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Civ. No. 07-00681-BB
Zuni River Basin Adjudication
Subproceeding 1 Zuni Indian Claims

Summary of Consumptive Irrigation Requirements, Farm Delivery Requirements, and Project Diversion Requirements for Past and Present Irrigated Lands Served by Permanent Works

Prepared for:

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1. Introduction

The purpose of this report is to complete an evaluation of consumptive use (both ideal and estimates of actual) on the irrigated acres associated with the Past and Present Irrigation from Permanent Works claims by the United States and the Zuni Indian Tribe in the Zuni River Adjudication, Case No. 07-00681-BB. Ideal estimates of consumptive use relate to irrigation requirements that ignore factors that could limit a crop's potential use, such as poor soils or limited water supplies. Typically these approaches are used for short-term irrigation scheduling for a specific field and crop with an existing irrigation system, or for initial estimates of demand for irrigation system design. Estimates of actual water use are often applied for assessing historical water use within a basin within a certain period of study.

The report is presented below and is comprised of the following sections. First, background is provided on several methods to calculate crop water requirements and actual consumptive use. The next section summarizes the compilation and review of historical cropping and yield data from readily available Bureau of Indian Affairs (BIA) cropping reports. Next, results are presented for consumptive use (CU) calculations completed with the following methods, Original Blaney-Criddle, Modified Blaney-Criddle and Hargreaves-Samani (H-S). Yield adjustment calculations that were made to the OBC, MBC and H-S analyses are also discussed. A review of the technical work prepared by the United States was completed. Results and conclusions are discussed at the end of the report.

The work provided in this report was prepared under the direction of John Longworth. In writing this report, Mr. Longworth incorporated information provided by Dr. Zohrab Samani, Gene Franzoy and Mary Kay Brengosz. This information is attached as appendices. Additionally, Molly Magnuson and Julie Valdez assisted Mr. Longworth.

1.1 Background

New Mexico Office of the State Engineer (OSE) has a long history of utilizing consumptive irrigation water requirements (CIR) in water rights adjudications. Engineering assumptions proposed by various references, manuals and research papers provide an overview of how CIR calculations can be applied. The OSE has historically followed five steps to estimate basin wide CIR. These steps include 1) an on-the-ground survey of presently irrigated acres, 2) a survey of available historical materials to estimate past irrigated acres, 3) an estimate of the amount of fallow lands, 4) an assessment of the irrigation facilities, and 5) establishing a cropping pattern. This information provides the basis to calculate a basin-wide CIR, farm delivery requirement (FDR), and project diversion requirement (PDR), collectively known as irrigation water requirement (IWR) estimates. These IWR estimates are typically provided in the context of the hydrographic survey prepared by the OSE. Historically, it is this complete picture that is assessed when estimating an IWR.

There are several methods that have been used in the past by the OSE to estimate CIR. From the period of 1960 though the early 2000's, the methodology proposed by

Blaney and Criddle (1962) commonly referred to as Original Blaney-Criddle (OBC), has been used for basin-wide estimates of CIR. Notably, the OBC method was created with information developed from landmark studies of the Upper Rio Grande Stream System, and the Pecos Stream System. The fact that these methods were derived from actual farming practices in New Mexico, including single farm information as well as basin-wide analyses, facilitated its acceptance and use in New Mexico. The OBC was developed for the express purpose of estimating seasonal crop water requirements absent any more detailed local information and complex climatological information. This calculation is well documented as an approach for estimating seasonal basin wide use. Additionally, the OSE commissioned a report, "Consumptive Use and Water Requirements in New Mexico", Blaney and Hanson, 1965 (TR-32) for the purpose of calculating CIR values that utilizes OBC in various areas around New Mexico.

The Modified Blaney-Criddle (MBC) method proposed in "Irrigation Water Requirements, Technical Release No. 21", USDA, Soil Conservation Service (TR-21), was first published in 1968 and later updated in 1970 for the purpose of irrigation planning (SCS, 1970). MBC was developed to provide a shorter term estimate of crop water demands for planning irrigation delivery systems and improving existing systems, as well as providing estimates of seasonal crop requirements.

The use of these two methods (OBC and MBC) for estimating beneficial use in the Zuni basin is supported by the process by which OBC was initially developed. The use of the OBC and MBC methods provide reasonable basis of actual use since they are based on comprehensive, basin-wide studies of CU of irrigation water in the two principal areas of agriculture in New Mexico, the Rio Grande and Pecos River basins (Blaney & Hanson, 1965).

As part of the request to evaluate CU calculations, two reference evapotranspiration (ET) methods as an approach to estimate ideal and historical use were reviewed, the ASCE Standardized Penman-Monteith (P-M) and the Hargreaves-Samani (H-S). As opposed to calculating the potential ET of each crop directly as is done with the OBC or MBC methods, reference methods first define the ET from a hypothetical standard reference crop. Crop coefficients are then applied to the reference ET to calculate the crop potential ET. Reference ET methods have been in use since at least 1974 (ASCE, 1973) and are related to Penman's published equation from the late 1940's. However, most of the publications that describe the use of reference ET methodologies only describe the application of the method for calculating potential crop ET, or as used in this report, ideal ET. Further, there does not exist a landmark basin wide investigation (such as the Joint Investigations performed with respect to the development of the OBC method) of the appropriateness of the reference methods in New Mexico for calculation of estimated actual historical use calculations.

The reference ET approach is well documented to show a physically derived basis for estimating the factors that influence soil evaporation and plant transpiration. It is less empirical than the OBC or MBC. However, the part of the method that incorporates the growth characteristics of the actual crops under investigation, the crop coefficient, K_c, is not standardized. The ASCE publication that describes the standardized approach to calculate reference ET suggests two different reference standards (grass and alfalfa). A grass-based reference ET is generally referred to as ET_o and an alfalfa-based reference ET is referred to as ET_r. This publication provides at least four different sources for crop coefficients appropriate for use with the grass reference, and at least four different sources for crop coefficients appropriate for use with the alfalfa reference, some of which must be adjusted "for relatively minor overestimation" of ET in the spring and fall. Some crop coefficients are presented as "dual" coefficients which separate the effects of crop growth and evaporation from irrigation, and some are "mean" crop coefficients which incorporate both effects.

Further investigation of these references clearly provides that these methods and the associated crop coefficients are intended for estimating crop water requirements to achieve optimal yields and provide for a crop's potential or ideal use. The potential is only realized in idealized growing environments, including no water shortages. The reference ET approach is recommended by academic researchers for 1) calculating reference ET, and in turn, crop ET, 2) developing new crop coefficients, and 3) facilitating transfer of existing crop coefficients. The ASCE publication does not discuss how to utilize this approach in a basin-wide historical use analysis, or if these equations provide a reasonable equivalent to actual historical use under less than ideal growing conditions. Another widely used publication that lists the P-M equation as a preferred approach notes that for predicting actual crop ET for use in "regional water balance studies … or estimating historical water use," adjustments must be made (FAO-56, 1998).

Another readily available reference, the Soil Conservation Service National Engineering Handbook (SCS-NEH, 1993) contains a discussion regarding the appropriateness of the use of MBC in the western United States in establishing water rights. While the SCS states that reference crop techniques provide improved accuracy and consistency, the SCS does not provide any discussion on the accuracy of these methods in assessing actual historical basin wide use. Rather, substantial discussion is made within this document that it is intended for planning irrigation systems and to predict future short-term and long-term crop needs, not estimating actual water use. It has been observed that in practice, especially in climates where water supplies are limited compared to abundant land, optimal ETs are seldom obtained (Samani, 2009).

There is clear evidence that at the level of a single field, single crop analysis, the state of the science is to utilize a reference ET method to forecast potential crop ET for irrigation scheduling to produce optimal yields and ideal ET rates. However, this is a different engineering question than estimating historical basin-wide use. The approach to estimate historical use has traditionally involved identifying active areas of irrigation, estimating total historically irrigated areas, calculating a reasonable estimate of fallowed acres, assessing facilities, and providing a cropping pattern. From this information, a CIR/FDR/PDR is estimated. This last step has been based on the OBC and MBC methods, which have been described by their authors as a "method of computing consumptive use and irrigation requirements for lands where few or no data, except climatological, are available". Conversely, reference ET methods do not have the same support by the authors of such texts and notably, describe situations whereby unspecified adjustments are necessary to "estimate historical use" when ideal (or standard) conditions do not exist.

1.2 Growing Season

Crops grown in the Zuni area can be separated into perennial and annual crops: perennial crops are those such as alfalfa, pasture, hay, and orchards while annual crops are those such as corn, wheat, other small grains, and assorted vegetables such as beans, squash, and chile.

The growing season for perennial crops is defined by threshold temperatures in the spring and fall that trigger the start and stop of growth, and may also be defined in the fall by freeze temperatures.

Annual crops have a growing season defined by planting and harvest dates. Planting dates are generally tied to mean daily air temperature and for use in calculating CU can be based on the temperature or on observed planting dates.

Different methods of computation of CU may have slightly different growing seasons due to the use of growing degree days versus set start and end temperatures or days. Growing season criteria used for each method is shown in a table in the pertinent section of the report. Local data is generally preferred and utilized in all methods when readily available.

1.3 Crop Characteristics

In the discussion of different methods for estimating crop CU, the manner in which a method considers the growing season and crop growth characteristics is captured in the crop coefficient (K_c). The OBC, MBC, and reference ET methods generally address this question in a similar manner. A brief discussion is provided to illuminate the principle differences between the methods.

The OBC method can generally be described by the formula U = CU = KF, where U is the growing season consumptive use, K is an empirical crop consumptive use coefficient for the season, and F is the sum of the monthly consumptive use factors. The crop coefficient combines both climatic and crop growth effects. This method provides an empirical approach to estimate seasonal crop demands based on measurements of CU in New Mexico, Arizona, and other areas in the western United States. The crop coefficients are based on the assumptions that 1) crops receive an adequate water supply throughout the growing season and 2) the fertility, crop vigor, crop stands and management are average. Additionally, the coefficients are defined for and applied for two periods within the growing season, 1) the frost free period and 2) before and after the frost free period.

The MBC utilizes a similar approach and the same basic equation as the OBC, but incorporates greater detail that provides short-term CU coefficients from five days to monthly. The first refinement is a climatic coefficient related to the mean air temperature. The second refinement is a crop growth stage coefficient. These additional factors are important for short time frames and provide a slightly less empirical approach than the seasonal coefficients in OBC.

For reference ET methods, two general approaches exist for incorporating crop characteristics for estimating potential crop ET. The first is the single crop coefficient and the other is the dual crop coefficient. Within these approaches, K_c can be expressed as a time series estimates or through the growing degree day approach. The single time averaged K_c incorporates averaged wetting effects into the K_c factor. The dual K_c approach separates the soil and plant impact to estimates of evaporation and transpiration separately.

The following citation from FAO-56 provides a good summary regarding the application of the single coefficient method.

"Most of the effects of the various weather conditions are incorporated into the ET_o estimate. Therefore, as ET_o represents an index of the climatic demand, K_c varies predominately with the specific crop characteristic and only to a limited extent with climate. This enables the transfer of standard values for K_c between locations and between climates. This has been a primary reason for the global acceptance and usefulness of the crop coefficient approach and the K_c factors developed in past studies."

The use of the crop coefficients between OBC/MBC and reference ET illuminates the difference between the two approaches. The OBC provides adequate seasonal estimates of crops demands considering average conditions. The MBC provides adequate estimates of crop demands for periods as short as five days to facilitate the design of irrigation, distribution and storage systems which are affected by short-term variations in demand over the season. For both OBC and MBC, crop coefficients were determined by research for many crops at many locations in the western U.S., incorporating a variety of soils, water supply and irrigation methods. On the other hand, reference ET methods, as noted in the previous section, are designed differently. Crop coefficients specifically developed for use with reference methods result in optimal or ideal crop demand.

1.4 Cropping Pattern

The cropping pattern used in this analysis is based on data compiled from fifty years of crop reports from the United States Bureau of Indian Affairs (BIA). The State of New Mexico obtained all known, readily available, crop reports for the Zuni Pueblo. Reports are for the following time periods: 1917, 1921-1934, 1936-1942, 1945, 1947-1950, 1952-1953, 1955, 1981-1993, 1997-2001, and 2003-2004. These crop reports provide valuable information for both the types and acreages of crops grown on the Pueblo as well as the yields from these crops. All the crop reports were analyzed for completeness of data such as acreage, yield, and irrigated versus non-irrigated notation. The 1947-1950 period had records for all five agricultural areas in the Zuni Pueblo: Zuni, Nutria, Ojo Caliente, Pescado, and Tekapo, and a summary sheet for the Zuni Pueblo, for 1947 and 1950. This was the most complete set of BIA crop reports that also had the most amount of irrigated acreage clearly identified for the period of available records. Therefore, the analysis in this report is based on the cropping pattern from the period 1947 to 1950. Other time periods may have indicated greater irrigated acreage amounts but the reports were not as complete. This time period provides a reasonable basis to estimate historical water use and a long-term idealized CIR estimate.

Reported crops included corn, wheat, barley, rye, oats, oat hay, rye hay, alfalfa, wild hay, pasture, orchard and various garden crops such as beans, potatoes, chile, melons and pumpkins. The following crops were combined to obtain the cropping pattern 1) small grains; includes oats, rye, barley, wheat, and small grain hay, 2) hay; includes hay and pasture and 3) garden crop; includes garden, beans, chile, melons, and pumpkins. Orchards were included with pasture due to the small acreage of orchards and the similar characteristics of these perennial crops. Alfalfa and corn were kept as individual crops. The crop percentage was determined using the reported irrigated acreage of each crop for a particular year (or combination of crops) divided by the annual total irrigated acreage reported for that year. The cropping pattern was analyzed for each individual year and an average of the 1947-1950 period. The yearly cropping pattern, the average cropping pattern and the average crop ratio percentage over the 1947-1950 time period is shown in Table 1.

Crop yield can be an important indicator of actual crop water use, therefore the yield records were analyzed for completeness of yield information. Crop yield is reported in many, but not all, of the BIA crop reports and some years do not contain yield information for all crops. The 1947-1950 time period had complete records of crop yields for alfalfa, corn and wheat. Wheat and other small grains were combined for development of the overall cropping pattern. However, wheat was separated from other small grains when the yield data was tabulated. This ensured that any yield adjustment to the potential consumptive use calculations, discussed later in this report, was only computed for wheat and not other small grains.

Table 1. Cropping Pattern for Zuni Pueblo for the Period 1947 – 1950

Year	1947		1948		1949		1950		1947-50 Average	
Crop	Crop %	Acres	Crop %	Acres	Crop %	Acres	Crop %	Acres	Crop %	Acres
Corn	23%	526.0	24%	614.0	24%	667.0	24%	635.0	24%	610.5
Small Grains	34%	761.0	36%	937.0	36%	996.5	37%	986.0	36%	920.1
Alfalfa	27%	613.0	24%	623.0	23%	638.0	24%	633.0	25%	626.8
Garden	14%	317.0	15%	376.0	15%	415.0	14%	371.0	14%	369.8
Pasture	2%	55.0	2%	41.0	2%	43.0	2%	43.0	2%	45.5
Total	100%	2272.0	100%	2591.0	100%	2759.5	100%	2668.0	100%	2572.6

1.5 Climate Data

Temperature, precipitation, and frost date data recorded at the Zuni Station No. 299897, and the Black Rock Station No. 291018, were used in this analysis. The Black Rock station has an elevation of 6450 feet and a period of record from 1914-1948. The Zuni station is a National Weather Service station with an elevation of 6310 feet and a period of record from 1949-2008. Although the Black Rock station was discontinued in 1949, it is similar enough to the Zuni station in location and elevation that the records were combined to create a single period of record from 1/1/1914 to 12/31/2008. This 95 year time period includes both dry and wet years, and was used to calculate the long-term average CIRs. However, as stated in the cropping pattern section of this report, the analysis also evaluates the 1947-1950 time period, the period of greatest irrigated area supported by BIA records. The climate data for each individual year was used to compute the estimated CIR for that year.

The precipitation, maximum and minimum daily temperatures were averaged for both the Zuni and Black Rock data sets to obtain monthly averages for the combined period of record. Appendix A provides a detailed listing of the review and quality assurance/quality control (QA/QC) procedure utilized for this report.

2. The Original Blaney-Criddle Method

The OBC method was briefly described in the background section of this report and was applied in this report as explained in TR-32. OBC CIRs were computed for each crop for each year of the 1947-1950 time period. Also, long-term climate data for the combined Black Rock and Zuni weather stations was used to calculate the long-term average CIR for each crop in this report.

2.1 Growing Season

The growing season criteria for each of the annual and perennial crops in the Zuni area are shown in Table 2. The OSE Technical Report 52 (Longworth, 2008) was used for garden as this provides a longer estimate of the growing season

Table 2. Long-term Average Temperature Growing Season Information Utilized in the Original Blaney-Criddle Method.

Crop	Growing Season Start Date Criteria	Growing Season End Date Criteria	Source	Number of Growing Days	Long Term Growing Season Start Date	Long Term Growing Season End Date
Corn	25-May	1-Oct	TR-32	130	25-May	1-Oct
Small Grains	20-Mar	15-Jul	TR-32	118	20-Mar	15-Jul
Alfalfa	50° F mean	28° F frost	TR-21	178	23-Apr	17-Oct
Garden	32° F mean	32° F mean	Longworth	139	22-May	7-Oct
Pasture	45° F mean	45° F mean	TR-21	214	3-Apr	2-Nov

2.2 Seasonal Consumptive Use Coefficients (CU)

The distinctive feature of the OBC method is that the CU coefficient (K) remains constant throughout the frost-free period. A different CU coefficient is used for that part of a crop's growing season that occurs before the last spring frost (T<32°F) or past the first fall frost (T>32°F). CU coefficients used in this report are provided in TR-32.

2.3 Potential Consumptive Use (CU)

The potential CU was computed following the procedure explained in TR-32.

2.4 USBR Effective Rainfall (R_e)

The amount of rainfall that becomes available to crops is influenced by the following factors: (1) duration and intensity of rainfall; (2) antecedent moisture condition of soil; (3) infiltration capacity of the soil; (4) presence of surface seals and crusts; (5) slope of fields; (6) root development of the crop; and (7) interception by the plant canopy.

As it was published in 1950, the OBC method did not include a procedure for estimating effective rainfall. Blaney (Blaney & Criddle, 1962) later adopted a method that was developed by the U.S. Bureau of Reclamation (USBR). The USBR method is used for calculation of effective rainfall for the potential consumptive use calculated with OBC for this report and is applied as explained in TR-32.

2.5 Consumptive Irrigation Requirement (CIR)

The monthly CIR for each crop in the cropping pattern is computed by subtracting the effective precipitation (Re) from the potential consumptive use (U) as explained in TR-32. The total or seasonal consumptive irrigation requirement for a specific crop is the sum of the monthly consumptive irrigation requirements.

2.6 Crop Distribution Ratio (CDR)

The crop distribution ratio (CDR) is computed by dividing the area planted in each individual crop by the total area for all crops included in the cropping pattern and is shown as a crop percentage in Table 1.

2.7 Smeal Alfalfa Yield Adjustment

In the 1980's, researchers at New Mexico State University Agricultural Science Center in Farmington, NM developed a crop production function for alfalfa that correlates annual evapotranspiration with annual crop yield (Smeal, 1995). The Smeal crop production function is shown in the following equation (in English units):

$$Y = -3786+403\ ET \qquad (1)$$

Where Y is the annual yield in pounds per acre at 15% moisture content (normal field-dried condition), and ET is the annual ET in inches. This estimate of crop ET needs to be adjusted for effective precipitation to obtain the CIR.

Rearranging equation (1) to calculate ET from reported yield gives the equation:

$$ET = (Y + 3786)/403 \qquad (2)$$

Substituting the reported yield for a specific calendar year into equation (2) provides an estimate for the corresponding ET for alfalfa for that year. For this report, alfalfa yields reported by the BIA for the period 1947-1950 were used to estimate ET for alfalfa, resulting in an ET_{adj} for alfalfa. The effective rainfall calculated with OBC for alfalfa is subtracted from the yield estimated ET_{adj} to obtain the adjusted CIR.

2.8 Weighted CIR (WCIR)

Multiplying the CIR by the crop distribution ratio yields the weighted CIR for a crop. The sum of all the weighted CIRs is the CIR for the overall cropping pattern. For the long-term average, the average 1947-1950 cropping pattern was applied to the 1914-2008 CIR. Table 3 below provides a summary of 1) the average CIR values for the 1947-1950 time period, 2) the average CIR for the 1947-1950 time period with an adjustment for reported alfalfa yields, and 3) the average CIR computed using long-term climate data (1914-2008) and the average cropping pattern for the period of 1947-1950.

Table 3. Summary of the Original Blaney-Criddle CIR Values

		Average for 1947-50		Average Adjusted for 1947-50		Long-term for 1914-2008	
Crop	% Acreage	CIR	WCIR	CIR	WCIR	CIR	WCIR
Corn	24%	1.3	0.3	1.3	0.3	1.2	0.3
Small Grains	36%	1.0	0.4	1.0	0.4	1.0	0.4
Alfalfa	25%	2.0	0.5	0.9	0.2	1.7	0.4
Garden	14%	1.3	0.2	1.3	0.2	1.0	0.1
Pasture	2%	2.0	0.0	2.0	0.0	1.7	0.0
Total	100%		1.4		1.1		1.2

Note: The CIR and WCIR values are in acre-feet/irrigated acre/annum

3. The Modified Blaney-Criddle Method

The MBC method was described in the background section of this report and was applied as explained in TR-21. MBC CIRs were computed for each crop for each year of the 1947-1950 time period. Also, long-term climate data for the combined Black Rock and Zuni weather stations was used to calculate long-term CIRs for each crop in this report for 1914-2008.

3.1 Growing Season

The growing seasons as identified within TR-21 and TR-32 for the annual and perennial crops in the Zuni area are shown in Table 4. TR-32 was chosen over TR-21 when sufficient local detail was provided. If local information was not of sufficient detail, TR-21 was used. The OSE Technical Report 52 (Longworth, 2008) was used for garden as this provides a longer estimate of the growing season.

Table 4 Long-term Average Temperature Growing Season Information Utilized in the Modified Blaney-Criddle Method.

Crop	Growing Season Start Date Criteria	Growing Season End Date Criteria	Source	Number of Growing Days	Long Term Growing Season Start Date	Long Term Growing Season End Date
Corn	25-May	1-Oct	TR-32	130	25-May	1-Oct
Small Grains	20-Mar	15-Jul	TR-32	118	20-Mar	15-Jul
Alfalfa	50° F mean	28° F frost	TR-21	178	23-Apr	17-Oct
Garden	32° F mean	32° F mean	Longworth	139	22-May	7-Oct
Pasture	45° F mean	45° F mean	TR-21	214	3-Apr	2-Nov

3.2 Consumptive Use Coefficients

The distinctive feature of the MBC method is the procedure used to arrive at the final value of the CU coefficient (k). First, the climatic coefficient (k_t), which is expressed as a function of the mean monthly temperature, is computed. Then the value of the crop growth stage coefficient (k_c) is obtained from a curve plotted on a graph or a tabulation. Because the growth characteristics of each crop are different, a separate curve is generally required for each crop. Curves for a limited number of crops were published in TR-21. In this report the coefficients from TR-21 were applied as explained in TR-21.

3.3 Potential Consumptive Use (CU)

The potential CU was computed following the procedure explained in TR-21.

3.4 Effective Rainfall (R_e) Computed Using the SCS Method

The Soil Conservation Service developed a method for estimating effective rainfall, which is a function of CU and rainfall, as a result of research that evaluated the soil-moisture balance derived from analysis of 50 years of precipitation records at each of

22 Weather Bureau stations in the United States. This method is generally applied in this report as explained in TR-21.

3.5 Consumptive Irrigation Requirement (CIR)

The monthly CIR for each crop in the cropping pattern is computed by subtracting the effective precipitation (R_e) from the potential CU. This calculation is expressed as:

$$CIR=CU-R_e$$

The total or seasonal CIR for a specific crop is the sum of the monthly CIRs.

3.6 Crop Distribution Ratio (CDR)

The crop distribution ratio (CDR) is computed by dividing the area planted in each individual crop by the total area for all crops included in the cropping pattern and is shown as a crop percentage in Table 1.

3.7 Smeal Alfalfa Yield Adjustment

The adjustments made utilizing the Smeal equation in Section 2.7 above are also used here. They are adjusted for effective precipitation utilizing the MBC results for alfalfa and the SCS method.

3.8 Weighted CIR (WCIR)

Multiplying the CIR by the crop distribution ratio yields the weighted CIR for a crop. The sum of all the weighted CIRs is the CIR for the cropping pattern. Table 5 below provides a summary of 1) the average CIR values for the 1947-1950 time period, 2) the average CIR for the 1947-1950 time period with an adjustment for reported alfalfa yields, and 3) the average CIR computed using long- term climate data (1914-2008) and the average cropping pattern for the period of 1947-1950.

Table 5. Summary of the Modified Blaney-Criddle CIR Values.

		Average for 1947-50		Average Adjusted for 1947-50		Long Term for 1914-2008	
Crop	% Acreage	CIR	WCIR	CIR	WCIR	CIR	WCIR
Corn	24%	1.3	0.3	1.3	0.3	1.2	0.3
Small Grains	36%	0.9	0.3	0.9	0.3	0.8	0.3
Alfalfa	25%	2.2	0.5	1.0	0.2	2.0	0.5
Garden	14%	1.2	0.2	1.2	0.2	0.9	0.1
Pasture	2%	1.9	0.0	1.9	0.0	1.7	0.0
Total	100%		1.4		1.1		1.2

Note: The CIR and WCIR values are in acre-feet/irrigated acre/annum

4. The Hargreaves-Samani Method

The Hargreaves-Samani equation was developed as a method for estimating grass reference ET. It has been widely used to predict potential ET, with many studies using the equation to produce historical time series of potential ET using historical air temperature data. In contrast to other methods of calculating reference ET which require data for several climatic parameters, this equation (generally referred to as the 1985 Hargreaves-Samani equation (H-S)) requires data only for maximum and minimum temperatures. The 1985 H-S equation has been extensively evaluated and is recommended for use where data quality is questionable or where historical data for additional parameters are missing. "When the weather data site is not located within a large, well-watered area, the 1985 Hargreaves-Samani method will generally have less aridity bias impact in the estimate of ET, as compared to the combination equations." (Hargreaves and Allen, 2003). This equation is less impacted than Penman-type equations when data are collected from arid or semiarid, non-irrigated sites. For the purposes of this report, H-S is applied on a daily basis to establish ET_o and ET_c and is then summed to establish an annual value. The H-S equation was selected due to the availability of local temperature and precipitation data and lack of locally available climate data required for other reference methods. In addition, the H-S equation was developed from Davis, California data where mean humidity and wind speed is similar to NM climate, thus does not require local calibration for NM.

4.1 Grass Reference Evapotranspiration ET_o

For the purposes of this report, H-S is applied on a daily basis to establish the reference $ET_{o.}$ ET_c is calculated from crop coefficients applied to the daily ET_o values. The daily values are then summed to establish an annual value for each crop.

4.2 Growing Season

The growing seasons for each of the annual and perennial crops in the Zuni area are shown in Table 6. The growing seasons were based upon temperatures from the various sources listed.

Table 6 Long-term Average Temperature Growing Season Information Utilized in the Modified Blaney-Criddle Method.

Crop	Growing Season Start Date Criteria	Growing Season End Date Criteria	Source	Number of Growing Days	Long Term Growing Season Start Date	Long Term Growing Season End Date
Corn	GDD	GDD	Wright	149	12-May	8-Oct
Small Grains	GDD	GDD	Wright	130	21-Mar	29-Jul
Alfalfa	GDD	GDD	GDD Smeal	240	19-Mar	14-Nov
Garden	GDD & 60F	GDD & Days Growing	FAO 56 & Wright	133	12-May	22-Sep
Pasture	7 days prior last -4°C	7 days after last -4°C	FAO 56	252	12-Mar	19-Nov

4.3 Crop Coefficients (K_C)

The potential crop ET_c is calculated by multiplying the ET_o by a crop coefficient K_c.

For this report, crop coefficients were obtained from information from Wright 1981, FAO-56, and using research data from Smeal et al, 1995. This work is presented in detail in Appendix B.

4.4 Potential Consumptive Use (CU)

Using the daily H-S ET_o and the K_c for the appropriate crop, the daily ET_c for each crop in the cropping pattern is calculated and then summed to obtain monthly ET_c for each crop. This ET_c represents a potential ET_c, based upon the daily climate data for the Black Rock and Zuni Pueblo data set. For well-managed, non-stressed fields that are not short of water, this ET_c would represent actual field conditions. The ET_c was calculated for each crop for each year of the 1947 – 1950 time period. Also, long-term climate data for the combined Black Rock and Zuni weather stations was used to calculate a long-term average ET_c for each crop in this report.

4.5 Effective Rainfall (R_e)

Calculation of R_e for the H-S method was done on a monthly basis for each crop, using the SCS method, the ET_c for that crop and the precipitation data for the appropriate period from the appropriate weather station. The monthly R_e was then totaled to get an annual (growing season) R_e.

4.6 Consumptive Irrigation Requirement (CIR)

The monthly CIR for each crop in the cropping pattern is computed by subtracting the effective precipitation (R_e) from the potential CU. This calculation is expressed as:

$$CIR=ET_c-R_e$$

The total or seasonal CIR for a specific crop is the sum of the monthly CIRs.

4.7 Crop Distribution Ratio (CDR)

The crop distribution ratio (CDR) is computed by dividing the area planted in each individual crop by the total area for all crops included in the cropping pattern and is shown as a crop percentage in Table 1.

4.8 Adjusted ET_c

The Food and Agriculture Organization of the United Nations, Irrigation and Drainage Paper No. 56 (FAO-56, 1998) provides an equation (Equation No. 103) that is used to calculate a stress factor (K_s) which is multiplied by ET_c to predict $ET_{c\ adj}$ in the presence of conditions which can reduce crop yields from potential levels. Such conditions may include water shortage or other environmental stress, low plant density, insects or disease or low plant virility. The stress factor approach is considered appropriate for use in predicting actual crop ET for use in regional water balance studies, for studies of ground-water depletions and recharge, or for estimating historical water use. Therefore, this equation is applicable for this estimate of historical water use. The equation uses actual crop yield (Y_a,) and potential crop yield (Y_m,), in combination with a crop specific yield response factor from Food and Agriculture Organization of the United Nations, Irrigation and Drainage Paper No. 33 (FAO 33, 1979), K_y to calculate K_s.

Yield data is a critical indicator of the actual use of water by crops on irrigated lands in the Zuni Pueblo. As stated above, it is inappropriate to apply the H-S equation to a basin-wide estimate of actual consumptive use without making adjustments to the calculated potential crop ET for effects due to non-standard conditions when conditions that reduce crop yield are known to exist in the area under investigation. This includes water shortages. Review of the reported yield data clearly show that regionally obtainable yields have not been realized. Actual yield (Y_a) data for the historically grown crops is provided in the BIA crop reports. Maximum yield (Y_m) obtained under actual farming conditions, is defined in the publication FAO-33 as "the harvested yield of a high producing variety, well-adapted to the given growing environment, including the time available to reach maturity, under conditions where water, nutrients and pests and diseases do not limit yield." Y_m values used in this analysis were obtained from FAO-33 for corn and wheat. The actual ET in this analysis using the FAO-33 method for adjusting yields was limited to no lower than 50% of the maximum crop ET, since the estimated actual ET values calculated with the actual yield data were substantially lower than the 50% amount. It should be noted that the FAO-33 relationship assumes no changes in crop density as the crop yield reduces below the potential. The alfalfa adjustment discussion in Section 2.7 above was then used to adjust the idealized alfalfa calculation. Table 7 shows the weighted CIR using the yield adjusted CIR values.

4.9 Weighted CIR (WCIR)

Multiplying the CIR by the crop distribution ratio yields the weighted CIR for a crop. The sum of all the weighted CIRs is the CIR for the cropping pattern. Table 7 below provides a summary of 1) the average CIR values for the 1947-1950 time period, 2) the average CIR for the 1947-1950 time period with an adjustment for reported alfalfa yields, and 3) the average CIR computed using long- term climate data (1914-2008) and the average cropping pattern for the period of 1947-1950.

Table 7. Summary of the Hargreaves-Samani CIR Values.

	Average for 1947-50			Average Adjusted for 1947-50			Long Term for 1914-2008		
Crop	% Acreage	CIR	WCIR	% Acreage	CIR	WCIR	% Acreage	CIR	WCIR
Corn	24%	2.0	0.5	24%	0.8	0.2	24%	1.8	0.4
Small Grains	36%	1.8	0.7	13%	1.8	0.2	36%	1.9	0.7
Wheat	0%	0.0	0.0	23%	0.8	0.2	0%	0.0	0.0
Alfalfa	25%	3.0	0.7	25%	0.9	0.2	25%	2.9	0.7
Garden	14%	1.3	0.2	14%	1.3	0.2	14%	1.3	0.2
Pasture	2%	2.4	0.0	2%	2.4	0.0	2%	2.6	0.0
Total	100%		2.1	100%		1.1	100%		2.0

Note: The CIR and WCIR values are in acre-feet/irrigated acre/annum

5. ASCE Standardized Penman-Monteith

The American Society of Civil Engineers (ASCE) "Standardized Reference Evapotranspiration Equation" (ASCE, 2005) was developed in response to a request from the Irrigation Association (IA) for the establishment of a benchmark reference evapotranspiration equation. This equation was applied to limited data for 1991-2008 as described in Appendix A to obtain a reference ET_o for the Zuni area. While there is data available at the Gallup Airport that can be applied to the ASCE equation, the data is collected in an area that does not represent standard conditions. ASCE provides that “Weather data must be screened before use in any ET equation, including the standardized equation, to ensure that data are of good quality and are representative of well-watered conditions.” Therefore, significant data quality assessments are necessary as well as steps to adjust the data to ensure it is representative of reference conditions. For the application to this analysis, it is concluded that the effort necessary is inconsistent with any accuracy gained. Therefore, the ASCE approach is not pursued any further.

6. Critique of 2008 Technical Report Prepared by L. Niel Allen Overall Summary

A critique of the report titled “Zuni Indian Reservation Identification of Lands and Estimation of Water Requirements for Past and Present Irrigated Lands Served by Permanent Irrigation Works, November 3, 2008” (prepared by L. Niel Allen of National Resources Consulting Engineers, Inc. (NRCE)) (Allen, 2008) and associated corrections has been completed. This critique was completed in response to a request to assess the Allen report. The request also included a task to summarize comments regarding the Allen report from Gene Franzoy, Mary Kay Brengosz, and Dr. Zohrab Samani. This critique is organized into two sections, the first is a summary of the listed expert’s comments and the second provides a detailed explanation of the comments prepared by the OSE. This section provides a list of the specific issues by general topic followed by a discussion. The listed items are in no particular order.

6.1 Cropping Pattern

Allen used county-wide agricultural statistics compiled by the National Agricultural Statistics Service in developing a final cropping pattern for Zuni Pueblo. Allen also incorporates a 20% pasture component in the cropping pattern based on the county data from recent years. However, there is locally available information from the Bureau of Indian Affairs (BIA) on cropping patterns within the area of the claim for historical time periods. These local data are preferred. The local BIA records do not support a 20% value for pasture.

6.2 Comparison of the Reference ET Methods

Allen provides a comparison of three reference ET methods, the ASCE Penman-Monteith method, the Hargreaves-Samani equation and the 1985 Hargreaves equation and ultimately chooses the Penman-Monteith method for calculation of potential consumptive use. Based on the Allen report, the Hargreaves-Samani methods and the ASCE Penman-Monteith method calculate substantially the same answer. Allen does not discuss why the Hargreaves–Samani methods are inappropriate to use for the purpose of calculating idealized water use in this matter. Although the reference ET calculated with the P-M method is similar, the method required use of data derived from distant weather stations. The Hargreaves–Samani approach is simpler, and can use data directly measured within the region. According to Dr. Samani's review, Allen appears to make a comparison of two different H-S equations. The references provided indicate that these are the same equation, based on different units. It is not clear why a comparison is made to the same equation.

6.3 Climate Data Set

Allen prepared climate data sets and calculated reference ET for three "elevation bands" or "elevation zones" that he applied to the various agricultural areas at Zuni Pueblo. Description of what elevation bands are and why they are necessary is not provided. The elevation bands appear to comprise 200 feet of elevation, but no basis for this is provided. It appears that three elevation bands were used to characterize the change in elevation of the irrigated areas at Zuni, which range from approximately 6200 feet at Ojo Caliente to 6800 feet at Nutria. The difference of approximately 600 feet of elevation does not warrant the additional complexity introduced by the use of the elevation bands. In addition, data for the highest elevation band appear to be derived from the McGaffey weather station, at an elevation of 8000 feet.

There is no explanation of why the Black Rock climate data is not used for more than for filling one year of data. This station can be used in combination with Zuni to obtain a substantially longer record that can be used with the H-S method. No supporting information is provided to substantiate limiting the record to Zuni plus one year of Black Rock.

Most of the additional data elements required for the P-M Method selected by Allen are not available at weather stations near Zuni Pueblo. Data for these additional parameters were obtained, either directly or through mathematical relationships, from weather stations located far from the Zuni area. Data sets for dewpoint temperature, wind speed and solar radiation were created from the non-local stations at Gallup airport for 1973-2004 and at Albuquerque airport for 1948-1972. The Gallup or Albuquerque climate stations are not located in standard reference environments. Also, the Albuquerque station is located 130 miles away across the Continental Divide. It is not clear why the P-M approach was selected for Allen's analysis when so much non-local input is required, particularly when other acceptable approaches exist with data measured locally.

Allen did not provide background to show that the data reported at these weather stations are collected in a way that allows use in a reference equation without adjustment. For example, many airports measure wind speed at ten meters height. Data collected at this measurement height must be adjusted to two meters to be properly used in the ASCE Penman-Monteith equation.

The validity of the extensive data filling with mathematical relationships at distant weather stations was not demonstrated. No comparisons of data sets are provided by Allen to illustrate the impacts (or lack thereof) of filled data and raw data. Predicted data were not compared with data measured in the study area, and time periods containing predominantly filled data were not compared to time periods containing more local data, particularly for filled data elements that were further subjected to elevation adjustment. For example, Mary Kay Brengosz points out that daily T_{Min} from the local data could have been compared with the filled T_{Dew} daily data from the airport locations.

6.4 Sky Cover and Solar Radiation

Allen used sky cover data to estimate solar radiation for part of the study period, and daily temperature range to estimate solar radiation, from which he estimated sky cover, for the later part of the study period. Sky cover data for Gallup airport, the nearest weather station with such data, were available for 1973-1996. For 1948-1973, the data were filled by a regression relationship with Albuquerque airport data, developed from the overlapping data in the 1973-1996 period. The resulting solar radiation was not compared to a theoretically derived clear sky solar radiation curve to check the validity of the method. Allen did not provide a comparison of the actual data from Gallup with the results of the regression equation from the same period. Allen did not adjust the sky cover for elevation. He did adjust dewpoint temperatures, used in the solar radiation equations, for the elevation bands, and this appeared to result in small changes in solar radiation for the 600-foot elevation change in the elevation bands. However, the dewpoint temperatures were derived from the Gallup and Albuquerque airports and data were not available at other weather stations to investigate the validity of the adjustments. It is not clear why this approach was used rather than the simpler temperature-based approach of the H-S method.

Another example of the use of non-local information is Allen's use of a relationship between sky cover and solar radiation that was developed by the Tennessee Valley Authority (TVA). No evidence of this relationship's validity or applicability to conditions in New Mexico was provided in the Allen report, and the publication cited was not listed in Allen's references in the November 2008 report.

Allen justifies his use of the Dingman equations for solar radiation on the basis that the ASCE recommendations and FAO-56 equations rely on a fixed albedo and do not consider the effect of snow-covered surfaces. Snow cover is typically not present in the growing season in New Mexico. The selection of alternate equations seems unnecessary.

6.5 Precipitation

Daily precipitation was filled by Allen using a complex procedure combining methods from two references, involving 22 stations within a 50 mile radius of McGaffey and Zuni/Black Rock. Up to nine stations are used to fill a single day of data. Without more information about the referenced methods for data filling, it is not clear if they are suitable for use in combination. Since no summaries or comparisons were provided, it is not clear if the complex procedure resulted in a better estimate of daily or monthly precipitation than simply filling from nearby stations. Given the complex procedure described in the report, there is no reasonable support for the necessity of its use.

The Allen report states that “better results” were obtained by using fewer stations and a smaller radius than his referenced methods recommended, but gives no indication of how “better” is defined. Is it better because it is more complete, or because of comparative analysis, or because it produces a higher or lower CIR?

These calculations required filling data from 22 stations. It is not clear that Allen has visited all 22 stations, documented site conditions, or investigated the quality and completeness of records.

In addition to filling of data at the Zuni and McGaffey stations, Allen then uses Zuni data to predict rainfall at elevations 200 feet higher and McGaffey data to predict rainfall at elevations 1200 feet lower. The lapse rate concept used in this effort is discussed later in this report. It is not clear that the method is appropriate to apply to elevation differences of 200 feet and if the annual lapse rate is appropriate to apply on a daily time step.

6.5.1 Effective Precipitation

Effective precipitation is calculated with 80 percent exceedance monthly precipitation rather than monthly mean precipitation. The 80 percent exceedance precipitation data is purportedly used as a “more conservative” estimate of crop water requirement that would not be satisfied by rainfall. The 80 percent exceedance rainfall is more appropriately used for irrigation system design and is not typically used for estimating historical actual use. However, effective precipitation is just one parameter amongst many other considerations when designing an irrigation system. No additional information is provided to support the use of the 80 percent exceedance design assumption.

The 80 percent exceedance analysis is not provided in the Allen report. It is not clear which weather data were used to develop the exceedance data.

6.5.2 Lapse Rates

Allen performed a regional analysis of “lapse rates” of variations of various climate data parameters with elevation. The regional lapse rate analysis used sixteen weather stations in two states that varied in elevation from 4160 feet to 8000 feet. Lapse rates for maximum and minimum temperature and precipitation were calculated from data for 1000-foot differences in elevation. The Zuni agricultural areas vary in elevation by approximately 600 feet. The regional analysis seems unnecessary for this relatively small elevation difference and may introduce additional uncertainty into the data sets.

The lapse rates appear to have been developed with data from stations that are filled with stations that are used to fill one another. Therefore, the lapse rate goodness of fit may be misleading. Further, the lapse rates provide an annual relationship of temperature and precipitation. Evidence of the appropriateness of utilizing this relationship on a monthly or daily basis is not provided in the Allen report.

6.6 Crop Coefficients (K_c)

The Allen report references the National Engineering Handbook (NEH) as a source for the crop coefficients used in the analysis (SCS-NEH, 1993). The crop coefficients in the NEH are based on a 1977 publication, FAO-24. However, in his report in the Ohkay Owingeh case recently reviewed by the OSE, Allen used the newer method for development of crop coefficients presented in FAO-56 (FAO-56, 1998). The Allen report does not discuss the reasons for selection of the NEH crop coefficient method.

The potential irrigation schedules and number of days for wetting events are not supported by information contained in the report and could not be reproduced. One reviewer noted that “The K_w (wetting coefficient) is calculated using 14 days frequency for hay and garden crops and 21 for other crops. If one assumes an average soil with typical available water of 1.5 inch/ft and a normal 4 ft root depth for hay or alfalfa, this will translate into 6 inches (152 mm) of available water between the irrigations. At peak ET rate of 7 mm/day, the minimum interval would be 21 days. However, this is the minimum interval. At early stage with average ET of 5 mm/day, the interval would be 30 days, and in late stage with average ET of 3 mm/day, the interval would be 50 days. Using an average of 21 days, would inadvertently result in higher K_c, and higher ET. This difference would be even more in grains and garden crops. Also, it is not clear how the rainfall wetting events was handled.”

6.6.1 K_{cb}

One reviewer points out that for the initial stage, the basal K_{cb} used by Allen is higher than average K_c found in FAO-56, a more recent reference. One would expect the K_{cb} to be lower than average K_c. The reason for this difference is not clear and is not addressed by Allen. Growing season source for this K_{cb} should be clarified. It is not stated if the “band” temperature is used to estimate growing season, or actual temperature data.

6.7 Twenty percent additional depletion

Total depletion for the project was calculated as the sum of the net irrigation requirement and 20 percent of the diverted flow that is lost. All experts who reviewed this document could not find an explanation of the basis for the 20 percent additional depletion.

6.8 Aridity Adjustment

An aridity adjustment is briefly discussed in the Allen report but the procedures are not fully described and it is not clear if such adjustments were actually applied to the data used to produce the results in the report. Adjustments and results of the adjustments are not summarized and the weather station or stations analyzed are not clearly identified.

6.9 Accuracy of Report

The methodology provided in the November 3, 2008 and June 30, 2009 reports is not the same as that used to calculate the claim. The author states at the end of his November 3, 2008 report that “After submittal of the Zuni historical irrigation water rights claims, subsequent work identified two modifications to the crop ET calculations.” After making the modifications, Allen concluded that “This difference is considered to be within the accuracy of the irrigation water use estimation methods. The conclusion is that the original diversion and depletion estimates provided in the claim do not need to be modified.” Further, on June 30, 2009, the author provided another report containing corrections of errors in the November 3, 2008 report. Based on these statements and corrections, the reports submitted do not provide an accurate description of or engineering support of the claims.

7. Critique of 2008 Technical Report Prepared by L. Niel Allen – OSE Comments

This subsection provides the OSE’s critique of the NRCE’s report titled *Zuni Indian Reservation Identification of Lands and Estimation of Water Requirements for Past and Present Irrigated Lands served by Permanent Irrigation Works* prepared by Niel Allen on December 31, 2008. This review does not include an assessment of the analysis used to determine the 7018.55 acres claimed as acreage served from permanent works. Quotations used in this review are taken directly from Allen’s report or from the SCS NEH. The format of this report is that the section or page number of Allen’s report being critiqued is shown on the left side of the page, followed by specific comments.

2.5 Allen states “Crop reports were not available for the years of 1935-51, 1953-80, 1992-96, and 2002.” The statement does not reflect the evidence identified by the State of New Mexico experts. **-**The State of New Mexico obtained all known existing crop reports for the Zuni Pueblo from the United States Bureau of Indian Affairs (BIA) for the following time periods: 1917, 1921-1934, 1936-1942, 1945, 1947-1950, 1952-1953, 1955, 1981-1993, 1997-2001, and 2003-2004.

Allen states “aerial photography acreage data represents a composite total of all acreages determined to have been irrigated, as opposed to the total acreage in any one year.” This indicates that the 7018.55 acres claimed includes acreage that was not irrigated at the time of the photography.

3.1 Allen’s crop mix was based on BIA crop reports from 1934-2004 and County data obtained from National Agricultural Statistics Service (NASS) for Cibola and McKinley County. The basis for utilizing County data in lieu of local data is not provided. Local data is preferred over County data as it provides the basis for County reports.

Allen states that "the cropping patterns were determined as a percentage of the total irrigated land." It is not clear if this refers to the claimed irrigated 7018.55 acres or to a percentage in any given year. If the latter, fallow acreage should be included to more accurately describe the overall "cropping pattern" relative to the claim.

Allen also states that "These changes [*in cropping pattern and irrigated area]* are due to numerous factors." It is unclear what is meant by this statement.

3.1.1 Allen does not explain why only a limited number of BIA crop reports were reviewed. The State of New Mexico found many more years and focused on years with most complete records (the 1947-50 period). Further, the cropping pattern as a percent is based on only those acres actively irrigated. The description that the cropping pattern trend is due to a reduction in the crop percent of grains and an increase in alfalfa is incomplete. When measured against a claim for 7018.55 acres, the notable trend is for a substantial reduction in irrigation.

This substantial reduction in annual irrigated land lends itself to a misleading view about the cropping pattern change.

3.1.2 The 1999 and 2000 data from NASS does not compare with the BIA crop reports. The NASS reports are county wide and include areas not considered in this claim. The 1999 and 2000 data from Allen's Table 3-3 appears to be New Mexico OSE data that was published in the 1999 and 2000 NASS reports and was compiled for the purpose of assessing water use statewide. Further, NASS county reports should only be relied on when local data is **not** available.

3.1.3 The reason for the inclusion of 20 percent pasture is ambiguous. Relying on reports with different reporting formats and different reporting agencies is not a reasonable alternative to the BIA data. The data used to support this addition of pasture are not provided.

3.2 Allen states that "The beginning of the small grains growing season was determined as the average date of the first continuous average temperature of 40° F (NMSU Henderson & Sorensen, 1968)." This is from NMSU Bulletin 531 which contains local growing season data for crops in New Mexico. It is not clear why Bulletin 531 (or other reference with local data) was used only for small grains and not all crops. Growing season analyses also exist in the Office of the State Engineer's Technical Report 32 and were not used.

Given the extensive climate data manipulation described later in Allen's report it is not clear how Allen used National Weather Service (NWS) data to determine the growing season for crops. Did he use NWS data directly or the manipulated data?

The statement "which climate stations were applied to the irrigation areas" could be viewed as misleading. A climate model, based on the same amount of estimated data, was employed to create a climate data set that was then used to extrapolate climate parameters to ET calculations. NWS data is the basis for this model.

4 Allen states "These variables influence the amount of **water loss** to the atmosphere through evaporation and the amount of water that is used by plant life though **transpiration**." This statement should be modified to include that CIR is the **potential** of a crop.

4.1 Climate data from each station have been filled by intricate and complex procedures. Further, it is apparent that actual raw data has not been used in the calculation of crop ET. Rather the report provides a climate data model and this data is used to calculate ET_o. Very little comparative analysis has been used to show the necessity of these procedures to obtain an idealized crop irrigation requirement.

According to Allen both the McGaffey station (# 5560) and Zuni station (# 9897) were used in his analysis. On page E-2 Allen provided a list of other climate stations used for the development of climatic inputs. There are seven stations used which include #5560 and #9897. Further, dew point temperature, total sky cover, and wind speed were derived from weather stations 30 to 130 miles from the subject area. Precipitation data was developed by incorporating a data filling procedure from 22 weather stations. Therefore, the statements in this section that localized observed climate data from stations #5560 and #9897 are used in the CIR analysis do not accurately depict the approach taken by Allen.

4.2 The section begins with the phrase "for each climate zone". This term is not defined or explained in the report. The climate data were purportedly adjusted by elevation to match the mean elevations of the irrigated areas, but the elevations are not provided in the report.

4.2.1 "Some of the climate inputs into the ASCE Penman-Montieth equation are not recorded at nearby climate stations #5566 and #9897, and must be obtained from climate stations located farther away or estimated based on climate and location conditions." This is inconsistent with the statement in paragraph 4.1.

4.3 The SCS-NEH method for calculation of effective precipitation has not been shown in this report. The precipitation data is extrapolated from precipitation data that is estimated. The extrapolation of data is based on stations that are not in the study area. This is not described in NEH. The use of 80 percent exceedance rainfall is not conservative with respect to calculating higher irrigation water demands.

4.6 "The depletion for each project area was calculated as the sum of the net irrigation requirement and 20 percent of the diverted flow that is lost due to conveyance and application inefficiencies." No basis for this estimate of 20 percent additional loss is provided.

The report states the original claim calculations summarized in Table 4-5, but which are not documented in the report, should be used instead of the calculations outlined in the report and summarized in Table 4-5. However, Table 4-5 does not include a 17.14 acre parcel in Nutria area, and yet shows a higher total depletion. A detailed comparison of the original and modified results is not provided, only total depletion for the areas that were applicable to each analysis.

Pg E-2 The Gallup and Albuquerque stations used for this analysis are located a substantial distance from the subject area. Further, these stations are located in areas that are not in reference conditions.

Pg E-4 Data were filled by several methods based on statistical relationships. Straight data substitution was not done. Comparisons of raw and filled data and summaries of data were not provided despite filling of significant portion of the data set. For example, 42 percent of the dewpoint data set was filled.

Pg E-7 It is not clear from the Allen report why three methods were necessary to fill total sky cover data. Total sky cover was used to estimate solar radiation, which is an important variable in the Penman-Monteith equation. Yet there are 11,060 days filled, or 53 percent of the 1/1/1948 through 12/31/2004 study period. Comparisons of the filling methods used for different periods were not provided, and no comparison of the resulting estimated solar radiation with theoretical clear sky radiation was provided.

Pg E-8 It is not clear if the wind data obtained from the airport locations was measured at or adjusted to the 2-meter measurement height used in the standardized P-M equation.

Pg E-24 Because the dewpoint temperature was derived from Gallup in a non-standard environment, it should have been checked against Tmin for each of the elevation bands.

Pg E-28 The albedo term appears in the equation at the top of Page E-28, but there is no indication of how the albedo was varied on a daily basis to account for snow cover.

Pg E-27 More explanation is needed for the selection of 0.3 for the constant "attenuation due to dust".

Pg E-28 The cited document for the empirical relationship between cloud cover and solar radiation developed by TVA is not listed in the References in the November 3, 2008 report. Although the June 30, 2009 report correction does provide the reference citation, there is no discussion of or explanation of the suitability of a coefficient developed in Tennessee for use in New Mexico.

Pg F-2 It is not clear why the latent heat of vaporization is different than the ASCE Penman-Monteith citations. This is unnecessarily confusing.

Pg F-3 It is not clear why the saturated vapor pressure is calculated utilizing an equation that is different than the reference cited in Allen's report.

The actual vapor pressure is calculated essentially with data from Albuquerque airport. Further, this data set is comprised by two different methods of measurement. Until circa 1994-95, a method utilizing wet bulb and dry bulb measurements was used to calculate T_{Dew}. Circa 1994-95, a new instrument was installed that measures T_{Dew} directly. No analysis has been provided by Allen to assess the effect of this change.

The slope of the saturation vapor pressure versus temperature curve is not consistent with Allen's reference and appears to result in a different output than his reference equation. A substitute equation has been provided from the Addendum, it is unknown which equation was used in the calculation of the claim.

Allen's listed approach for the psychrometric constant is not the same as his citation.

Pg F-5 It is not clear how this discussion of aridity effects is used. It would be helpful to compare original sources to reference conditions. A comparison with data in the Albuquerque area would provide a useful assessment of the suitability of Albuquerque airport data for ET calculations, and the same can be said about data from the Gallup Airport. Note that data from these two stations provide three of the necessary climatic parameters for Penman-Monteith.

Pg F-8 The Allen report states that the comparison of the methods results in less than a five percent difference in reference ET. The information on the comparison chart on page F-8 of the Allen report shows differences of approximately one percent. The report does not state what data are used as input for the comparison. This information would be helpful to better characterize the conclusion. Is the data used derived from "bands", or "filled data" or "raw National Weather Service data"?

Pg F-9 Given statements on page H-1 of Allen's report, it is unknown if this statement accurately reflects the steps taken by the claimant. Is the Allen report a revised description? The original estimate is not modified. Does this section, F-2, represent the original claim? If so the K_w discussion is erroneous. If this does describe what was done, there is insufficient information to determine how K_w was developed. For example, how precipitation was included. Another example comes from the direction in the National Engineering Handbook (NEH), the function provided by Allen requires "observing soil conditions following an irrigation." No information is provided by Allen on what soil texture was used in his analysis.

Pg F-10 A logical interpretation of the phrase "irrigated lands in the future" would not include the lands presently occupied by buildings.

Pg F-11 No basis is given for irrigation frequency.

Pg F-12 While Allen attempts to characterize his approach as merely a "conservative estimate of the amount of crop water requirement that would be satisfied by rainfall", Allen appears to arbitrarily adjust rainfall to obtain a higher number for CIR.

Allen's approach to creation of precipitation data, which is not detailed in this section, is difficult to follow, and does not provide any information that it 1) reflects better results, 2) is technically necessary and 3) is appropriate for effective precipitation analysis.

Pg H-1 This section seems to suggest that the November 3, 2008 report provided does not represent the reference ET calculations and the K_c calculations that were used to develop the claim and that the values in the original claim should be used rather than the values in the November 3, 2008 report. While it describes the changes from the claim values as minor, it is unknown how those values originally claimed were developed. The methods and data used to prepare the original claims are not described or documented. Finally, the fact that both the initial ET_o calculations and K_c calculations were improperly applied could be an indication of the challenges in applying the ASCE method.

8. Discussion

Background

This report provides a description of three methodologies applied to estimate idealized and actual CU in the Zuni area. These methods range from approaches derived with information on irrigation practices within New Mexico to idealized research based reference ET approaches and are summarized below.

Cropping Pattern

This report has identified a period that was irrigated with the most complete BIA reports. This period, 1947-1950 provides both complete project acreage and yield reports. This acreage was analyzed year by year with the various CU methods described above and then averaged.

Original Blaney-Criddle
This approach is based on estimates of CU within basins in New Mexico. It is this background that provides reasonable support to apply this approach in the Zuni area. This method was utilized to calculate a CU estimate for each year during the period of 1947-1950. However, the alfalfa CU estimate was replaced by the result of the yield/ET relationship developed by NMSU. This adjustment was incorporated to the historical1947-50 use calculations. Also, this OBC was applied utilizing a long-term average climatic data set. The results are summarized in the Table 3 above.

Modified Blaney-Criddle
This method has been applied extensively throughout the western United States to estimate CU. This method was utilized to calculate a CU estimate for each year during the period of 1947-1950. However, the alfalfa CU estimate was replaced by the result of the yield/ET relationship developed by NMSU. This adjustment was incorporated to the historical use calculations. Also, the MBC method was applied with a long-term average climatic data set without an alfalfa yield adjustment. The results are summarized in Table 5 above.

Hargreaves-Samani
This method has been applied to the same time periods described in the OBC section above. First there is an idealized CIR calculation for each year from 1947-1950. This time period is also reported with adjustments for yield utilizing the FAO-33 method, but limiting the yield reduction to no lower than 50% of the estimated maximum crop ET. These yield adjustments are only applied for wheat and corn. These results also include the NMSU adjustment for alfalfa. Other crops are not adjusted in this analysis. A long-term climatic average calculation was completed with the H-S method for idealized conditions and no adjustment for yields. These results are summarized in the Table 7 above.

The results from these different approaches provide a range of values to consider when estimating consumptive use and are broken down into categories; the first is the idealized approach and the second is an approach to estimate historical use. The idealized approach proposed by the experts for the United States is complicated by the fact that they must obtain significant amounts of data from non-standard conditions from a weather station 130 miles away. By contrast, the approach taken in this report in evaluating idealized use is to present a range of values utilizing different approaches based on local data. This first is OBC, the second is the MBC, and the third approach is utilizing the H-S equations with crop coefficients from local sources as well as experimental sources. Table 8 below summarizes these results.

Table 8. Estimates of CIR for the 1947-50 Cropping Pattern using the Average Climate Data for the Zuni Pueblo Area.

Method	Long-term CIR
Original Blaney-Criddle	1.2
Modified Blaney-Criddle	1.2
Hargreaves-Samani	2.0

Note: The CIR value is reported as acre-feet/irrigated acre/annum

The second category of approach presented in this report provides three different methods to estimate historical use. This first is the application of OBC with a locally derived yield/ET adjustment for alfalfa. The second approach applied the MBC methodology also adjusting the CIR with a yield/ET relationship for alfalfa. This adjustment gives an approximation of actual ET for alfalfa. The third approach applies the H-S equation in combination with FAO-33 methodologies for adjusting crop ET based on the reported yield data and the locally derived alfalfa yield/ET adjustment. It is noted that the yield data is so low that the ET adjustments were limited to no lower than 50% of the maximum ET for corn and wheat. Table 9 below summarizes the results from these analyses.

Table 9. Estimates of CIR for Historic Use for the 1947-50 Cropping Pattern with 1947-50 Climate Data from the Zuni Pueblo Area.

Method	1947-50 Adjusted CIR
Original Blaney-Criddle	1.1
Modified Blaney-Criddle	1.1
Hargreaves-Samani	1.1

Note: The CIR value is reported as acre-feet/irrigated acre/annum

9. Conclusion

This report is in response to a request to evaluate idealized water use estimates for CIR as well as provide estimates for historical uses. The range of estimated potential, or idealized, CIR values (reported as acre-feet/irrigated acre/annum) based on historical average data are 1.2 for OBC, 1.2 for MBC and 2.0 for H-S. The estimated historical use produced similar results for all methods.

The use of the MBC approach for estimating water use has been used throughout the western United States and in New Mexico for estimating CU and for determining CIRs. In the process of evaluating its usefulness in estimating historic use for the Zuni area, it appears the yields associated with the irrigated areas are very low, which is an indication that crops have not utilized water to their potential. Given this reality, it is reasonable to adjust alfalfa for yield since it is a crop with a very high potential CU and there is no evidence that this CU has been realized for the irrigated areas in the Zuni Pueblo. For these reasons, this report concludes that the historic use estimate utilizing the MBC method adjusted for alfalfa yields is reasonable. This value is provided in Table 10 below to estimate the Farm Delivery Requirement and Project Diversion Requirement for each section of the Zuni Pueblo. Finally, a total depletion estimate is provided for the average irrigated acres for the period from 1947 to 1950 in Table 11.

Table 10. Summary of the Farm Delivery Requirement and Project Diversion Requirement for each section of the Zuni Pueblo.

Agricultural Area	Zuni Pueblo MBC w/alfalfa adjustment CIR (ac-ft/ac)	On-farm Efficiency, %	Farm Delivery Requirement (ac-ft/ac)	Conveyance Efficiency, %	Project Delivery Requirement (ac-ft/ac)	1947-1950 Average Irrigated Acreage
Nutria	1.1	60%	1.76	71%	2.48	217.3
Pescado	1.1	50%	2.11	70%	3.02	382.2
Zuni	1.1	55%	1.92	73%	2.63	1371.1
Tekapo	1.1	60%	1.76	71%	2.48	137.5
Ojo Caliente	1.1	60%	1.76	80%	2.20	464.5
Average			1.86		2.56	

Table 11. Total Depletion Estimate is Provided for the Average Irrigated Acres for the Period from 1947 to 1950

Average Irrigated Acreage	CIR (ac-ft/ac)	Depletion (ac-ft)
2572.6	1.1	2717

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Appendix A

Climate Data Assessment and Calculation of Crop ET and Reference ET_o, Zuni Pueblo

by Mary Kay Brengosz, P.E.

STATE EX REL. STATE ENGINEER v. A & R PRODUCTIONS, ET AL.
Case No. CIV 07-00681 BDB/WDS, Subproceeding 1

Climate Data Assessment and Calculation of Crop ET and Reference ETo, Zuni Pueblo

Prepared for:

State of New Mexico
Office of the State Engineer
Santa Fe, New Mexico

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February 25, 2010

Appendix B

Calculation of Crop Coefficients (K_c) for Zuni Pueblo

by Dr. Zohrab Samani, P.E.

State Ex Rel. State Engineer, Zuni Indian Tribe, Navajo Nation v. A & R Productions, et al.

Civ. No. 07-00681 BDB/WDS
Zuni River Basin Adjudication
Subproceeding 1 Zuni Indian Claims

Calculation of Crop Coefficients (K_c)

for Zuni Pueblo

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February 26, 2010

Appendix C

Water Delivery and Use Efficiencies

by Carl Eugene Franzoy, P.E.

UNITED STATES OF AMERICA, and STATE of NEW MEXICO, ex rel. STATE ENGINEER, Plaintiffs and ZUNI INDIAN TRIBE, NAVAJO NATION, Plaintiffs in Intervention, v. A&R PRODUCTIONS, et al., Defendants
CIV. No. 07-00681 BDB/WDS, ZUNI RIVER BASIN ADJUDICATION, Sub-proceedings 1, Zuni Indian Claims

Report on
Water Delivery and Use Efficiencies

Prepared for:

State of New Mexico
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February 25, 2010