.0	11.0	140.0	2.8	112.2	-	27.8	27.8	25.0	64.8	7.3	295.6	230.9	-	-	21.0	33.0	13.8	561.6	528.6	-	-	81.0	93.0	11.1	449.4	356.4	-	-
1991	120	120	12.0	2,344.0	2,476.0	2.8	112.2	-	2,363.8	120.0	24.0	156.0	7.3	295.6	139.6	-	-	5.0	17.0	13.8	561.6	544.6	-	-	5.0	17.0	11.1	449.4	432.4	-	-
1992	120	120	12.0	402.0	534.0	2.8	112.2	-	421.8	120.0	73.0	205.0	7.3	295.6	90.6	-	-	10.0	22.0	13.8	561.6	539.6	-	-	2.0	14.0	11.1	449.4	435.4	-	-
1993	120	120	12.0	1,434.0	1,566.0	2.8	112.2	-	1,453.8	120.0	336.0	468.0	7.3	295.6	-	172.4	120.0	29.0	161.0	13.8	561.6	400.6	-	-	1.0	13.0	11.1	449.4	436.4	-	-
1994	120	120	12.0	51.0	183.0	2.8	112.2	-	70.8	70.8	17.0	99.8	7.3	295.6	195.9	-	-	9.0	21.0	13.8	561.6	540.6	-	-	2.0	14.0	11.1	449.4	435.4	-	-
1995	120	120	12.0	857.0	989.0	2.8	112.2	-	876.8	120.0	215.0	347.0	7.3	295.6	-	51.4	51.4	10.0	73.4	13.8	561.6	488.3	-	-	3.0	15.0	11.1	449.4	434.4	-	-
1996	120	120	12.0	25.0	157.0	2.8	112.2	-	44.8	44.8	53.0	109.8	7.3	295.6	185.9	-	-	11.0	23.0	13.8	561.6	538.6	-	-	15.0	27.0	11.1	449.4	422.4	-	-
1997	120	120	12.0	445.0	577.0	2.8	112.2	-	464.8	120.0	21.0	153.0	7.3	295.6	142.6	-	-	33.0	45.0	13.8	561.6	516.6	-	-	116.0	128.0	11.1	449.4	321.4	-	-
1998	120	120	12.0	2,529.0	2,661.0	2.8	112.2	-	2,548.8	120.0	38.0	170.0	7.3	295.6	125.6	-	-	6.0	18.0	13.8	561.6	543.6	-	-	30.0	42.0	11.1	449.4	407.4	-	-
1999	120	120	12.0	65.0	197.0	2.8	112.2	-	84.8	84.8	18.0	114.8	7.3	295.6	180.9	-	-	8.0	20.0	13.8	561.6	541.6	-	-	61.0	73.0	11.1	449.4	376.4	-	-
2000	120	120	12.0	68.0	200.0	2.8	112.2	-	87.8	87.8	4.0	103.8	7.3	295.6	191.9	-	-	11.0	23.0	13.8	561.6	538.6	-	-	4.0	16.0	11.1	449.4	433.4	-	-
2001	120	120	12.0	28.0	160.0	2.8	112.2	-	47.8	47.8	2.0	61.8	7.3	295.6	233.9	-	-	3.0	15.0	13.8	561.6	546.6	-	-	4.0	16.0	11.1	449.4	433.4	-	-
2002	120	98	12.0	2.0	112.0	2.8	112.2	0.2	-	-	6.0	18.0	7.3	295.6	277.6	-	-	5.0	17.0	13.8	561.6	544.6	-	-	5.0	17.0	11.1	449.4	432.4	-	-
2003	120	120	12.0	43.0	175.0	2.8	112.2	-	62.8	62.8	40.0	114.8	7.3	295.6	180.9	-	-	4.0	16.0	13.8	561.6	545.6	-	-	4.0	16.0	11.1	449.4	433.4	-	-
2004	120	120	12.0	444.0	576.0	2.8	112.2	-	463.8	120.0	3.0	135.0	7.3	295.6	160.6	-	-	2.0	14.0	13.8	561.6	547.6	-	-	16.0	28.0	11.1	449.4	421.4	-	-
2005	120	120	12.0	195.0	327.0	2.8	112.2	-	214.8	120.0	14.0	146.0	7.3	295.6	149.6	-	-	-	12.0	13.8	561.6	549.6	-	-	-	12.0	11.1	449.4	437.4	-	-
2006	120	61	12.0	1.0	74.0	2.8	112.2	38.2	-	-	-	12.0	7.3	295.6	283.6	-	-	-	12.0	13.8	561.6	549.6	-	-	-	12.0	11.1	449.4	437.4	-	-
2007	120	0	12.0	104.0	116.0	2.8	112.2	-	3.8	3.8	1.0	16.8	7.3	295.6	278.9	-	-	-	12.0	13.8	561.6	549.6	-	-	8.0	20.0	11.1	449.4	429.4	-	-

$ data taken from Petronis (2010)

Table 13 (continued).). Last column presents surface water supply availability as percent of water diversion demand.

August							September							October							Annual Totals		
monthly discharge (ac-ft)	monthly supply with springflow and reservoir storage (ac-ft)	monthly irrigation unit diversion req'ments (in)	demand (ac-ft)	shortage (ac-ft)	surplus (ac-ft)	Ending reservoir storage (ac-ft)	monthly discharge (ac-ft)	monthly supply with springflow and reservoir storage (ac-ft)	monthly irrigation unit diversion req'ments (in)	demand (ac-ft)	shortage (ac-ft)	surplus (ac-ft)	Ending reservoir storage (ac-ft)	monthly discharge (ac-ft)	monthly supply with springflow and reservoir storage (ac-ft)	monthly irrigation unit diversion req'ments (in)	demand (ac-ft)	shortage (ac-ft)	surplus (ac-ft)	Ending reservoir storage (ac-ft)	Demand (ac-ft)	Shortage (ac-ft)	Percent Supply
93.0	105.0	11.3	460.3	355.3	-	-	7.0	19.0	4.9	198.9	179.9	-	-	6.0	18.0	3.5	142.3	124.3	-	-	2,220.4	1,785.2	19.6
2.0	14.0	11.3	460.3	446.3	-	-	73.0	85.0	4.9	198.9	113.9	-	-	21.0	33.0	3.5	142.3	109.3	-	-	2,220.4	1,898.4	14.5
4.0	16.0	11.3	460.3	444.3	-	-	3.0	15.0	4.9	198.9	183.9	-	-	149.0	161.0	3.5	142.3	-	18.7	18.7	2,220.4	1,856.1	16.4
23.0	35.0	11.3	460.3	425.3	-	-	6.0	18.0	4.9	198.9	180.9	-	-	2.0	14.0	3.5	142.3	128.3	-	-	2,220.4	1,511.5	31.9
76.0	88.0	11.3	460.3	372.3	-	-	10.0	22.0	4.9	198.9	176.9	-	-	36.0	48.0	3.5	142.3	94.3	-	-	2,220.4	1,668.4	24.9
6.0	18.0	11.3	460.3	442.3	-	-	7.0	19.0	4.9	198.9	179.9	-	-	4.0	16.0	3.5	142.3	126.3	-	-	2,220.4	1,797.2	19.1
29.0	41.0	11.3	460.3	419.3	-	-	10.0	22.0	4.9	198.9	176.9	-	-	4.0	16.0	3.5	142.3	126.3	-	-	2,220.4	1,980.4	10.8
39.0	51.0	11.3	460.3	409.3	-	-	7.0	19.0	4.9	198.9	179.9	-	-	2.0	14.0	3.5	142.3	128.3	-	-	2,220.4	1,915.4	13.7
4.0	16.0	11.3	460.3	444.3	-	-	4.0	16.0	4.9	198.9	182.9	-	-	4.0	16.0	3.5	142.3	126.3	-	-	2,220.4	1,865.2	16.0
82.0	94.0	11.3	460.3	366.3	-	-	2.0	14.0	4.9	198.9	184.9	-	-	4.0	16.0	3.5	142.3	126.3	-	-	2,220.4	1,476.5	33.5
4.0	16.0	11.3	460.3	444.3	-	-	6.0	18.0	4.9	198.9	180.9	-	-	9.0	21.0	3.5	142.3	121.3	-	-	2,220.4	1,578.5	28.9
144.0	156.0	11.3	460.3	304.3	-	-	25.0	37.0	4.9	198.9	161.9	-	-	26.0	38.0	3.5	142.3	104.3	-	-	2,220.4	1,691.2	23.8
182.0	194.0	11.3	460.3	266.3	-	-	24.0	36.0	4.9	198.9	162.9	-	-	7.0	19.0	3.5	142.3	123.3	-	-	2,220.4	1,396.2	37.1
138.0	150.0	11.3	460.3	310.3	-	-	2.0	14.0	4.9	198.9	184.9	-	-	145.0	157.0	3.5	142.3	-	14.7	14.7	2,220.4	1,213.2	45.4
8.0	20.0	11.3	460.3	440.3	-	-	114.0	126.0	4.9	198.9	72.9	-	-	65.0	77.0	3.5	142.3	65.3	-	-	2,220.4	1,684.2	24.2
18.0	30.0	11.3	460.3	430.3	-	-	12.0	24.0	4.9	198.9	174.9	-	-	12.0	24.0	3.5	142.3	118.3	-	-	2,220.4	1,495.5	32.6
60.0	72.0	11.3	460.3	388.3	-	-	9.0	21.0	4.9	198.9	177.9	-	-	65.0	77.0	3.5	142.3	65.3	-	-	2,220.4	1,784.4	19.6
295.0	307.0	11.3	460.3	153.3	-	-	49.0	61.0	4.9	198.9	137.9	-	-	17.0	29.0	3.5	142.3	113.3	-	-	2,220.4	1,227.5	44.7
39.0	51.0	11.3	460.3	409.3	-	-	8.0	20.0	4.9	198.9	178.9	-	-	10.0	22.0	3.5	142.3	120.3	-	-	2,220.4	1,732.2	22.0
16.0	28.0	11.3	460.3	432.3	-	-	48.0	60.0	4.9	198.9	138.9	-	-	9.0	21.0	3.5	142.3	121.3	-	-	2,220.4	1,722.4	22.4
83.0	95.0	11.3	460.3	365.3	-	-	27.0	39.0	4.9	198.9	159.9	-	-	7.0	19.0	3.5	142.3	123.3	-	-	2,220.4	1,764.4	20.5
5.0	17.0	11.3	460.3	443.3	-	-	107.0	119.0	4.9	198.9	79.9	-	-	12.0	24.0	3.5	142.3	118.3	-	-	2,220.4	1,758.2	20.8
440.0	452.0	11.3	460.3	8.3	-	-	6.0	18.0	4.9	198.9	180.9	-	-	11.0	23.0	3.5	142.3	119.3	-	-	2,220.4	1,374.2	38.1
12.0	24.0	11.3	460.3	436.3	-	-	5.0	17.0	4.9	198.9	181.9	-	-	2.0	14.0	3.5	142.3	128.3	-	-	2,220.4	1,583.5	28.7
3.0	15.0	11.3	460.3	445.3	-	-	7.0	19.0	4.9	198.9	179.9	-	-	7.0	19.0	3.5	142.3	123.3	-	-	2,220.4	1,920.4	13.5
207.0	219.0	11.3	460.3	241.3	-	-	12.0	24.0	4.9	198.9	174.9	-	-	11.0	23.0	3.5	142.3	119.3	-	-	2,220.4	1,458.2	34.3
149.0	161.0	11.3	460.3	299.3	-	-	198.0	210.0	4.9	198.9	-	11.1	11.1	28.0	51.1	3.5	142.3	91.2	-	-	2,220.4	1,537.4	30.8
861.0	873.0	11.3	460.3	-	412.7	120.0	359.0	491.0	4.9	198.9	-	292.1	120.0	11.0	143.0	3.5	142.3	-	0.7	0.7	2,220.4	980.6	55.8
21.0	33.0	11.3	460.3	427.3	-	-	6.0	18.0	4.9	198.9	180.9	-	-	232.0	244.0	3.5	142.3	-	101.7	101.7	2,220.4	1,684.8	24.1
144.0	156.0	11.3	460.3	304.3	-	-	18.0	30.0	4.9	198.9	168.9	-	-	8.0	20.0	3.5	142.3	122.3	-	-	2,220.4	1,694.4	23.7
11.0	23.0	11.3	460.3	437.3	-	-	18.0	30.0	4.9	198.9	168.9	-	-	15.0	27.0	3.5	142.3	115.3	-	-	2,220.4	1,885.4	15.1
259.0	271.0	11.3	460.3	189.3	-	-	5.0	17.0	4.9	198.9	181.9	-	-	8.0	20.0	3.5	142.3	122.3	-	-	2,220.4	1,707.4	23.1
5.0	17.0	11.3	460.3	443.3	-	-	30.0	42.0	4.9	198.9	156.9	-	-	6.0	18.0	3.5	142.3	124.3	-	-	2,220.4	1,979.4	10.9
11.0	23.0	11.3	460.3	437.3	-	-	5.0	17.0	4.9	198.9	181.9	-	-	14.0	26.0	3.5	142.3	116.3	-	-	2,220.4	1,895.4	14.6
3.0	15.0	11.3	460.3	445.3	-	-	3.0	15.0	4.9	198.9	183.9	-	-	5.0	17.0	3.5	142.3	125.3	-	-	2,220.4	1,884.2	15.1
65.0	77.0	11.3	460.3	383.3	-	-	-	12.0	4.9	198.9	186.9	-	-	-	12.0	3.5	142.3	130.3	-	-	2,220.4	1,837.2	17.3
179.0	191.0	11.3	460.3	269.3	-	-	43.0	55.0	4.9	198.9	143.9	-	-	-	12.0	3.5	142.3	130.3	-	-	2,220.4	1,852.4	16.6
17.0	29.0	11.3	460.3	431.3	-	-	3.0	15.0	4.9	198.9	183.9	-	-	-	12.0	3.5	142.3	130.3	-	-	2,220.4	2,003.4	9.8
																						Average (%)	24.0
																						Maximum (%)	56.0
																						Minimum (%)	10

Table 14: Summary of surface water supply availability (as percent of water diversion demand) for Nutria unit computed by Petronis (2010; assumes Allen ,2008 acreage of 976.6 acre) and AMEC using maximum single-year acreage (488 acres).

			Petronis (2010)	AMEC (using monthly CIR demand from gridded ET PM calculation)	% Difference wrt Petronis (2010)
Nutria agricultural unit	Including the Nutria reservoir storage	Minimum	5.0%	10.0%	-100.0
		Maximum	38.0%	56.0%	-47.4
		Average	13.0%	24.0%	-84.6
	Excluding the Nutria reservoir storage	Minimum	3.0%	6.0%	-100.0
		Maximum	34.0%	45.0%	-32.4
		Average	11.0%	19.0%	-72.7
Zuni agricultural unit	Including the Black Rock reservoir storage	Minimum	0.3%	1.0%	-233.3
		Maximum	44.0%	67.0%	-52.3
		Average	12.0%	24.0%	-100.0
	Excluding the Black Rock reservoir storage	Minimum	0.1%	0.0%	100.0
		Maximum	31.0%	41.0%	-32.3
		Average	7.0%	13.1%	-87.1

4. SUMMARY AND CONCLUSIONS

This report provides a record of a detailed data and information compilation, review, and evaluation for the Past and Present Irrigation from Permanent Works ("PPIW") on the Zuni Reservation by Dr. Jim McCord, P.E. and staff under his direction at AMEC Earth & Environmental, Inc. This work was undertaken on behalf of the Navajo Nation to evaluate the crop consumptive use and irrigated acreage associated with PPIW lands claimed by the Zuni Indian Tribe and the United States on behalf of the Zuni Tribe under Subproceeding 1 of the Zuni River Basin adjudication, Case No. 07-00681-BB Included in our evaluation was reviewing the work of the US expert (Allen, 2008) and experts of the State of New Mexico (e.g., Longworth et al., 2010) on this matter. In addition to reviewing the work of other expert, our efforts consisted of: (i) reviewing historical BIA crop reports and agricultural unit maps for the Zuni reservation, as well as aerial photography to ascertain historically irrigated acreage on the reservation, (ii) evaluating trends in historical cropping patterns, and (iii) estimating historical and expected water diversions and depletions associated with the PPIW lands.

Based on our review, analyses, and evaluations, it is Dr. McCord's opinion that within a reasonable degree of scientific certainty:

1. Up to 7,018.55 acres have been historically irrigated from permanent works on the Zuni Reservation, although not that much in any single year.
2. Of that 7,018.55 acreage that has at some time in the past been subject to irrigation from permanent work, available data and information from BIA crop reports indicates that the maximum amount irrigated in a single year was 2,759.5 acres in 1949.
3. Based on BIA crop reports, the period between 1947 and 1950 experienced an average annual irrigated cropping of 2,572.6 acres.
4. Historical water depletions estimated using the Blaney – Criddle methods and adjustments to account for reported historical alfalfa yields are on the

order of 1.1 acre-ft/acre. Historical water depletions estimates using the ASCE reference ET methods are on the order of 2.1 acre-ft/acre.

5. Using estimated on-farm and conveyance system efficiencies, historical water diversions would have been on the order of 6,600 acre-ft per annum to meet CIR demand estimated using Blaney – Criddle methods.
6. Using estimated on-farm and conveyance system efficiencies, water diversions would be on the order of 12,400 acre-ft per annum to meet CIR demand estimated using Penman – Monteith reference ET methods.
7. If the historically irrigated acreage were cropped in a pattern representative of that observed in the past, and available water supplies were successfully diverted to the cropped fields, one would expect up to depletions on the order of 5,300 acre-ft per annum and diversions on the order of 12,400 acre-ft per annum.

These opinions are based on data and information reviewed to date, including expert reports and associated data provided by experts of the US and the State of New Mexico in this matter. If additional data or information becomes available, Dr. McCord reserves the right to acquire and review that data, and if necessary update his opinions.

5. REFERENCES

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Figure 1: Zuni Indian Reservation site location map (adapted from Wear, 2010).

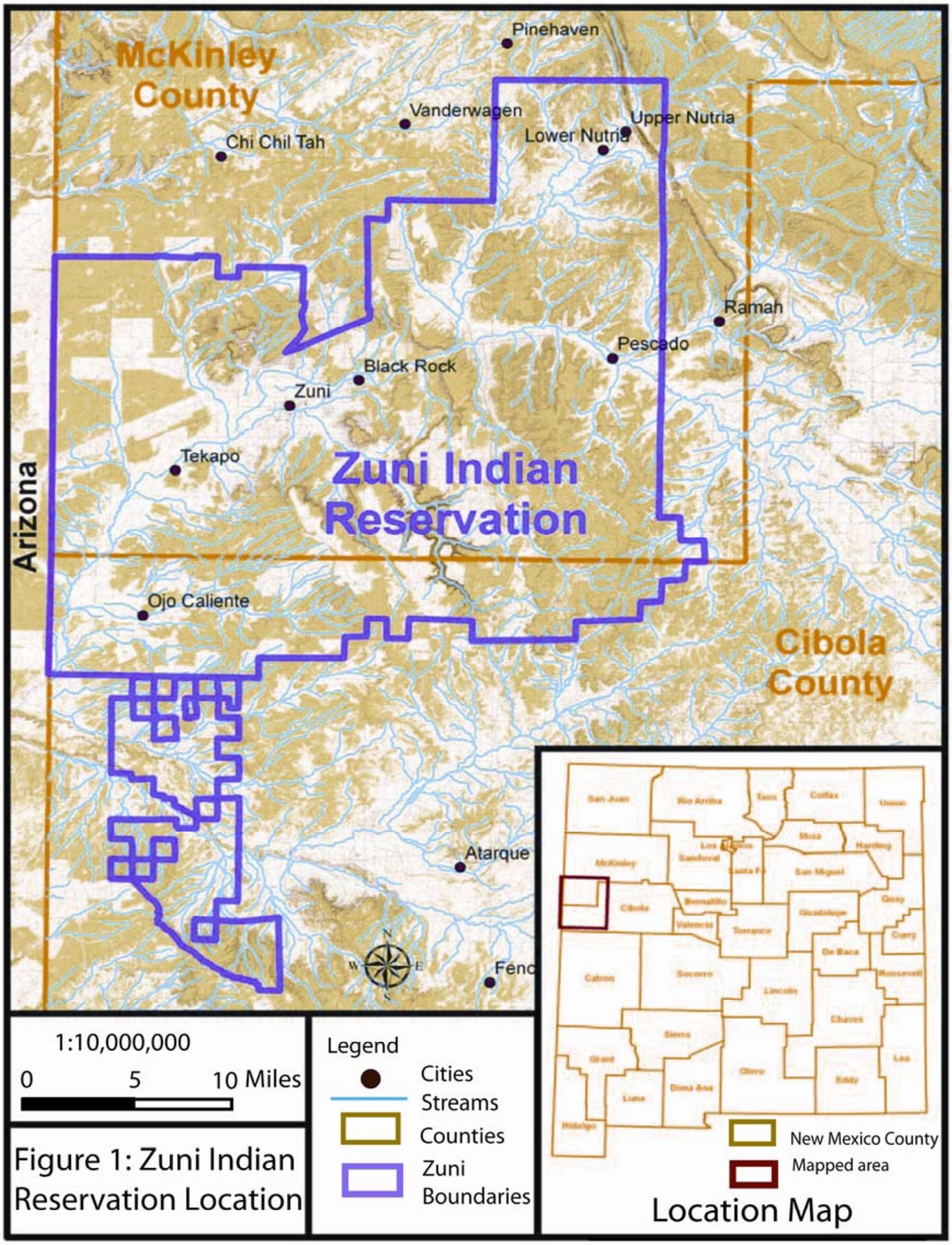
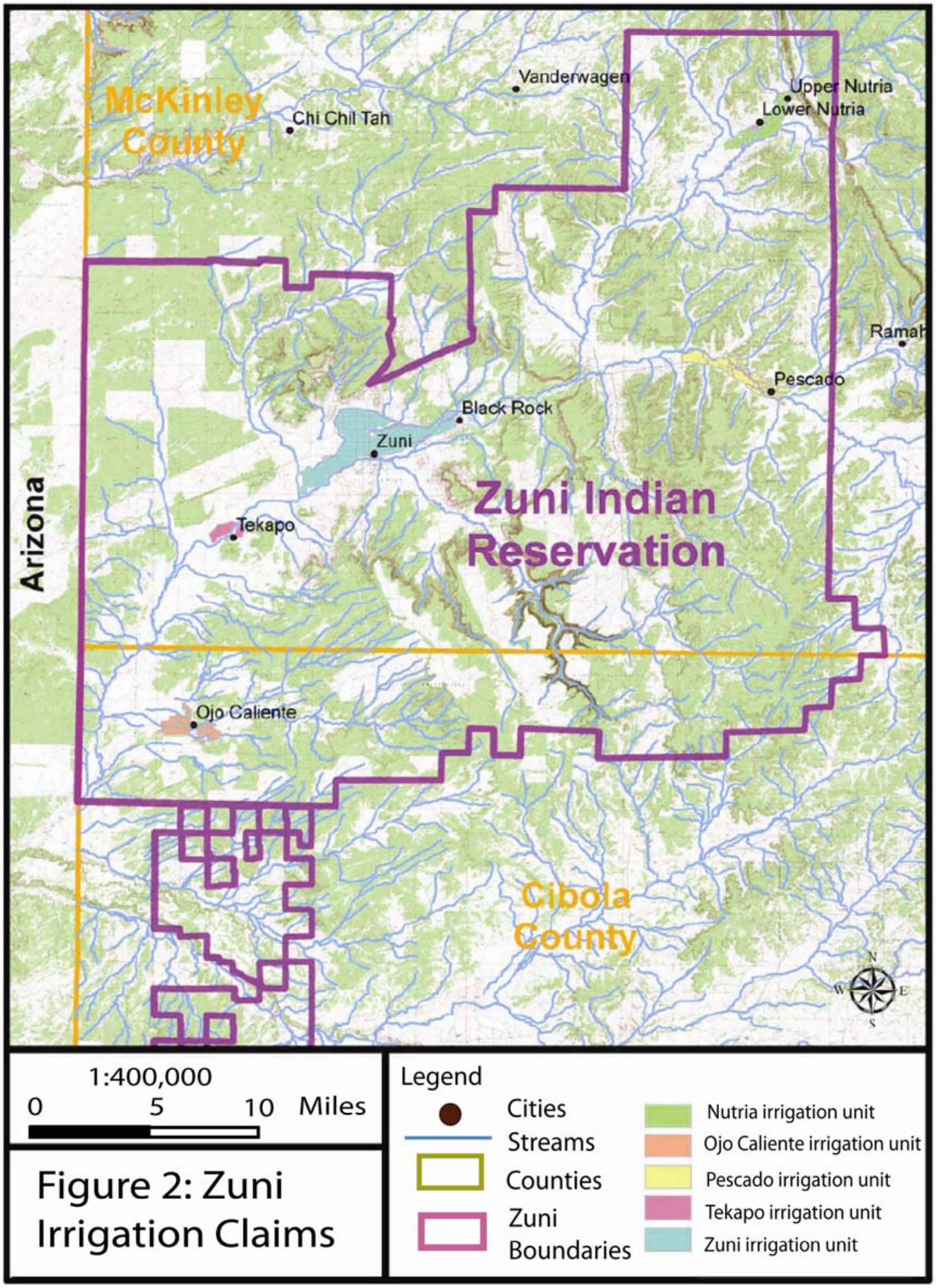


Figure 2: Map showing Zuni Reservation PPIPW agricultural units (adapted from Wear, 2010).



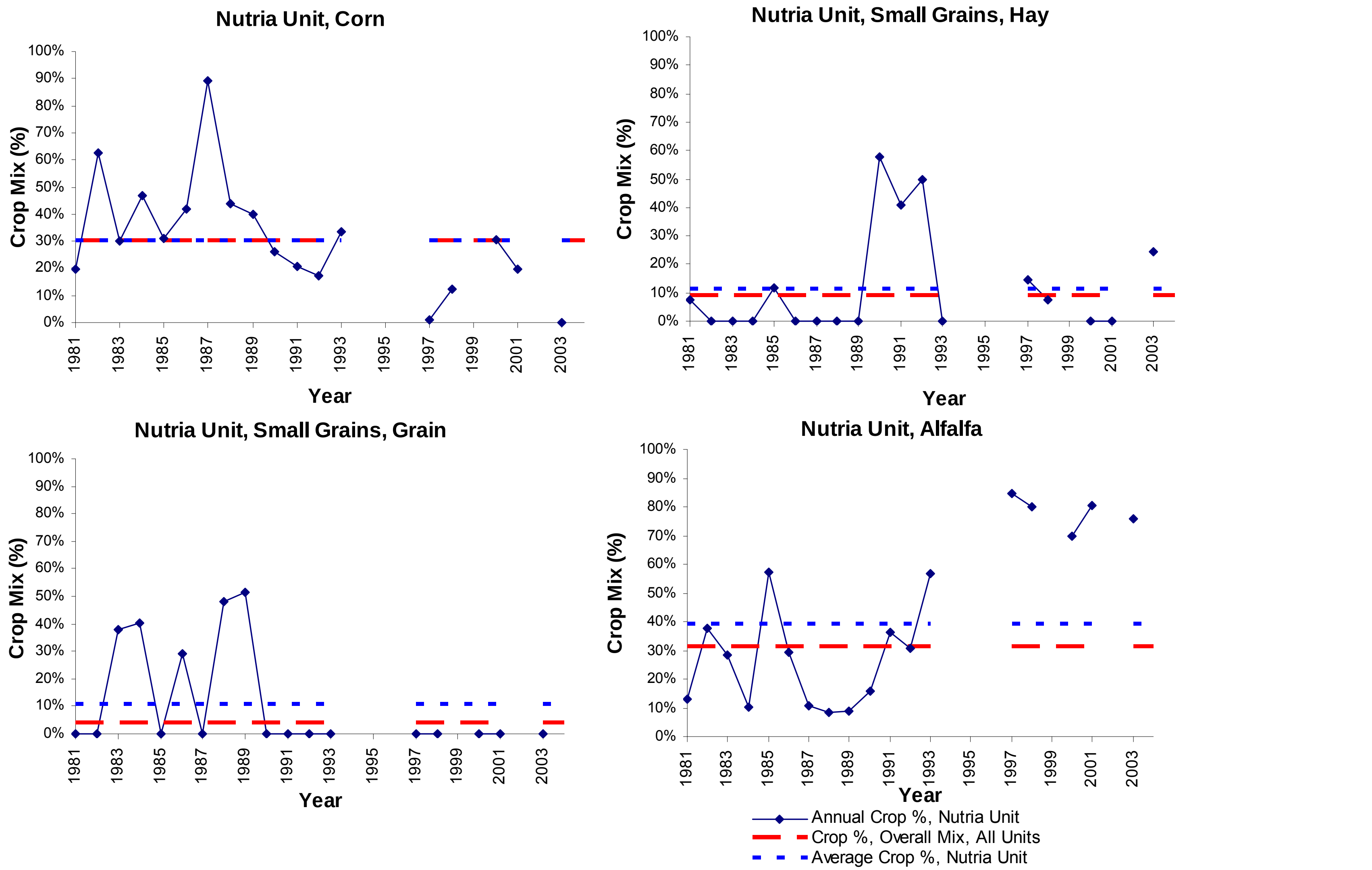


Figure 3: Cropping pattern data for Nutria unit from BIA crop reports between 1981 and 2004.

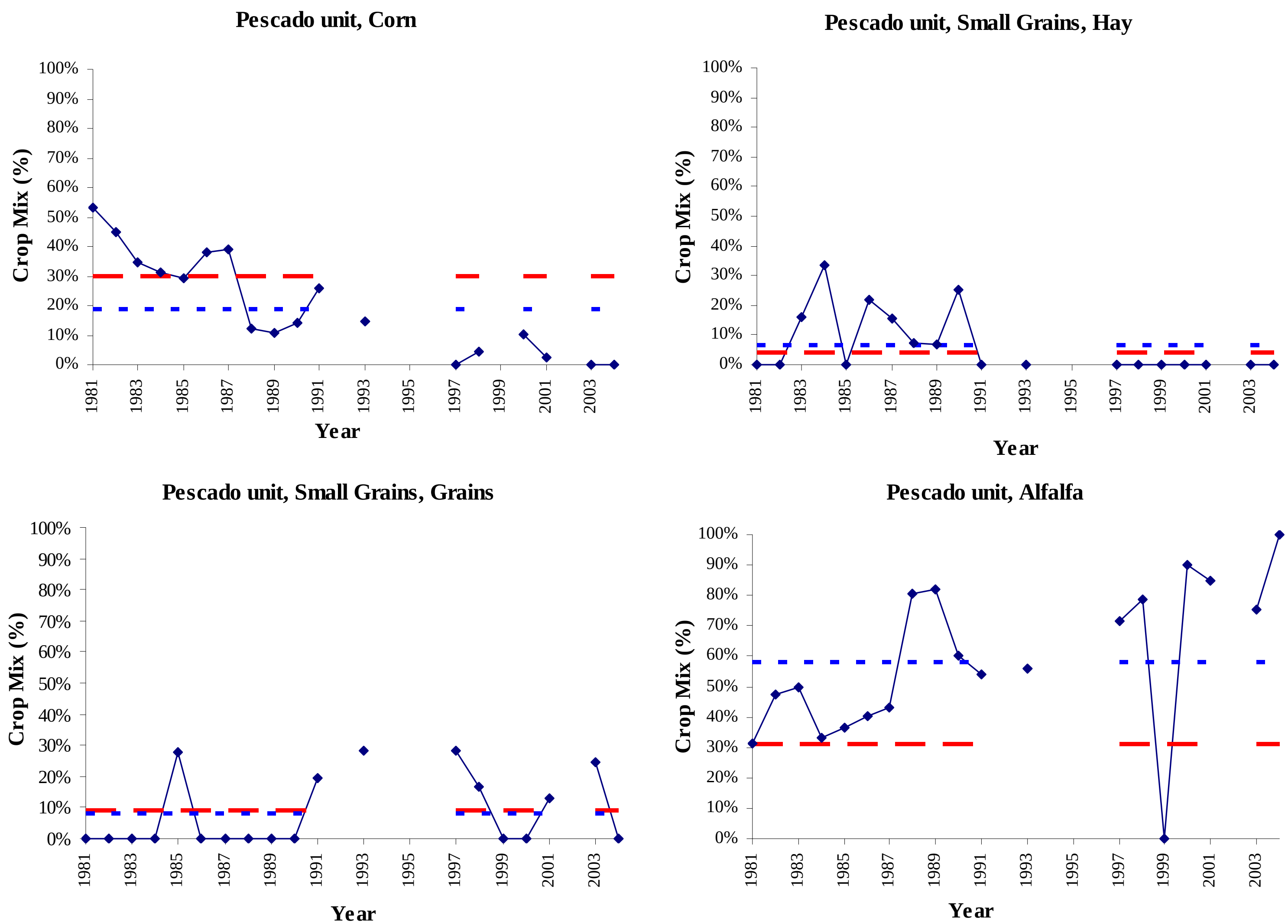


Figure 4: Cropping pattern data for Pescado unit from BIA crop reports between 1981 and 2004.

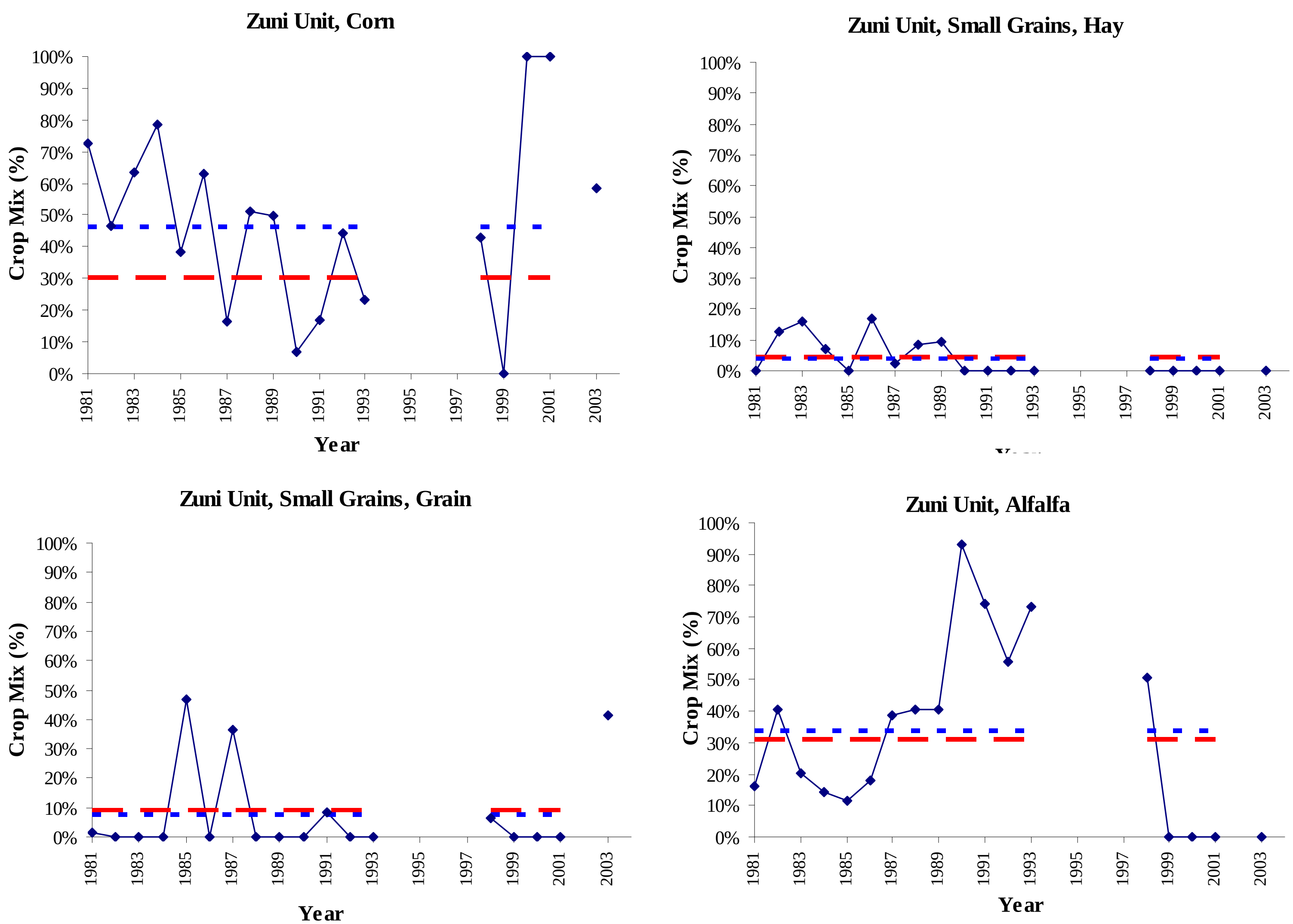


Figure 5: Cropping pattern data for Zuni unit from BIA crop reports between 1981 and 2004.

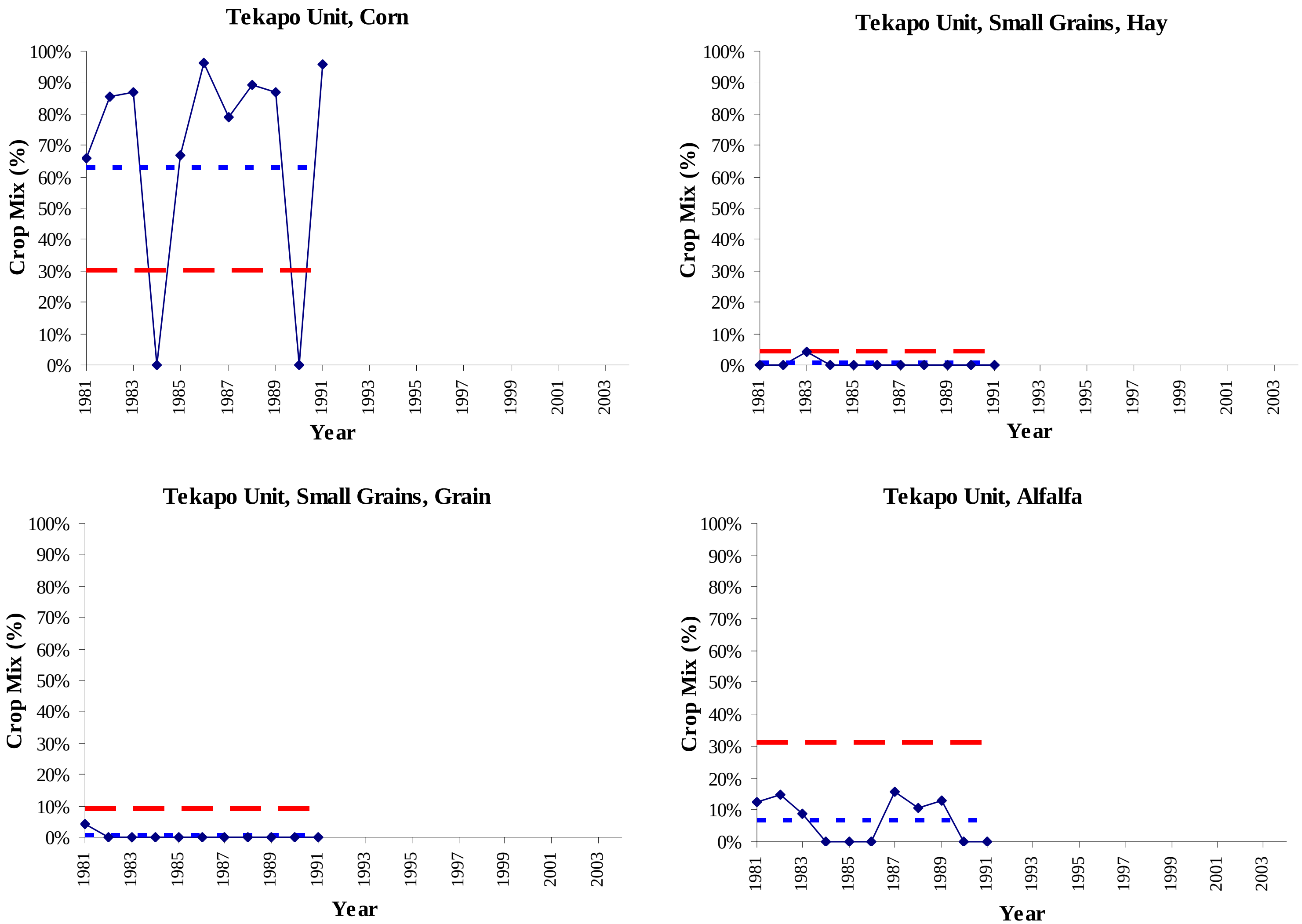


Figure 6: Cropping pattern data for Tekapo unit from BIA crop reports between 1981 and 2004.

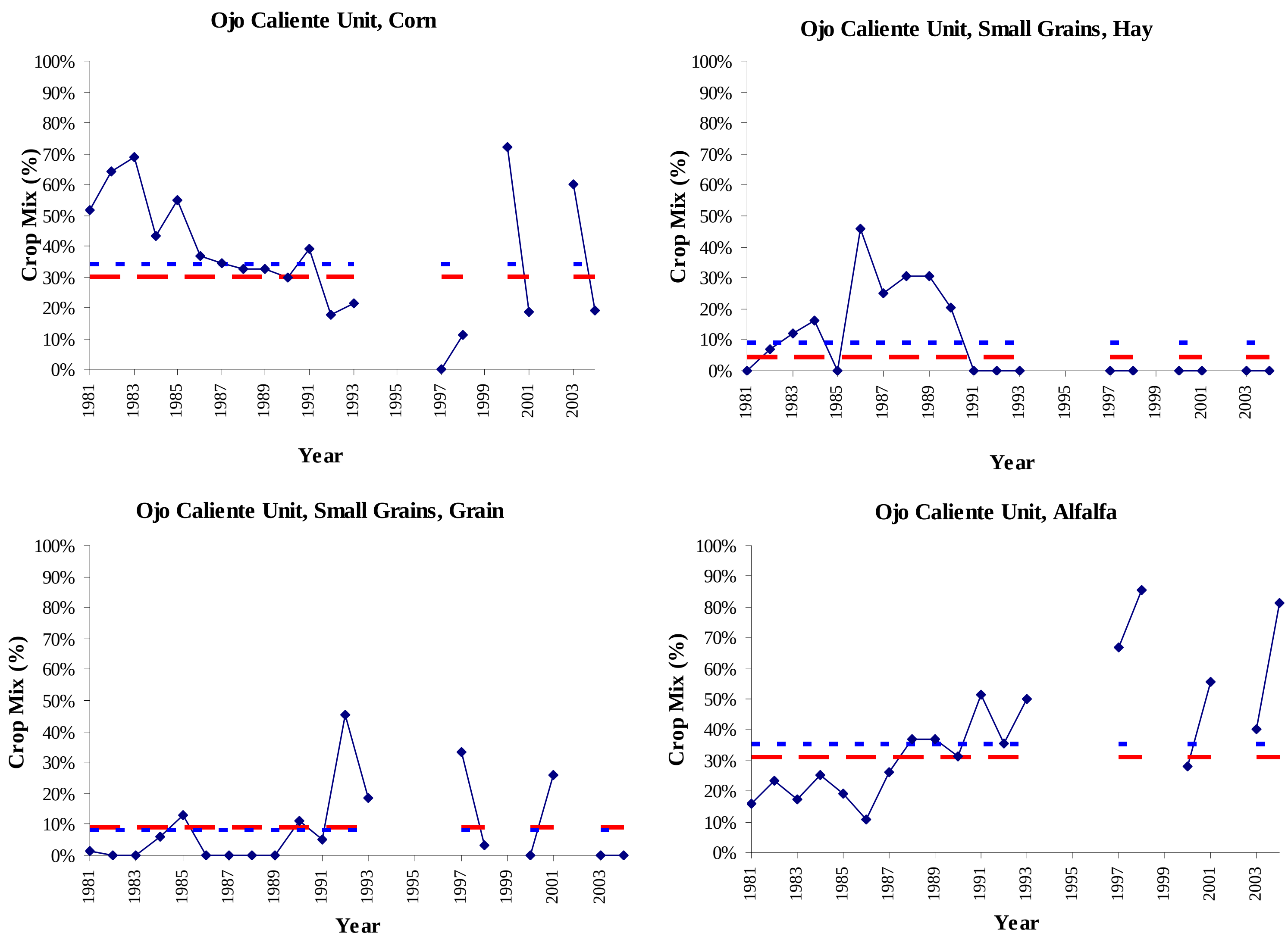
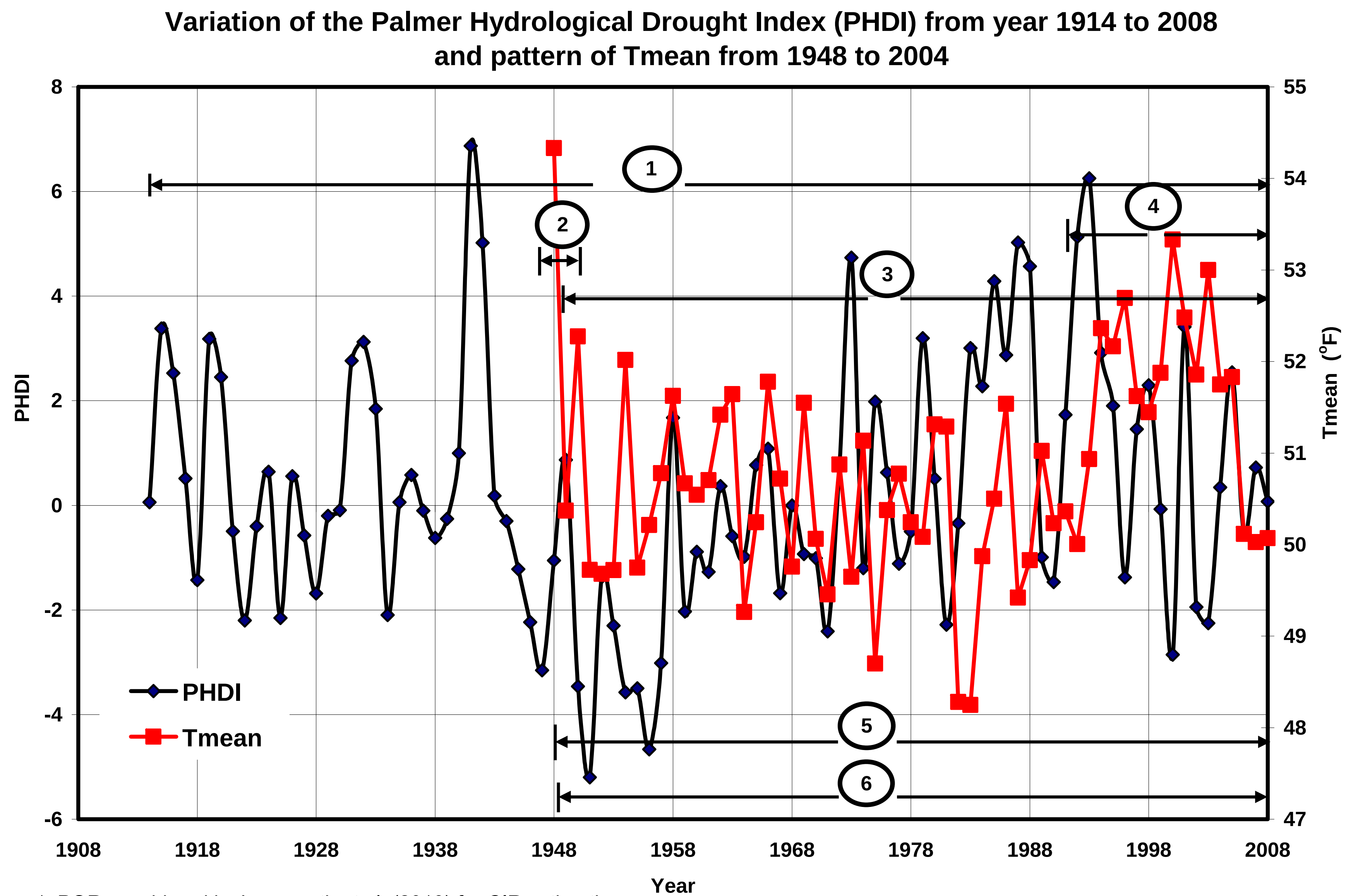


Figure 7: Cropping pattern data for Ojo Caliente unit from BIA crop reports between 1981 and 2004.



Index	description
≤ -4.00	extreme drought
-3.99 to -3.00	severe drought
-2.99 to -2.00	moderate drought
-1.99 to 1.99	mid-range
2.00 to 2.99	moderately moist
3.00 to 3.99	very moist
≥ 4.00	extremely moist

ASCE-PM: the standard ASCE Penman Monteith equation
CIR: Crop Irrigation Requirement
ET_o : Reference ET for a short grass
H-S: Hargreaves-Samani equation (1985)
ET_o POR: Period of Record

1: POR considered by Longworth et al. (2010) for CIR estimation
2: POR considered by Longworth et al. (2010) for determining crop pattern for the whole project area (Note: same POR is used for determining the irrigated acreage for the whole project area
3: POR considered by Stetson Engineers, Inc. (2009) for ETo calculation for the Nutria agricultural unit
4: POR considered by Brengosz (2010) for ETo comparison between ASCE-PM and H-S, 1985
5: POR considered by NRCE (2008) for ETo calculation (Note: in the report, NRCE zstates that the climate data can be completely filled/ extended from July 1, 1948, to December 31, 2004, but it has used the filled/extended data from January 1, 1948, to December 31, 2004.)
6. POR considered by AMEC (STEP 2 and STEP 3) ETo calculation

Figure 8: Time series of Palmer Hydrologic Drought Index (PHDI) for New Mexico between 1914 and 2008 plotted along with mean annual temperature at the Zuni-Black Rock stations (from 1948 – 2004) and indicators of the period-of-records used by AMEC and the US and State of New Mexico experts in their analyses of crop water demands for the Zuni PPIPW lands.