# Response to Comments on the Preliminary Hopi HSR Related to Consumptive Use of Water by Crops

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## LIST OF ACRONYMS

ADWR – Arizona Department of Water Resources

ASCE – American Society of Civil Engineers

CU – Consumptive Use

DRY – Precipitation/native irrigated land

ET – Evapotranspiration

$ET_c$ – Evapotranspiration of actual crop

$ET_o$ – Evapotranspiration of reference crop

FAO-56 – Food and Agriculture Organization and Drainage Paper No. 56

$F_c$ – fraction of soil surface shaded by vegetation

GDD – Growing degree days

h – plant height

Hopi PHSR – Preliminary Hydrographic Survey Report for the Hopi Indian Reservation

$K_c$ – crop coefficient

$K_{c\ initial}$ – Initial Crop Coefficient

$K_{c\ mid}$ – Peak of crop coefficient curve

MOVE.1 – Method of Variance Extension, Type 1

NDI – Non-deficit irrigated land

NDVI – Normalized Difference Vegetation Index

NIR – Net Irrigation Requirement

NRCE – National Resource Consulting Engineers

NWS – National Weather Service

Rs – Solar Radiation [MJ m-2 day -1]

SID – Supplemental Irrigation Demand

$T_{dew}$ – Dew Point Temperature

$T_{dew\ (Brwn)}$ – Tdew estimated using the Brown technique

$T_{dew\ (Move.1)}$ – Tdew estimated using MOVE.1 record extension

$T_{min}$ – Minimum daily temperature

## 1.0 BACKGROUND

This report was prepared under contract to the Arizona Department of Water Resources (ADWR) in support of its work to finalize a hydrographic survey report (HSR) for the Hopi Indian Reservation (Reservation). The author was an employee of ADWR from January 2007 through January 2009 at which time he authored the report *Consumptive Use of Crops Grown on the Hopi Indian Reservation* (Crowley, 2007). That report was presented as Appendix F of a preliminary HSR for the Reservation (Hopi PHSR). The Hopi PHSR was released by ADWR in December 2008 as part of the Little Colorado River General Stream Adjudication currently pending before the Apache County Superior Court. For reference, a copy of the author's prior report is included here as **Appendix A**.

The purpose of this report is to respond to comments received by ADWR on the Hopi PHSR related to the consumptive use (CU) of water by crops. Where appropriate, this report also describes changes made to ADWR's original CU methods and calculations. Three parties filed comments on the topic:

- Hopi Tribe;
- Navajo Nation (represented by AMEC consultants); and
- United States, on behalf of the Hopi Tribe (represented by NRCE consultants).

**Table 1.1** provides a summary of the comments and indicates which sections they are addressed in this report. A copy of the original comments is found in **Appendix B**.

## 2.0 RESPONSE TO COMMENTS

### 2.1 MODEL UPDATES

Some comments were on whether the Modified Penman-Monteith equation, adopted by the United Nations Food and Agriculture Organization (FAO), and the American Society Civil Engineers (ASCE) was the best model to calculate evapotranspiration (ET). This model has proven to be one of the most accurate models in a wide range of environments, even in areas with very little climate data available, as is the case on the Hopi Reservation (Allen et al, 1998). As with any model, the precision and accuracy of the model output is dependent upon the quality of the model input. The following subsections address comments made on the four climate variables used in the Modified Penman-Monteith (FAO-56) model to estimate reference crop evapotranspiration ($ET_o$): dew point temperature ($T_{dew}$), wind speed ($U_2$), air temperature ($T_{max}$ and $T_{min}$), and Solar Radiation ($R_s$).

#### 2.1.1 AVAILABLE CLIMATE DATA

The U.S. suggested that ADWR should have used daily climate data rather than mean monthly values to estimate ET. ADWR's approach reflects the purpose of the project and data availability.

The purpose of this project is to quantify the historical and current average annual water use by crops for the entire Reservation. A monthly time-step is appropriate for characterizing climate variations on the Reservation. As stated in FAO-56, "the value of the reference evapotranspiration calculated with mean monthly weather data is indeed very similar to the average of the daily $ET_o$ values calculated with daily average weather data for that month" (Allen et al, 1998). Weekly, daily, and hourly time-steps are more appropriate for field-specific crop water demands and establishing daily or weekly irrigation schedules. Use of daily time-steps for estimating historical averages is not expected to yield substantially different $ET_o$ results.

With regards to data availability, the most reliable sources of long-term climate information are the National Weather Service (NWS) stations located at Keams Canyon and Tuba City. Calculations of $ET_o$ with FAO-56 require data on air temperature, wind speed, humidity, and solar radiation. Of these, humidity and wind speed were derived using data from other stations and sources, as explained later in this report and in Crowley (2007). Solar radiation was derived from temperature measurements at the two NWS stations using the Hargreaves equation (Hargreaves and Samani, 1982). With regards to the Hargreaves equation, it is recommended for monthly $ET_o$ calculations and, "caution is required when daily computations are needed. . . .It is recommended that daily estimates of $ET_o$ that are based on estimated $R_s$ be summed or averaged over a several-day period, such as a week or month to reduce prediction error" (Allen et al, 1998, p. 61). With a monthly time-step recommended to estimate solar radiation, it is most appropriate to use this data in conjunction with the other climate variables on the same, monthly time-step.

ADWR considers the Keams Canyon and Tuba City weather stations to be good sources of climate data for this study. Both stations have periods of record in excess of 100 years and are located on or immediately adjacent to the Reservation. In addition, greater than 82% of total agricultural field acreage that ADWR identified on the Reservation in 2005 is situated at elevations between the two stations. The majority of fields located outside the range of weather station elevations are higher in elevation (13%) which is expected to cause a slight decrease in ET. **Table 2.1** compares the elevations of fields identified by ADWR in 2005 to the elevations of Keams Canyon and Tuba City. Weather data from these stations is considered sufficient for the scope of this project, without the need to incorporate weather data collected from off the Reservation. Reference crop evapotranspiration $ET_o$ values have been modified in this report to incorporate the entire periods of record for both stations.

### 2.1.2 DEW POINT ($T_{dew}$)

The Navajo Nation and the U.S. commented on ADWR's methods for computing $T_{dew}$. ADWR used different methods to calculate $T_{dew}$ for the two irrigation methods modeled: Non-deficit irrigated land (NDI) and precipitation/native irrigated land (DRY). (See **Table 1.2** for a comparison of the irrigation methods claimed by the Hopi and U.S. to ADWR's methods.) For NDI conditions, it is assumed that there is a well-watered crop, which is actively transpiring. These conditions create a microclimate in which there is greater humidity, and $T_{dew}$ is therefore less than the surrounding climate. This is why it is recommended that $T_{dew}$ and temperature data be modified when measured off site, even where long-term records are available. When

humidity data are unavailable, estimation procedures that take into account microclimate effects should be employed (Allen et al, 1998). The ASCE (2005) outlines a procedure to estimate $T_{dew}$ based upon measured minimum daily temperatures ($T_{min}$), substituting missing $T_{dew}$ values for $T_{min} - K_o$, with a recommended $K_o$ of 2-4°C. $K_o$ values often varied between 2-5°C in Arizona (ASCE, 2005). Per Brown (2007), ADWR used $K_o$ values of 2°C for the monsoon season of July-August, when $T_{dew}$ is more likely to approach $T_{min}$, and values of 5°C for all other months of the year. This method of $T_{dew}$ calculations is abbreviated by $T_{dew(Brwn)}$ in this report.

For DRY conditions, ADWR used $T_{dew}$ values that most accurately represent current and historic field conditions on the Reservation. Because of the relatively small fields and widely spaced crops (Bradfield, 1971; Ferguson, 2004; ADWR, 2005), humidity within the agricultural fields is not expected to differ greatly, if at all, from the surrounding environment. Therefore, using on-site $T_{dew}$ data would best portray DRY conditions. While no humidity data have been collected at either of the two National Weather Service stations in the area (Keams Canyon and Tuba City), data do exist collected from the Hopi Tribe's meteorological stations. Since the periods of record for these stations are somewhat limited (beginning in 2003, with several month-long gaps) the Move.1 record extension method (Hirsch, 1982) was used to extend $T_{dew}$ measurements from the Hopi Tribe's stations based upon $T_{min}$ data collected at Keams Canyon and Tuba City. This method of calculating $T_{dew}$ is abbreviated by $T_{dew(Move.1)}$ in this report.

**Figures 2.1** and **2.2** compare the differences between the two methods of calculating average monthly $T_{dew}$ at Keams Canyon and Tuba City, respectively. On average, $T_{dew(Brwn)}$ predicts a monthly average 5.08 °F higher than the $T_{dew(Move.1)}$ method at Keams Canyon and 4.93°F higher at Tuba City.

A literature review suggests there is no standard practice for conducting sensitivity analyses on climate variables used in evapotranspiration models (Saxton 1975; Irmak et al. 2006; Estevez et al. 2009). Multi-variable analyses are complicated by the fact that input variables in ET models are co-dependent. This effect is illustrated in **Tables 2.2** and **2.3** as the percent increase in total $ET_o$ changes at wind speeds ($U_2$) of 3 m/s versus 5 m/s, when comparing ADWR's different methods of calculating $T_{dew}$. At Keams Canyon, using $T_{dew(Move.1)}$ in the ET model results in a 9% increase in average monthly $ET_o$ when $U_2$ = 3 m/s and an 11.4% increase in average monthly $ET_o$ when $U_2$ = 5 m/s. These wind speeds represent the upper and lower limits for both NDI and DRY conditions as computed in Crowley (2007). Air temperature and solar radiation were not varied for this sensitivity analysis because their values remained the same for both NDI and DRY conditions.

Further analysis of the sensitivity of $ET_o$ to the $T_{dew(Move.1)}$ method is illustrated in **Figures 2.3**, **2.4**, **2.5**, and **2.6**. Once again, the co-dependence of input variables is evident as $ET_o$ fluctuates at different rates when compared with different wind speeds. These figures show the sensitivity of computed average monthly $ET_o$ rates when the mean $T_{dew}$ value from the MOVE.1 record extension is compared to the $10^{th}$, $25^{th}$, $75^{th}$, and $90^{th}$ percentile $T_{dew}$ values from this model in comparison to the mean values of available data.

In summary, this section explains and illustrates the sensitivity analysis performed on $T_{dew}$ used by ADWR's CU analysis as requested by the Navajo Nation. This analysis demonstrates that $T_{dew}$ is a relatively significant variable in CU calculations, varying dependently with $U_2$. Upon

review of these results, ADWR decided not to change $T_{dew}$ values except to incorporate more recent measurements since publication of Crowley (2007).

### 2.1.3 WIND SPEED ($U_2$)

Wind is a major factor in the evapotranspiration process. As a plant transpires and water evaporates from the soil surface, the air in proximity of the evaporation surface becomes saturated. In response, the ET process is slowed and can stop, unless the air is displaced by unsaturated, drier air. The displacement of this saturated air with drier air is facilitated by, and greatly depends upon wind speed. The Jensen-Haise reference ET model, employed by the NRCE on behalf of the U.S. does not account for wind speed.

**Figures 2.7** and **2.8** illustrate how daily $ET_o$ at Keams Canyon vary with $T_{dew(Brwn)}$ and $T_{dew(Move.1)}$, respectively, for wind speeds of 0, 2, 3, 5, and 6 m/s. **Figures 2.9** and **2.10** illustrate these differences at Tuba City. In the FAO-56 model used by ADWR, wind speeds of 3 m/s were used for the lower bounds, and 5 m/s were used for the upper bounds for both NDI and DRY conditions. These values are based on measured wind speed, anecdotal accounts, and FAO procedures to estimate wind speeds (Crowley, 2007). As summarized in **Table 2.4,** the FAO-56 model used is relatively sensitive to wind speeds.

### 2.1.4 SOLAR RADIATION ($R_s$)

The U.S. used the Flagstaff Regional Airport weather station, located more than 90 miles from the Hopi Reservation to evaluate ADWR's solar radiation estimates. Solar radiation is a function of several variables including latitude and the Flagstaff station is located greater than 60 miles south of Moenkopi, AZ. Besides the relatively large distance between the two stations, Flagstaff is geographically different enough from the Reservation to have considerably different local weather patterns, enough to make comparisons between the two locations questionable.

The Hargreaves equation of calculating $R_s$ is recommended by Allen et al (1998) in situations where it is "not appropriate to import radiation data from a regional station. . .because homogenous climate conditions do not occur, or because data for the region is lacking."

In response to the U.S. comments on solar radiation ADWR checked the accuracy of the Hargreaves equation using solar radiation measurements from the Bureau of Land Management and National Forest Service's Remote Automated Weather Station (RAWS) station number 020312, located on the Hopi Indian Reservation. **Figure 2.11** illustrates the measured $R_s$ versus estimated $R_s$ using the Hargreaves equation (Hargreaves and Samani, 1982) at the Hopi station for its entire period of record (2002-2010). The Hargreaves equation appears to overestimate $R_s$ in months April – September, and underestimate $R_s$ in months October – March, with the greatest difference occurring in July. These findings are consistent with other research on the performance of the Hargreaves equation in semi-arid environments (Bautista et al, 2009; Gavilan et al, 2006). When $ET_o$ was modeled using measured $R_s$ values from this weather station, average yearly $ET_o$ decreased by 32 mm, or 1.93%, compared to ET estimates based on the Hargreaves equation. Results of this comparison can be found in **Table 2.5**.

Based on the results, weather data from Keams Canyon and Tuba City were adjusted accordingly and modified $R_s$ values entered into FAO-56 to estimate $ET_o$. The updated $ET_o$ values are reflected in **Tables 2.9 – 2.12**.

## 2.2 CROP COEFFICIENT

In ET estimations, crop coefficients ($K_c$) account for physiological differences between the reference and actual crop that lead to different amounts of transpiration. The U.S. and Navajo Nation commented on ADWR's methodology to adjust $K_c$ to represent DRY conditions on the Hopi Reservation, which are addressed in the following sections.

### 2.2.1 $K_c$-SINGLE vs. $K_c$-DUAL

There are two approaches for $K_c$ outlined in FAO-56. The first uses a single-$K_c$ that represents both evaporation and transpiration. The second uses a dual-$K_c$ which separates transpiration and evaporation into two variables. The approach selected depends on site conditions, available data, and the required frequency of ET estimations.

In response to the U.S.'s comment regarding soil moisture accounting, ADWR does not consider it necessary to use the dual-$K_c$ approach. ADWR recognizes that evaporation from bare soil is an important component to total ET, especially during the initial crop growth stages when the amount of exposed soil is largest. However, when soil water applications are infrequent, and the evaporation potential of the ambient climate is high, as is the case on the Reservation, the portion of ET from soil evaporation can often drop to zero (Allen et al, 1998).

In addition, using the dual-$K_c$ approach to distinguish soil evaporation from plant transpiration is inappropriate for the purpose of this project. The dual-$K_c$ approach allows for daily ET estimations and therefore precise irrigation scheduling for individual fields. Allen et al (1998) recommend that "this approach be followed when improved estimates for $K_c$ are needed, for example to schedule irrigations for individual fields on a daily basis." In addition the use of this approach is not feasible given currently available data. Since output from the dual-Kc approach is intended for precise water management (hourly or daily ET rates), it is important to input precisely measured data to have confidence in the accuracy of the ET estimates. Application of this approach without accurate on-site measurements of soil moisture per agricultural field is a misuse of the method and inappropriate when an annual average of crop water usage is the desired output.

The single-$K_c$ approach used by ADWR is appropriate for this project. This approach incorporates plant transpiration and evaporation into the same curve. The U.S. is therefore incorrect in assuming that ADWR calculations do not account for bare soil moisture evaporation. See **Figure 2.12**.

Agricultural practices on the Reservation are also an important consideration in selecting a $K_c$ approach. Farming under DRY conditions leaves little water to be available for soil evaporation. Seasonally, precipitation, and native irrigation farming do not involve regularly scheduled

irrigation and therefore, soil water evaporation only occurs in direct response to precipitation events. Additionally, for native irrigation farmed lands supplied by water from temporary canals and conveyances, only a small percentage of the soil is actually wetted. For fields located along flood plains and in washes, the wettings are more wide-spread, yet still occur only in direct response to infrequent, large precipitation events. Soil evaporation ceases when the available soil water approaches 0, which happens relatively quickly in windy, arid environments with infrequent wetting events. For areas on the Reservation which receive more intensive, regularly scheduled irrigation (perennial irrigation in the Moenkopi area), the $K_c$-dual approach would be appropriate but only if daily estimations are needed in order to schedule irrigations. This approach is not necessary when annual water use is being estimated.

### 2.2.2 $K_{c\ initial}$

The single-$K_c$ approach begins by establishing $K_c$ initial. This is the beginning point for the curve and incorporates climate variables that control the ET rate when the plant is in its initial growth stage. During this time, the majority of ET comes from soil evaporation. Therefore, basic soil information, soil wetting frequency, and evaporative demand of the atmosphere determine $K_{c\ initial}$. Allen et al (1998) developed figures that incorporate these phenomena into a series of curves (**Figure 2.13**).

The $ET_o$ that ADWR used for the starting point of the curve was the $ET_o$ averaged between the two weather stations for the growing period starting dates used in this report (April 7 for the upper bounds, and May 15 for the lower bounds). **Table 2.6** lists values for the input variable that ADWR used in **Figure 2.13** to establish $K_{c\ initial}$ for the upper and lower bounds of DRY. The only variable that has changed since Crowley (2007) is the wetting frequency, due to improved effective precipitation ($P_e$) estimates (**Section 2.3** of this report). Use of this curve has been compared with measured evaporation and indicates good performance with no regional calibration required (Allen et al, 2005). The $K_{c\ initial}$ values used for the upper and lower bounds of the DRY conditions are 0.15 and 0.12, respectively.

### 2.2.3 $K_{c\ mid}$

Because growing conditions on the Reservation are less than ideal, with crops often subject to water stress due to lack of available water, $K_c$ values had to be reduced. ADWR used an approach based on effective ground cover. Further discussion of this approach is provided in Chapter 9 of FAO-56, '$ET_c$ for natural, non-typical and non-pristine vegetation.' The U.S. stated that this approach modifies the basal crop coefficient and only accounts for transpiration, not bare soil evaporation. That statement is incorrect since this approach is being used for single-$K_c$ not dual-$K_c$. Allen et al (1998) clearly state:

> "When the single crop coefficient of Chapter 6 is used, the average effects of soil wetting are incorporated into a general mean Kc. . . .Equations 97 and 98 can be used to determine $K_c$ instead of $K_{cb}$. . . .The use of $K_c$ initial incorporates effects of soil evaporation and therefore serves as a lower limit on the estimate for $K_c$ mid." (pg 184)

Equation 98 of FAO-56 is:

$$K_{cbmid} = K_{cmin} + (K_{cbfull} - K_{cmin})\left(\min\left(1, 2f_c, (f_{ceff})\left(\frac{1}{1+h}\right)\right)\right)$$

where,

$K_{cb\ mid}$ estimated basal $K_{cb}$ during the mid-season when plant density and/or leaf area are lower than for full cover conditions,

$K_{cb\ full}$ estimated basal $K_{cb}$ during the mid-season (at peak plant size or height) for vegetation having full ground cover or LAI > 3 (see Equations 99 and 100),

$K_{c\ min}$ the minimum $K_c$ for bare soil (in the presence of vegetation),

$f_c$ observed fraction of soil surface that is covered by vegetation as observed from nadir (overhead) [0.01 - 1],

$f_{c\ eff}$ the effective fraction of soil surface covered or shaded by vegetation [0.01-1],

h the plant height [m].

For this report, $K_{c\ min}$ is equal to $K_{c\ initial}$ (described in **Section 2.2.2** of this report) and $f_{c\ eff}$ was set to 1.

$K_{cb\ full}$ was estimated using FAO-56 Equation 99:

$$K_{cbfull} = K_{cbmidTable} + \left[0.04(u_2 - 2) - 0.004(RH_{min} - 45)\right]\left(\frac{h}{3}\right)^{0.3}$$

where,

$u_2$ mean value for wind speed at 2 m height during the mid-season [m $s^{-1}$],

$RH_{min}$ mean value for minimum daily relative humidity during the mid-season [%].

h mean maximum plant height [m].

The same values for ($u_2$, $RH_{min}$, and h) were used here as previously used by Crowley (2007) for the upper and lower bounds of DRY. Values for $f_c$ were derived from ADWR's 2005 field survey, with a mean value of 0.103 used. On average, 10.3% of the soil surface was estimated to be shaded when looking from directly overhead. As part of ADWR's field survey, percent crop cover was recorded and in order to improve values from Crowley (2007), only those values associated with corn crops in "bloom" were considered for $f_c$ in this report.

Historical crop spacing measurements presented in the PHSR were used as supporting evidence of the relatively large spacing between corn plants grown on the Reservation. Those earlier measurements were not, however, used in $f_c$ calculations.

A sensitivity analyses on $f_c$ was performed using the minimum, 25$^{th}$ percentile, mean, 75$^{th}$ percentile, and maximum values of percent crop cover for corn that ADWR recorded in 2005. **Figures 2.14** and **2.15** illustrate the percent change in total actual crop evapotranspiration ($ET_c$) resulting from varying values of $f_c$ at Keams Canyon and Tuba City, respectively. **Tables 2.7** and **2.8** list these percent changes as well as the entire year's $ET_c$ with varying $f_c$ values. This analysis shows that $ET_c$ estimates are highly sensitive to crop cover. However, the mean $f_c$ value (0.103) is still considered most representative of field conditions on the Reservation and was used in final CU estimates in this report.

### 2.2.4 $K_c$ CURVE

The $K_c$ curve is derived from four crop stages, represented by four lines that connect $K_{c\ initial}$, $K_{c\ crop\ development}$, $K_{c\ mid}$, and $K_{c\ harvest}$ . Crop stage duration for corn on the Reservation and the $K_c$ values for each stage under DRY conditions are included in **Tables 2.9** and **2.10** (formerly Tables 2.6 and 2.7 in Crowley, 2007).

## 2.3 EFFECTIVE PRECIPITATION

Effective precipitation ($P_e$) is defined as the amount of precipitation available for crop consumptive use. In response to comments by the U.S., a different method of calculating $P_e$ was used in this report than in Crowley (2007). The United States Department of Agriculture's (1970) method was selected since it better represents actual effective precipitation in environments characteristic of the Hopi Reservation. This method accounts for, among other variables, potential crop water consumption – an important factor when calculating $P_e$ in a windy, arid environment.

The new $P_e$ values are presented in **Tables 2.9 – 2.12** and used in calculating Supplemental Irrigation Demand (SID), which is consumptive use less $P_e$. In response to comments by the U.S. and Navajo Nation for NDI, SID was calculated by only reducing CU by $P_e$ during the growing season. For DRY, SID was calculated by reducing CU by $P_e$ through the year since these fields are located in topographical settings that maximize available moisture, during both the growing season and winter precipitation.

## 2.4 GROWING SEASON

ADWR's strategy for quantifying crop water usage on the Reservation was to bracket annual variations in the actual amount between upper and lower limits. Use of different growing seasons was one means to define these upper and lower limits. The growing season on the Reservation varies from year to year with climate. An upper limit of 170 days and a lower limit of 115 days were used to bracket this variability and thereby capture most possible season-

lengths variations due to location, elevation, topography, or climate. These periods are supported by literature on the subject (see references in Crowley, 2007). ADWR does not, therefore, consider it appropriate to "tailor growing seasons to subbasins" as suggested by the U.S.

## 2.5 CONSUMPTIVE USE OF RANGE PASTURE LANDS

The Hopi PHSR did not consider consumptive use of pasture lands on the Reservation. The Hopi Tribe and Navajo Nation requested that the water use be estimated by ADWR so that a comparison could be made to the original Statement of Claim. In this report, ADWR used the same $ET_o - K_c$ approach for pasture as previously used for other Hopi crops, with some modifications.

According to Priscilla Pavatea (personal communication, 2009), director of the Hopi Office of Range Management, common vegetation on currently grazed pasture lands include blue and black grama, alkali sacaton, western wheatgrass, sage, and scrub brush. She also noted that no pasture lands on the Reservation (with the possible exception of the Moenkopi area) receive irrigation. Since no published $K_c$ values for these species in Arizona were identified through a literature review, a $K_c$ curve was constructed based on Normalized Difference Vegetation Index (NDVI) following methods established by the ASCE and University of Idaho (ASCE-EWRI, 2005; Allen et al, 2006; Allen and Robison, 2007).

NDVI values were computed for five fields claimed by the Hopi as pasture lands. **Table 2.13** lists these fields and their corresponding acreage. First, NDVI values were computed by compiling multi-spectral images from NASA's Landsat satellite and creating a single band image represented by NDVI. Second, these raster data were compared to the range pasture fields to compute descriptive statistics for the NDVI values. Third, the NDVI values were converted into equivalent $K_c$ values using the relationship, $K_c = 1.18*NDVI + .04$. This equation provided a "potential" $K_c$ value which represents an upper limit of plant water use (Allen and Robison, 2007). To determine seasonal $K_c$ trends, several NDVI values must be calculated over the growing season or year. For this report, one Landsat image every month during 2005 was considered sufficient to establish a $K_c$ curve for range pasture lands. Since these $K_c$ values represent an upper limit of potential plant $K_c$, maximum NDVI values for each field were used and a weighted average then calculated to develop a Reservation-wide $K_c$ curve.

**Figure 2.16** illustrates the final $K_c$ curve developed for range pasture lands on the Reservation. The curve is similar in shape to other published references, with an increase in plant water usage from March to May as the weather warms and there is adequate stored soil moisture from the winter. The curve then declines beginning in May, when temperatures become hotter and soil water potentially becomes too low to support the $K_c$. $K_c$ values increase again in August when monsoon rain events provide soil moisture.

The season for pasture lands on the Reservation is based upon thermal units. An approximation using historical temperature data from Keams Canyon and Tuba City results in a start date of March 15 and a finishing date of October 15.

Because $K_c$ values derived from the NDVI approach serve as an upper limit for range CU estimates, $ET_o$ was calculated assuming $U_2$ = 5m/s, and using $T_{dew(Move.1)}$.

The lower limit for Hopi range CU estimates is effective rainfall since some of the pasture lands are not located in strategic locations to capture runoff. The entire year's $P_e$ was used in calculating this lower limit due to the importance of stored soil moisture throughout the winter season. **Table 2.14** lists upper and lower limits for range pasture CU on the Reservation.

## 2.6 CROP MIXING

ADWR estimated CU on the Reservation based on the water demand of a typical crop mix (corn, beans, fruit trees, melon, and squash). The percentage of crops in the mix was based on ADWR field surveys and historical documentation – a weighted estimate of CU was calculated based on these percentages. The U.S. estimates CU for only corn and pasture and the Navajo Nation suggested that, for comparison, ADWR recalculate CU for only these two crop types.

**Table 2.15** lists values for CU and SID for corn and pasture only. This crop mix is not recommended to estimate actual crop water demands of the Reservation because beans, fruit trees, and other garden varieties have different water requirements.

## 2.7 MINOR AND EDITORIAL COMMENTS

In addition to the major comments addressed in the sections above, there were minor and editorial comments on Crowley (2007) that are addressed below:

There is a typo in Section 2.1.3.4, in which the sentence should read: "Under these conditions, the reference crop would be actively transpiring, causing the relative humidity to increase and the Tdew to *increase*."

The Hopi Tribe questioned the validity of referencing Table 21 from FAO-24 for $K_c$ variables. This table was indeed the original source of $K_c$ variables and it was used with ET estimates from the FAO-56 Modified Penman Monteith equation.

The Hopi Tribe also questioned, "why there are multiple GDD curves shown in Figure 2.9 if the only variable is mean temperature." The curves show cumulative GDD's based on temperature beginning at different days on the calendar (representing the two growing season lengths under NDI and DRY conditions.)

Finally, the Hopi Tribe questioned whether Tables 2.6 – 2.9 match the data in Figures 2.12 and 2.13 of Crowley 2007. The tables have been modified in this report (see **Tables 2.9 – 2.12**).

## 3.0 RECOMMENDATIONS FOR THE FINAL HSR

In response to comments received on the Hopi PHSR, several improvements were made to the previous CU estimates that were presented in Crowley (2007). These improvements include:

1) Updated $T_{dew}$ and air temperature values based on longer climate record;
2) $R_s$ values calculated from the Hargreaves equation were adjusted using on-Reservation solar radiation measurements;
3) $K_{c\ initial}$ values better reflect on-site climate variables and soil wetting frequency;
4) New $K_{c\ mid}$ values calculated based on updated percent crop cover ($f_c$) data;
5) Effective precipitation was recalculated using a method that better reflects site conditions; and,
6) SID for NDI agriculture was recalculated to only reduce water demand by growing-season effective precipitation.

These improvements effect $ET_c$ and SID values for all crop varieties grown on the Reservation. **Tables 2.16** through **2.18** list revised $ET_c$ values for these crops. Revised SID estimates are listed in **Table 2.19**. **Table 2.20** lists the CU variables that were revised and their corresponding section numbers in this report and in Crowley (2007).

Finally, note that the sensitivity analyses performed and described here were useful in identifying which input parameters in the FAO-56 model are most important to enter accurately. It was found that ET estimates are most sensitive to $U_2$ and $f_c$, and least sensitive to $T_{dew}$. The values ultimately selected for these parameters to estimate $ET_c$ and SID for agriculture on the Reservation reflect the best data available to ADWR and for the purpose of this project.

***The new recommended SID's for agriculture on the Reservation are 2.06 – 2.70 ft/yr for NDI agriculture, and 0.36 – 0.98 ft/yr for DRY conditions.***

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# TABLES

| Table 1.1: Summary of Comments Received Regarding Appendix F of the Hopi Tribe PHSR | | | |
|---|---|---|---|
| **Subject** | **Comment Summary** | **Commenting Party** | **Sections Addressed in this Report** |
| Climate Data | | | |
| | Perform sensitivity analysis. | Navajo Nation | 2.1.1, 2.1.2 |
| | Utilize all available climate data from the Keams Canyon and Tuba City meteorological stations. | U.S. | 2.1.3 |
| | Incorporate data from regional meteorological stations to account for climate variability across the reservation. | U.S. | 2.1.3 |
| | Use a more appropriate method to estimate solar radiation. | U.S. | 2.1.4 |
| | Calculate ETo based on daily rather than mean monthly climate inputs. | U.S. | 2.1.3 |
| | Weigh ETc values based on proximity to meteorological stations. | Navajo Nation | 2.1.3 |
| | Determine exceedence probability for daily ETc values. | U.S. | 2.1.3 |
| Kc | | | |
| | Adjust for non-standard conditions, such as increased evaporation where crops do not reach effective cover (U.S.) and clumped corn stalks (Hopi Tribe) under DRY conditions. | U.S., Hopi Tribe | 2.2.3 |
| | Include soil moisture accounting in calculations. | U.S. | 2.2.1 |
| | Use crop spacing values more representative of field conditions. | U.S. | 2.2.3 |
| | Perform sensitivity analysis. | Navajo Nation | 2.2.3 |
| Effective Precipitation | | | |
| | Use more reasonable values. | U.S. | 2.3 |
| | For NDI conditions, recalculate based only on growing season data. | Navajo Nation, Hopi Tribe | 2.3 |
| Growing Season | | | |
| | Adjust to reflect elevation changes across the reservation. | U.S. | 2.4 |

**(Table 1.1 Continued)**

| | | | |
|---|---|---|---|
| Crop Mix | | | |
| | Calculate NIR for pasture land. | Hopi Tribe, Navajo Nation | 2.5 |
| | For a better comparison to the claims, calculate NIR for reservation assuming only corn and pasture lands. | Navajo Nation | 2.6 |
| Farming Methods | | | |
| | Specify which claimed irrigation categories are represented by DRY and NDI. | Navajo Nation Nation | 2.1.1 |
| Minor/Editorial | | | |
| | Check and/or correct the statement on p. 2-5 of Crowley (2007) that Tdew decreases with increasing relative humidity. | Navajo Nation Nation | 2.6 |
| | Verify that Table 21 from FAO 24 is the correct reference for the DRY Kc curve | Hopi Tribe | 2.6 |
| Tables and Figures in Crowley (2007) | | | |
| | In Figure 2.9, explain why there are multiple GDD curves shown if the only variable is mean temperature. | Hopi Tribe | 2.6 |
| | Verify that Figures 2.12 and 2.13 match the data in Tables 2.6 through 2.9. | Hopi Tribe | 2.6 |
| | In Table 2.1, correct days specified for the 170-day growing season. | U.S. | Tables 2.8 - 2.11 |

**Table 1.2:** Comparison of ADWR and Claimed Irrigation Methods

| Claimed Irrigation Methods | Claimed Acreage | ADWR Irrigation Method |
|---|---|---|
| Perennial | 564 | NDI |
| Seasonal | 6,186 | DRY |
| Native | 23,091 | DRY |
| Spring | 151 | DRY |
| Precipitation Farming | 1,042 | DRY |
| Range Pasture | 7,522 | Range CU |

**Table 2.1:** Comparison of Hopi Agricultural Field Elevations in 2005 to Elevations for Keams Canyon and Tuba City

| **Hopi Agricultural Field Elevations** | | |
|---|---|---|
| **Agricultural Field Elevations** | **Acreage of Fields** | **Percent of Total** |
| Fields lower than Tuba City (4,980 ft) | 518 | 9.22% |
| Fields between 4,980 ft and 6,120 ft | 4,656 | 82.94% |
| Fields higher than Keams Canyon (6,120 ft) | 439 | 7.84% |
| TOTAL | 5,613 | 100.00% |

**Table 2.2:** $ET_o$ Sensitivity to $T_{dew\ (Brwn)}$ vs. $T_{dew\ (Move.1)}$ with Varying $U_2$ at Keams Canyon, AZ

| $ET_o$ at Keams Canyon, AZ with $U_2$ of 3m/s | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Monthly average |
| Keams Canyon | Tdew (Brwn) (mm/day) | 1.83 | 2.38 | 3.25 | 4.60 | 5.91 | 7.22 | 6.97 | 6.18 | 5.17 | 4.05 | 2.64 | 1.89 | 4.34 |
| | Tdew (Move.1) (mm/day) | 2.03 | 2.62 | 3.50 | 4.88 | 6.23 | 7.54 | 7.69 | 6.94 | 5.85 | 4.35 | 2.89 | 2.10 | 4.72 |
| | difference (mm/mo) | 6.2 | 6.96 | 7.75 | 8.4 | 9.92 | 9.6 | 22.32 | 23.56 | 20.4 | 9.3 | 7.5 | 6.51 | 11.54 |
| | % increase | **10.9%** | **10.1%** | **7.7%** | **6.1%** | **5.4%** | **4.4%** | **10.3%** | **12.3%** | **13.2%** | **7.4%** | **9.5%** | **11.1%** | **9.0%** |

| $ET_o$ at Keams Canyon, AZ with $U_2$ of 5m/s | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Monthly average |
| Keams Canyon | Tdew (Brwn) (mm/day) | 2.27 | 2.88 | 3.79 | 5.28 | 6.67 | 8.43 | 8.03 | 7.12 | 6.08 | 4.95 | 3.27 | 2.36 | 5.09 |
| | Tdew (Move.1) (mm/day) | 2.55 | 3.21 | 4.16 | 5.70 | 7.16 | 8.96 | 9.22 | 8.35 | 7.14 | 5.40 | 3.64 | 2.65 | 5.68 |
| | difference (mm/mo) | 8.68 | 9.57 | 11.47 | 12.6 | 15.19 | 15.9 | 36.89 | 38.13 | 31.8 | 13.95 | 11.1 | 8.99 | 17.86 |
| | % increase | **12.3%** | **11.5%** | **9.8%** | **8.0%** | **7.3%** | **6.3%** | **14.8%** | **17.3%** | **17.4%** | **9.1%** | **11.3%** | **12.3%** | **11.4%** |

**Table 2.3:** $ET_o$ Sensitivity to $T_{dew\ (Brwn)}$ vs. $T_{dew\ (Move.1)}$ with Varying $U_2$ at Tuba City, AZ

| $ET_o$ at Tuba City, AZ with $U_2$ of 3m/s | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Monthly average |
| | Tdew (Brwn) (mm/day) | 1.86 | 2.50 | 3.59 | 4.81 | 6.23 | 7.54 | 7.38 | 6.70 | 5.97 | 4.31 | 2.75 | 1.89 | 4.63 |
| | Tdew (Move.1) (mm/day) | 2.11 | 2.78 | 3.89 | 5.16 | 6.59 | 7.93 | 8.17 | 7.50 | 6.37 | 4.65 | 3.03 | 2.13 | 5.03 |
| | difference (mm/mo) | 7.75 | 8.12 | 9.3 | 10.5 | 11.16 | 11.7 | 24.49 | 24.8 | 12 | 10.54 | 8.4 | 7.44 | 12.18 |
| | % increase | **13.4%** | **11.2%** | **8.4%** | **7.3%** | **5.8%** | **5.2%** | **10.7%** | **11.9%** | **6.7%** | **7.9%** | **10.2%** | **12.7%** | **9.3%** |

| $ET_o$ at Tuba City, AZ with $U_2$ of 5m/s | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Monthly average |
| | Tdew (Brwn) (mm/day) | 2.34 | 3.07 | 4.27 | 5.59 | 7.24 | 8.87 | 8.58 | 7.82 | 7.26 | 5.32 | 3.44 | 2.37 | 5.51 |
| | Tdew (Move.1) (mm/day) | 2.68 | 3.46 | 4.71 | 6.11 | 7.81 | 9.52 | 9.90 | 9.16 | 7.91 | 5.85 | 3.85 | 2.71 | 6.14 |
| | difference (mm/mo) | 10.54 | 11.31 | 13.64 | 15.6 | 17.67 | 19.5 | 40.92 | 41.54 | 19.5 | 16.43 | 12.3 | 10.54 | 19.12 |
| | % increase | **14.5%** | **12.7%** | **10.3%** | **9.3%** | **7.9%** | **7.3%** | **15.4%** | **17.1%** | **9.0%** | **10.0%** | **11.9%** | **14.3%** | **11.6%** |

**Table 2.4**: $ET_o$ Sensitivity with varying $U_2$ at Keams Canyon

| **$ET_o$ at Keams Canyon, AZ using $T_{dew(Brwn)}$*** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Monthly average | Total/yr |
| U2 = 0m/s | 0.52 | 0.98 | 1.78 | 2.86 | 4.05 | 4.52 | 4.73 | 4.15 | 3.12 | 1.84 | 0.91 | 0.53 | 2.50 | 29.99 |
| U2 = 2m/s | 1.51 | 2.04 | 2.87 | 4.15 | 5.41 | 6.46 | 6.33 | 5.61 | 4.61 | 3.46 | 2.20 | 1.56 | 3.85 | 46.21 |
| U2 = 3m/s | 1.83 | 2.38 | 3.25 | 4.60 | 5.91 | 7.22 | 6.97 | 6.18 | 5.17 | 4.05 | 2.64 | 1.89 | 4.34 | 52.09 |
| U2 = 5m/s | 2.27 | 2.88 | 3.79 | 5.28 | 6.67 | 8.43 | 8.03 | 7.12 | 6.08 | 4.95 | 3.27 | 2.36 | 5.09 | 61.13 |
| U2 = 6m/s | 2.44 | 3.06 | 3.99 | 5.55 | 6.97 | 8.93 | 8.47 | 7.51 | 6.44 | 5.30 | 3.51 | 2.53 | 5.39 | 64.7 |
| % increase (2-6) | **61.6%** | **50.0%** | **39.0%** | **33.7%** | **28.8%** | **38.2%** | **33.8%** | **33.9%** | **39.7%** | **53.2%** | **59.5%** | **62.2%** | **44.5%** | |

| **$ET_o$ at Keams Canyon, AZ using $T_{dew(Move.1)}$*** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Monthly average | Total/yr |
| U2 = 0m/s | 0.49 | 0.95 | 1.73 | 2.8 | 3.95 | 4.38 | 4.43 | 3.88 | 2.91 | 1.76 | 0.87 | 0.5 | 2.39 | 28.65 |
| U2 = 2m/s | 1.66 | 2.2 | 3.06 | 4.34 | 5.62 | 6.66 | 6.76 | 6.07 | 5.04 | 3.66 | 2.38 | 1.72 | 4.10 | 49.17 |
| U2 = 3m/s | 2.03 | 2.62 | 3.50 | 4.88 | 6.23 | 7.54 | 7.69 | 6.94 | 5.85 | 4.35 | 2.89 | 2.10 | 4.72 | 56.62 |
| U2 = 5m/s | 2.55 | 3.21 | 4.16 | 5.70 | 7.16 | 8.96 | 9.22 | 8.35 | 7.14 | 5.40 | 3.64 | 2.65 | 5.68 | 68.14 |
| U2 = 6m/s | 2.74 | 3.42 | 4.41 | 6.02 | 7.53 | 9.54 | 9.86 | 8.94 | 7.67 | 5.81 | 3.92 | 2.85 | 6.06 | 72.71 |
| % increase (2-6) | **65.1%** | **55.5%** | **44.1%** | **38.7%** | **34.0%** | **43.2%** | **45.9%** | **47.3%** | **52.2%** | **58.7%** | **64.7%** | **65.7%** | **51.3%** | |

*$ET_o$ Values are in mm

**Table 2.5** $ET_o$ modeled with measured vs. calculated solar radiation at RAWS Station 020312 (2002-2009)

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Yearly Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | |
| Tmax (°F) | 47.8 | 51.48 | 58.63 | 66.98 | 78.35 | 87.57 | 94.09 | 89.41 | 81.75 | 69.62 | 58.91 | 45.9 | |
| Tmin (°F) | 20.48 | 24.13 | 28.01 | 33.05 | 43.48 | 49.75 | 60.19 | 57.94 | 49.48 | 38.11 | 27.56 | 19.25 | |
| U2 (m/s) | 3.2 | 3.3 | 3.9 | 4.4 | 3.8 | 3.7 | 2.8 | 2.9 | 3.4 | 3.7 | 3.4 | 3.2 | |
| RH % | 64.85 | 58.38 | 43.89 | 31.4 | 29.85 | 20.27 | 32.89 | 45.11 | 38.68 | 44 | 46.21 | 63.4 | |
| | | | | | | | | | | | | | |
| Rs measured (langleys/day) | 294 | 371 | 486 | 571 | 619 | 663 | 585 | 546 | 502 | 424 | 323 | 249 | |
| ETo (mm/day) | 1.34 | 1.99 | 3.43 | 5.26 | 6.59 | 8.26 | 7.18 | 6.26 | 5.75 | 4.05 | 2.56 | 1.31 | 1645.58 |
| | | | | | | | | | | | | | |
| Rs Hargreaves (langleys/day) | 261 | 337 | 459 | 593 | 672 | 731 | 679 | 598 | 511 | 394 | 301 | 239 | |
| ETo (mm/day) | 1.33 | 1.95 | 3.37 | 5.31 | 6.77 | 8.52 | 7.64 | 6.50 | 5.78 | 4.00 | 2.55 | 1.31 | 1677.92 |

**Table 2.6:** Input variables used to develop $K_{c\ initial}$

| | Upper (April 7) | | Lower (May 15) | |
|---|---|---|---|---|
| | Keams Canyon | Tuba City | Keams Canyon | Tuba City |
| $ET_o$ (mm/day) | 5.28 | 4.80 | 6.06 | 7.61 |
| Average (mm/day) | 5.04 | | 6.84 | |
| Wetting Frequency | 15 days | | 15 days | |
| | | | | |
| Kc initial (from Fig. 2.13) | 0.15 | | 0.12 | |

**Table 2.7:** $ET_c$ Sensitivity to $f_c$ at Tuba City, AZ

| Varying values of $f_c$ at Tuba City, AZ | | | | |
|---|---|---|---|---|
| | | $f_c$ | Total $ET_c$ (ft/yr) | % change from mean |
| Upper Limit | min | 0.030 | 0.92 | -35.5% |
| | 25th | 0.058 | 1.11 | -22.1% |
| | mean | 0.103 | 1.42 | 0.0% |
| | 75th | 0.150 | 1.74 | 22.8% |
| | max | 0.200 | 2.09 | 47.1% |
| | | | | |
| Lower Limit | min | 0.030 | 0.43 | -41.3% |
| | 25th | 0.058 | 0.55 | -25.7% |
| | mean | 0.103 | 0.74 | 0.0% |
| | 75th | 0.150 | 0.94 | 26.6% |
| | max | 0.200 | 1.15 | 54.9% |

**Table 2.8:** $ET_c$ Sensitivity to $f_c$ at Keams Canyon, AZ

| ETc with varying values of fc at Keams Canyon, AZ | | | | |
|---|---|---|---|---|
| | | $f_c$ | Total $ET_c$ (ft/yr) | % change from mean |
| Upper Limit | min | 0.030 | 0.85 | -35.5% |
| | 25th | 0.058 | 1.03 | -22.1% |
| | mean | 0.103 | 1.32 | 0.0% |
| | 75th | 0.150 | 1.62 | 22.9% |
| | max | 0.200 | 1.95 | 47.2% |
| | | | | |
| Lower Limit | min | 0.030 | 0.44 | -40.1% |
| | 25th | 0.058 | 0.54 | -26.3% |
| | mean | 0.103 | 0.73 | 0.0% |
| | 75th | 0.150 | 0.87 | 20.2% |
| | max | 0.200 | 1.06 | 45.3% |

**Table 2.9**: Corn ETc values for Hopi DRY lower limit

## Dryland Farmed Fields (DRY)
## Lower Bound for Corn

**Tuba City**

| Season | | FAO56PM ETo | | Kc | | | ETc | | |
|---|---|---|---|---|---|---|---|---|---|
| month | days/mo | mm/day | mm/mo | | | | | | |
| April | 0 | 5.09 | 0.00 | Crop Stage | Days per Stage | Kc | | | |
| May | 15 | 6.39 | 95.85 | | | | | | |
| June | 30 | 7.60 | 228.00 | 1 | 20 | 0.12 | | | |
| July | 31 | 7.68 | 238.08 | 2 | 35 | interpolation | mm/yr | in/yr | ft/yr |
| Aug | 31 | 7.24 | 224.44 | 3 | 40 | 0.40 | **225.47** | **8.88** | **0.74** |
| Sept | 8 | 6.31 | 50.48 | 4 | 20 | 0.19 | | | |
| | days/yr | mm/yr | ft/yr | | | | | | |
| Totals | 115 | 924.29 | 3.03 | | | | | | |

**Keams Canyon**

| Season | | FAO56PM ETo | | Kc | | | ETc | | |
|---|---|---|---|---|---|---|---|---|---|
| month | days/mo | mm/day | mm/mo | | | | | | |
| April | 0 | 4.82 | 0.00 | Crop Stage | Days per Stage | Kc | | | |
| May | 15 | 6.06 | 103.95 | | | | | | |
| June | 30 | 7.26 | 242.40 | 1 | 20 | 0.12 | | | |
| July | 31 | 7.29 | 259.47 | 2 | 35 | interpolation | mm/yr | in/yr | ft/yr |
| Aug | 31 | 6.74 | 222.27 | 3 | 40 | 0.40 | **213.88** | **8.42** | **0.70** |
| Sept | 8 | 5.82 | 50.40 | 4 | 20 | 0.19 | | | |
| | days/yr | mm/yr | ft/yr | | | | | | |
| Totals | 115 | 878.49 | 2.88 | | | | | | |

| Lower Bound ETo Input Variables | | | |
|---|---|---|---|
| Wind | Growing Season | Tdew | Kc |
| 3 m/s | 115 days | Actual (MOVE.1) | Kc adj Sparse Veg |

| **Rainfall (in)** | | |
|---|---|---|
| | **Keams Canyon** | **Tuba City** |
| Annual | 10.31 | 6.41 |
| Growing Season (Apr-Sept) | 5.07 | 3.31 |
| Annual Effective | 6.40 | 3.86 |
| Growing Season (effective) | **3.11** | **1.99** |

**Table 2.10**: Corn ETc values for Hopi DRY upper limit

## Dryland Farmed Fields (DRY)
## Upper Bound for Corn

**Tuba City**

| Season | | FAO56PM ETo | | Kc | | | ETc | | |
|---|---|---|---|---|---|---|---|---|---|
| month | days/mo | mm/day | mm/mo | | | | | | |
| April | 23 | 6.04 | 138.92 | Crop Stage | Days per Stage | Kc | | | |
| May | 31 | 7.61 | 235.91 | | | | | | |
| June | 30 | 9.19 | 275.70 | 1 | 30 | 0.15 | | | |
| July | 31 | 9.45 | 292.95 | 2 | 50 | interpolation | mm/yr | in/yr | ft/yr |
| Aug | 31 | 8.89 | 275.59 | 3 | 55 | 0.40 | **432.80** | **17.04** | **1.42** |
| Sept | 24 | 7.82 | 187.68 | 4 | 35 | 0.19 | | | |
| | days/yr | mm/yr | ft/yr | | | | | | |
| Totals | 170 | 1406.75 | 4.62 | | | | | | |

**Keams Canyon**

| Season | | FAO56PM ETo | | Kc | | | ETc | | |
|---|---|---|---|---|---|---|---|---|---|
| month | days/mo | mm/day | mm/mo | | | | | | |
| April | 23 | 5.65 | 129.95 | Crop Stage | Days per Stage | Kc | | | |
| May | 31 | 7.02 | 217.62 | | | | | | |
| June | 30 | 8.72 | 261.60 | 1 | 30 | 0.15 | | | |
| July | 31 | 8.87 | 274.97 | 2 | 50 | interpolation | mm/yr | in/yr | ft/yr |
| Aug | 31 | 8.18 | 253.58 | 3 | 55 | 0.40 | 402.97 | **15.86** | **1.32** |
| Sept | 24 | 7.12 | 170.88 | 4 | 35 | 0.19 | | | |
| | days/yr | mm/yr | ft/yr | | | | | | |
| Totals | 170 | 1308.60 | 4.29 | | | | | | |

| Upper Bound ETo Input Variables | | | |
|---|---|---|---|
| Wind | Growing Season | Tdew | Kc |
| 5 m/s | 170 days | Actual (MOVE.1) | Kc adj Sparse Veg |

| **Rainfall (in)** | | |
|---|---|---|
| | **Keams Canyon** | **Tuba City** |
| Annual | 10.31 | 6.41 |
| Growing Season (Apr-Sept) | 5.07 | 3.31 |
| Annual Effective | 6.40 | 3.86 |
| Growing Season (effective) | **3.11** | **1.99** |

**Figure 2.11**: Corn ETc values for Hopi NDI upper limit

## Non-deficit Irrigated Land (NDI)
## Upper Bound

| | Season | | FAO56PM Eto | | GDD | Kc | ETc | | |
|---|---|---|---|---|---|---|---|---|---|
| | month | days/mo | mm/day | mm/mo | | | mm/mo | mm/day | |
| Tuba City | April | 23 | 5.53 | 127.19 | 138 | 0.35 | 44.52 | 2.19 | |
| | May | 31 | 7.04 | 218.24 | 395 | 0.72 | 157.13 | 5.24 | |
| | June | 30 | 8.55 | 256.50 | 724 | 1.04 | 266.76 | 9.27 | |
| | July | 31 | 8.08 | 250.48 | 1133 | 1.07 | 268.01 | 9.27 | |
| | Aug | 31 | 7.55 | 234.05 | 1526 | 0.56 | 131.07 | 4.40 | |
| | Sept | 24 | 7.19 | 172.56 | 1732 | 0.12 | 20.71 | 0.83 | |
| | | days/yr | mm/yr | ft/yr | | | mm/yr | **in/yr** | **ft/yr** |
| | Totals | 170 | 1259.02 | 4.13 | | | 888.20 | **34.97** | **2.91** |

| | Season | | FAO56PM Eto | | GDD | Kc | ETc | | |
|---|---|---|---|---|---|---|---|---|---|
| | month | days/mo | mm/day | mm/mo | | | mm/mo | mm/day | |
| Keams Canyon | April | 23 | 5.23 | 120.29 | 105 | 0.29 | 34.88 | 1.52 | |
| | May | 31 | 6.52 | 202.12 | 308 | 0.6 | 121.27 | 3.91 | |
| | June | 30 | 8.18 | 245.4 | 594 | 0.94 | 230.68 | 7.69 | |
| | July | 31 | 7.63 | 236.53 | 947 | 1.12 | 264.91 | 8.55 | |
| | Aug | 31 | 6.93 | 214.83 | 1281 | 0.95 | 204.09 | 6.58 | |
| | Sept | 24 | 6.05 | 145.2 | 1530 | 0.55 | 79.86 | 3.33 | |
| | | days/yr | mm/yr | ft/yr | | | mm/yr | **in/yr** | **ft/yr** |
| | Totals | 170 | 1164.37 | 3.82 | | | 935.69 | **36.84** | **3.07** |

| Upper Bound ETo Input Variables | | | |
|---|---|---|---|
| Wind | Growing Season | Tdew | Kc |
| 5 m/s | 170 days | ASCE Method | NM GDD Curve |

| **Rainfall (in)** | | |
|---|---|---|
| | **Keams Canyon** | **Tuba City** |
| Annual | 10.31 | 6.41 |
| Growing Season (Apr-Sept) | 5.07 | 3.31 |
| Annual Effective | 6.4 | 3.86 |
| Growing Season (effective) | **3.11** | **1.99** |

**Figure 2.12**: Corn ETc values for Hopi NDI lower limit

## Non-deficit Irrigated Land (NDI)
## Lower Bound

| | Season | | FAO56PM Eto | | GDD | Kc | ETc | | |
|---|---|---|---|---|---|---|---|---|---|
| | month | days/mo | mm/day | mm/mo | | | mm/mo | mm/day | |
| Tuba City | April | 0 | 4.98 | 0 | 0 | 0.12 | 0 | 0 | |
| | May | 15 | 6.60 | 99.00 | 156 | 0.37 | 37.09 | 2.47 | |
| | June | 30 | 7.56 | 226.80 | 485 | 0.83 | 187.59 | 6.25 | |
| | July | 31 | 7.43 | 230.33 | 894 | 1.11 | 256.37 | 8.27 | |
| | Aug | 31 | 6.74 | 208.94 | 1287 | 0.94 | 197.12 | 6.36 | |
| | Sept | 8 | 6.04 | 48.32 | 1376 | 0.83 | 39.98 | 5 | |
| | | days/yr | mm/yr | ft/yr | | | mm/yr | **in/yr** | **ft/yr** |
| | Totals | 115 | 813.39 | 2.67 | | | 718.16 | **28.27** | **2.36** |

| | Season | | FAO56PM Eto | | GDD | Kc | ETc | | |
|---|---|---|---|---|---|---|---|---|---|
| | month | days/mo | mm/day | mm/mo | | | mm/mo | mm/day | |
| Keams Canyon | April | 0 | 4.62 | 0.00 | 0 | 0.12 | 0 | 0 | |
| | May | 15 | 6.21 | 93.15 | 127 | 0.33 | 30.62 | 2.04 | |
| | June | 30 | 7.26 | 217.80 | 413 | 0.74 | 161.34 | 5.38 | |
| | July | 31 | 6.98 | 216.38 | 766 | 1.07 | 230.63 | 7.44 | |
| | Aug | 31 | 6.15 | 190.65 | 1100 | 1.09 | 207.56 | 6.70 | |
| | Sept | 8 | 5.5 | 44.00 | 1175 | 1.05 | 46.01 | 5.75 | |
| | | days/yr | mm/yr | ft/yr | | | mm/yr | **in/yr** | **ft/yr** |
| | Totals | 115 | 761.98 | 2.50 | | | 676.17 | **26.62** | **2.22** |

| Lower Bound ETo Input Variables | | | |
|---|---|---|---|
| Wind | Growing Season | Tdew | Kc |
| 3 m/s | 115 days | ASCE Method | NM GDD Curve |

| **Rainfall (in)** | | |
|---|---|---|
| | **Keams Canyon** | **Tuba City** |
| Annual | 10.31 | 6.41 |
| Growing Season (Apr-Sept) | 5.07 | 3.31 |
| Annual (effective) | 6.4 | 3.86 |
| Growing Season (effective) | **3.11** | **1.99** |

**Table 2.13: Acreage of fields previously claimed as Range Pasture**

| Field (Polygon ID) | Acres | USGS Topo Quad |
|---|---|---|
| 1 | 6 | Tovar Mesa West |
| 2 | 69 | Tovar Mesa West |
| 564 | 235 | Polacca |
| 1154 | 252 | Garces Mesas SE |
| 1163 | 147 | Egloffstein Butte |
| **Total** | **709** | |

**Table 2.14: CU of Range Pasture Lands on the Hopi Indian Reservation (ft)**

| | Keams Canyon | Tuba City | Composite |
|---|---|---|---|
| Upper Limit (NDVI) | 1.18 | 1.27 | 1.22 |
| Lower Limit (Pe) | 0.53 | 0.32 | 0.43 |

**Table 2.15: CU and SID estimates for corn and pasture on the Hopi Reservation**

| Corn and Pasture Water Demands (ft/yr) | | | | |
|---|---|---|---|---|
| | CU | | SID | |
| | Corn | Pasture | Corn | Pasture |
| NDI - Upper | 2.99 | 1.22 | 2.78 | .79 |
| NDI - Lower | 2.29 | n/a | 2.08 | n/a |
| DRY - Upper | 1.37 | 0.43 | 0.94 | 0 |
| DRY - Lower | 0.72 | n/a | 0.29 | n/a |

**Table 2.16:** $ET_c$ for crops grown on the Hopi Reservation

| | Crop | NDI | | DRY | |
|---|---|---|---|---|---|
| | | ETc Upper (ft/yr) | ETc Lower (ft/yr) | ETc Upper (ft/yr) | ETc Lower (ft/yr) |
| **Keams Canyon** | Corn | 3.07 | 2.22 | 1.32 | 0.7 |
| | Beans (dry) | 1.99 | 1.70 | 1.00 | 0.83 |
| | Trees (orchard) | 3.24 | 2.76 | 1.83 | 1.02 |
| | Melon | 1.96 | 1.68 | 1.96 | 1.68 |
| | Squash | 1.76 | 1.50 | 1.76 | 1.50 |
| **Tuba City** | Corn | 2.91 | 2.36 | 1.42 | 0.74 |
| | Beans (dry) | 1.92 | 1.63 | 0.92 | 0.77 |
| | Trees (orchard) | 3.51 | 2.96 | 1.96 | 1.14 |
| | Melon | 2.09 | 1.78 | 2.09 | 1.78 |
| | Squash | 1.87 | 1.59 | 1.87 | 1.59 |

**Table 2.17:** Average $ET_c$ for crops grown on the Hopi Reservation

| Combined ETc for Crops on Hopi Reservation | | | | |
|---|---|---|---|---|
| | NDI | | DRY | |
| Crop | ETc Upper (ft/yr) | ETc Lower (ft/yr) | ETc Upper (ft/yr) | ETc Lower (ft/yr) |
| Corn | 2.99 | 2.29 | 1.37 | 0.72 |
| Beans (dry) | 1.96 | 1.67 | 0.96 | 0.80 |
| Trees (orchard) | 3.38 | 2.86 | 1.90 | 1.08 |
| Melon | 2.03 | 1.73 | 2.03 | 1.73 |
| Squash | 1.82 | 1.55 | 1.82 | 1.55 |

Note: Based on average of ETc values calculated separately for Keams Canyon and Tuba City (see **Table 2.16**)

**Table 2.18**: Composite ETc values for agriculture grown on the Hopi Indian Reservation

| Crop | NDI | | DRY | |
|---|---|---|---|---|
| | ETc Upper (ft/yr) | ETc Lower (ft/yr) | ETc Upper (ft/yr) | ETc Lower (ft/yr) |
| Corn | 2.43 | 1.86 | 1.11 | 0.58 |
| Beans (dry) | 0.13 | 0.11 | 0.06 | 0.05 |
| Trees (orchard) | 0.27 | 0.23 | 0.15 | 0.09 |
| Melon | 0.05 | 0.04 | 0.05 | 0.04 |
| Squash | 0.03 | 0.03 | 0.03 | 0.03 |
| **Total ETc** | **2.91** | **2.27** | **1.41** | **0.79** |

Note: Based on average ETc values (see **Table 2.17**) weighted to account for expected reservation crop mix

**Table 2.19:** Revised SID Estimates for Agriculture on the Hopi Indian Reservation

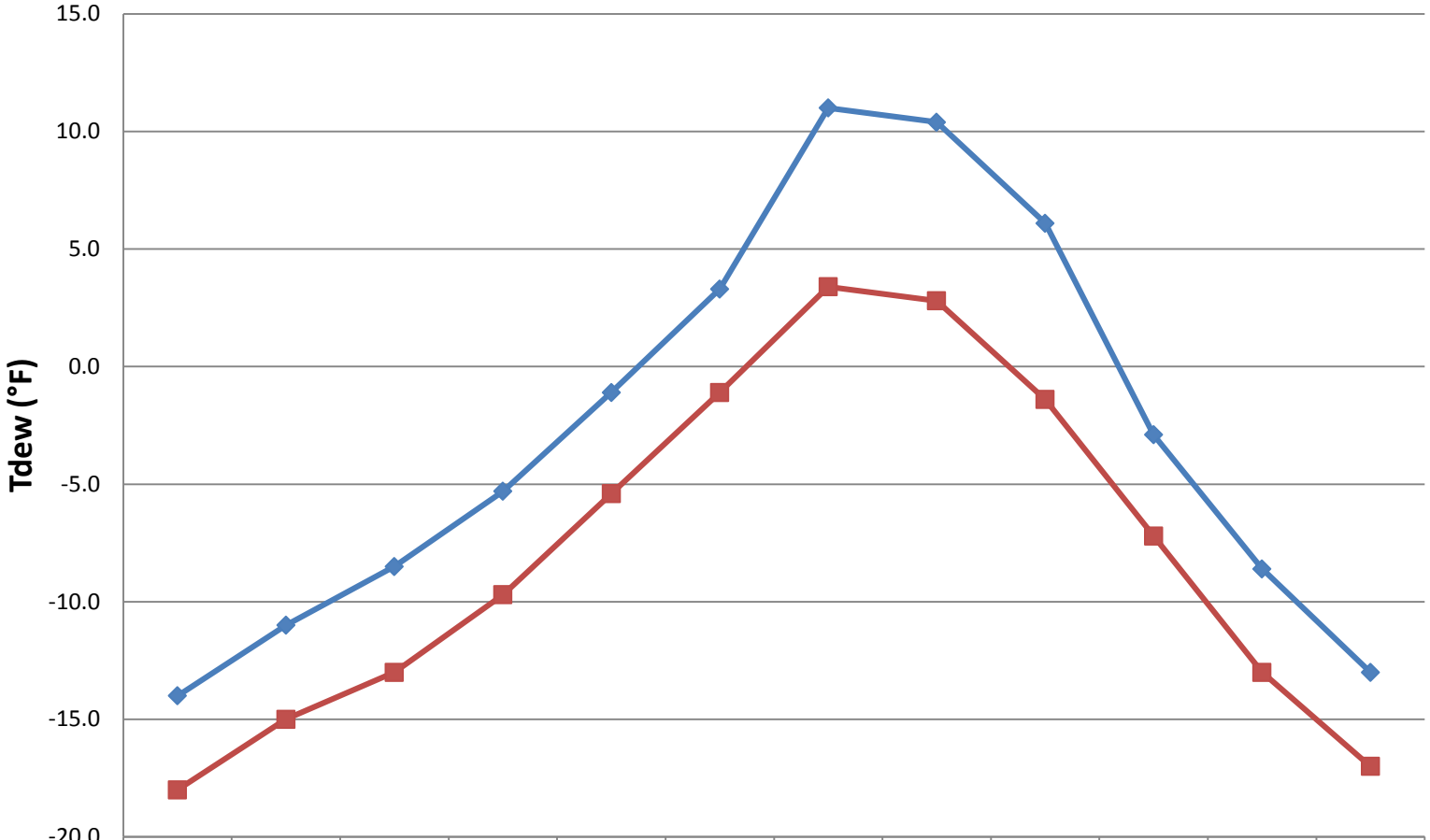
| | Lower Limit (ft/yr) | Upper Limit (ft/yr) |
|---|---|---|
| NDI | **2.06** | **2.70** |
| DRY | **0.36** | **0.98** |

**Table 2.20: Comparison of revised CU variables based on comments received on Hopi PHSR**

| | This Report | Crowley (2007) | |
|---|---|---|---|
| **Revised CU Variable** | **Section** | **Section** | **Description of Change** |
| Tdew | 2.1.1 | 2.1.3.4, 2.1.3.5 | Updated to reflect greater station period of record |
| Air Temperature | 2.1.3 | 2.1.3.1 | Updated to reflect greater station period of record |
| Rs | 2.1.4 | 2.1.3.2 | Adjusted to RAWS weather station |
| Kc initial | 2.2.2 | 2.2.1 | Increased based on soil wetting frequency |
| fc | 2.2.3 | 2.2.1 | Revised percent cover estimates |
| Kc mid | 2.2.3 | 2.2.1 | Due to change in fc values |
| Pe | 2.3 | 2.4 | Revised model based on site conditions |
| Range Kc | 2.5 | n/a | Added based on comments received |
| CU and SID | 2.6 | 2.6 | Incorporated all changes above |

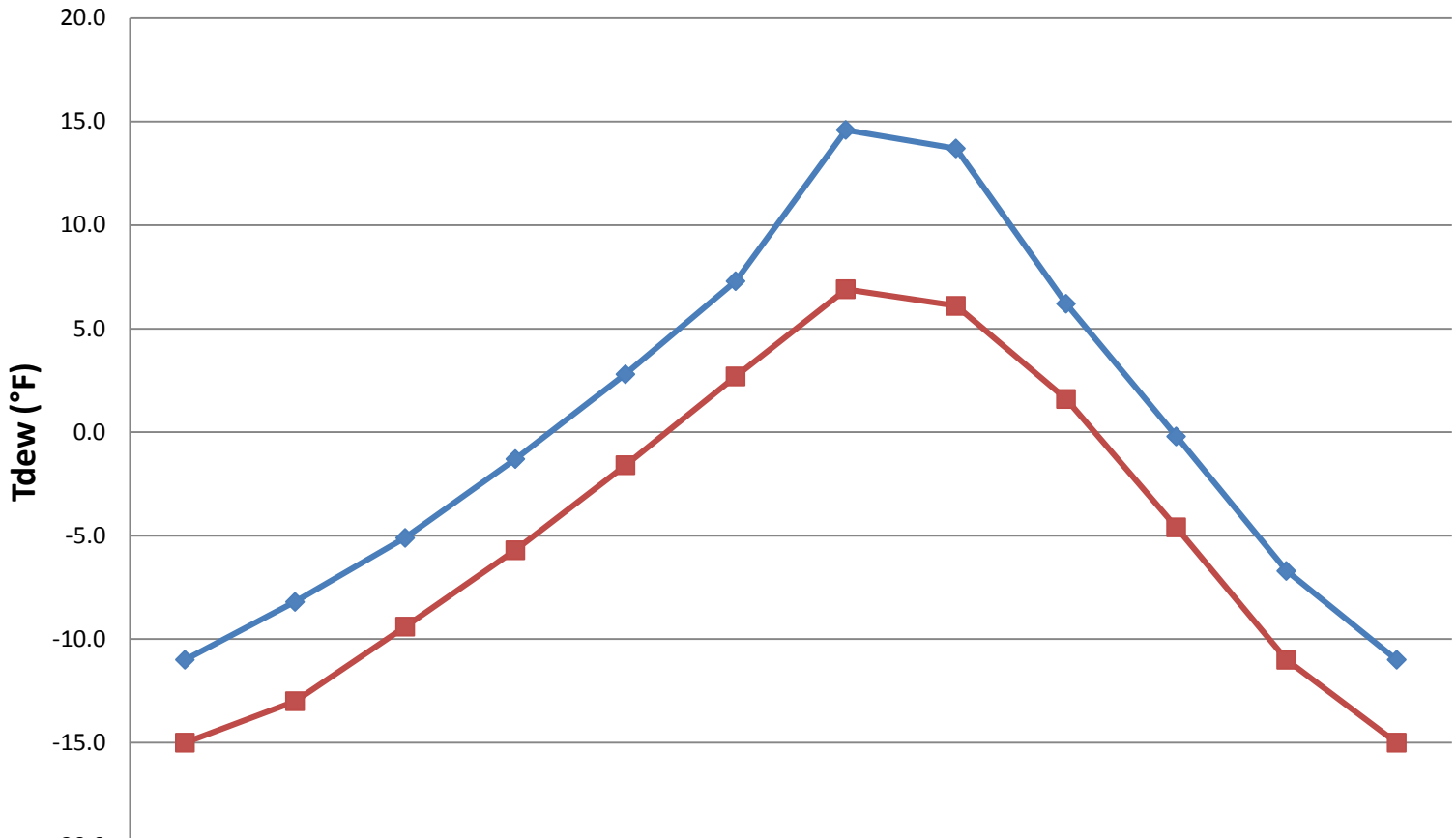
# FIGURES

## Figure 2.1 Comparison between monthly Tdew(Brwn) and Tdew(Move.1) for Keams Canyon, AZ



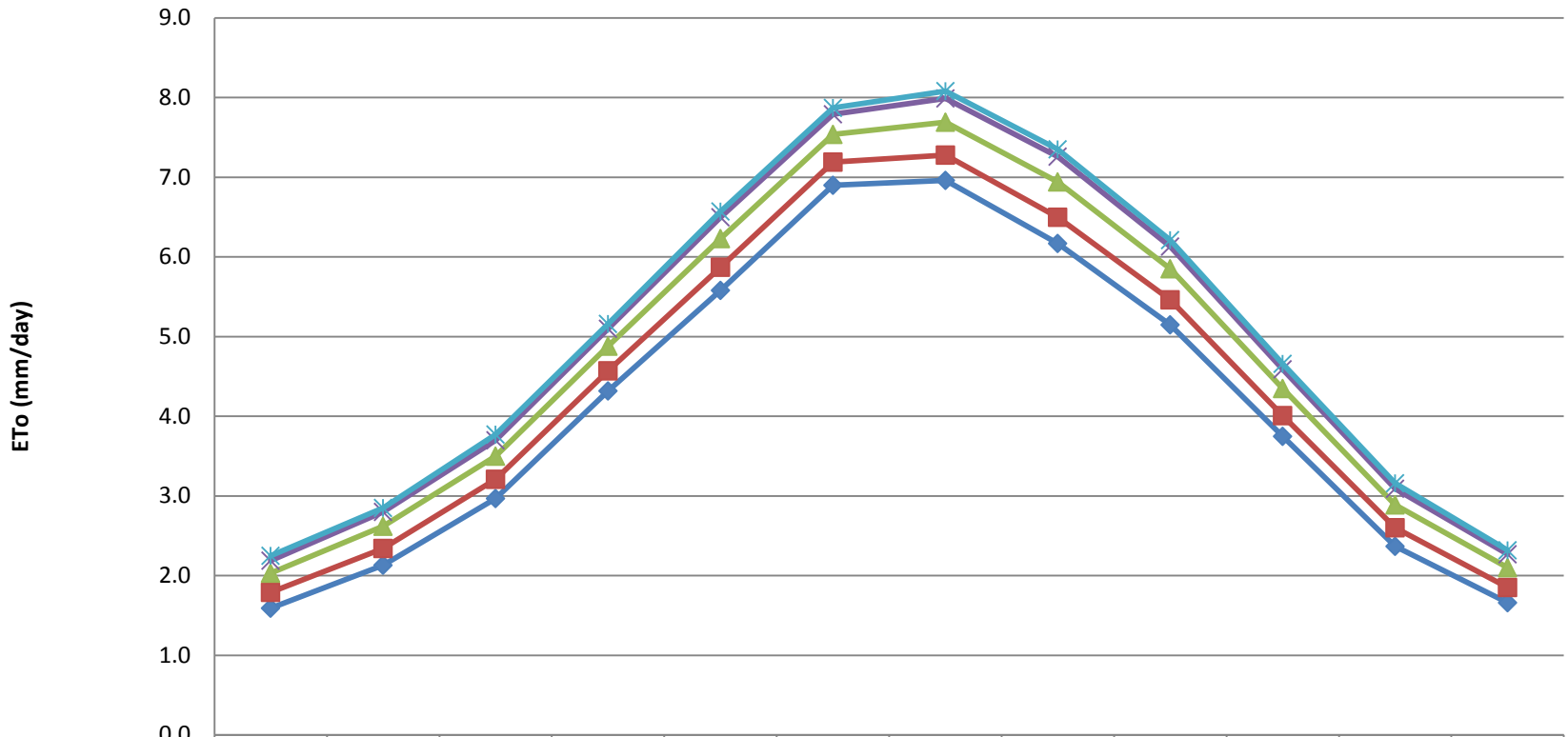

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tdew (Brwn) | -14.0 | -11.0 | -8.5 | -5.3 | -1.1 | 3.3 | 11.0 | 10.4 | 6.1 | -2.9 | -8.6 | -13.0 |
| Tdew (Move.1) | -18.0 | -15.0 | -13.0 | -9.7 | -5.4 | -1.1 | 3.4 | 2.8 | -1.4 | -7.2 | -13.0 | -17.0 |

## Figure 2.2: Comparison between monthly Tdew(Brwn) and Tdew(Move.1) for Tuba City, AZ



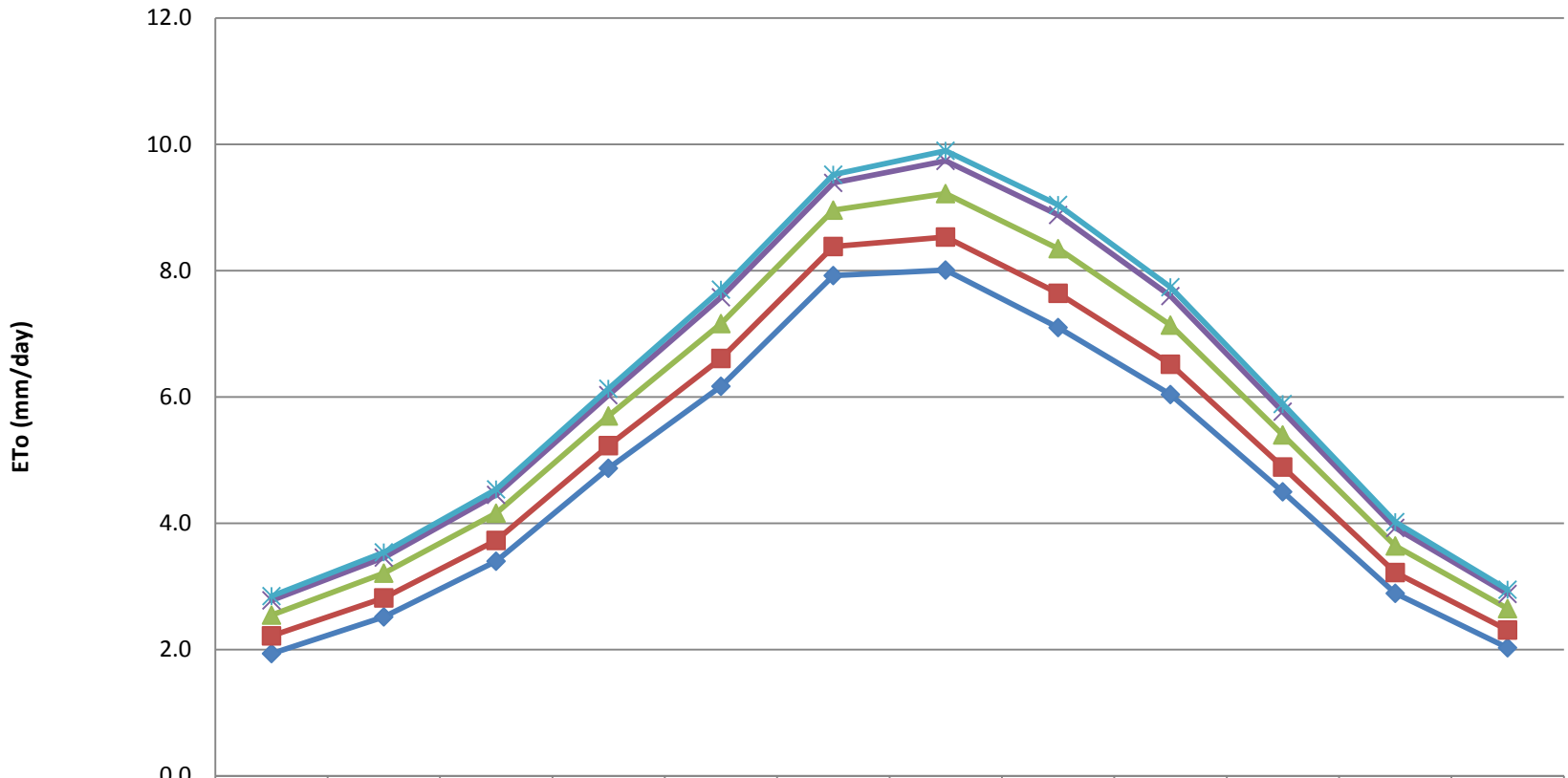

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tdew (Brwn) | -11.0 | -8.2 | -5.1 | -1.3 | 2.8 | 7.3 | 14.6 | 13.7 | 6.2 | -0.2 | -6.7 | -11.0 |
| Tdew (Move.1) | -15.0 | -13.0 | -9.4 | -5.7 | -1.6 | 2.7 | 6.9 | 6.1 | 1.6 | -4.6 | -11.0 | -15.0 |

## Figure 2.3: $ET_o$ Sensitivity with Varying Dew Point Temperatures at Keams Canyon, AZ with $U_2$ = 3m/s



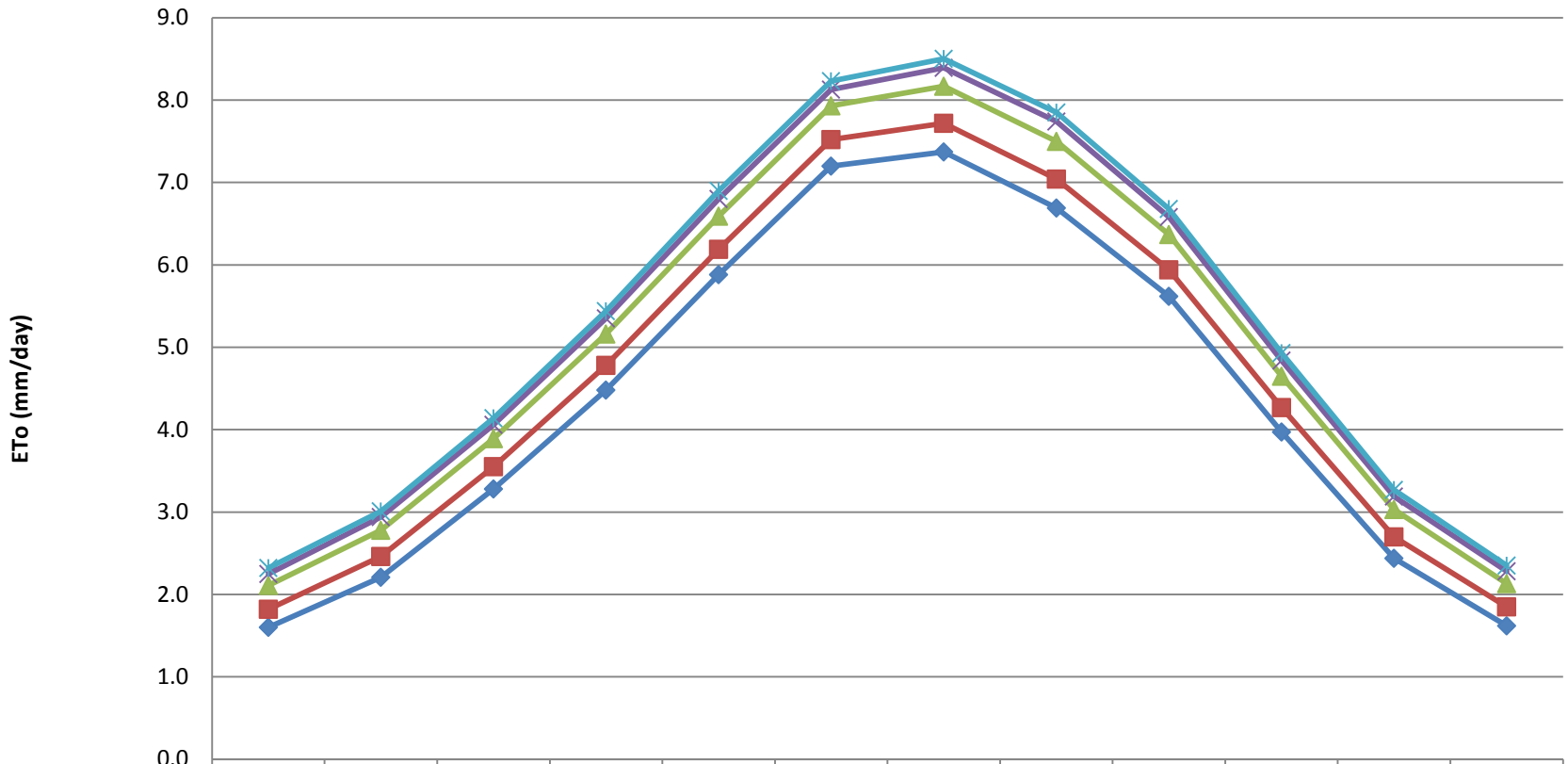

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tdew(10th) | 1.59 | 2.13 | 2.97 | 4.32 | 5.58 | 6.90 | 6.96 | 6.17 | 5.15 | 3.75 | 2.37 | 1.66 |
| Tdew(25th) | 1.79 | 2.34 | 3.21 | 4.57 | 5.87 | 7.19 | 7.28 | 6.50 | 5.46 | 4.01 | 2.60 | 1.85 |
| Tdew(mean) | 2.03 | 2.62 | 3.50 | 4.88 | 6.23 | 7.54 | 7.69 | 6.94 | 5.85 | 4.35 | 2.89 | 2.10 |
| Tdew(75th) | 2.19 | 2.80 | 3.70 | 5.10 | 6.50 | 7.79 | 7.99 | 7.26 | 6.13 | 4.59 | 3.09 | 2.27 |
| Tdew(90th) | 2.25 | 2.85 | 3.77 | 5.16 | 6.57 | 7.87 | 8.08 | 7.35 | 6.21 | 4.66 | 3.16 | 2.32 |

## Figure 2.4: $ET_o$ Sensitivity with Varying Dew Point Temperatures at Keams Canyon, AZ with $U_2$ of 5m/s



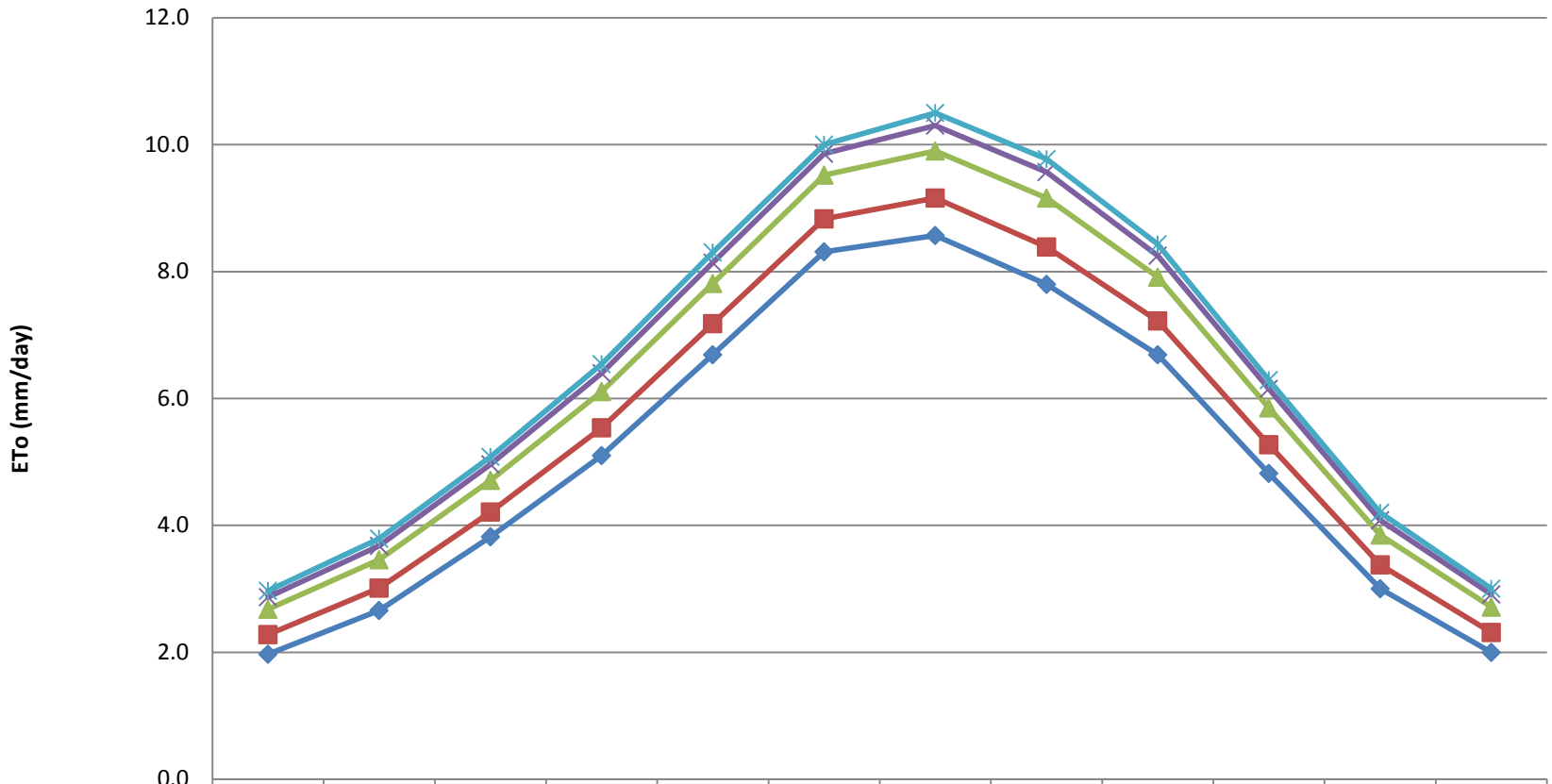

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tdew(10th) | 1.94 | 2.52 | 3.4 | 4.87 | 6.17 | 7.92 | 8.01 | 7.1 | 6.04 | 4.5 | 2.89 | 2.03 |
| Tdew(25th) | 2.22 | 2.82 | 3.73 | 5.23 | 6.61 | 8.38 | 8.53 | 7.64 | 6.52 | 4.89 | 3.22 | 2.31 |
| Tdew(mean) | 2.55 | 3.21 | 4.16 | 5.70 | 7.16 | 8.96 | 9.22 | 8.35 | 7.14 | 5.40 | 3.64 | 2.65 |
| Tdew(75th) | 2.78 | 3.46 | 4.45 | 6.03 | 7.58 | 9.39 | 9.74 | 8.88 | 7.60 | 5.77 | 3.93 | 2.88 |
| Tdew(90th) | 2.85 | 3.54 | 4.54 | 6.13 | 7.7 | 9.52 | 9.9 | 9.04 | 7.74 | 5.89 | 4.02 | 2.95 |

## Figure 2.5: $ET_o$ Sensitivity with Varying Dew Point Temperatures at Tuba City, AZ with U2 = 3m/s



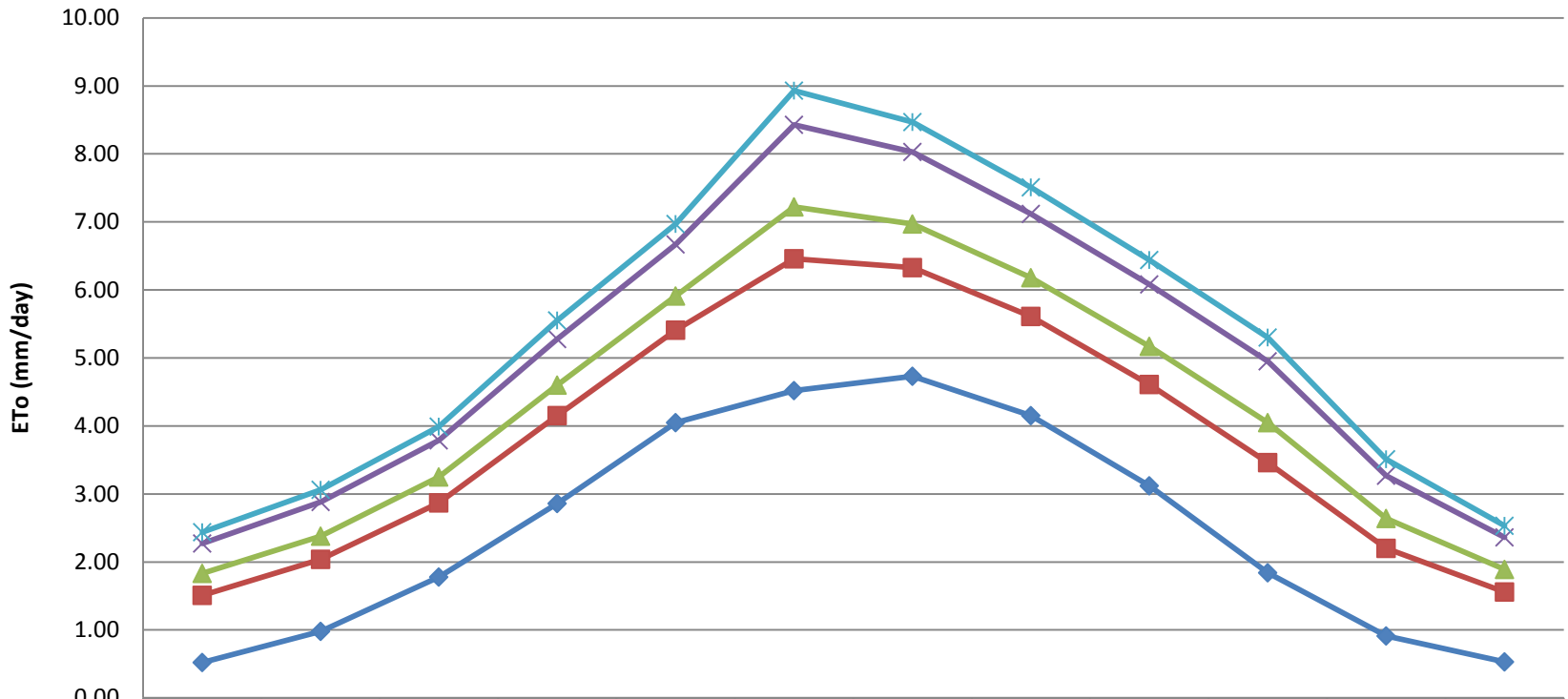

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tdew(10th) | 1.60 | 2.21 | 3.28 | 4.48 | 5.88 | 7.20 | 7.37 | 6.69 | 5.62 | 3.97 | 2.44 | 1.62 |
| Tdew(25th) | 1.82 | 2.46 | 3.55 | 4.78 | 6.19 | 7.52 | 7.72 | 7.04 | 5.94 | 4.27 | 2.70 | 1.85 |
| Tdew(mean) | 2.11 | 2.78 | 3.89 | 5.16 | 6.59 | 7.93 | 8.17 | 7.50 | 6.37 | 4.65 | 3.03 | 2.13 |
| Tdew(75th) | 2.25 | 2.94 | 4.06 | 5.35 | 6.80 | 8.13 | 8.39 | 7.74 | 6.58 | 4.84 | 3.19 | 2.28 |
| Tdew(90th) | 2.32 | 3.01 | 4.14 | 5.44 | 6.9 | 8.23 | 8.5 | 7.85 | 6.68 | 4.93 | 3.27 | 2.35 |

## Figure 2.6: $ET_o$ Sensitivity with Varying Dew Point Temperatures at Tuba City, AZ with U2 = 5m/s



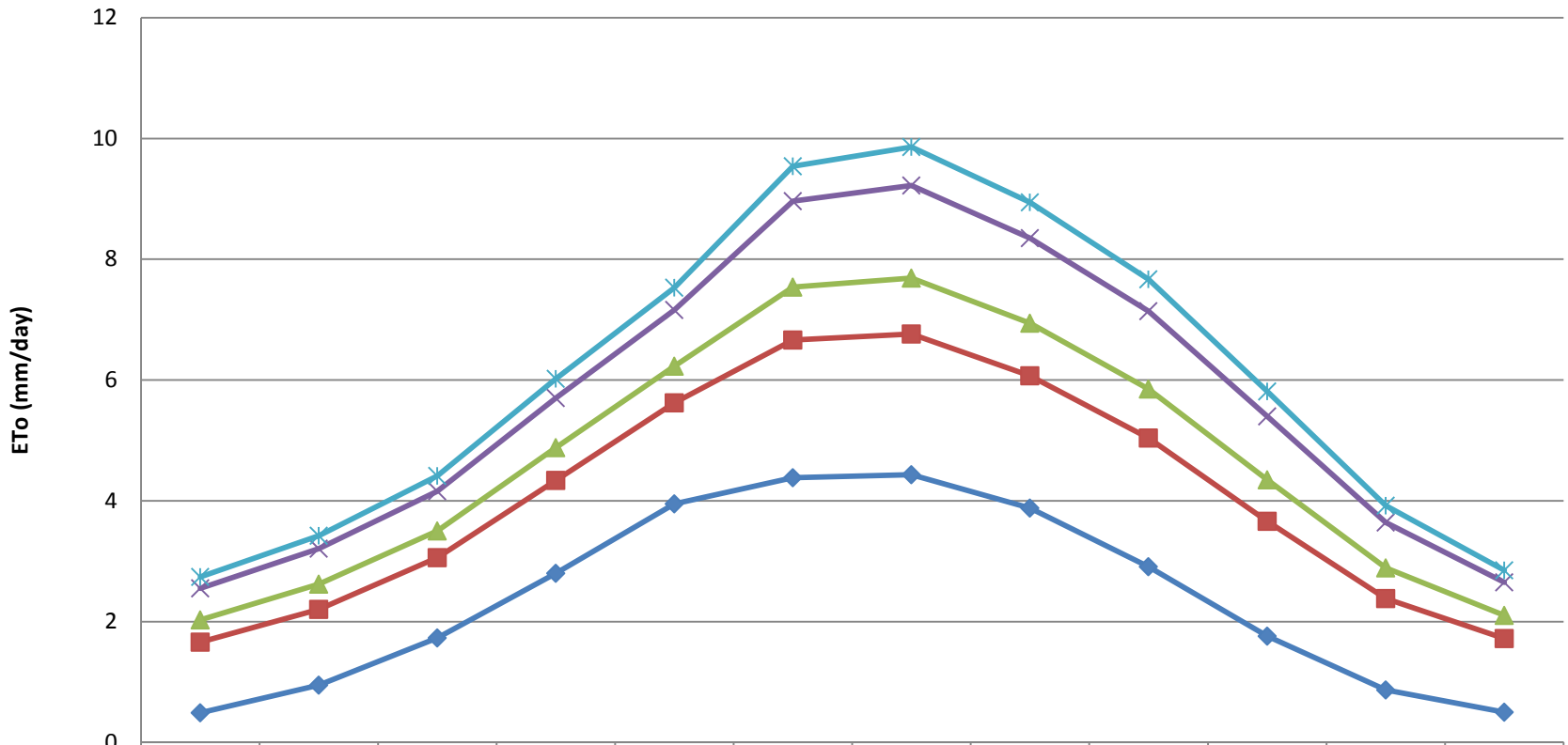

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tdew(10th) | 1.97 | 2.66 | 3.82 | 5.10 | 6.69 | 8.31 | 8.57 | 7.80 | 6.69 | 4.82 | 3.00 | 2.00 |
| Tdew(25th) | 2.28 | 3.01 | 4.21 | 5.54 | 7.18 | 8.83 | 9.16 | 8.39 | 7.22 | 5.27 | 3.38 | 2.31 |
| Tdew(mean) | 2.68 | 3.46 | 4.71 | 6.11 | 7.81 | 9.52 | 9.90 | 9.16 | 7.91 | 5.85 | 3.85 | 2.71 |
| Tdew(75th) | 2.87 | 3.68 | 4.96 | 6.40 | 8.14 | 9.86 | 10.30 | 9.57 | 8.25 | 6.15 | 4.08 | 2.91 |
| Tdew(90th) | 2.97 | 3.79 | 5.08 | 6.54 | 8.30 | 10.00 | 10.50 | 9.77 | 8.43 | 6.29 | 4.20 | 3.00 |

## Figure 2.7: $ET_o$ Sensitivity with Varying $U_2$ at Keams Canyon, AZ using $T_{dew(Brwn)}$



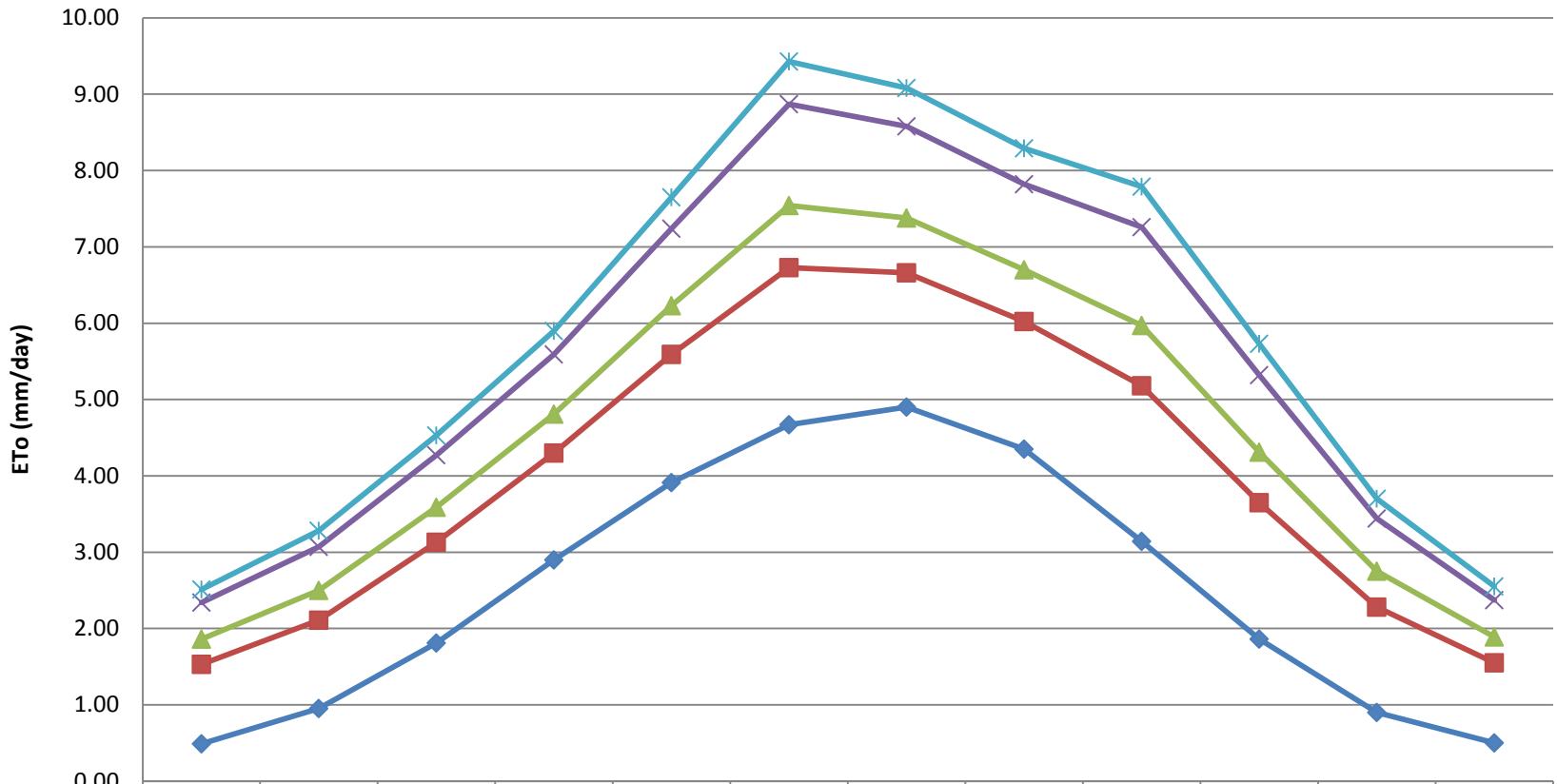

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 m/s | 0.52 | 0.98 | 1.78 | 2.86 | 4.05 | 4.52 | 4.73 | 4.15 | 3.12 | 1.84 | 0.91 | 0.53 |
| 2 m/s | 1.51 | 2.04 | 2.87 | 4.15 | 5.41 | 6.46 | 6.33 | 5.61 | 4.61 | 3.46 | 2.20 | 1.56 |
| 3 m/s | 1.83 | 2.38 | 3.25 | 4.60 | 5.91 | 7.22 | 6.97 | 6.18 | 5.17 | 4.05 | 2.64 | 1.89 |
| 5 m/s | 2.27 | 2.88 | 3.79 | 5.28 | 6.67 | 8.43 | 8.03 | 7.12 | 6.08 | 4.95 | 3.27 | 2.36 |
| 6 m/s | 2.44 | 3.06 | 3.99 | 5.55 | 6.97 | 8.93 | 8.47 | 7.51 | 6.44 | 5.30 | 3.51 | 2.53 |

## Figure 2.8: $ET_o$ Sensitivity with Varying $U_2$ at Keams Canyon, AZ using $T_{dew(Move.1)}$



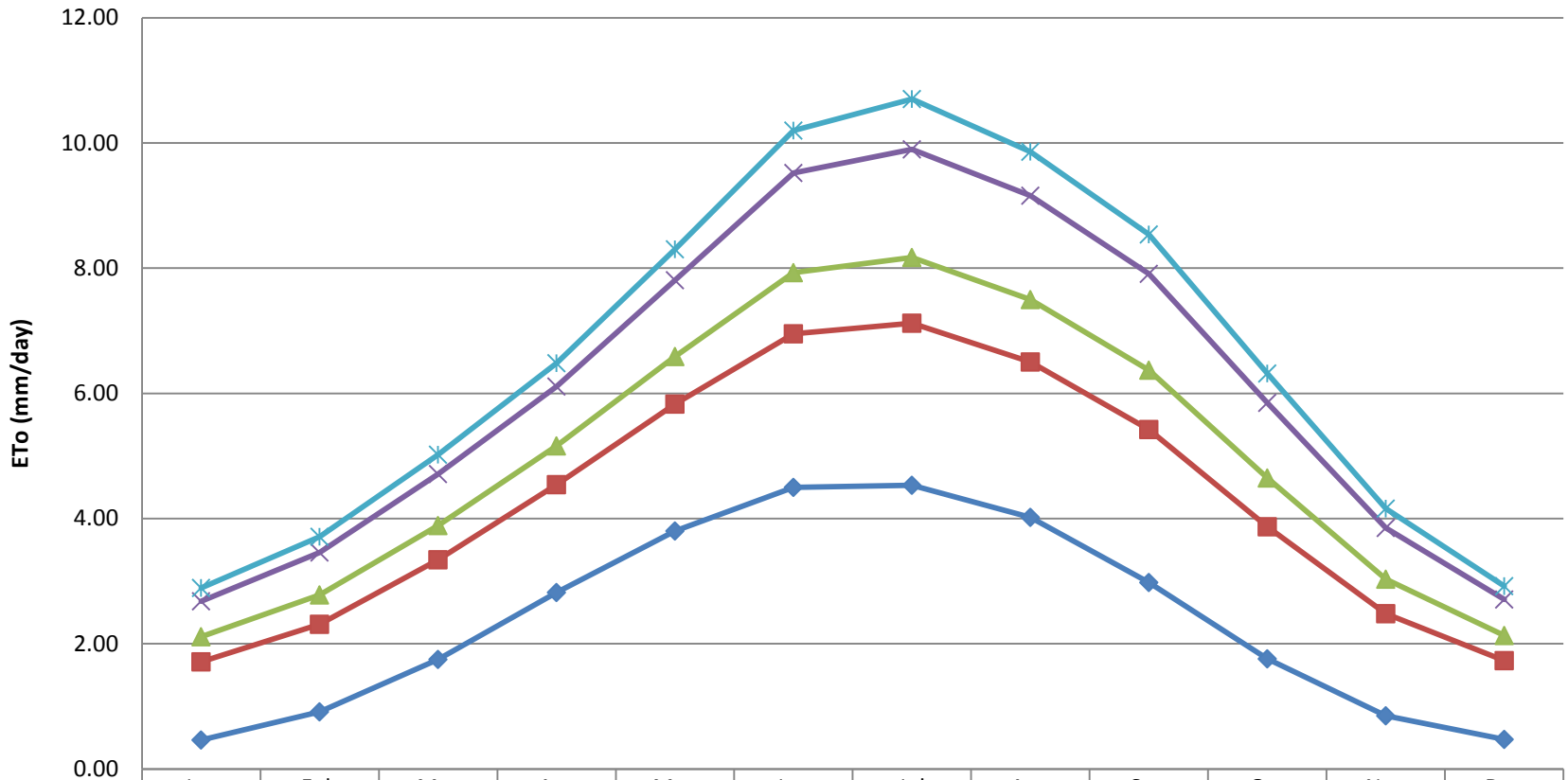

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 m/s | 0.49 | 0.95 | 1.73 | 2.8 | 3.95 | 4.38 | 4.43 | 3.88 | 2.91 | 1.76 | 0.87 | 0.5 |
| 2 m/s | 1.66 | 2.2 | 3.06 | 4.34 | 5.62 | 6.66 | 6.76 | 6.07 | 5.04 | 3.66 | 2.38 | 1.72 |
| 3 m/s | 2.03 | 2.62 | 3.50 | 4.88 | 6.23 | 7.54 | 7.69 | 6.94 | 5.85 | 4.35 | 2.89 | 2.10 |
| 5 m/s | 2.55 | 3.21 | 4.16 | 5.70 | 7.16 | 8.96 | 9.22 | 8.35 | 7.14 | 5.40 | 3.64 | 2.65 |
| 6 m/s | 2.74 | 3.42 | 4.41 | 6.02 | 7.53 | 9.54 | 9.86 | 8.94 | 7.67 | 5.81 | 3.92 | 2.85 |

## Figure 2.9: $ET_o$ Sensitivity with Varying $U_2$ at Tuba City, AZ using $T_{dew(Brwn)}$




| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 m/s | 0.49 | 0.95 | 1.81 | 2.90 | 3.91 | 4.67 | 4.90 | 4.35 | 3.14 | 1.86 | 0.90 | 0.50 |
| 2 m/s | 1.53 | 2.11 | 3.13 | 4.30 | 5.59 | 6.73 | 6.66 | 6.02 | 5.18 | 3.65 | 2.28 | 1.55 |
| 3 m/s | 1.86 | 2.50 | 3.59 | 4.81 | 6.23 | 7.54 | 7.38 | 6.70 | 5.97 | 4.31 | 2.75 | 1.89 |
| 5 m/s | 2.34 | 3.07 | 4.27 | 5.59 | 7.24 | 8.87 | 8.58 | 7.82 | 7.26 | 5.32 | 3.44 | 2.37 |
| 6 m/s | 2.51 | 3.28 | 4.53 | 5.90 | 7.65 | 9.43 | 9.08 | 8.29 | 7.79 | 5.73 | 3.70 | 2.55 |

## Figure 2.10: $ET_o$ Sensitivity with Varying $U_2$ at Tuba City, AZ using $T_{dew(Move)}$




| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 m/s | 0.46 | 0.91 | 1.75 | 2.82 | 3.80 | 4.50 | 4.53 | 4.02 | 2.98 | 1.76 | 0.85 | 0.47 |
| 2 m/s | 1.71 | 2.31 | 3.34 | 4.54 | 5.83 | 6.95 | 7.12 | 6.50 | 5.42 | 3.87 | 2.48 | 1.73 |
| 3 m/s | 2.11 | 2.78 | 3.89 | 5.16 | 6.59 | 7.93 | 8.17 | 7.50 | 6.37 | 4.65 | 3.03 | 2.13 |
| 5 m/s | 2.68 | 3.46 | 4.71 | 6.11 | 7.81 | 9.52 | 9.90 | 9.16 | 7.91 | 5.85 | 3.85 | 2.71 |
| 6 m/s | 2.89 | 3.71 | 5.02 | 6.48 | 8.30 | 10.20 | 10.70 | 9.86 | 8.54 | 6.32 | 4.16 | 2.92 |

**Figure 2.11: Average monthly solar radiation based on data from RAWS weather station 020312**

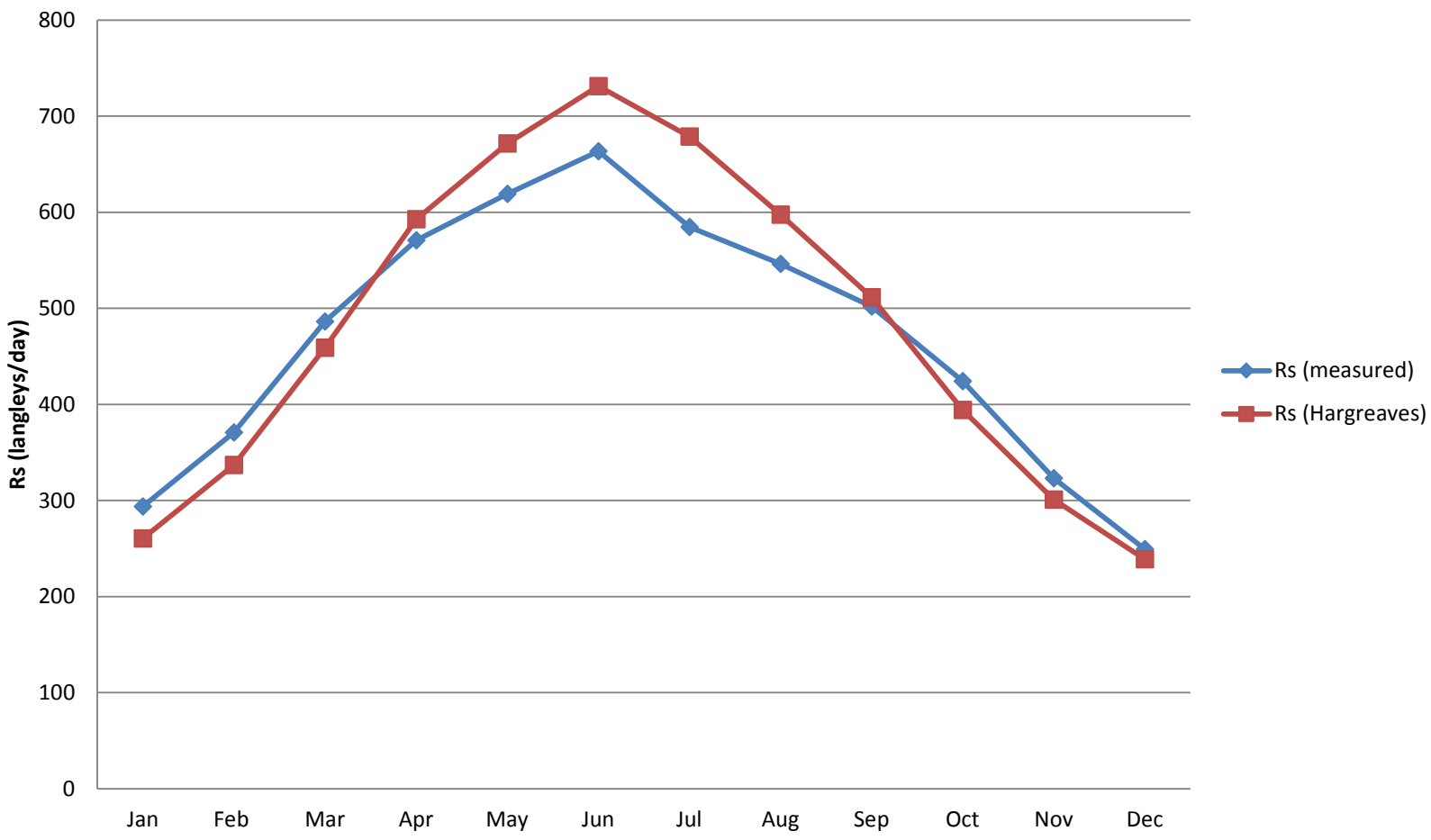


**Figure 2.12**: Crop coefficient curves showing basal Kcb (thick line), soil evaporation Ke (thin line) and the corresponding single Kc (dashed line). (Figure 26 in Allen et al. 1998)

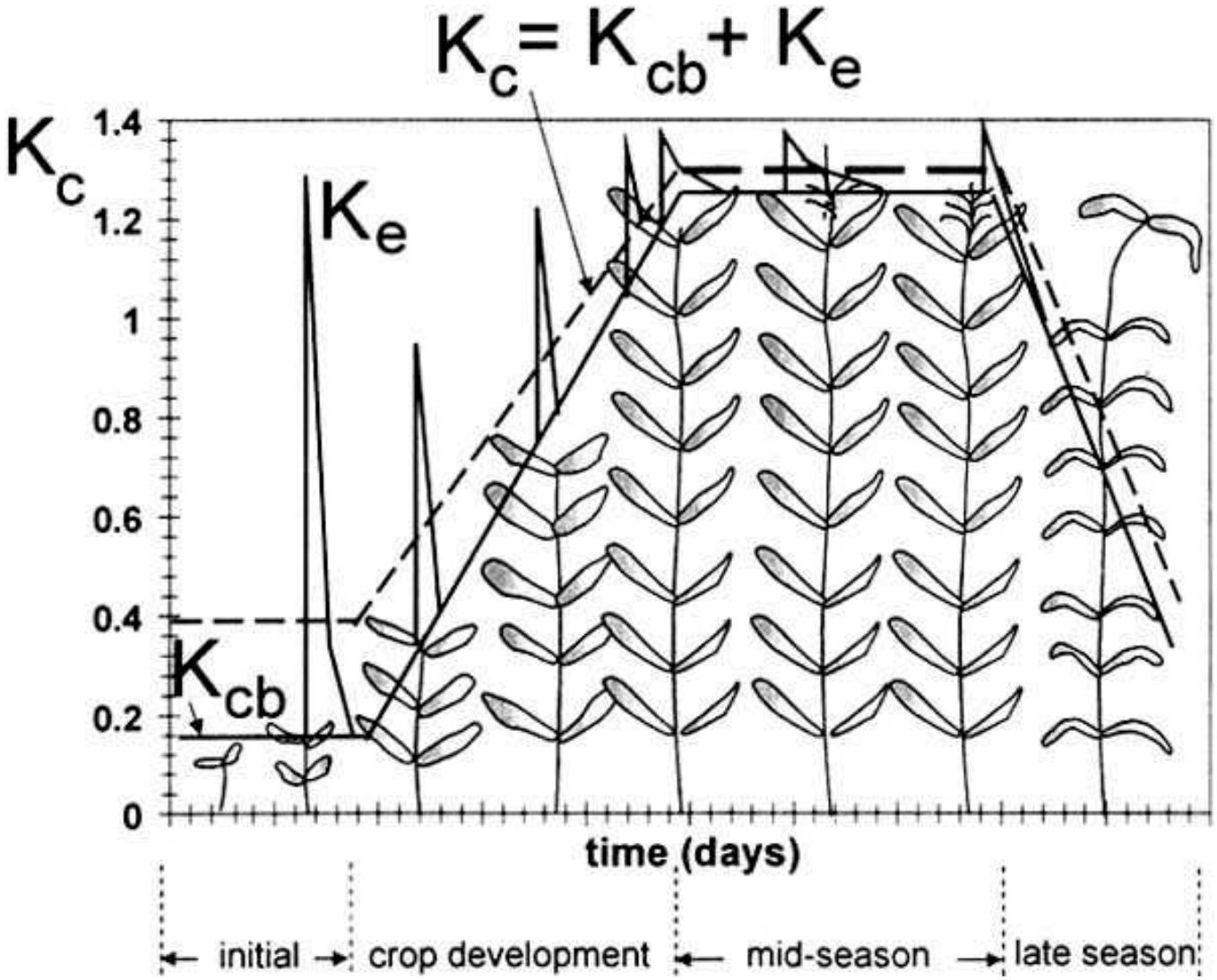
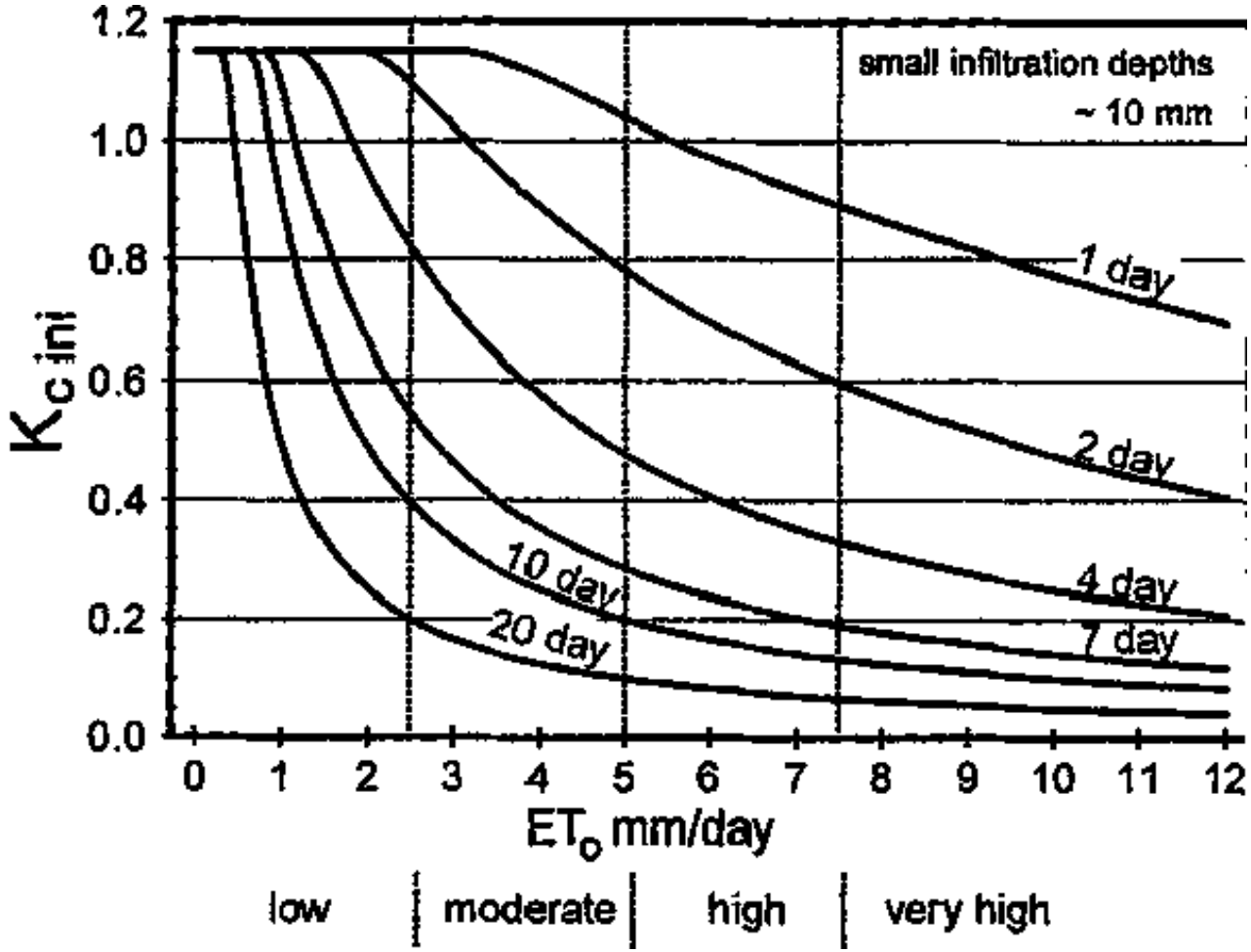


**Figure 2.13**: Average Kc initial related to ETo and the interval between irrigations and/or significant rain for all soil types when wetting events are light to medium (3-10mm per event). (Figure 29 in Allen et al, 1998.)



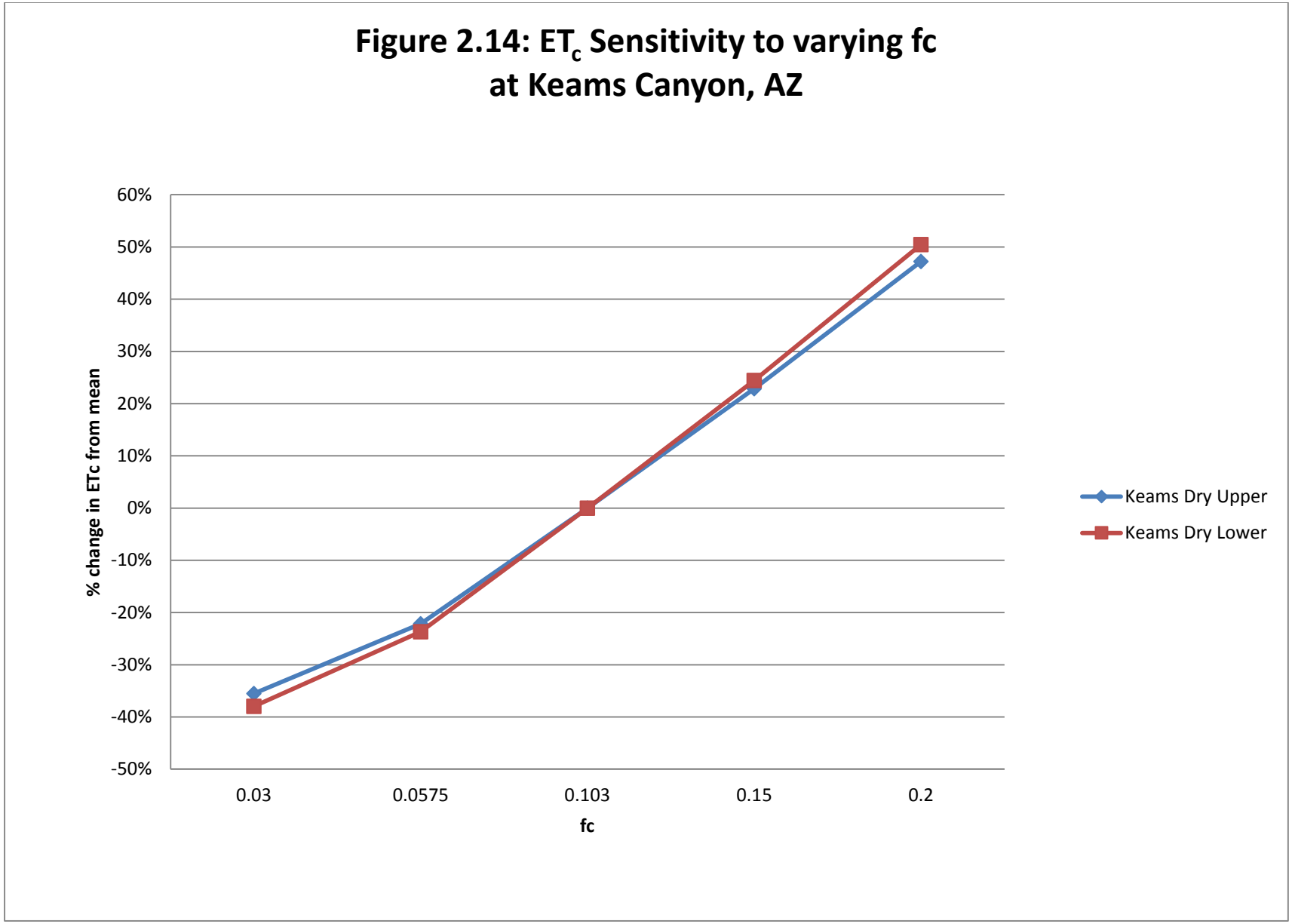


Figure 2.14: ETc Sensitivity to varying fc
at Keams Canyon, AZ
60%
50%
40%
30%
20%
10%
0%
-10%
-20%
-30%
-40%
-50%
% change in ETc from mean
0.03
0.0575
0.103
0.15
0.2
fc
Keams Dry Upper
Keams Dry Lower

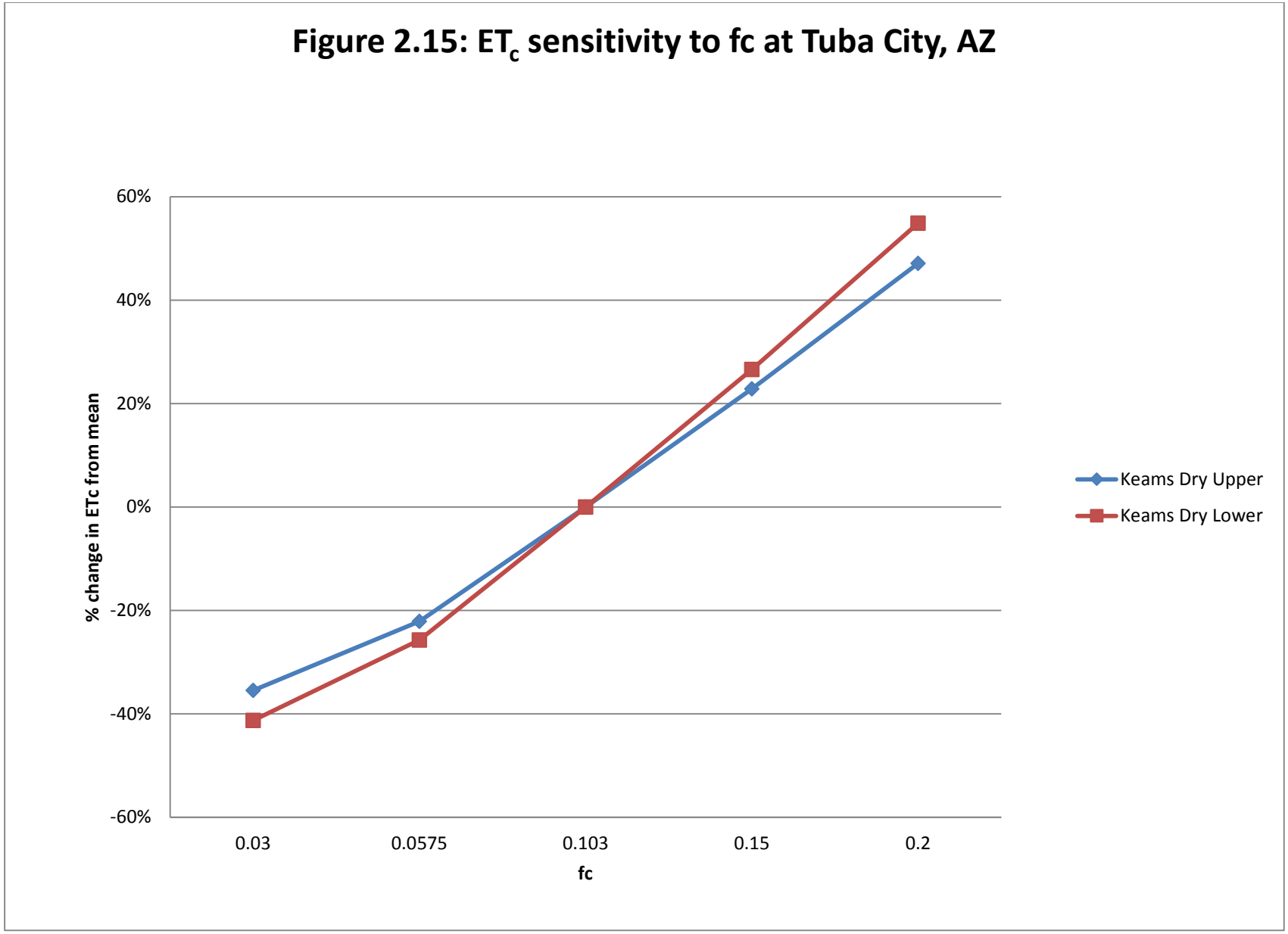
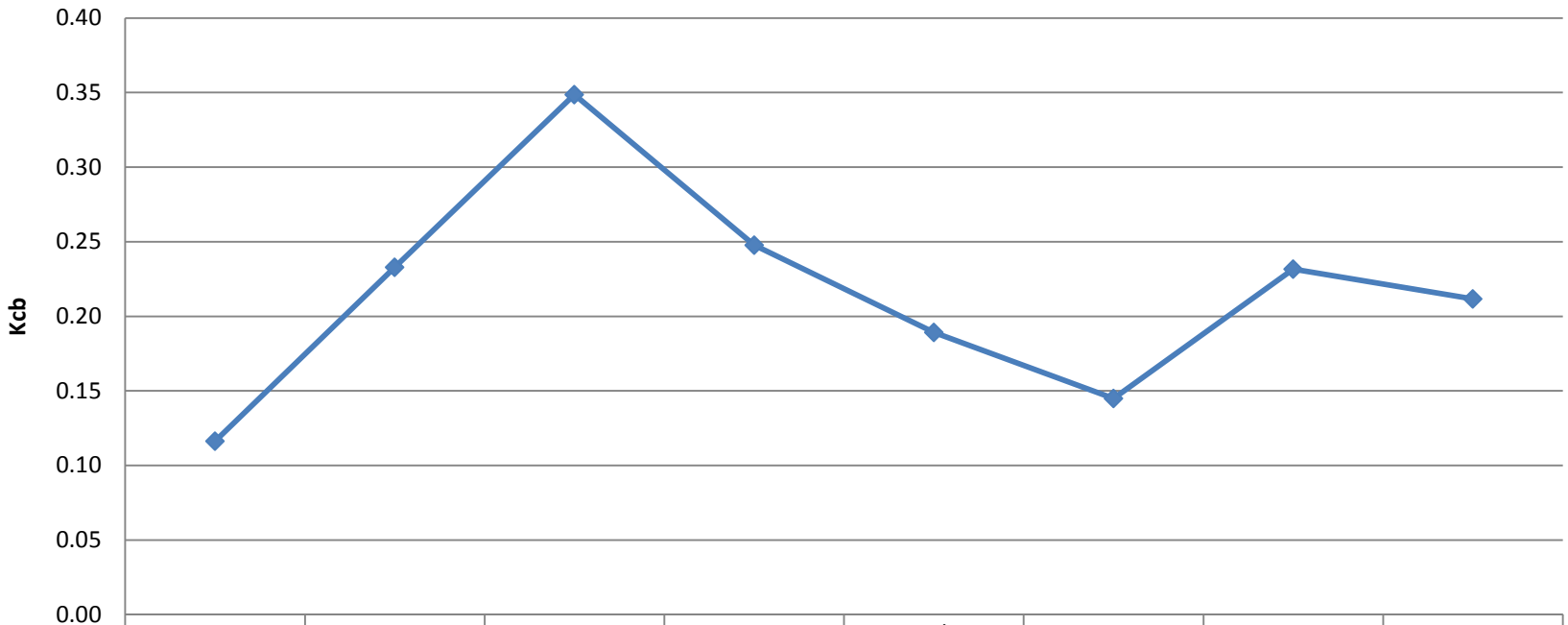


Figure 2.15: ETc sensitivity to fc at Tuba City, AZ
60%
40%
20%
0%
-20%
-40%
-60%
% change in ETc from mean
0.03
0.0575
0.103
0.15
0.2
fc
Keams Dry Upper
Keams Dry Lower

## Figure 2.16: Maximum Crop Coefficient for Range Pasture on the Hopi Reservation




| | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct |
|---|---|---|---|---|---|---|---|---|
| Kcb | 0.12 | 0.23 | 0.35 | 0.25 | 0.19 | 0.14 | 0.23 | 0.21 |

STATE OF ARIZONA
DEPARTMENT OF WATER RESOURCES

# Consumptive Use of Crops Grown on the Hopi Indian Reservation

**Patrick M. Crowley**
**Adjudications and Technical Support**
**Statewide Planning**

**December 2007**

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## LIST OF ACRONYMS

ADWR – Arizona Department of Water Resources

ASCE – American Society of Civil Engineers

CU – Consumptive Use

DRY – Precipitation-irrigated land

ET – Evapotranspiration

$ET_c$ – Evapotranspiration of actual crop

$ET_o$ – Evapotranspiration of reference crop

FAO-24 – Food and Agriculture Organization Irrigation and Drainage Paper No. 24

FAO-56 – Food and Agriculture Organization Irrigation and Drainage Paper No. 56

$f_c$ – Fraction of soil surface that is covered by vegetation

GDD – Growing Degree Days

h – Plant height

HI – Harvest Index

$K_c$ – Crop Coefficient

met – Meteorological

MOVE.1 – Method of Variance Extension, Type 1

NDI – Non-deficit Irrigated land

$R_s$ – Solar Radiation [MJ $m^{-2}$ $day^{-1}$]

SID – Supplemental Irrigation Demand

$T_{dew}$ – Dew point temperature

$T_{max}$ – Maximum air temperature

$T_{min}$ – Minimum air temperature

## LIST OF ACRONYMS (Continued)

WRCC – Western Regional Climate Center

# Text

# CHAPTER 1
# INTRODUCTION

## 1.1 BACKGROUND

The scope and purpose of this report is to estimate the consumptive use (CU) of crops grown on the Hopi Indian Reservation in Northeastern Arizona. The final version of this report will be used in preparation of a Hydrographic Survey Report (HSR) of the Hopi Indian Reservation. The HSR is being prepared as part of the Little Colorado River General Stream Adjudication. Pursuant to A.R.S. section 45-256 (B) the purpose of the HSR is to report the "proposed water right attributes. . .and to examine the physical factors of water use and supply and land arability" (Ballinger, 2002). This report attempts to quantify the consumptive use of crops that have been historically and currently grown on the Reservation.

## 1.2 HOPI AGRICULTURE

The Hopi Indians or their ancestors have continuously farmed the south central Colorado Plateau since the first millennium A.D. (Ferguson, 2004; Prevost, et. al, 1984; Thompson, 1947.) Agriculture is an integral part of Hopi religious beliefs and social customs and much of their cultural identity revolves around ceremonies and gatherings based on the agricultural season. The Reservation is located at a high elevation, with an arid environment characterized by relatively high winds, low precipitation, and cold winter temperatures. As a result, the Hopis have developed a sophisticated, innovative, and sustainable system of agriculture that has been adapted to the harshness of their environment. In addition, the plants selected for farming on the Reservation have been adapted to the specific environmental conditions present.

The growing season for Hopi agriculture is determined by temperature and restricted by the late spring and the early fall frosts. Fields planted early in the season are vulnerable to the threat of a crop-killing freeze in late spring, just as crops planted later in the season are at risk to an early fall frost. Based on data from the Western Regional Climate Center (WRCC), there is still a 50% chance at Keams Canyon that nightly temperatures will drop below freezing by May 20$^{th}$ and a 50% chance that the first frost will occur here before October 10$^{th}$. At Tuba City, there is still a 50% chance of frost by April 28$^{th}$ and a 50% chance that the first frost will occur before October 23$^{rd}$ (WRRC, 2007).

Prevailing winds blow from the southwest and affect much of the topography on the Reservation. Aeolian sand is carried from the Little Colorado River basin and deposited on the Reservation on the lee side of four main mesas or in the form of sand dunes elsewhere on the Reservation (Ferguson, 2004). Strong winds have an adverse effect upon crop production by decreasing plant moisture, removing the topsoil from cleared fields, and causing physical destruction during initial stages of plant development. Strong winds are common on the Reservation during the spring planting months and large tracts of land on the Reservation are susceptible to soil blowing, "and intensive measures are needed to control erosion if the soils are cultivated" (NRCS, 1996:50).

The majority of soils located on the Hopi Indian Reservation have potential for crop production (NRCS, 1996:49). The soils on the Reservation are also described as generally deep and arable, but that "crop production is limited by the climate and the lack of irrigation water" (NRCS, 1996:51). The soils in which a large majority of Hopi fields are located contain a surface layer of fine sand, 4-6 inches deep, below which a clay-sand loam is found (Bradfield, 1971). The upper sandy layer acts as a mulch that protects the underlying loamy soil from the harsh, dry winds that are prevalent on the Reservation. Even during long periods between precipitation events, the loamy soil is able to retain a significant amount of moisture.

Despite the limiting effects of wind and soil condition, the major limiting factor to crop production is the availability of water (Manolescu, 1995; NRCS, 1996; Prevost et. al, 1984). The majority of fields in production on the Reservation are watered via dryland farming techniques (Moon, 2004). Also referred to as "ak-chin," this type of farming is directly dependent upon the rainfall as a source of irrigation. However, Hopi farmers also refer to dryland fields as those which "receive water from a combination of precipitation and surface run-off directed to crops by earthen berms, check dams, and other constructed features" (Ferguson, 2004).

Mean annual rainfall recorded at Tuba City, AZ is 6.39 in and 10.08 in Keams Canyon, AZ (WRRC 2007). Due to the relatively low rainfall, fields are strategically placed by the Hopi in areas that maximize runoff and stored soil moisture. Typical geomorphological locations of cropped fields include, but are not limited to, the base of sand dunes, within arroyos, floodplains adjacent to streams, gentle slopes below rock escarpments, and alluvial fans. Field placement is not limited to topographical characteristics, but is also dependent on identifying which species of native vegetation are growing, and to what density, in a given area (Ferguson, 2004; Dominguez and Kolm 2005). This strategy is used to identify areas that typically have a higher soil moisture content, as reflected by the condition of the natural plant community. Gardens are often located closer to homes as many of these are watered by hand, or irrigated with water from springs. Images of Hopi fields are presented in **Figures 1** through **6**.

Hopis have addressed the environmental conditions that limit crop production with "unusually intensive management practices" (Prevost, et. al, 1984). Hopi crops are traditionally planted by hand, with practices that minimize top soil erosion, and take full advantage of underlying, retained soil moisture. Many of these planting practices are unique to the area and have been adapted through centuries in order to protect the plant from harsh environmental and biological conditions while still preserving the field for future planting seasons. The fields are also typically small, usually between 1 and 5 acres which mitigates to some degree the amount of wind erosion upon the topsoil.

Seedlings of Hopi corn (the main crop on the reservation) also contain special adaptations which aid in their survival. These adaptations include an elongated *mesocotyl* (the portion of the plant that reaches from the seed to the surface of the soil) and the development of a single, deeply thrusting *radicle* (the embryonic root of the plant which

grows downward into the soil), in place of a number of seminal roots (Bradfield, 1971). Both of these adaptations provide corn plants with access to a critical source of moisture. The elongated mesocotyl is typically 10-12 inches in length, as opposed to the 4-6 inches found on ordinary varieties. This elongation allows a Hopi farmer to plant corn seeds much deeper into the soil than an ordinary variety would be planted. This deeper planting helps in three main ways; it provides access to the deep, moist subsoil, it adds extra protection from crop-killing freezes, and it allows the seed to be planted past the depth of many seed-eating insects. The development of a single radicle allows the plant to access deeper, stored moisture throughout critical stages in the plant's development.

Through the use of water conservation techniques, innovative farming practices, and adapted crop varieties, the Hopi Indians have continually farmed the area of Black Mesa for the past millennium. In a region prone to extreme seasonal and yearly climatic variability, ditch irrigation is not generally feasible and the Hopi have developed farming methods that rely heavily upon rainfall and stored soil moisture. This, in turn, results in a variety of crops grown, farming methods employed, filed locations, and overall crop production.

## 1.3 CONSUMPTIVE USE ESTIMATIONS

Measuring the CU of crops requires the measurement of two hydrologic processes; evaporation, and transpiration. The combination of these two processes is known as evapotranspiration (ET). The methods used by ADWR to estimate ET are based upon an energy balance equation. ET is driven by energy in the form of sensible heat or radiant energy. Estimating the fluxes of energy at the vegetation and soil surface provide an estimate of how much water is evapotranspirated through this energy exchange. The variables that are entered into the energy balance equation are commonly, as they are in this report, derived from meteorological data which include air temperature and humidity, solar radiation, and wind speed. Additional measurements can be taken to reduce error in the ET estimates, or to produce a more precise time-scale of ET rates (i.e. mm/hour vs. mm/month). These measurements include, but are not limited to, atmospheric pressure, soil moisture, soil salinity, soil water availability, crop yield, crop canopy cover, and leaf area index. These additional data can be estimated or calculated when no measurements exist, however, this likely increases the error of overall ET estimates and decreases the precision of reliable time-scale for such estimates.

Typical units for reporting ET estimates are mm/day, mm/month, or in the case of this report, ft/yr. This one dimensional unit is then multiplied by the total amount of acreage under cultivation to quantify a total volume of water in which the agricultural lands use in a given season or year. The units of volume presented in this report are in acre-ft.

## 1.4 RANGE OF VALUES

It is the intent of ADWR in this report to calculate a reasonable range of values that bracket the actual CU rates for crops on the Reservation. Calculation of a range of CU values is largely a result of the dearth of available meteorological data. As explained

later in more detail, less meteorological data increases the errors associated with ET estimates. A range of values attempts to address these potential errors by providing an upper and lower confidence interval on the CU estimates. This report also attempts to quantify water use by crops on the Reservation not limited by water availability (non-deficit irrigation). These estimates were made based on analysis of current and historical literature and ADWR makes no assumptions as to the feasibility nor practicality of implementing a system of Hopi agriculture which is not limited by water availability. Current and historical consumptive use is represented in this report as "DRY" and non-deficit irrigation is represented as "NDI". An upper and a lower confidence interval are calculated for both categories.

## 1.5 CROP MIXING

Agricultural fields on the Hopi Reservation are in continual rotation and the area under cultivation for any specific crop will vary from year to year. However, literature reviewed and ADWR's own field survey, suggest a typical percentage of crops under cultivation in any given year. To estimate CU for all Hopi fields, crop mixing values were needed to quantify the percentage of cultivated fields attributed to each cultigen.

The predominant crop cultivated on the Reservation is corn (*Zea mays*). The varieties of corn grown on the Reservation have been selected and adapted over time to suit the environmental conditions of the area, and differ in phenology from typical Western varieties. These adaptations, namely the elongated mesocotyl and the single, deep radicle, provide the crop with a drought tolerance that is essential to cultivation under given conditions. The Hopi corn plant itself is relatively short, rarely exceeding 5 feet in height, producing slender cobs, usually five to seven inches long (Ferguson 2004:23). In a 1989 survey, 17 different corn varieties were identified to be grown by various Hopi households on the Reservation (Soleri and Smith 1995). Despite these numerous varieties, ADWR has classified all types as 'corn' for purposes of ET calculations. From a compilation of available literature on the subject, combined with ADWR's own field survey, the composited average percentage of agricultural fields that contain a corn crop is estimated to be 81.2% (ADWR, 2005; BIA, 1924-1955; Ellis, 1974; Ferguson, 2004). **Table 1** lists the mixing for crops grown on the Reservation.

The second most prevalent field crop on the Reservation is beans (*Phaseolus spp.*) of which more than 30 varieties have been historically grown on the Reservation, although the recent number of varieties is closer to 20 (Ferguson 2004:25). As with corn, for the purpose of this study all varieties are generally classified as 'beans.' **Table 1** lists the percentage of Hopi fields dedicated to growing beans is estimated at 6.7%

The Hopi Reservation has had fruit trees in cultivation since the arrival of the Spaniards in the seventeenth century (Ferguson 2004:27). These include peaches (*Prunus persica*), pears (*Pyrus communis*), apples (*Malus sylvestris*), and apricots (*Prunus armeniaca*). All of these trees were combined into one category referred to in this report as 'orchards.' The percentage of agricultural lands on the Reservation dedicated to orchards is estimated at 8.1% (**Table 1**).

Together, the three crops listed above account for an estimated 96% of Hopi cultivated fields. The remaining crops are referred to as garden varieties as they are frequently grown in small gardens, usually close in proximity to the home, and often close to a perennial source of water. ADWR has split the remaining 4% of fields between melons (2.3%) and squash/other (1.7%), according to current and historic literature and field work (ADWR 2005; BIA, 1924-1955; Ellis, 1974; Ferguson, 2004). This is thought to be representative of the garden varieties that are currently grown on the Reservation and not necessarily dry-land farmed.

# CHAPTER 2:
# CALCULATING EVAPOTRANSPIRATION

The Reference Evapotranspiration ($ET_o$) method was used in this report to calculate the CU of crops grown on the Hopi Reservation. This method involves first calculating the ET for a reference surface, assuming an unlimited supply of water, based on meteorological conditions of a given environment. $ET_o$ is a climatic parameter that represents the evaporative ability of the atmosphere under ambient climatic conditions. Because $ET_o$ does not take into account crop characteristics, nor soil factors, it can be computed based on weather data alone. Once $ET_o$ is computed, it is multiplied by a crop coefficient ($K_c$) which incorporates the various physical and physiological differences between the reference surface and the crop of interest. $K_c$ can also be adjusted to account for varying degrees of environmental stress that can inhibit the growth and crop evapotranspiration ($ET_c$) of a plant. These stressors can include soil moisture depletion, high soil salinity, disease, poor plant stands, varying crop covers, etc. The final equation to compute $ET_c$ of a desired crop is:

$$ET_o * K_c = ET_c$$

The Food and Agriculture Organization of the United Nation's Irrigation and Drainage Paper 24 (FAO-24), defines crop water requirements developed using the Reference ET method as "the depth of water needed to meet the water loss through evapotranspiration ($ET_c$) of a disease-free crop, growing in large fields under non-restricting soil conditions including soil water fertility and achieving full production potential under the given growing environment" (Doorenbus and Pruitt 1977). $ET_c$ values representative of these conditions are designated here as non-deficit irrigation, or "NDI" values. Adjustments were made to the method to better represent actual $ET_c$ values on the Hopi Reservation, and are characterized by "DRY" values. The methods and data that were used to compute $ET_o$, $K_c$, and $ET_c$ are outlined in the following sections.

## 2.1 REFERENCE EVAPOTRANSPIRATION ($ET_o$)

Data to compute $ET_o$ came from the Western Regional Climate Center (WRCC, 2007) and the Hopi Tribe Water Resources Program (HWRP, 2007). A map of the meteorological stations used is presented in **Figure 2.1**. The following sections outline the models and methods employed to calculate $ET_o$.

### 2.1.1 ETo MODELS

Three models were selected to compute $ET_o$. These models are the FAO-24 Blaney-Criddle, 1985 Hargreaves-Samani, and FAO-56 Modified Penman-Monteith. Each model uses the $ET_o * K_c$ approach and use grass as the reference surface with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s $m^{-1}$ and an albedo of 0.23. These models were selected based on the availability of climatic data, general acceptance of the

models, and applicability of the models to the local environment. All three models are also based on the conservation of energy approach and use climate data readily available on the Hopi Reservation. The only available data for the Reservation with an acceptable period of record (>10 years) to compute $ET_o$ is air temperature. As explained below, the models selected are either temperature-based, or have approaches to compute or estimate missing climate data.

#### 2.1.1.1 FAO-24 BLANEY-CRIDDLE

The FAO-24 Blaney-Criddle model was selected based on its general familiarity and historic use by the scientific community. This method is suggested in FAO-24 for areas where available climate data is restricted to air temperature (Doorenbus and Pruitt, 1977). However, in the more recent FAO-56 publication, Allen et. al (1998:18) state that "temperature methods remain empirical and require local calibration in order to achieve satisfactory results." The FAO-24 Blaney-Criddle model was used in this study for comparative purposes only and no final consumptive use estimates were calculated based on the $ET_o$ values generated by this model.

#### 2.1.1.2 1985 HARGREAVES-SAMANI

The 1985 Hargreaves-Samani model is another temperature-based method to compute $ET_o$. However, FAO-56 expresses greater confidence in this method over other temperature-based models as it "has shown reasonable $ET_o$ results with global validity" (Allen et. al 1998:18). Although it is generally accepted as the most reliable temperature-based model, it has been shown to be less accurate in windy areas, without local calibration. The Hargreaves and other temperature-based models have been shown to underestimate ET values in areas of high winds and therefore also require a local calibration (Gavilan et. al, 2006: Martinez-Cob and Tejero-Juste, 2003; Jensen et. al, 1997). ADWR determined that there was not enough climate data available to perform such calibration and the uniqueness of the local geography made it difficult to incorporate data from other locations. Similar to the FAO-24 Blaney-Criddle model, the 1985 Hargreaves-Samani model was used for comparitive purposes only and no final CU estimates were calculated based on the $ET_o$ values generated by this model.

#### 2.1.1.3 FAO-56 PENMAN-MONTEITH

The consensus from a May,1990 FAO meeting was to recommend the FAO Penman-Monteith model as the standard method to define and compute $ET_o$ (Allen et. al, 1998: 15). As a result, this model has become a standard by which other models are compared. Data input requirements for this model are air temperature, solar radiation, air humidity, and wind speed. FAO-56 outlines methods to estimate humidity, wind speed, and radiation data when it is not readily available, as was the case in this study. As indicated earlier, the only available climate data from the Hopi Reservation with a satisfactory

period of record was air temperature. FAO-56 strongly recommends that climate data be estimated when it is not available, as opposed to using temperature-based models (Allen et. al 1998).

Nevertheless, the Hargreaves-Samani model has been shown to provide relatively accurate results when compared to FAO-56 Penman-Monteith, and lysimeter data (Allen et. al 1998; Diodato and Bellochi 2007). However, the area of the Hopi Reservation is prone to high winds, and evidence suggests an underestimation of $ET_o$ values are computed when not incorporating wind into the ET (Gavilan et. al 2006; Jensen et. al 1997; Martinez-Cob and Tejero-Juste 2003). ADWR deemed it necessary to use a model which incorporated wind as a function of $ET_o$ since it plays a substantial role in the ET process, especially in areas prone to high winds, such as the Hopi Reservation. The alternative would be to calibrate a temperature-based model against areas with more available weather, including wind speed. However, due to the unique topography of the area, this approach was not pursued.

In summary, based on current international consensus and appropriateness to the reference environment, the FAO-56 Peman-Monteith model was selected to calculate final $ET_o$ values for the Hopi Indian Reservation.

#### 2.1.1.4 OTHER MODELS

Other methods to calculating $ET_o$ include the water balance approach, pan evaporation, and radiation-based models such as the Jensen-Haise and the Priestly-Taylor methods. The water balance approach requires lysimeter measurements and monitoring which is beyond the scope of this report. Pan evaporation measurement techniques have been shown to have relatively large error due to the poor relationship between evaporation rates of open water and crop ET. According to Allen et. al, (1998) "radiation methods show good results in humid climates. . .but performance in arid conditions is erratic and tends to underestimate evapotranspiration." ADWR did not, therefore, incorporate radiation-based models into the ET estimates for the Hopi Reservation.

### 2.1.2 SOFTWARE USED TO CALCULATE ETo

The three $ET_o$ models described above were run using the Ref-ET program developed at the University of Idaho by Allen (2003) to estimate $ET_o$ for a reference crop (grass) of standard uniform specifications. Data entered into the program were compiled by ADWR from the WRCC (2007) and the HWRP (2007). Program default values were used when data was not readily available. Default values were developed or approved by the FAO-56.

### 2.1.3 CLIMATE VARIABLES

Estimating $ET_o$ with the FAO-56 Penmen-Monteith method requires air temperature, wind speed, air humidity, and solar radiation data. Of all these climate variables, only air temperature had a satisfactory period of record (>10 years) on the Hopi Reservation. All other climate variables were estimated, interpolated, or calculated via methods explained later in this report. To assess a reasonable range of $ET_c$ values for the Reservation, some climate variables were calculated via different means to provide upper and lower limits of NDI and DRY. All $ET_o$ calculations were based on monthly climate averages.

#### 2.1.3.1 AIR TEMPERATURE (T)

Air temperature data were taken from two meteorological stations reported by the Western Regional Climate Center (WRCC) – Tuba City, AZ (Station 028792) and Keams Canyon, AZ (Station 024586). The period of record for the Tuba City station is 1900 – 2006 and the period of record for the Keams Canyon station is 1948 – 2006. The location of these stations is shown in **Figure 2.1**. Other meteorological stations on the Reservation were available online from the WRCC website, however, these had limited periods of record and were therefore not incorporated into this report. Also, off-Reservation meteorological stations were not used due to differences in elevation, geography, and topography.

Monthly averages of minimum ($T_{min}$) and maximum temperatures ($T_{max}$) were reported on the WRCC website for both met stations (WRRC 2007). Data for the entire period of record were utilized, except for those months with more than five days of record missing.

#### 2.1.3.2 SOLAR RADIATION (Rs)

Solar radiation was estimated from the difference between maximum and minimum air temperatures. The amount of cloud cover on any given day affects this difference. Little to no cloud cover results in a relatively large difference between $T_{max}$ and $T_{min}$ because incoming solar radiation is not impeded (higher $T_{max}$) as it is when cloud cover exists, nor is outgoing longwave radiation impeded at night (lower $T_{min}$). Greater cloud cover absorbs much of this radiation and results in smaller differences between $T_{max}$ and $T_{min}$.

The Hargreaves radiation formula was used to estimate radiation data for the Hopi Reservation. An adjustment coefficient of 0.16 was used, as recommended for interior, non-coastal regions. The procedure followed is outlined on page 60 of FAO-56 (Allen et. al, 1998).

### 2.1.3.3 WIND SPEED (u)

The Hopi Reservation is known as an area of relatively high winds and has been qualitatively described as such by various sources (NRCS 1996, Prevost et. al 1984, Ferguson 2004). Wind is a major contributor to plant ET and ADWR judged that any ET model that did not incorporate wind speed into the model would be at risk of underestimating plant ET. Allen et al. (1998) suggest methods to estimate missing wind data in FAO-56 (see **Table 2.10** in this report). As indicated in this table, "moderate to strong wind" is quantified as 3-5 m/s measured at 2 m above the ground. This estimate is consistent with data from 8 Hopi met stations on the Reservation where wind speeds during the growing season average 3.32 m/s (corrected to a measurement height of 2 m) between the years 2003 and 2007 (Hopi 2007). The location of met stations owned and operated by the HWRP is shown in **Figure 2.1**. For $ET_o$ estimates, a wind speed of 3m/s was assumed for a lower bound of 3 m/s and 5 m/s was assumed for an upper bound.

### 2.1.3.4 DEW POINT TEMPERATURE ($T_{dew}$) FOR NDI

$T_{dew}$ is the only climate variable in the FAO-56 model where input data for NDI differed from DRY. This accounts for varying field conditions and micro-climates that result from a non-deficit irrigated farm verses a dryland farmed field.

In the case of NDI, it is assumed that the crop is a well-watered crop and reaches full canopy cover. Also, no restrictions are assumed as to field size, nor acreage under cultivation. Under these conditions, the reference crop would be actively evapotranspiring, causing the relative humidity to increase and the $T_{dew}$ to decrease. In the ASCE manual, Walter et. al (2005) outline methods to estimate $T_{dew}$ from $T_{min}$. These methods are similar to those outlined in FAO-56, however, much of the data in which the method was developed for ASCE are specifically taken from Arizona therefore, are likely to be more applicable to an arid region such as the Hopi Reservation. The ASCE method involves a substitution of $T_{dew}$ for "$T_{min}$ - $K_o$". A $K_o$ value in the range of 2-4°C is recommended for semiarid and arid regions (Allen, 1996). However, in Arizona, the value of $K_o$ was found to vary from 2-5°C over the course of a year (Walter et. al 2005). In accordance with this finding, and per (Brown, 2007), the $K_o$ values for the months of April-June was assumed to equal 5°C, and a $K_o$ value of 2°C was assumed for the months of July-Sept during the monsoon season when $T_{dew}$ is more likely to approach $T_{min}$. When $T_{dew}$ is estimated using this method, no further adjustment is needed for air temperature data to represent reference conditions (Walter et. al, 2005).

### 2.1.3.5 DEW POINT TEMPERATURE FOR DRY

In the case of DRY, $T_{dew}$ measurements were estimated based on available relative humidity measurements taken from the 8 Hopi met stations (Hopi, 2007). These measurements, however, are available for a short period of record and include several

large data gaps. To address this data limitation, the Method of Variance Extension, Type 1 or MOVE.1 (Hirsch, 1982) was used to create a relationship between $T_{min}$ and $T_{dew}$ for each month in the growing season using available. This relationship was then applied to measured temperature data from Keams Canyon and Tuba City (WRCC, 2007) to extend the record of relative humidity data. Monthly averages for $T_{dew}$ were then computed and used in the Ref-ET program to calculate $ET_o$ for DRY.

No attempt was made to correct $T_{dew}$ measurements for non-reference conditions. Even with a well-watered but sparse crop, it is assumed that this would not have a significant impact on humidity measurements. Methods used to calculate DRY conditions, represent conditions associated with current agricultural practices. A potential decrease in $T_{dew}$ is limited by the size of Hopi fields which are typically much smaller and less dense in comparison to traditional Western agriculture, which can create a microclimate effect. In addition, the ASCE (2005) manual suggest that $T_{dew}$ correction procedures may not be effective at identifying reference environments in regions prone to large nighttime winds. Doorenbos and Pruitt (1977) also suggest that no $T_{dew}$ correction factors be applied to small fields. Therefore, due to the current and historic condition of Hopi fields, actual $T_{dew}$ measurements were used in calculating $ET_o$ for DRY

### 2.1.4 SUMMARY OF $ET_o$

**Table 2.1** lists the climate variables which were used to calculate upper and lower $ET_o$ values for NDI and DRY conditions. Four climate variables (air temp, $T_{dew}$, $R_s$, and u) were entered into the Ref-ET program to compute average monthly ETo rates using the FAO-24 Blaney-Criddle, the 1985 Hargreaves-Samani, and the FAO-56 Penman-Monteith models. Of these variables, only $T_{dew}$ was calculated differently for NDI and DRY as described above in **Sections 2.1.3.4** and **2.1.3.5**. Different wind speeds were entered into the models for the upper and lower $ET_o$ values.

### 2.1.5 COMPARISON BETWEEN MODELS

Average monthly $ET_o$ values calculated by the three models are listed in **Tables 2.2** and **2.3** and are illustrated in **Figures 2.2** and **2.3** for Keams Canyon and Tuba City, respectively. The total yearly differences in $ET_o$ between the various models is illustrated in **Figures 2.4 – 2.7**. The upper and lower bounds represented in these tables and figures are based on the assumed growing season of Hopi corn, with an upper bound of 170 days and a lower bound of 115 days (and are also affected by the different wind speeds). This difference is explained in **Section 2.2.1**.

When compared to the FAO-56 model, the Blaney-Criddle model overestimated the range of $ET_o$ values under both NDI and DRY conditions. This overestimation ranges between 3.2% and 14% and is congruent with the FAO-56 findings (Allen et. al, 1998). On the other hand, when compared to the FAO-56 Penman-Monteith method, the Hargreaves model underestimated the range of $ET_o$ values. These underestimations range

between 7.3% and 18.1% and are consistent with current literature on applying the Hargreaves model to arid, windy regions (Gavilan et. al, 2006; Jensen et. al, 1997; Martinez-Cob and Tejero-Juste, 2003). These differences are summarized in **Table 2.4**. The FAO-56 $ET_o$ values for the upper and lower limits of NDI and DRY are found in **Table 2.5**. Note that $ET_o$ values for DRY conditions are higher than for NDI. This is a result of the different $T_{dew}$ values entered into the model. $T_{dew}$ values for DRY are representative of current and historical farming practices on the Hopi Reservation which reflect smaller fields and relatively wide crop spacing (Ferguson, 2004; Bradfield, 1971) that do not create a microclimate in which Tdew alterations are necessary.

## 2.2 CALCULATING $K_c$ VALUES

$ET_o$ values provide an estimate of the ET of a hypothetical reference crop under ambient climatic conditions. $K_c$ values are needed to account for the difference in ET between this hypothetical crop and the crop grown on the Reservation. This approach assumes adequate water and soil fertility. However, water is a limiting factor in crop production on the Hopi Reservation and has dictated many of the Hopi's agricultural practices (Bradfield, 1971; Ferguson, 2004; Moon, 2004; Prevost, et. al, 1984). Therefore, to estimate $ET_c$ on the Hopi Reservation, $K_c$ values must be adjusted to reflect conditions that better represent those found on the Reservation. This adjustment was performed for the DRY condition and explained in later sections of this report. Pre-established methodologies and published values of crop $K_c$ values were used for the NDI condition as it is intended to reflect a scenario which is not limited by water supply.

### 2.2.1 CORN Kc

Corn $K_c$ values for the NDI condition are intended to reflect values for a well-watered corn crop with no environmental stress. The only difference between $ET_o$ and $ET_c$ will be the physical and physiological differences between a corn plant and grass, the reference crop. $K_c$ values change over the stages of the plant's life, and therefore, a $K_c$ curve is needed.

A $K_c$ curve for NDI Corn was developed for this study based on growing-degree-days (GDD). Crop development is a function of heat units and a physiological clock can be developed based upon GDD (Sammis et. al 1985). GDD are calculated by subtracting a base temperature from the average between $T_{max}$ and $T_{min}$. A base temperature of 50°F was used for corn. The WRCC (2007) site provides $T_{max}$ and $T_{min}$ data and these data were used to get GDD for Keams Canyon and Tuba City.

Sammis et. al (1995) computed GDD and corresponding $K_c$ values for well-watered corn at 2 sites in New Mexico with the goal of producing a $K_c$ curve for corn that could be applicable to similar geographical areas. The mean cumulative GDD for the New Mexico sites was 1,725 compared to the mean GDD for Tuba City of 1,706 based on WRCC weather data from April – September. Because of the similar values, the $K_c$

curve developed by Sammis et. al was used to calculate NDI values for $ET_c$ on the Hopi Reservation. A graph that shows Hopi data fall along this curve is shown in **Figure 2.8**. The cumulative GDD's for the growing season are illustrated in **Figure 2.9**.

To model actual growing conditions on the Hopi Reservation (DRY), a daily soil moisture budget would be helpful to $ET_c$ estimations. Due to infrequent watering, readily available water within the soil declines to the point of zero which causes the $ET_c$ to also approach zero. In other words, when there is no moisture in the soil, the plant does not transpire. To correct $K_c$ for such conditions, soil moisture needs to be quantified. Because these data could not be obtained, an alternative approach to correcting $K_c$ was used.

A $K_c$ curve based on **Table 21** from FAO-24 was used for DRY conditions. However, the $K_c$ values were modified using techniques outlined in Chapter 9 of FAO-56, '$ET_c$ for natural, non-typical and non-pristine vegetation.' The intent of this chapter is to outline methods to estimate $K_c$ values for agricultural vegetation when $K_c$ values are not available, as is the case for crops grown on the Hopi Reservation. The procedure used was a modification of $K_c$ values based on effective ground cover. There is a decrease in ET per unit area of a field when plants are spaced further apart than typical conditions, since this results in fewer plants per unit area. <u>However, the reduction in ground cover also increases the amount of solar radiation that is reflected off the bare soil and transferred to each plant.</u> The procedure described above was reviewed and approved by Dr. Richard Allen in January 2008 (Allen, 2008).

FAO-24 lists values for four $K_c$ curves based on minimum relative humidity and wind speed. The curves are created by connecting four $K_c$ values; Initial $K_c$ [$K_{c\ (initial)}$], Crop Development $K_c$ [$K_{c\ (crop\ dev.)}$, Mid-season $K_c$ [$K_{c\ (mid)}$], and a Harvest $K_c$ [$K_{c\ (harvest)}$]. For all FAO-24 $K_c$ values it was assumed $RH_{min}$<20% with a wind speed of 0-5m/sec. A $K_c$ (initial) of 0.12 was selected based on Sammis et. al (1995) and Figure 6 in FAO-24 (Doorenbus and Pruitt, 1977:38). $K_{c\ (crop\ dev.)}$ was calculated via linear interpolation from $K_{c\ (initial)}$ and $K_{c\ (mid\text{-}season)}$.

Equations 98 and 99 from FAO-56 (see **Appendix C**) were used in order to estimate the basal $K_c$ during mid-season when plant density is lower than full cover conditions. The fraction of soil surface that is covered by vegetation ($f_c$) values were based on ADWR's field investigation (2005) and corroborated by photographs of historic and current agricultural fields (Ferguson, 2004). An $f_c$ of 0.091, with a plant height of 1m was used for calculating the $K_{c\ mid}$ for DRY conditions for corn (ADWR 2005). Other values entered to the model are outlined in sections **2.1.3.3** and **2.1.3.5**. Values for all $K_c$ stages for upper and lower bounds of DRY conditions are listed in **Tables 2.6** and **2.7**.

Note in **Figures 2.10** and **2.11**, that the lower bound of Corn $K_c$ for NDI exceeds that of the upper for the months of August and September, as indicated by the lower bound $K_c$ for NDI curve crossing over the curves for the upper bounds. This effect is due to the use of the same GDD curve for different growing seasons. A later planting date causes the plant's ET to be less initially, as plant development is trailing the crop with an earlier

planting date. In the early months of the season, the plant has had less time to develop and will evapotranspirate less water than a crop planted earlier in the season which has had more time to grow. Later in the season, however, a crop that has fully developed throughout its entire growing season, reacts differently than a crop that was planted later in the season (due to frost or lack of available water). Applying both of these potential cropping seasons to the same GDD curve is the basis for this incongruity. Brown (2007) suggests not adjusting the GDD curve to account for planting date as it would likely introduce more error into the model than would be gained in accuracy. Also, the lower bound's higher $K_c$ value later in the season may actually represent field conditions.

**Tables 2.6 – 2.9** list the final $ET_c$ values for NDI and DRY which are illustrated in **Figures 2.12 and 2.13**.

The growing season for corn on the Hopi Reservation is limited by late spring frosts, and early fall frosts. According to the Hopi Drought Plan, "the Hopi growing season. . .is between 120 and 160 days long depending on location. . . .The planting season ranges from mid-April for early ceremonial corn to June for the principal corn crop" (Hopi Tribe, 2000). Several reliable sources cite similar numbers for the growing period, with a range from 115 to 170 days (Adams, 1979; Ferguson, 2004; Manolescu, 1995; Bradfield, 1971; Prevost et. al 1984; Soleri and Cleveland 1993). Monthly ET rates were calculated based on a growing season of 115 days for lower bound ET estimates, and a growing season of 170 days for upper bounds of ET estimates. Because $ET_o$ rates were calculated as a monthly average, these were adjusted through linear interpolation when an entire month did not fall within a growing season. This adjustment was also made for $K_c$ values that were based on average monthly GDD's.

### 2.2.2 BEAN $K_c$

As with corn, beans are field crops that are typically grown in dryland fields by the Hopi and actual field conditions do not meet reference crop criteria. NDI calculations are based on what a potential bean crop could produce if not limited by water. $K_c$ values used for NDI bean were taken from Table 21 in FAO-24 (Doorenbus and Pruitt, 1977:40).

To calculate ET for beans under DRY conditions, the $K_c$ curve had to be adjusted to represent dryland farming conditions. Therefore, FAO-24 values were modified using the same technique as was used for corn. The approach is outlined in Chapter 9 of FAO-56 and the values for these modifications were based on data outlined in sections **2.1.3.3** and **2.1.3.5**, with an $f_c$ of 0.14 and a plant height of 0.3m, based on data from ADWR (2005).

A crop season of 110 days and an average planting date of May 15 for beans was based on available literature (Ferguson 2004; Bradfield 1971). The $ET_c$ rates from the $K_c$ values established for Hopi beans are illustrated in **Figure 2.12** and **Figure 2.13**.

### 2.2.3 ORCHARD $K_c$

Development of the $K_c$ values for orchards on the Hopi Reservation followed a similar methodology as was used for corn and bean $K_c$ values. $K_c$ values from Table 26 of FAO-24 were used (Doorenbus and Pruitt, 1971:49). Because the fruit trees do not experience as dramatic a growth process during the growing season, $K_c$ values are provided by month rather than by developmental stages. $K_c$ values were selected to represent several fruits (peaches, apricots, pears, and plums); a cold winter with killing frost; dry, light to moderate wind (0-5 m/sec); and no ground cover crop. The growing season under these specifications extends from April thru October.

Although other varieties of trees are grown on the Reservation, most prevalent are peach trees (*Prunus persica*) (Ferguson 2004; Bradfield 1971). A single $K_c$ that represents peach trees was considered adequate for this study. However, orchards are frequently located in fields that are considered dryland farmed and therefore an adjustment to the $K_c$ value was necessary.

For DRY conditions, these $K_c$ values were modified to once again represent sparse vegetation or tree stands. An $f_c$ of 0.34 and plant height of 2m was used for Equations 98 and 99 in FAO-56 based on ADWR's field survey (2005).

**Figures 2.16 and 2.17** show $ET_c$ values for orchards under NDI and Dry conditions at Keams Canyon and Tuba City.

### 2.2.4 MELON Kc

The fourth most prevalent crop on the Hopi Reservation is melons. Melons and squash (Section 2.2.5) were assumed to represent the common crops grown in Hopi gardens. While the majority of Hopi fields are dependent upon direct precipitation and supplemental surface flow during storm events, Hopi gardens are often located near a perennial water supply (most often a spring) in which hand watering is frequently practiced (Ferguson, 2004). Because of this difference in water supply, the DRY condition was not calculated. In addition, melons and squash combined are believed to account for only 4% of the total field acreage and therefore do not account for a large percentage of the agricultural consumptive use on the Reservation. $K_c$ values for melon were taken from Table 21 in FAO-24 (Doorenbus and Pruitt, 1977:40). The average planting date (May 1) and length of season (120 days) were based on present literature on the subject of Hopi agriculture (Ferguson 2004; Bradfield 1971).

$ET_c$ values calculated for Hopi melons are illustrated in **Figures 2.18** and **2.19**.

### 2.2.5 SQUASH Kc

As explained in the above section, squash was assumed a Hopi garden crop with different watering and agricultural techniques than other crops grown on the Reservation. As with melons, no DRY condition was calculated for Hopi squash and the only variation in ET estimates are due to differences in $ET_o$ variables. $K_c$ values were obtained from Table 21 in FAO-24 (Doorenbus and Pruitt, 1977:41) with again the $K_c$ (soil) equal to 0.12. The planting date assumed was May 1 and the growing season consists of 110 days (Ferguson 2004; Bradfield 1971). $ET_c$ rates throughout the growing season are illustrated in **Figures 2.20** and **2.21**.

## 2.3 FINAL $ET_c$ CALCULATIONS

Final crop $ET_c$ values are listed in **Table 2.11** and provide upper and lower estimates for five different crops at Keams Canyon and Tuba City under NDI and DRY conditions. Values for Keams Canyon and Tuba City were combined and the average listed in **Table 2.12**, which demonstrates a composite estimate of $ET_c$ for the range of conditions on the Hopi Reservation. To apply a single $ET_c$ value to all Hopi fields, a weighted average (based on crop mixing percentages in **Table 1.1**) was taken and the results are presented in **Table 2.13**. These values can be applied to the total acreage under cultivation to produce a Reservation-wide crop consumptive use value. ***Under current and historic agricultural practices and using current and historical plant varieties adapted to the region, the range of consumptive use for Hopi agricultural fields is 0.92-1.43 ft/acre. If water were not a limiting factor on the Reservation, the consumptive use of non-deficit irrigated crops on the Reservation would be 2.29-3.03 ft/acre.***

The values presented above represent crop water use per unit of area. Individual plants grown on the Reservation likely use an amount of water closer to a plant grown under traditional Western practices. However, the spacing of individual plants is much greater than in a traditional Western field. Ferguson (2004:53) reported corn clumps spaced 8 to 12 feet apart with rows spaced in accordance to the farmer's estimate of available soil moisture. According to Bradfield (1971:5), "the wide spacing of plants in fields is an important element in Hopi planting as this helps to insure that each clump of corn receives adequate moisture." This practice has developed as a land-management technique intended to cope with harsh environmental stressors, mainly the lack of available water. Therefore, although an individual corn plant may use a quantity of water more similar to an individual corn plant planted elsewhere, the wide spacing between plants leads to a lower "per unit area" quantity on the Reservation. In other words, there are fewer plants per unit area which means less overall water usage. If crop spacing was not dictated by water availability, water usage on a per unit area basis would therefore increase substantially.

It should also be noted that these $ET_c$ values represent average water consumption based on available data. Because Hopi crops are so dependent on rainfall, in years in which

there is relatively little available water, the actual consumptive use will be lower. Conversely, in years in which there is a greater rainfall than average, the consumptive use of crops will increase to a greater value than here.

The Hopi Tribe has followed agricultural and lifestyle practices that compensate for this hardship. The DRY method values presented in this report are intended to estimate actual historical and current consumption values which are limited by the supply of rainwater and do not represent water use based on a desired or ideal crop yield.

## 2.4 EFFECTIVE PRECIPITATION

The majority of Hopi corn fields are dryland farmed, relying heavily upon precipitation and stored soil moisture (Ferguson, 2004; Hopi Tribe, 2000; Moon, 2004). $ET_c$ estimates for Hopi corn fields are corroborated by estimations of effective precipitation on the Reservation. Effective precipitation refers to the amount of rainfall that is utilizable to plants and is based on the amount, frequency, and intensity of rainfall. Rainfall that runs off a field and any water that percolates beyond the root zone are examples of ineffective precipitation.

In some cases, effective precipitation is calculated using the amount of rain that falls only during the growing season. However, since Hopi fields are geographically situated as to maximize effective precipitation by taking advantage of deeply stored soil moisture (Ferguson, 2004; Dominguez and Kolm, 2005), it is more appropriate that effective precipitation be calculated from total annual rainfall.

For Keams Canyon, annual effective precipitation, as estimated with FAO techniques using monthly consumptive use and precipitation (Dastane, 1978), is approximately 52-89% of estimated DRY $ET_c$ (Tuba City is approximately 33-56%). **Tables 2.6** through **2.9** include, growing season, annual effective, and growing season effective rainfall for these two stations.

## 2.5 OTHER CU ESTIMATES

The National Resource Consulting Engineers, Inc. conducted a consumptive use study using the Jensen-Haise model to calculate ET (see **Appendix A and B**). This is a radiation-based model and according to Allen et. al, (1998) "radiation methods show good results in humid climates. . .but performance in arid conditions is erratic and tends to underestimate evapotranspiration." In addition to the lack of reliability of this model in arid environments, there are also no radiation measurements with an extensive period of record located on the Hopi Reservation, therefore, a model based on radiation would be greatly subject to all of the potential errors involved in estimating radiation data.

The modifications to $K_c$ values were based on "a 30 percent reduction to account for field conditions." The NRCE makes no reference as to data that supports this reduction.

The NRCE also quantifies the spacing of corn crops as "spaced on about 4- to 5-foot rows with spacing of about 3 feet between plant clusters, as compared to typical 2.5-foot row spacing and 0.75- to 1-foot plant spacing along rows" (See Appendix 2). These values contradict values gathered by ADWR (2005) as well as literature on the subject. For example, Bradfield writes that "A Hopi corn field is planted in rows, with some 3 paces between rows, and 3 to 4 paces between the separate 'hills' in a row." [Depending on the definition of 'pace,' this is 7.5ft x 7.5-10ft, or 15ft x 15-20ft.] (1971:5). Ferguson also reports that "corn clumps are spaced 8 to 12 feet apart. Farmers determine the exact spacing of corn within a row and in alternate transverse rows according to their estimates of how much soil moisture is available when they plants" (2004; p.53). These values of crop spacing are double that of the information presented by the NRCE.

The harvesting season of 120 days used in the NRCE report is also contradictory to many sources (Ferguson, 2004; Manolescu, 1995; Bradfield, 1971; Prevost et. al 1984; Soleri and Cleveland 1993).

## 2.6 SUPPLEMENTAL IRRIGATION DEMAND

Supplemental irrigation demand (SID) is the consumptive use demand of a crop which is not satisfied by effective precipitation. In this study, the SID was estimated by subtracting the annual effective precipitation (see **Tables 2.6** through **2.9**) from the consumptive use requirement of crops grown on the Hopi Reservation (see **Table 2.13**).

SID was also estimated from the Hopi Tribe's Statement of Claim (see **Appendix A**) using an alternative method. The 'average irrigation depletion' and the 'maximum irrigation depletion' were divided by the quantity of irrigated acres (non-precipitation farmed acres), as claimed by the Hopi Indian Tribe, to yield 'average SID' and 'maximum SID.' These values are compared to the SID calculated by ADWR in **Table 2.14.**

# CHAPTER 3:
# STUDY LIMITATIONS

The intent of this report is to provide a scientifically-based estimation of the consumptive use of crops grown on the Hopi Reservation using available and reliable data and following standard and accepted methods.

$K_c$ curves were adjusted to represent dryland farming conditions based on a relationship between ET and sparseness of vegetation. The data used to quantify this sparseness were based on an ADWR field survey from 2005. That was corroborated with data from Ferg. Although evidence suggests that the Hopi agricultural practices, including crop spacing, have remained relatively constant (Ferguson 2004; Manolescu, 1995), a more extensive field investigation, spanning several growing seasons, might add to the accuracy of sparseness estimations.

The $K_c$ curves presented in this report are a best, first order estimation of crop water use on the Hopi Reservation. The $ET_o$ values reported are based primarily on temperature measurements with estimations and extrapolation of other meteorological data. Better estimates of crop water use may be possible if additional, site specific data were available. These data include but are not limited to, soil moisture, wind speed, solar radiation, crop canopy cover, and harvest index ratio. These should be collected throughout the growing period and during consecutive years so that an adequate period of record is established. Desert environments are characterized by droughts and wet periods that vary in duration and magnitude. These can cause annual crop water usage to fluctuate substantially.

The temperature data used in this report was obtained from two met stations located on the Hopi Reservation. Data from additional met stations on the Reservation with a significant period of record may improve ET estimates.

# Tables

**Table 1.1: Hopi Crop Mixing**

| Crop Mixing for Hopi Agriculture* | |
|---|---|
| **Crop** | **Percentage** |
| Corn** | 81.2% |
| Orchards** | 8.1% |
| Beans** | 6.7% |
| Melons | 2.3% |
| Squash/other | 1.7% |

*Estimate based on mean values from current and historic field surveys (ADWR, 2005; BIA, 1924-1955; Ellis, 1974; Ferguson, 2004)
**Includes all varieties

**Table 2.1: Data Input for Hopi Corn ETc**

| | Non-deficit Irrigated Land (NDI) | | | | Dryland/Actual Conditions (DRY) | | | |
|---|---|---|---|---|---|---|---|---|
| | Upper Bound | | Lower Bound | | Upper Bound | | Lower Bound | |
| | Method | Source | Method | Source | Method | Source | Method | Source |
| **Temperature** | measured data | (WRCC, 2007) | measured data | (WRCC, 2007) | measured data | (WRCC, 2007) | measured data | (WRCC, 2007) |
| **Dew Point (Tdew)** | ASCE estimation | (ASCE, 2005), (Brown, 2007) | ASCE estimation | (ASCE 2001), (Brown 2007) | MOVE.1 Record Extension | (HOPI 2007), (Hirsch 1982) | MOVE.1 Record Extension | (HOPI 2007), (Hirsch 1982) |
| **Solar Radiation** | Hargreaves | (FAO-56) | Hargreaves | (FAO-56) | Hargreaves | (FAO-56) | Hargreaves | (FAO-56) |
| **Wind Speed (u)** | 5 m/s | (FAO-56) (Hopi, 2007) | 3 m/s | (FAO-56) (Hopi, 2007) | 5 m/s | (FAO-56) (Hopi, 2007) | 3 m/s | (FAO-56) (Hopi, 2007) |
| **Growing Season** | 170 days (April 7-Sept 20) | (Ferguson, 2004; Manolescu, 1995; Bradfield, 1971; Prevost et. al 1984; Soleri and Cleveland 1993) | 115 days (May 15-Sept 8) | (Ferguson, 2004; Manolescu, 1995; Bradfield, 1971; Prevost et. al 1984; Soleri and Cleveland 1993) | 170 days (April 7-Sept 20) | (Ferguson, 2004; Manolescu, 1995; Bradfield, 1971; Prevost et. al 1984; Soleri and Cleveland 1993) | 115 days (May 15-Sept 8) | (Ferguson, 2004; Manolescu, 1995; Bradfield, 1971; Prevost et. al 1984; Soleri and Cleveland 1993) |
| **Kc Value** | NM GDD Curve | (Sammis, et. al 1985) | NM GDD Curve | (Sammis, et. al 1985) | Kc adj for Sparse Vegetation | (FAO-56, Ch. 9) | Kc adj for Sparse Vegetation | (FAO-56, Ch. 9) |

**Table 2.2: $ET_o$ Rates for Hopi NDI fields**

| | | Monthly $ET_o$ Rates for NDI | | | | | |
|---|---|---|---|---|---|---|---|
| | | FAO56-PM (upper) | FAO56-PM (lower) | FAO24-BC (upper) | FAO24-BC (lower) | Harg-Sam (upper) | Harg-Sam (lower) |
| | | mm/day | mm/day | mm/day | mm/day | mm/day | mm/day |
| Tuba City | April | 6.34 | 4.98 | 5.56 | 4.96 | 4.13 | 4.13 |
| | May | 7.29 | 6.60 | 7.53 | 6.80 | 5.59 | 5.59 |
| | June | 8.90 | 7.56 | 9.63 | 8.74 | 6.95 | 6.95 |
| | July | 8.65 | 7.43 | 9.55 | 8.71 | 7.18 | 7.18 |
| | Aug | 7.88 | 6.74 | 8.31 | 7.57 | 6.23 | 6.23 |
| | Sept | 6.88 | 6.04 | 6.79 | 6.14 | 4.85 | 4.85 |
| Keams Canyon | April | 5.83 | 4.62 | 4.85 | 4.31 | 3.83 | 3.83 |
| | May | 6.69 | 6.21 | 6.73 | 6.05 | 5.11 | 5.11 |
| | June | 8.46 | 7.26 | 9.01 | 8.16 | 6.57 | 6.57 |
| | July | 8.03 | 6.98 | 8.78 | 7.98 | 6.67 | 6.67 |
| | Aug | 7.08 | 6.15 | 7.40 | 6.71 | 5.65 | 5.65 |
| | Sept | 6.14 | 5.50 | 5.96 | 5.37 | 4.39 | 4.39 |

**Table 2.3: $ET_o$ Rates for Hopi DRY fields**

| | | Monthly $ET_o$ Rates for DRY | | | | | |
|---|---|---|---|---|---|---|---|
| | | FAO56-PM (upper) | FAO56-PM (lower) | FAO24-BC (upper) | FAO24-BC (lower) | Harg-Sam (upper) | Harg-Sam (lower) |
| | | mm/day | mm/day | mm/day | mm/day | mm/day | mm/day |
| Tuba City | April | 7.20 | 5.40 | 5.84 | 5.21 | 4.13 | 4.13 |
| | May | 8.49 | 7.39 | 8.48 | 7.61 | 5.59 | 5.59 |
| | June | 10.40 | 8.44 | 10.90 | 9.87 | 6.95 | 6.95 |
| | July | 11.00 | 8.80 | 11.60 | 10.40 | 7.18 | 7.18 |
| | Aug | 9.17 | 7.52 | 9.25 | 8.37 | 6.23 | 6.23 |
| | Sept | 7.96 | 6.79 | 7.55 | 6.79 | 4.85 | 4.85 |
| Keams Canyon | April | 6.65 | 5.05 | 5.30 | 4.70 | 3.83 | 3.83 |
| | May | 7.78 | 6.93 | 7.60 | 6.80 | 5.11 | 5.11 |
| | June | 9.86 | 8.08 | 10.30 | 9.25 | 6.57 | 6.57 |
| | July | 10.40 | 8.37 | 10.90 | 9.81 | 6.67 | 6.67 |
| | Aug | 8.75 | 7.17 | 8.63 | 7.77 | 5.65 | 5.65 |
| | Sept | 7.23 | 6.30 | 6.67 | 5.98 | 4.39 | 4.39 |

**Table 2.4: ETo Model Comparison to FAO-56**

*values based on corn growing season (upper = 170 days; lower =115 days)

| | Percentage Difference from the FAO-56 Penman-Monteith ETo Model for the Hopi Reservation | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | NDI | | | | DRY | | | |
| | Tuba City | | Keams Canyon | | Tuba City | | Keams Canyon | |
| | Upper | Lower | Upper | Lower | Upper | Lower | Upper | Lower |
| Blaney-Criddle | 3.2% | 14.0% | 1.8% | 10.6% | 7.7% | 9.0% | 5.4% | 9.0% |
| Hargreaves-Samani | -18.1% | -7.3% | -17.5% | -8.3% | -15.2% | -12.7% | -16.7% | -14.4% |

**Table 2.5: FAO-56 ETo Rates for NDI and DRY Fields**

| Comparison of Hopi ETo Rates (FAO-56) | | | | | |
|---|---|---|---|---|---|
| | | NDI | | DRY | |
| | | upper | lower | upper | lower |
| | month | mm/day | mm/day | mm/day | mm/day |
| Tuba City | April | 6.34 | 4.98 | 7.20 | 5.40 |
| | May | 7.29 | 6.60 | 8.49 | 7.39 |
| | June | 8.90 | 7.56 | 10.40 | 8.44 |
| | July | 8.65 | 7.43 | 11.00 | 8.80 |
| | Aug | 7.88 | 6.74 | 9.17 | 7.52 |
| | Sept | 6.88 | 6.04 | 7.95 | 6.79 |
| Keams Canyon | April | 5.83 | 4.62 | 6.65 | 5.05 |
| | May | 6.69 | 6.21 | 7.78 | 6.93 |
| | June | 8.46 | 7.26 | 9.86 | 8.08 |
| | July | 8.03 | 6.98 | 10.40 | 8.37 |
| | Aug | 7.08 | 6.15 | 8.75 | 7.17 |
| | Sept | 6.14 | 5.50 | 7.23 | 6.30 |

**Table 2.6: Corn ETc values for Hopi DRY upper limit**

## Dryland Farmed Fields (DRY)
## Upper Bound for Corn

| | Season | | FAO56PM ETo | | Crop Stage | Days per Stage | Kc | ETc | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | month | days/mo | mm/day | mm/mo | | | | mm/mo | mm/day | |
| Tuba City | April | 23 | 7.20 | 165.60 | 1 | 30 | 0.12 | 18.46 | 0.00 | |
| | May | 31 | 8.49 | 263.19 | 2 | 50 | interpolation | 44.67 | 1.44 | |
| | June | 30 | 10.40 | 312.00 | 3 | 55 | 0.36 | 95.25 | 3.18 | |
| | July | 31 | 11.00 | 341.00 | 4 | 35 | 0.19 | 115.49 | 3.73 | |
| | Aug | 31 | 9.17 | 284.27 | | | | 103.50 | 3.34 | |
| | Sept | 24 | 7.95 | 190.80 | | | | 47.26 | 1.97 | |
| | | days/yr | mm/yr | ft/yr | | | | mm/yr | **in/yr** | **ft/yr** |
| | Totals | 170 | 1556.86 | 5.11 | | | | 424.63 | **16.72** | **1.39** |
| | Season | | FAO56PM ETo | | Crop Stage | Days per Stage | Kc | ETc | | |
| | month | days/mo | mm/day | mm/mo | | | | mm/mo | mm/day | |
| Keams Canyon | April | 23 | 6.65 | 152.95 | 1 | 30 | 0.12 | 17.11 | 0.00 | |
| | May | 31 | 7.78 | 241.18 | 2 | 50 | interpolation | 41.28 | 0.98 | |
| | June | 30 | 9.86 | 295.80 | 3 | 55 | 0.36 | 90.03 | 1.48 | |
| | July | 31 | 10.40 | 322.40 | 4 | 35 | 0.19 | 109.34 | 1.81 | |
| | Aug | 31 | 8.75 | 271.25 | | | | 97.98 | 1.57 | |
| | Sept | 24 | 7.23 | 173.52 | | | | 43.00 | 1.35 | |
| | | days/yr | mm/yr | ft/yr | | | | mm/yr | **in/yr** | **ft/yr** |
| | Totals | 170 | 1457.1 | 4.78 | | | | 398.74 | **15.70** | **1.31** |

| Upper Bound ETo Input Variables | | | |
|---|---|---|---|
| Wind | Growing Season | Tdew | Kc |
| 5 m/s | 170 days | Actual (MOVE.1) | Kc adj Sparse Veg |

| **Rainfall (in)** | | |
|---|---|---|
| | **Keams Canyon** | **Tuba City** |
| Annual | 9.97 | 6.48 |
| Growing Season (Apr-Sept) | 4.97 | 3.32 |
| Annual (effective) | 8.19 | 5.48 |
| Growing Season (effective) | **4.60** | **3.13** |

**Table 2.7: Corn ETc values for Hopi DRY lower limit**

## Dryland Farmed Fields (DRY)
## Lower Bound for Corn

| | Season | | FAO56PM ETo | | Crop Stage | Days per Stage | Kc | ETc | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | month | days/mo | mm/day | mm/mo | | | | mm/mo | mm/day | |
| Tuba City | April | 0 | 5.40 | 0.00 | 1 | 20 | 0.12 | 0.00 | 0.00 | |
| | May | 15 | 7.39 | 110.85 | 2 | 35 | interpolation | 15.07 | 1.00 | |
| | June | 30 | 8.44 | 253.20 | 3 | 40 | 0.36 | 53.59 | 1.79 | |
| | July | 31 | 8.80 | 272.80 | 4 | 20 | 0.19 | 91.56 | 2.95 | |
| | Aug | 31 | 7.52 | 233.12 | | | | 79.40 | 2.56 | |
| | Sept | 8 | 6.79 | 54.32 | | | | 7.08 | 0.89 | |
| | | days/yr | mm/yr | ft/yr | | | | mm/yr | **in/yr** | **ft/yr** |
| | Totals | 115 | 924.29 | 3.03 | | | | 246.70 | **9.71** | **0.81** |
| | Season | | FAO56PM ETo | | Crop Stage | Days per Stage | Kc | ETc | | |
| | month | days/mo | mm/day | mm/mo | | | | mm/mo | mm/day | |
| Keams Canyon | April | 0 | 5.05 | 0.00 | 1 | 20 | 0.12 | 0.00 | 0.00 | |
| | May | 15 | 6.93 | 103.95 | 2 | 35 | interpolation | 14.14 | 0.98 | |
| | June | 30 | 8.08 | 242.40 | 3 | 40 | 0.36 | 51.15 | 1.48 | |
| | July | 31 | 8.37 | 259.47 | 4 | 20 | 0.19 | 87.17 | 1.81 | |
| | Aug | 31 | 7.17 | 222.27 | | | | 75.36 | 1.57 | |
| | Sept | 8 | 6.30 | 50.40 | | | | 6.59 | 1.35 | |
| | | days/yr | mm/yr | ft/yr | | | | mm/yr | **in/yr** | **ft/yr** |
| | Totals | 115 | 878.49 | 2.88 | | | | 234.41 | **9.23** | **0.77** |

| Lower Bound ETo Input Variables | | | |
|---|---|---|---|
| Wind | Growing Season | Tdew | Kc |
| 3 m/s | 115 days | Actual (MOVE.1) | Kc adj Sparse Veg |

| **Rainfall (in)** | | |
|---|---|---|
| | **Keams Canyon** | **Tuba City** |
| Annual | 9.97 | 6.48 |
| Growing Season (Apr-Sept) | 4.97 | 3.32 |
| Annual (effective) | 8.19 | 5.48 |
| Growing Season (effective) | **4.60** | **3.13** |

**Table 2.8: ETc values for Hopi NDI upper limit for Corn**

| Non-deficit Irrigated Land (NDI) Upper Bound | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Tuba City | Season | | FAO56PM ETo | | GDD | Kc | ETc | | |
| | month | days/mo | mm/day | mm/mo | | | mm/mo | mm/day | |
| | April | 23 | 6.34 | 145.82 | 138.00 | 0.35 | 50.45 | 2.19 | |
| | May | 31 | 7.29 | 225.99 | 395 | 0.72 | 162.39 | 5.24 | |
| | June | 30 | 8.9 | 267 | 724 | 1.04 | 278.11 | 9.27 | |
| | July | 31 | 8.65 | 268.15 | 1133 | 1.07 | 287.48 | 9.27 | |
| | Aug | 31 | 7.88 | 244.28 | 1526 | 0.56 | 136.40 | 4.40 | |
| | Sept | 24 | 6.88 | 165.12 | 1732 | 0.12 | 19.81 | 0.83 | |
| | Totals | days/yr | mm/yr | ft/yr | | | mm/yr | **in/yr** | **ft/yr** |
| | | 170 | 1316.36 | 4.32 | | | 934.65 | **36.80** | **3.07** |

| Keams Canyon | Season | | FAO56PM ETo | | GDD | Kc | ETc | | |
|---|---|---|---|---|---|---|---|---|---|
| | month | days/mo | mm/day | mm/mo | | | mm/mo | mm/day | |
| | April | 23 | 5.83 | 134.09 | 105 | 0.29 | 39.31 | 1.71 | |
| | May | 31 | 6.69 | 207.39 | 308 | 0.60 | 124.81 | 4.03 | |
| | June | 30 | 8.46 | 253.8 | 594 | 0.94 | 238.43 | 7.95 | |
| | July | 31 | 8.03 | 248.93 | 947 | 1.12 | 278.60 | 8.99 | |
| | Aug | 31 | 7.08 | 219.48 | 1281 | 0.95 | 208.43 | 6.72 | |
| | Sept | 24 | 6.14 | 147.36 | 1530 | 0.55 | 81.09 | 3.38 | |
| | Totals | days/yr | mm/yr | ft/yr | | | mm/yr | **in/yr** | **ft/yr** |
| | | 170 | 1211.05 | 3.97 | | | 970.68 | **38.22** | **3.18** |

| Upper Bound ETo Input Variables | | | |
|---|---|---|---|
| Wind | Growing Season | Tdew | Kc |
| 5 m/s | 170 days | ASCE Method | NM GDD Curve |

| **Rainfall (in)** | | |
|---|---|---|
| | **Keams Canyon** | **Tuba City** |
| Annual | 9.97 | 6.48 |
| Growing Season (Apr-Sept) | 4.97 | 3.32 |
| Annual (effective) | 8.19 | 5.48 |
| Growing Season (effective) | **4.60** | **3.13** |

**Table 2.9: ETc values for Hopi NDI lower limit for Corn**

| Non-deficit Irrigated Land (NDI) Lower Bound | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Tuba City | Season | | FAO56PM ETo | | GDD | Kc | ETc | | |
| | month | days/mo | mm/day | mm/mo | | | mm/mo | mm/day | |
| | April | 0 | 4.98 | 0 | 0 | 0.12 | 0.00 | 0.00 | |
| | May | 15 | 6.6 | 99 | 156 | 0.37 | 37.09 | 2.47 | |
| | June | 30 | 7.56 | 226.8 | 485 | 0.83 | 187.59 | 6.25 | |
| | July | 31 | 7.43 | 230.33 | 894 | 1.11 | 256.37 | 8.27 | |
| | Aug | 31 | 6.74 | 208.94 | 1287 | 0.94 | 197.12 | 6.36 | |
| | Sept | 8 | 6.04 | 48.32 | 1376 | 0.83 | 39.98 | 5.00 | |
| | Totals | days/yr | mm/yr | ft/yr | | | mm/yr | **in/yr** | **ft/yr** |
| | | 115 | 813.39 | 2.67 | | | 718.16 | **28.27** | **2.36** |

| Keams Canyon | Season | | FAO56PM ETo | | GDD | Kc | ETc | | |
|---|---|---|---|---|---|---|---|---|---|
| | month | days/mo | mm/day | mm/mo | | | mm/mo | mm/day | |
| | April | 0 | 4.62 | 0 | 0 | 0.12 | 0.00 | 0.00 | |
| | May | 15 | 6.21 | 93.15 | 127 | 0.33 | 30.62 | 2.04 | |
| | June | 30 | 7.26 | 217.8 | 413 | 0.74 | 161.34 | 5.38 | |
| | July | 31 | 6.98 | 216.38 | 766 | 1.07 | 230.63 | 7.44 | |
| | Aug | 31 | 6.15 | 190.65 | 1100 | 1.09 | 207.56 | 6.70 | |
| | Sept | 8 | 5.5 | 44 | 1175 | 1.05 | 46.01 | 5.75 | |
| | Totals | days/yr | mm/yr | ft/yr | | | mm/yr | **in/yr** | **ft/yr** |
| | | 115 | 761.98 | 2.50 | | | 676.17 | **26.62** | **2.22** |

| Lower Bound ETo Input Variables | | | |
|---|---|---|---|
| Wind | Growing Season | Tdew | Kc |
| 3 m/s | 115 days | ASCE Method | NM GDD Curve |

| **Rainfall (in)** | | |
|---|---|---|
| | **Keams Canyon** | **Tuba City** |
| Annual | 9.97 | 6.48 |
| Growing Season (Apr-Sept) | 4.97 | 3.32 |
| Annual (effective) | 8.19 | 5.48 |
| Growing Season (effective) | **4.60** | **3.13** |

**Table 2.10 FAO-56 Wind Estimations** (Allen et. al 1998)

| Description | Mean monthly wind speed at 2m above ground surface |
|---|---|
| light wind | ...≤1.0 m/s |
| light to moderate wind | 1 -- 3 m/s |
| moderate to strong wind | 3 -- 5 m/s |
| strong wind | ...≥ 5.0 m/s |

**Table 2.11: ETc for Crops on the Hopi Reservation**

| | ETc for Crops on Hopi Reservation | | | | |
|---|---|---|---|---|---|
| | | NDI | | DRY | |
| | Crop | ETc Upper (ft/yr) | ETc Lower (ft/yr) | ETc Upper (ft/yr) | ETc Lower (ft/yr) |
| Keams Canyon | Corn | 3.18 | 2.22 | 1.31 | 0.77 |
| | Beans (dry) | 2.06 | 1.78 | 1.12 | 0.91 |
| | Trees (orchard) | 3.34 | 2.87 | 2.27 | 1.95 |
| | Melon | 2.03 | 1.75 | 2.03 | 1.75 |
| | Squash | 1.83 | 1.58 | 1.83 | 1.58 |
| Tuba City | Corn | 3.07 | 2.36 | 1.39 | 0.81 |
| | Beans (dry) | 2.24 | 1.91 | 1.19 | 0.96 |
| | Trees (orchard) | 3.66 | 3.11 | 2.49 | 2.11 |
| | Melon | 2.20 | 1.88 | 2.20 | 1.88 |
| | Squash | 1.97 | 1.68 | 1.97 | 1.68 |

**Table 2.12: Average ETc for Crops on Hopi Reservation**

| Combined ETc for Crops on Hopi Reservation | | | | |
|---|---|---|---|---|
| | NDI | | DRY | |
| Crop | ETc Upper (ft/yr) | ETc Lower (ft/yr) | ETc Upper (ft/yr) | ETc Lower (ft/yr) |
| Corn | **3.13** | **2.29** | **1.35** | **0.79** |
| Beans (dry) | **2.15** | **1.85** | **1.16** | **0.94** |
| Trees (orchard) | **3.50** | **2.99** | **2.38** | **2.03** |
| Melon | **2.12** | **1.81** | **2.12** | **1.82** |
| Squash | **1.90** | **1.63** | **1.90** | **1.63** |

**Table 2.13: Composite Hopi Agiculture $ET_c$ Values**

| Composite $ET_c$ for Crops on Hopi Reservation* | | | | |
|---|---|---|---|---|
| | NDI | | DRY | |
| Crop | ETc Upper (ft/yr) | ETc Lower (ft/yr) | ETc Upper (ft/yr) | ETc Lower (ft/yr) |
| Corn | 2.54 | 1.86 | 1.10 | 0.64 |
| Beans (dry) | 0.17 | 0.15 | 0.09 | 0.08 |
| Trees (orchard) | 0.23 | 0.20 | 0.16 | 0.14 |
| Melon | 0.05 | 0.04 | 0.05 | 0.04 |
| Squash | 0.03 | 0.03 | 0.03 | 0.03 |
| **Total $ET_c$** | **3.03** | **2.29** | **1.43** | **0.92** |

*Table based on average $ET_c$ Values (see **Table 2.12**) weighted to account for expected crop mix on the Reservation (see **Table 1.1**)

**Table 2.14: Supplemental Irrigation Demand Estimates for Agriculture on the Hopi Indian Reservation**

| Hopi Supplemental Irrigation Demand for Agriculture on the Hopi Indian Reservation | |
|---|---|
| Average | Maximum |
| 0.61 | 0.99 |

(Based on irrigation depletion estimates and irrigated acreages from the Hopi Tribe's Statement of Claim, see Appendix A, this report)

| | ADWR Supplemental Irrigation Demand for Agriculture on the Hopi Indian Reservation | |
|---|---|---|
| | Lower Limit | Upper Limit |
| NDI | 1.72 | 2.46 |
| DRY | 0.35 | 0.86 |

# Figures

**Figure 1.1 Corn Field in Moenkopi Wash**
Photograph by Tad Nichols 1954. Northern Arizona University Neg. No. PH.99.3.6.35 (Ferguson, 2004).

**Figure 1.2: Corn Field in Pasture Canyon**
Photo by ADWR 3/2007.

**Figure 1.3: Hopi Corn and Bean Fields near Moenkopi**
Photo by ADWR 10/2005.

**Figure 1.4: Hopi Corn Field near Kykotsmovi**
Photo by ADWR 9/2005

**Figure 1.5: Hopi Bean Field near Hotevilla**
Photo by ADWR 9/2005.

**Figure 1.6: Hopi Garden near Hotevilla**
Photo by ADWR 9/2005.

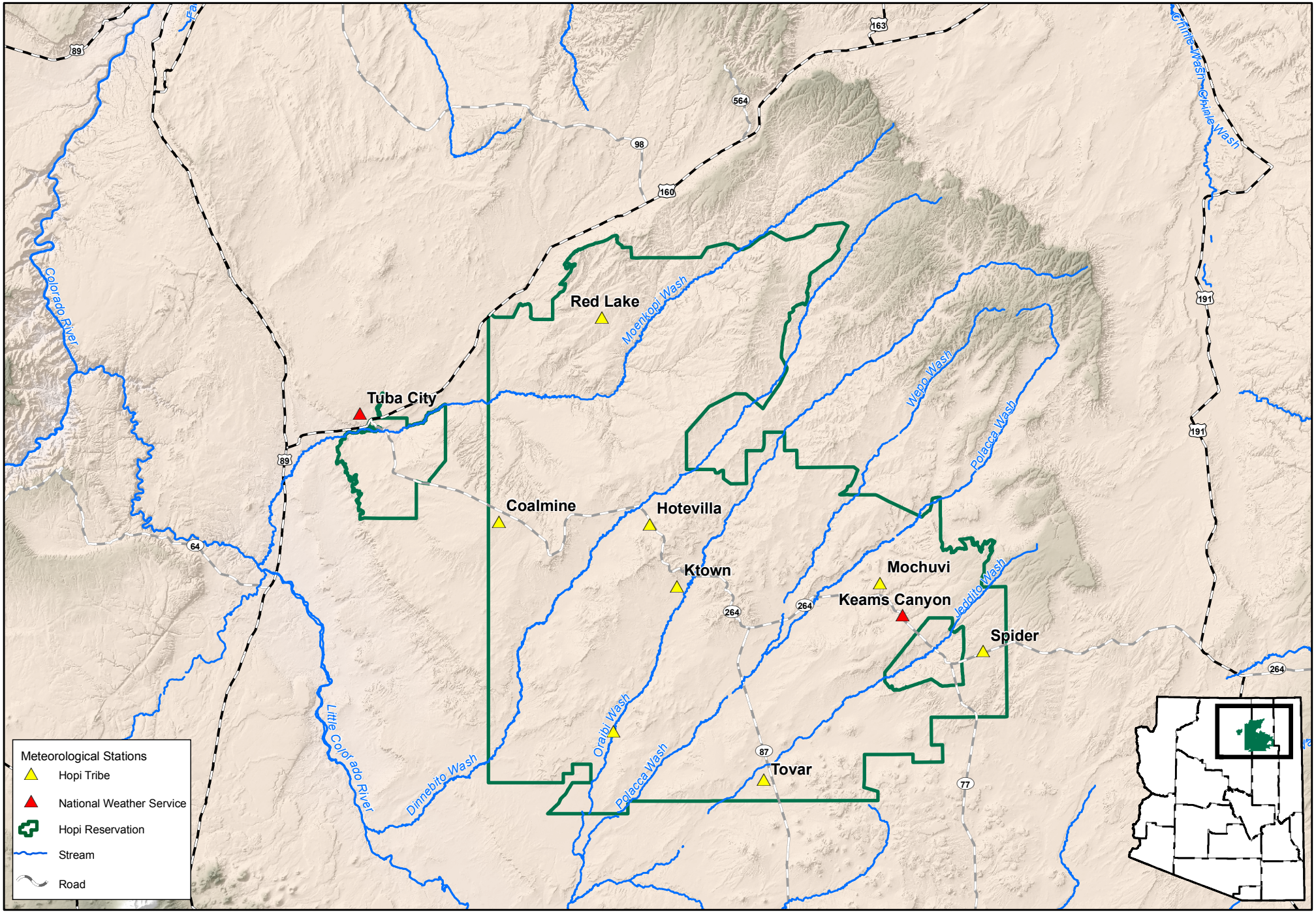


Figure 2.1 Meteorological Stations on and Adjacent to the Hopi Indian Reservation. (Data Sources: HWRP, 2007; WRCC, 2007)

0 2.5 5 10 15 20 Miles

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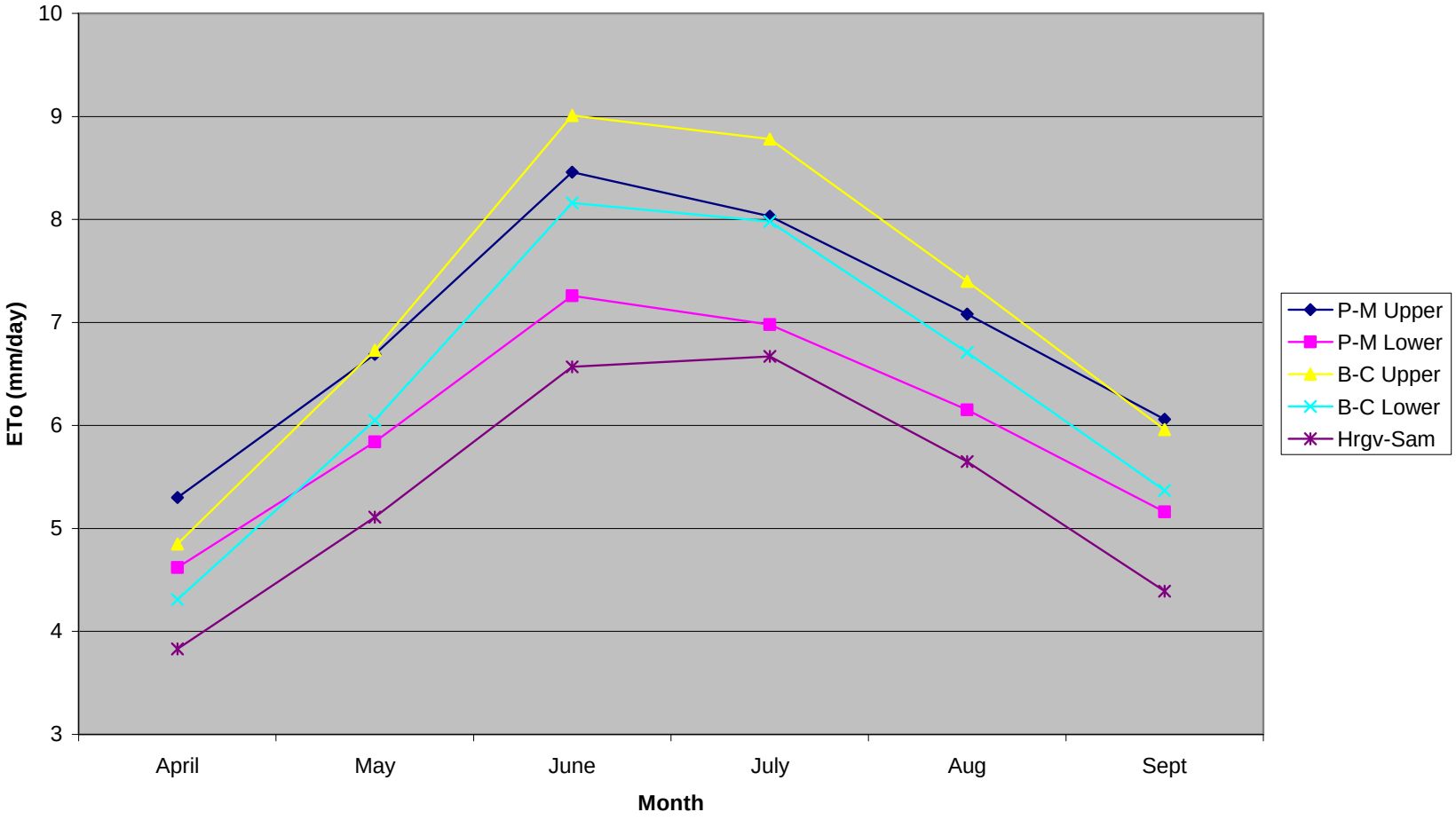
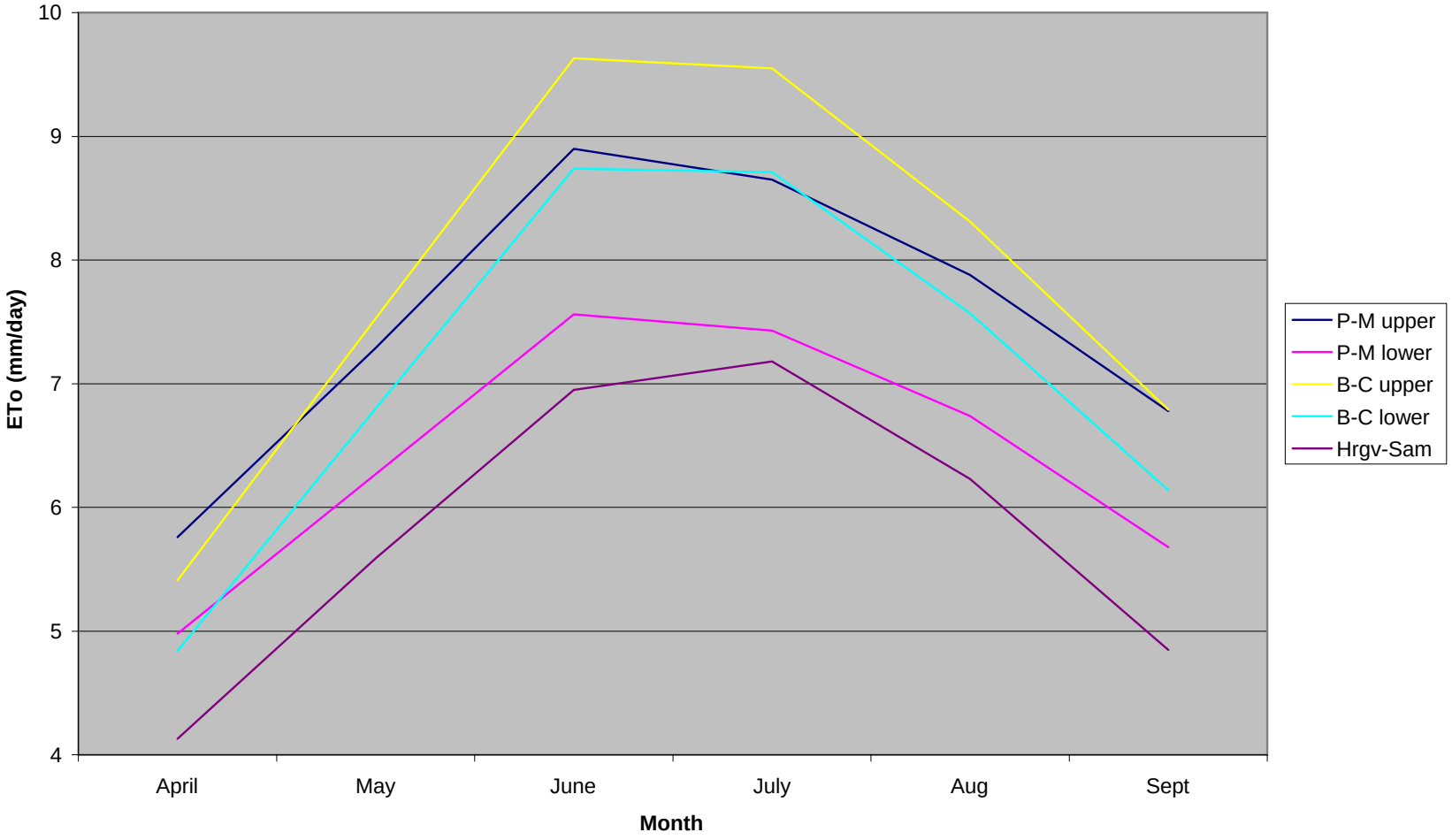
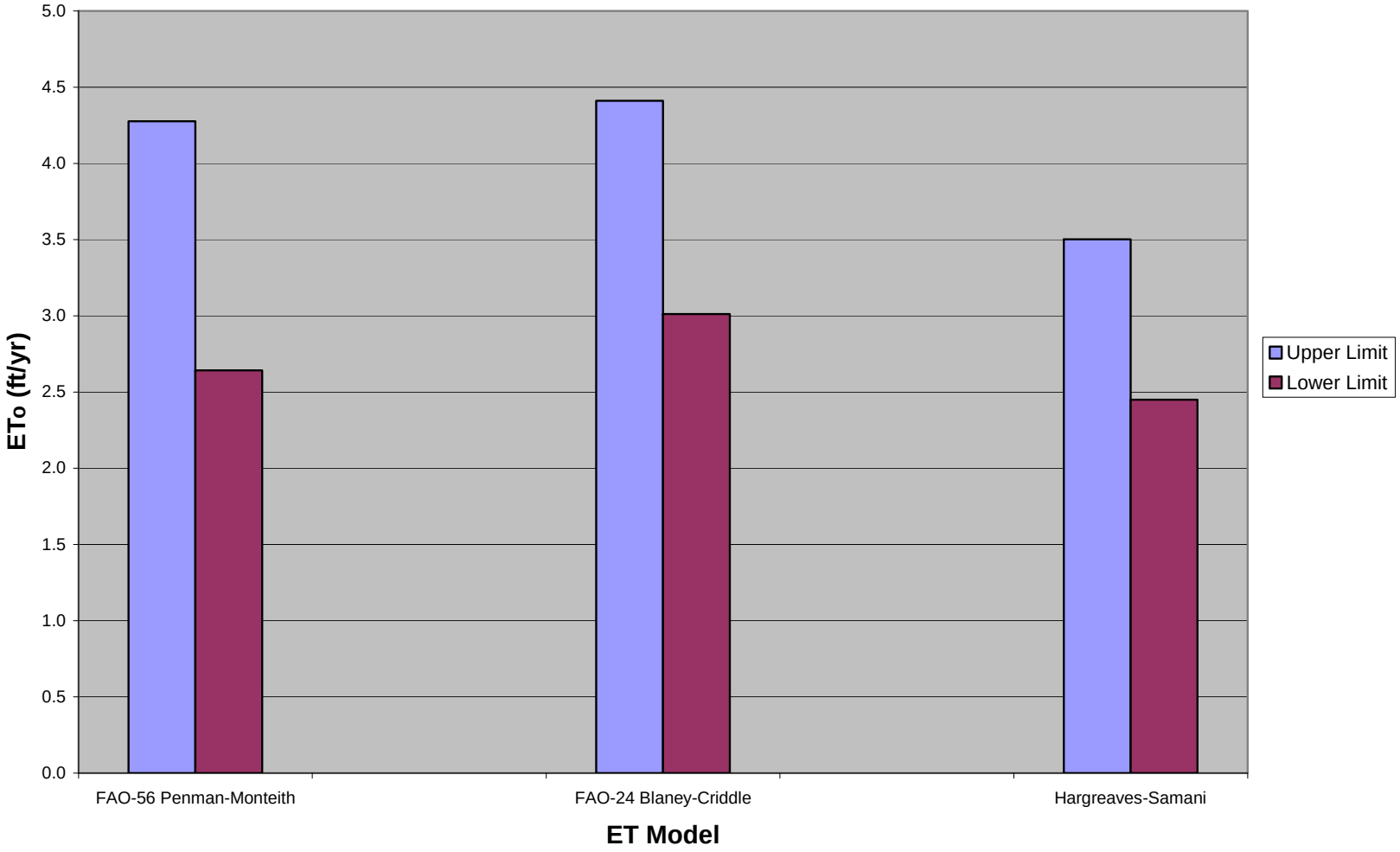
**Figure 2.2 Keams Canyon**
**ETo Models for Hopi CU**



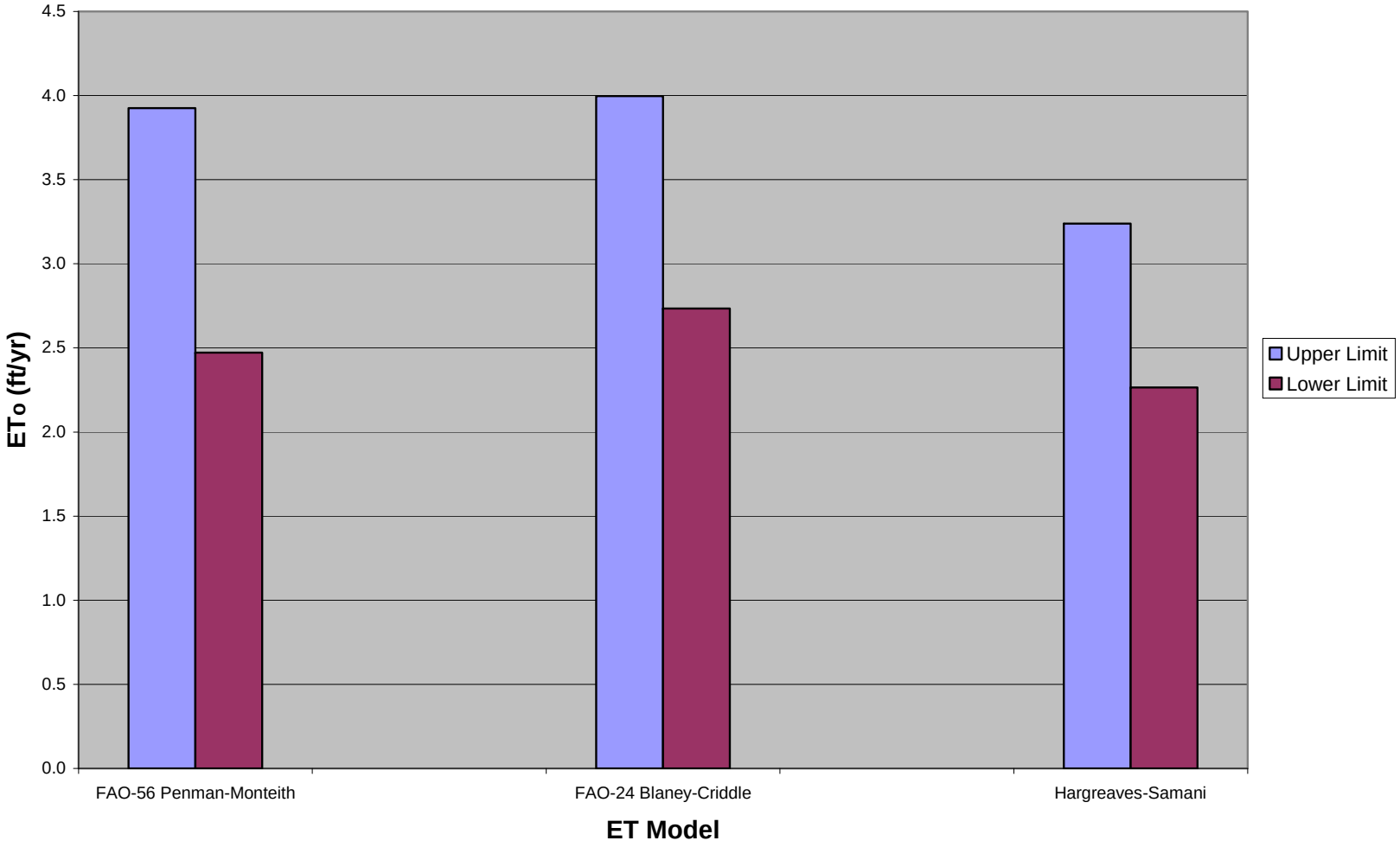
# Figure 2.3 Tuba City
# ETo Models for Hopi CU



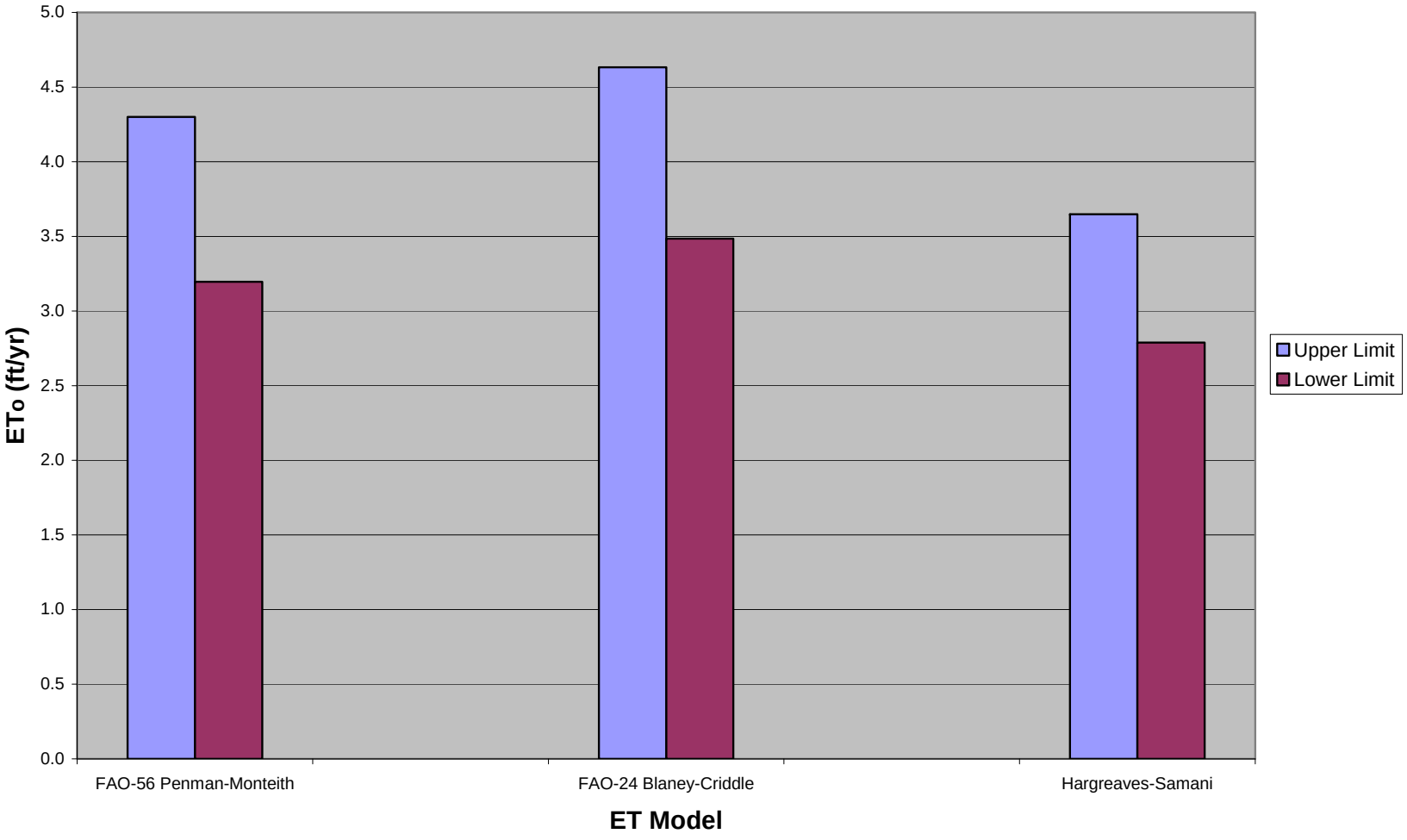
## Figure 2.4: Tuba City $ET_o$ NDI Model Comparison



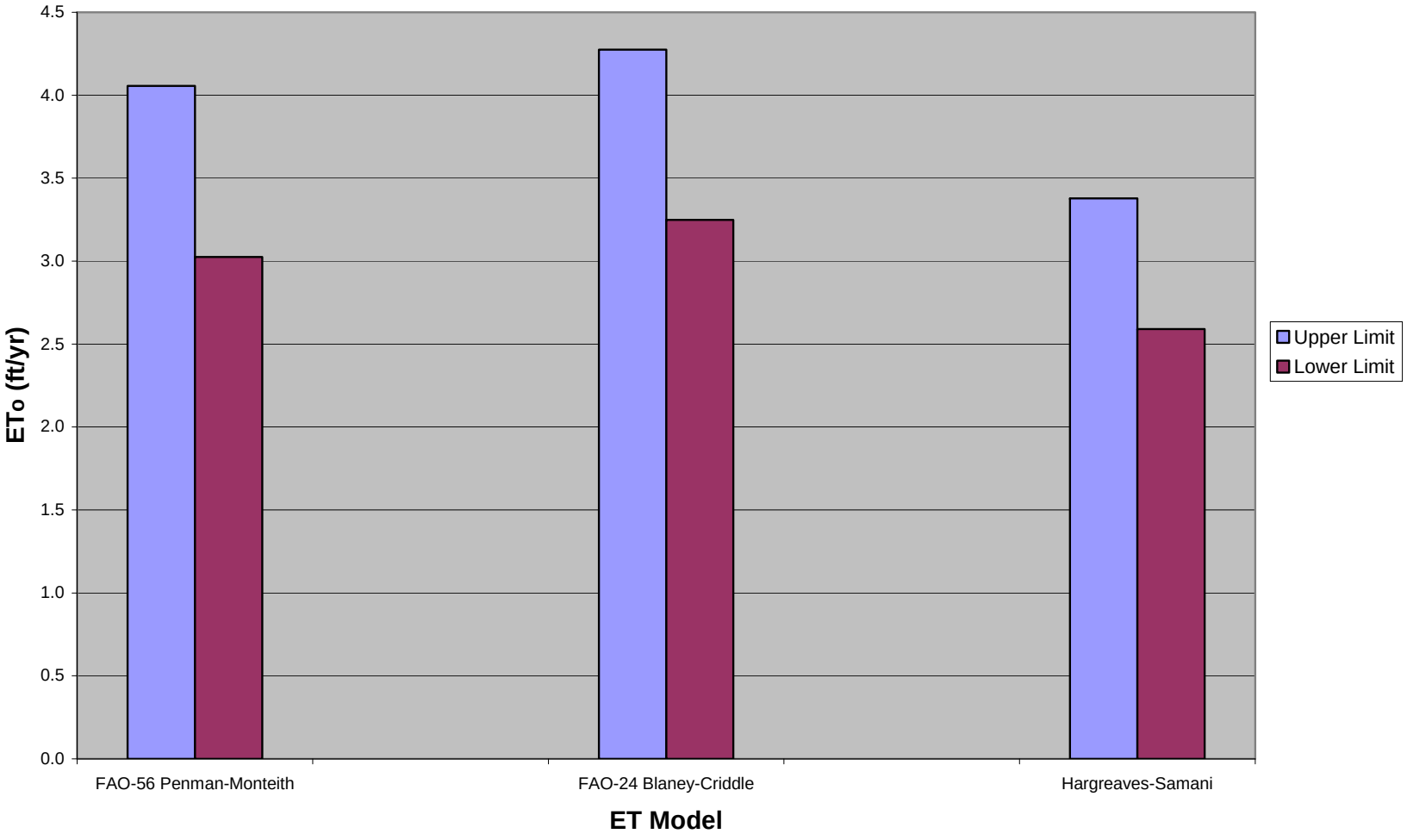
## Figure 2.5: Keams Canyon $ET_o$ NDI Model Comparison



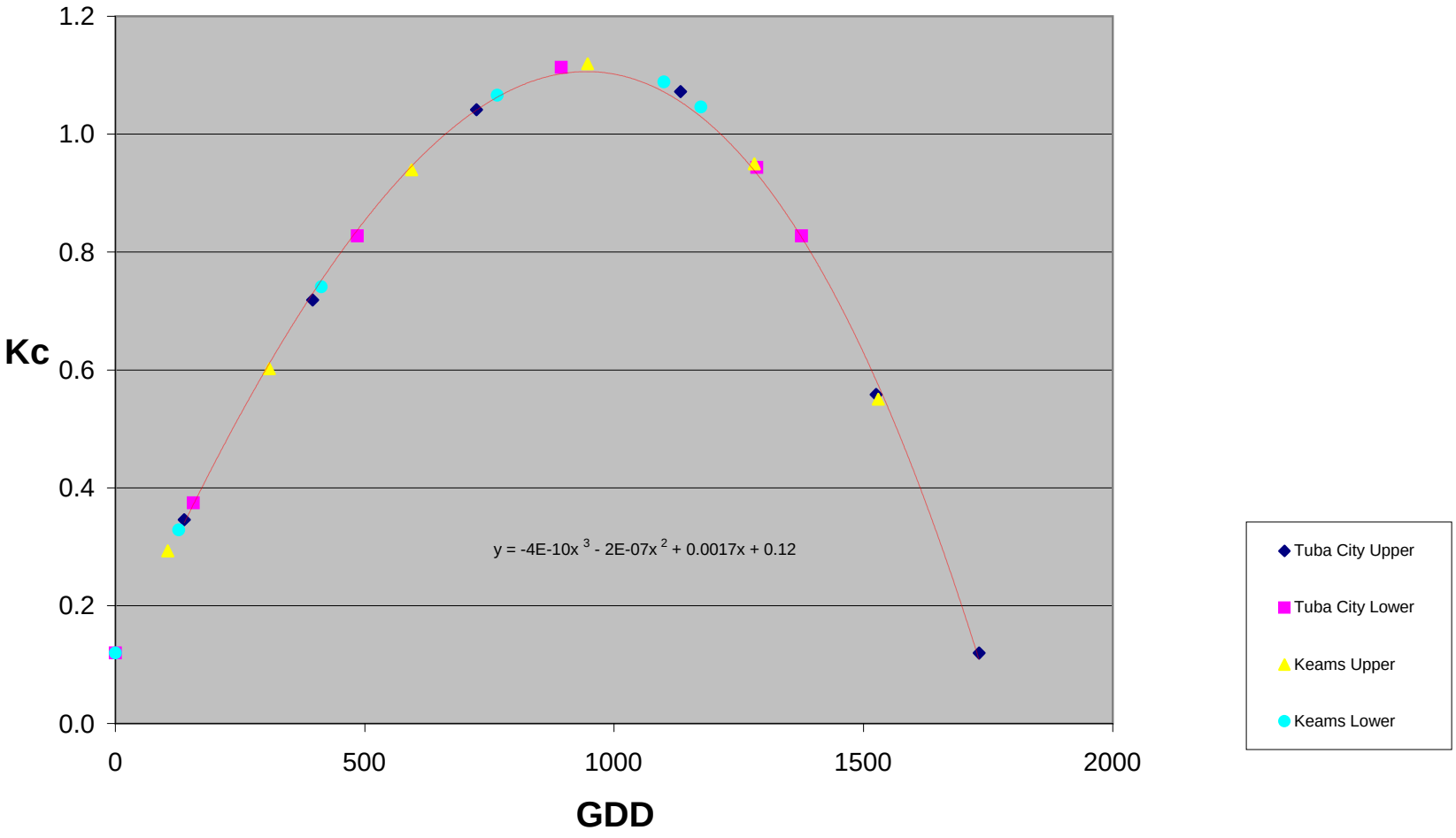
## Figure 2.6: Tuba City $ET_o$ DRY Model Comparison



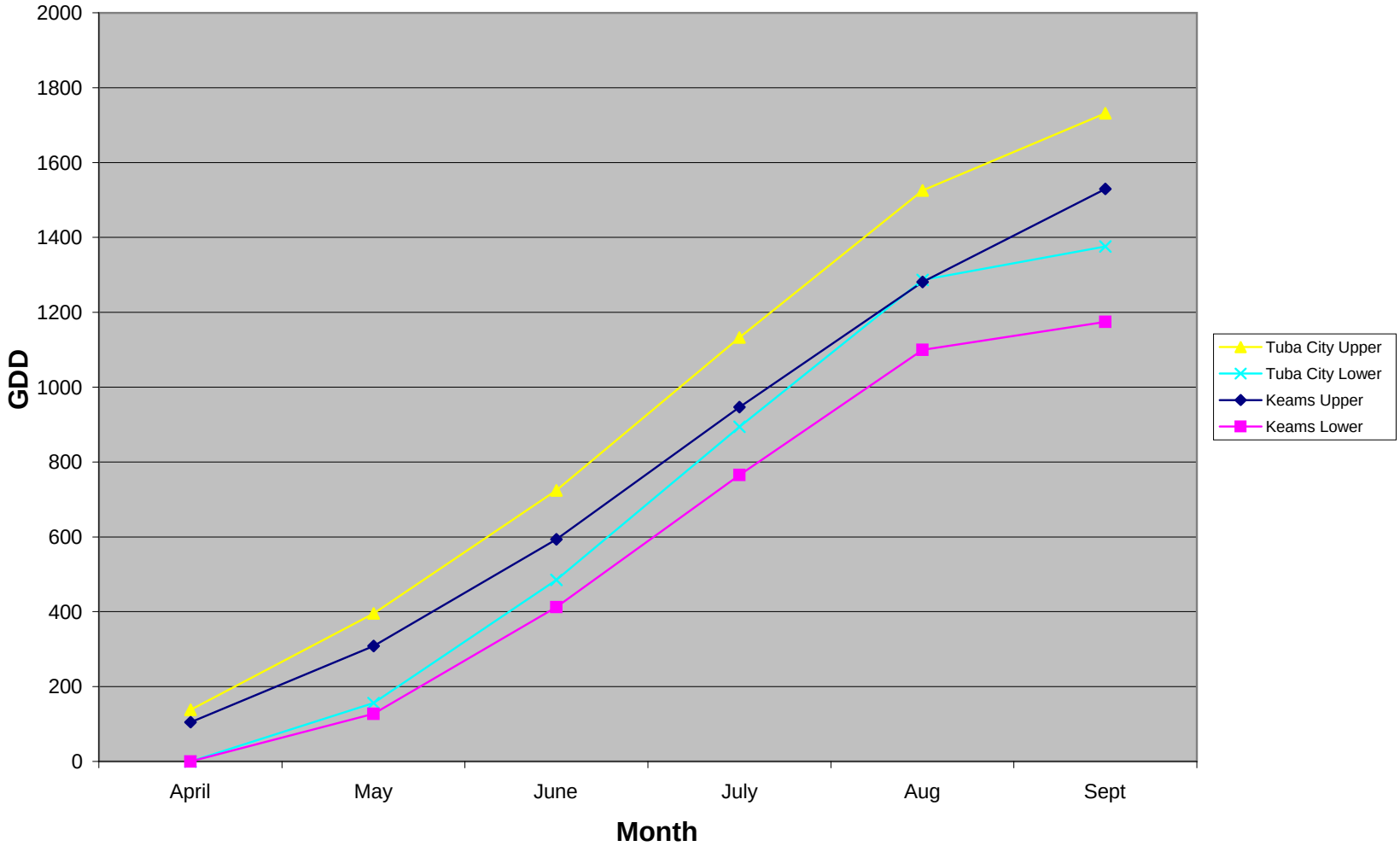
## Figure 2.7: Keams Canyon $ET_o$ DRY Model Comparison



## Figure 2.8: GDD Curve for Hopi Corn



# Figure 2.9: Cumulative GDD for Hopi Reservation



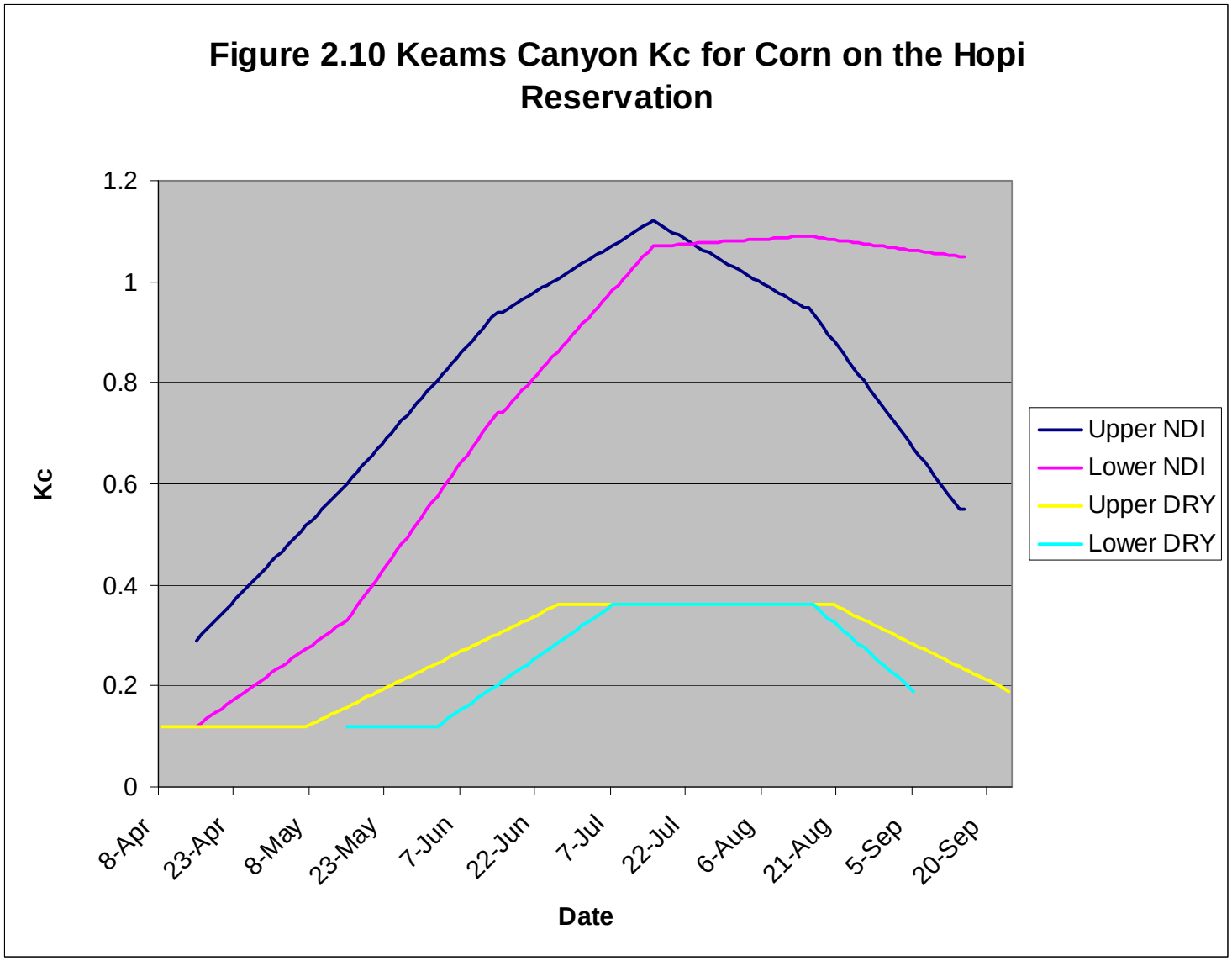


Figure 2.10 Keams Canyon Kc for Corn on the Hopi Reservation
1.2
1
0.8
0.6
0.4
0.2
0
Kc
8-Apr
23-Apr
8-May
23-May
7-Jun
22-Jun
7-Jul
22-Jul
6-Aug
21-Aug
5-Sep
20-Sep
Date
Upper NDI
Lower NDI
Upper DRY
Lower DRY

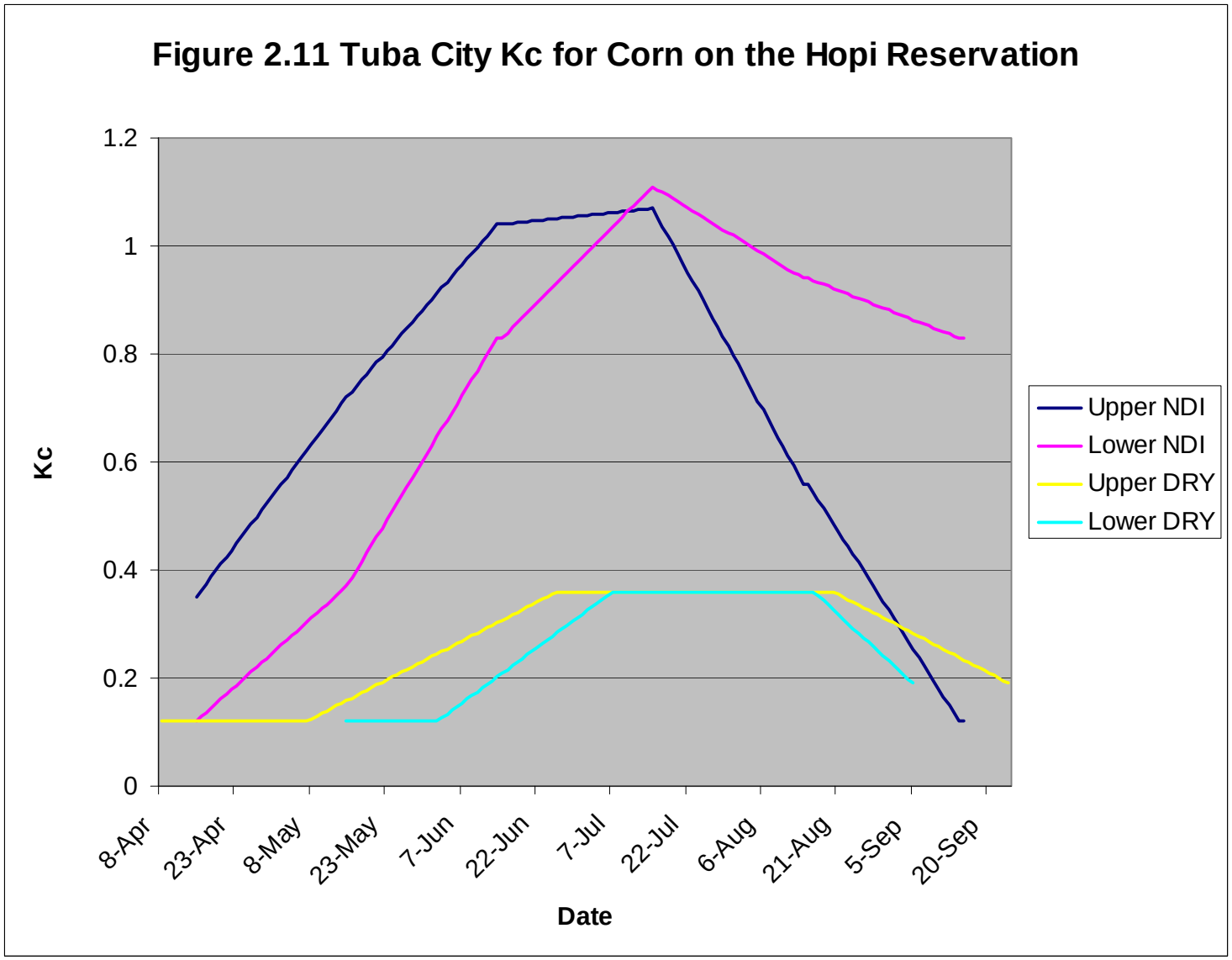


Figure 2.11 Tuba City Kc for Corn on the Hopi Reservation
1.2
1
0.8
0.6
0.4
0.2
0
Kc
8-Apr
23-Apr
8-May
23-May
7-Jun
22-Jun
7-Jul
22-Jul
6-Aug
21-Aug
5-Sep
20-Sep
Date
Upper NDI
Lower NDI
Upper DRY
Lower DRY

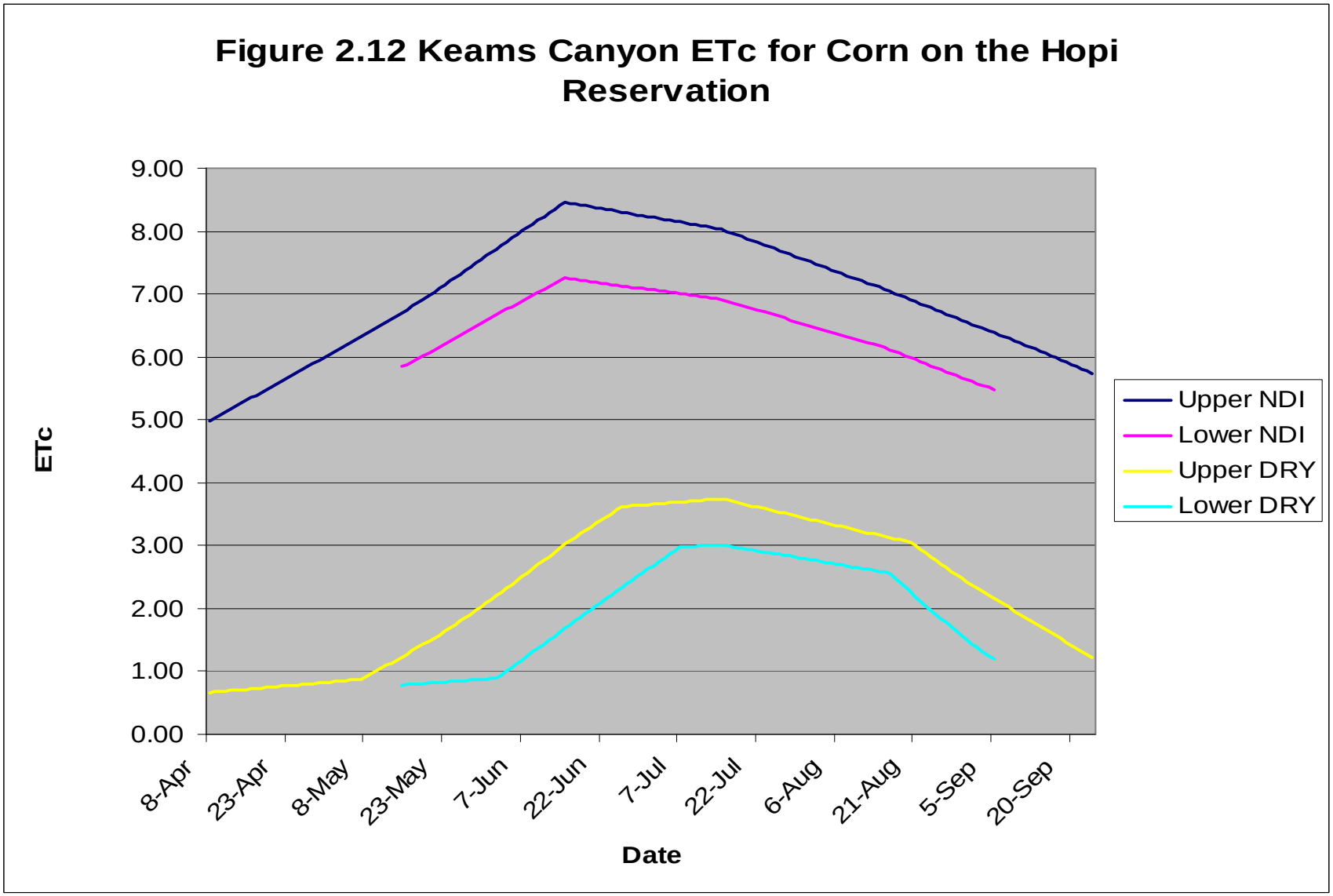


Figure 2.12 Keams Canyon ETc for Corn on the Hopi Reservation
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
ETc
8-Apr
23-Apr
8-May
23-May
7-Jun
22-Jun
7-Jul
22-Jul
6-Aug
21-Aug
5-Sep
20-Sep
Date
Upper NDI
Lower NDI
Upper DRY
Lower DRY

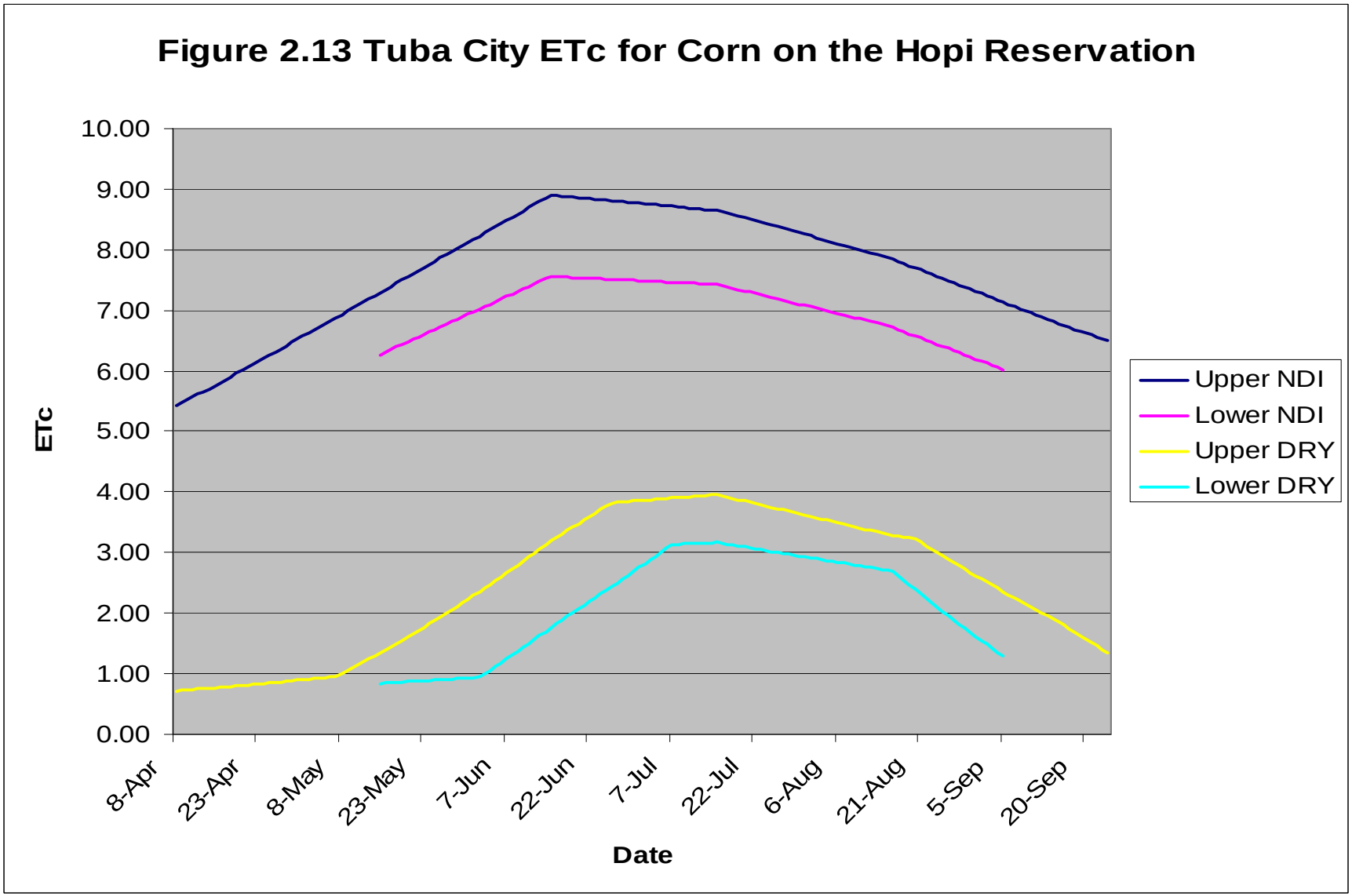
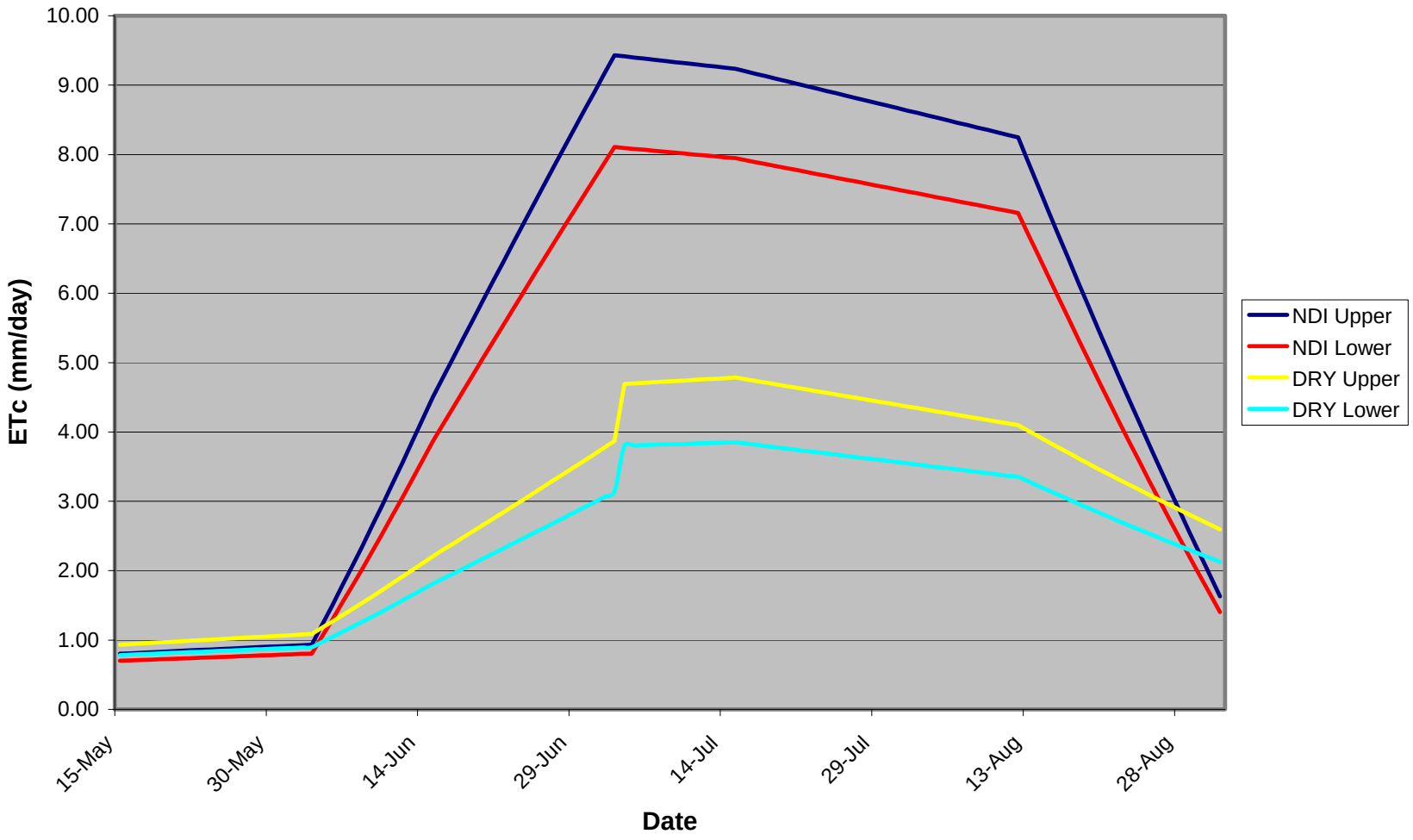
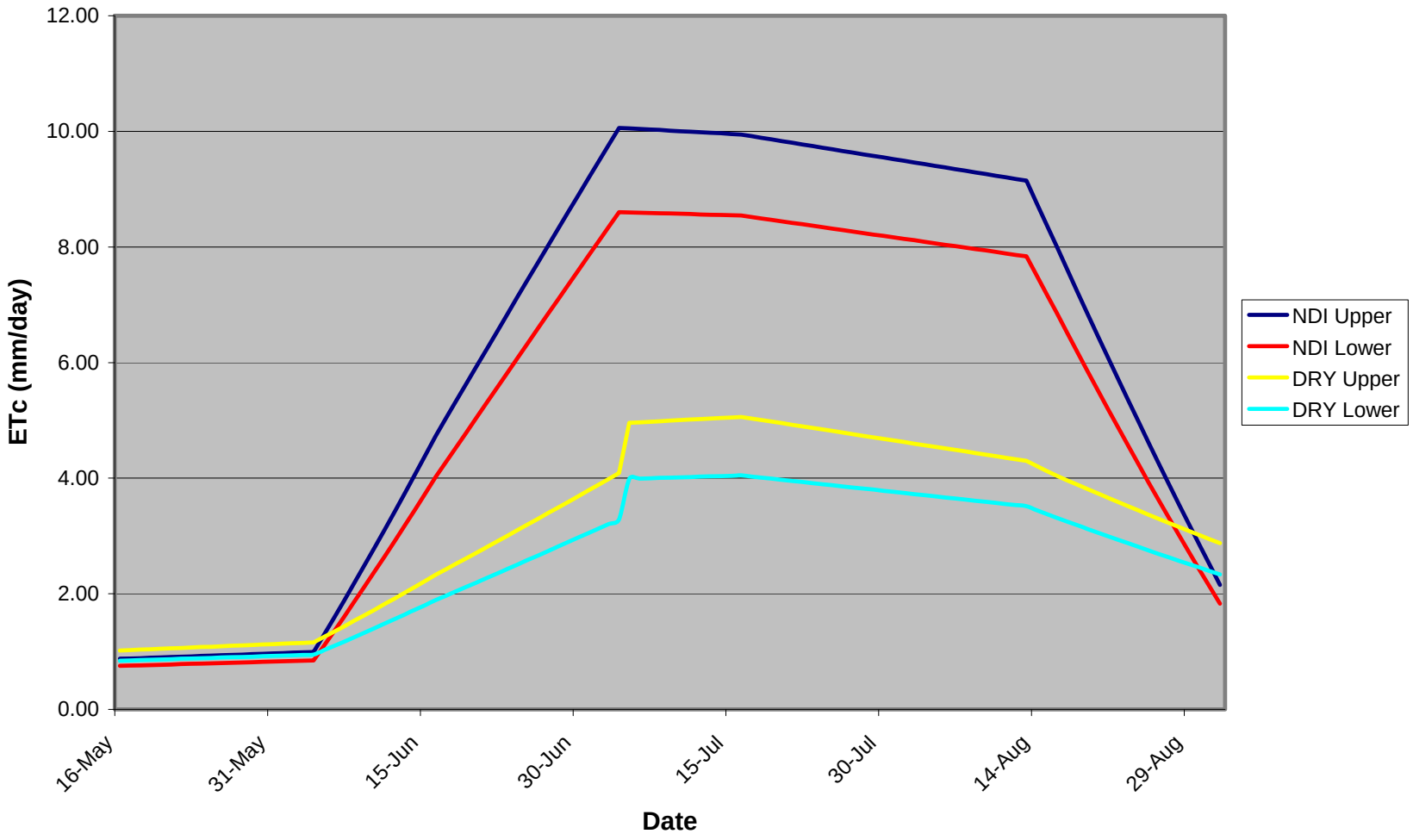


Figure 2.13 Tuba City ETc for Corn on the Hopi Reservation
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
ETc
8-Apr
23-Apr
8-May
23-May
7-Jun
22-Jun
7-Jul
22-Jul
6-Aug
21-Aug
5-Sep
20-Sep
Date
Upper NDI
Lower NDI
Upper DRY
Lower DRY

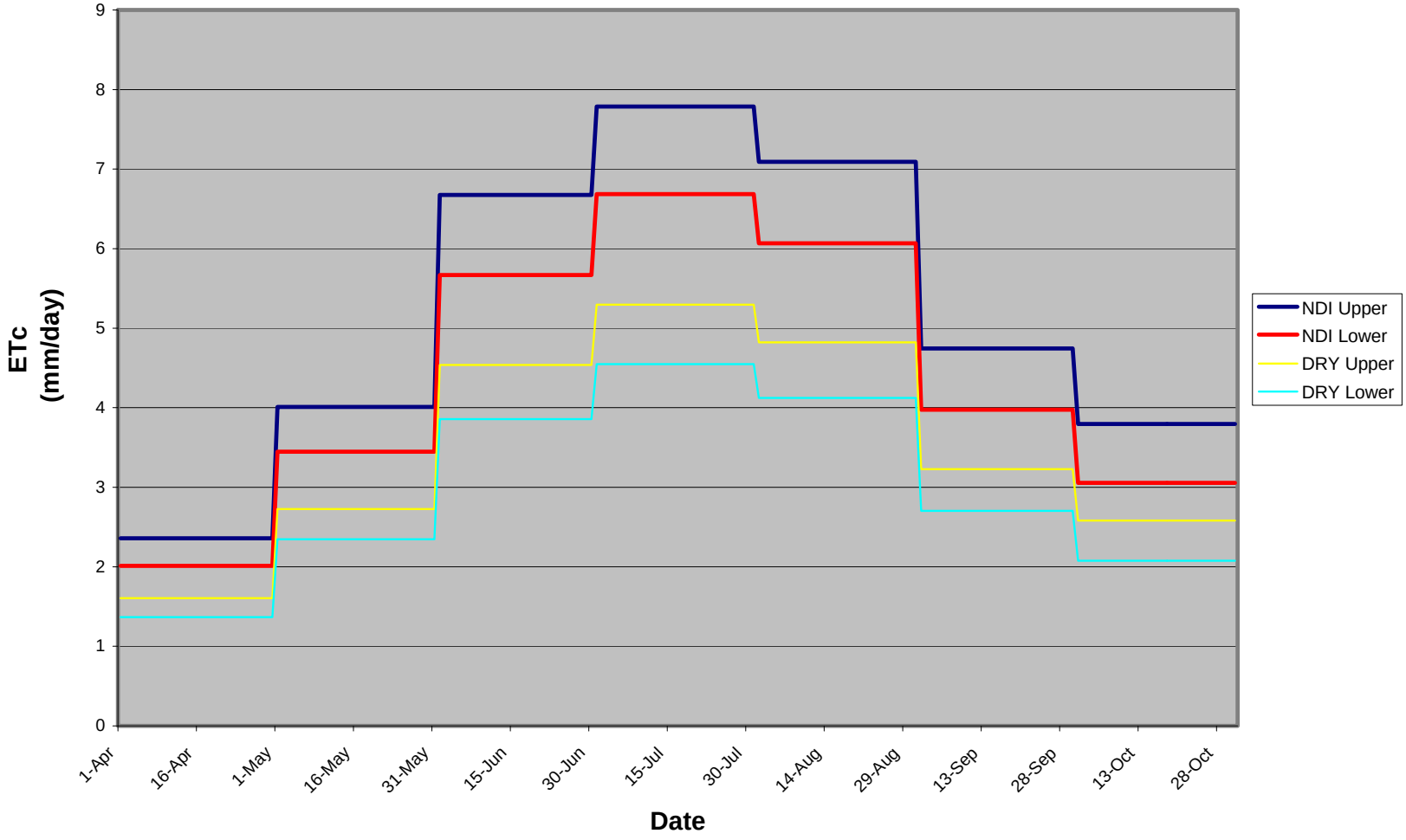
## Figure 2.14 Keams Canyon ETc for Hopi Beans



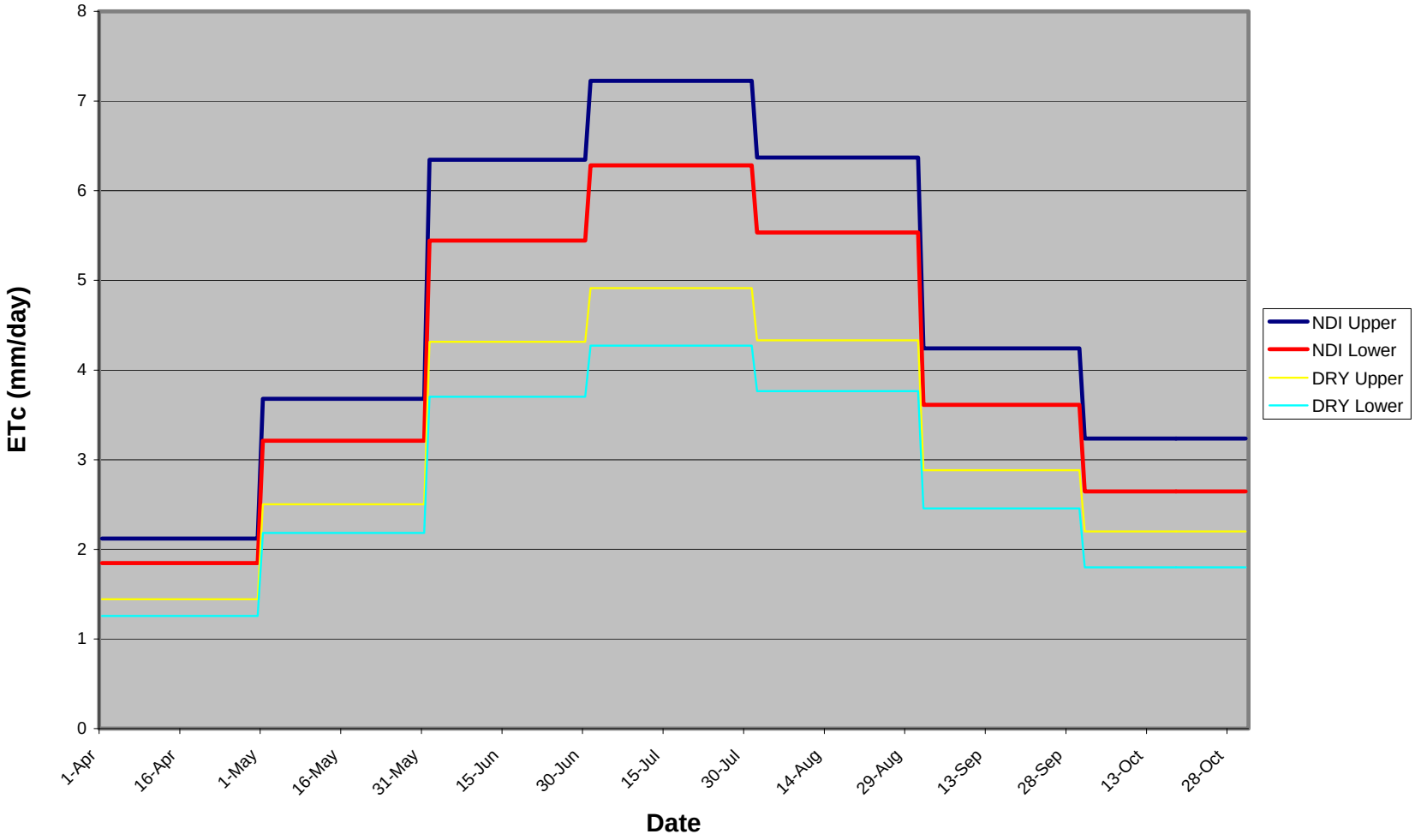
## Figure 2.15: Tuba City ETc for Hopi Beans



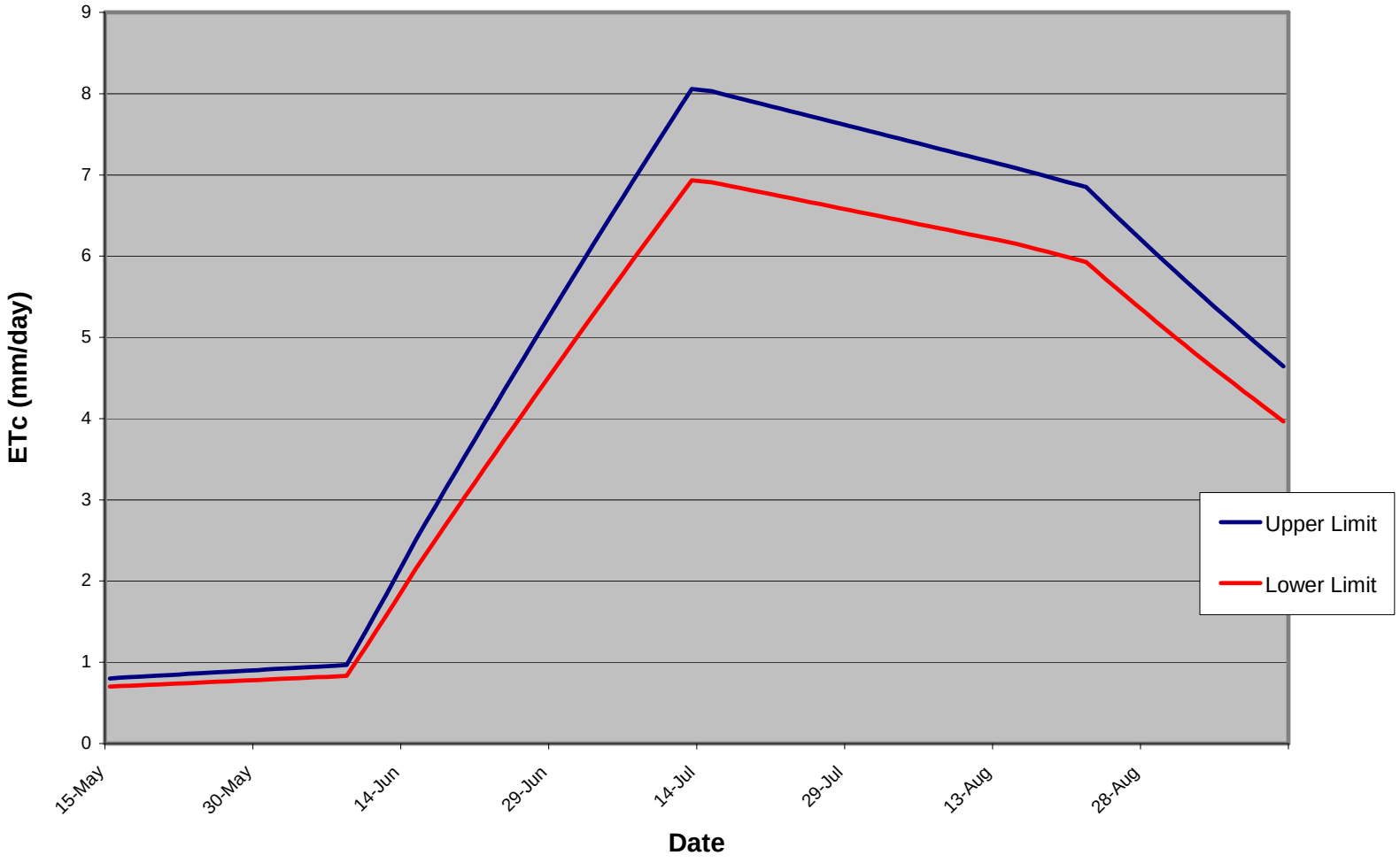
## Figure 2.14 Tuba City ETc for Hopi Orchards



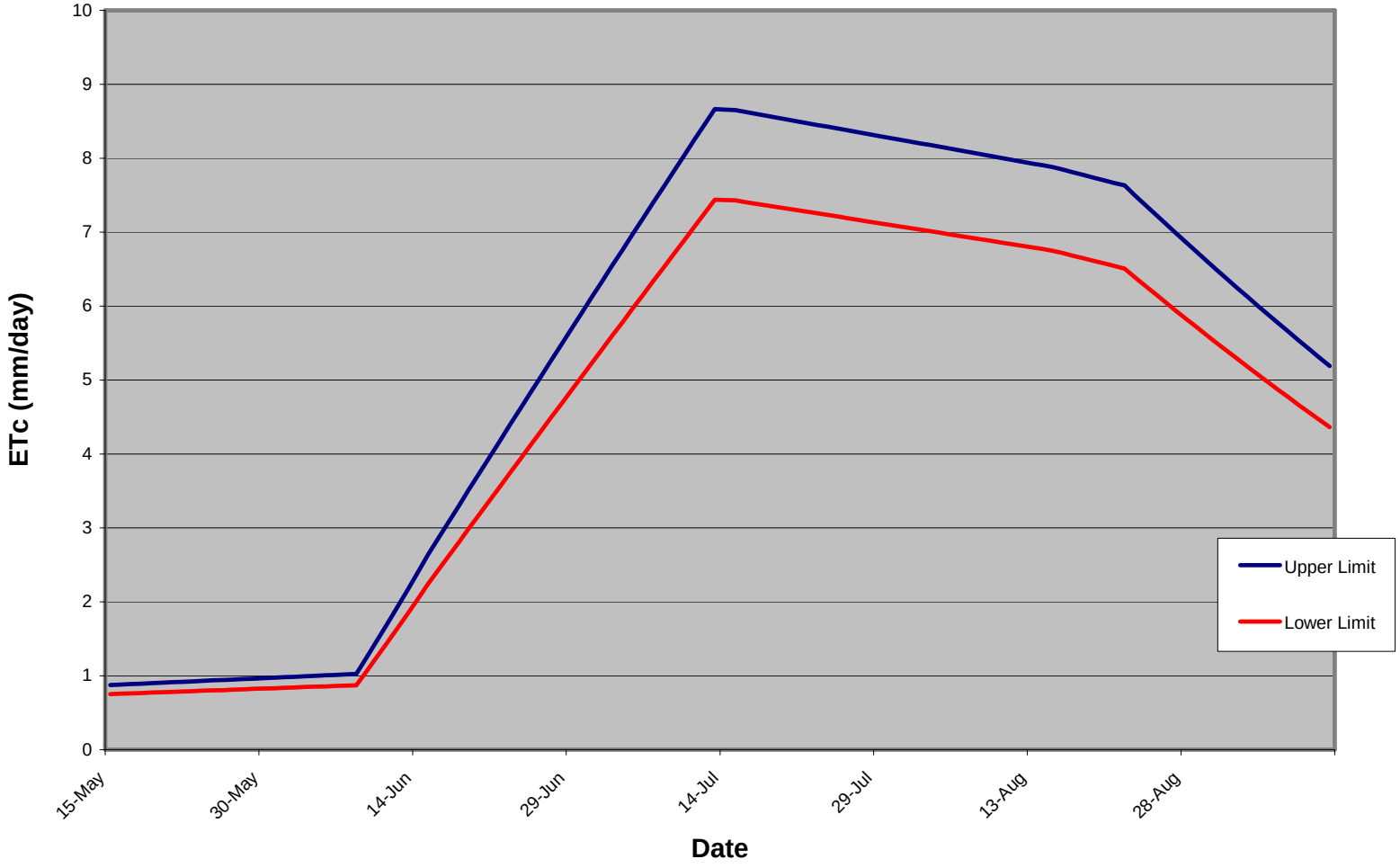
## Figure 2.17: Keams Canyon ETc for Hopi Orchards

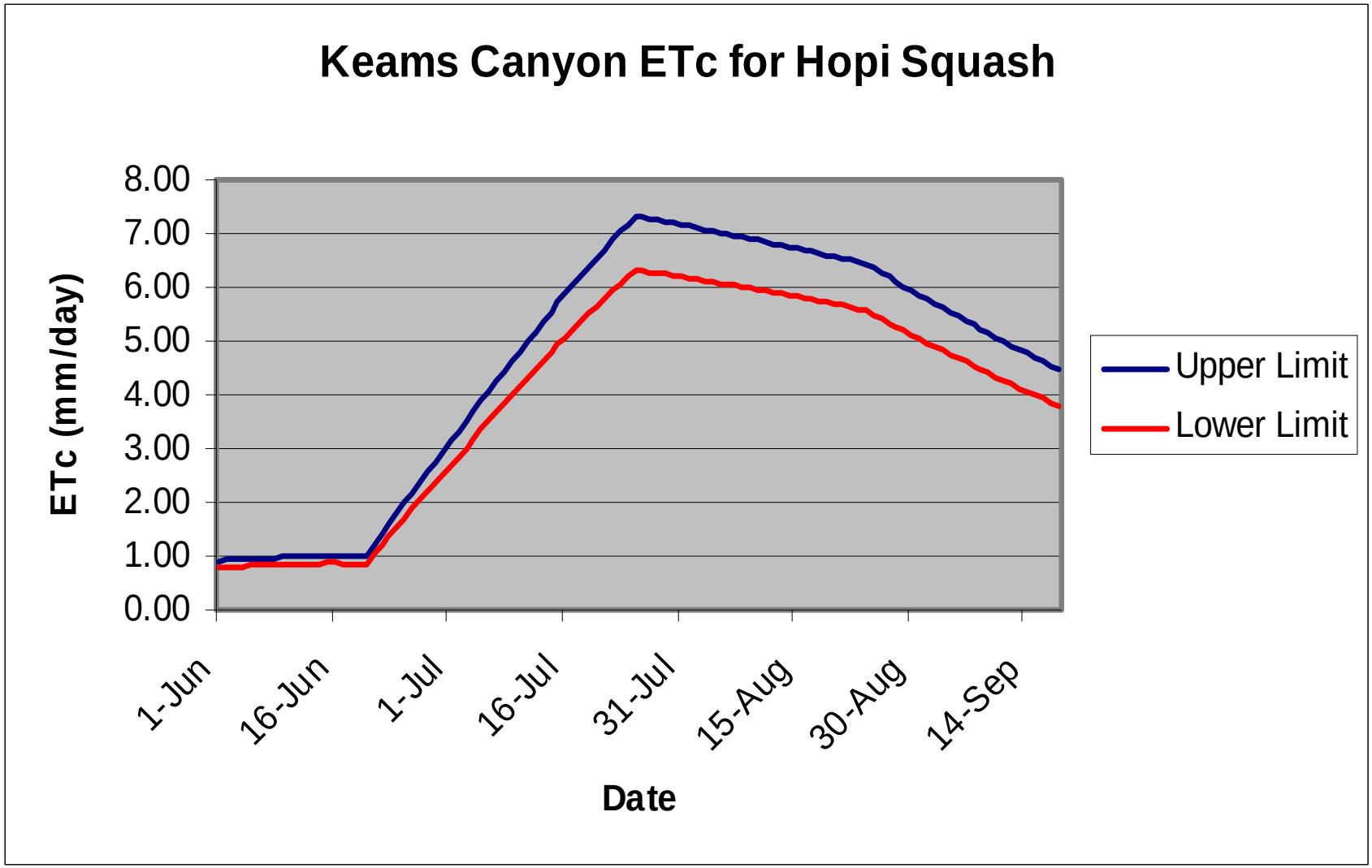


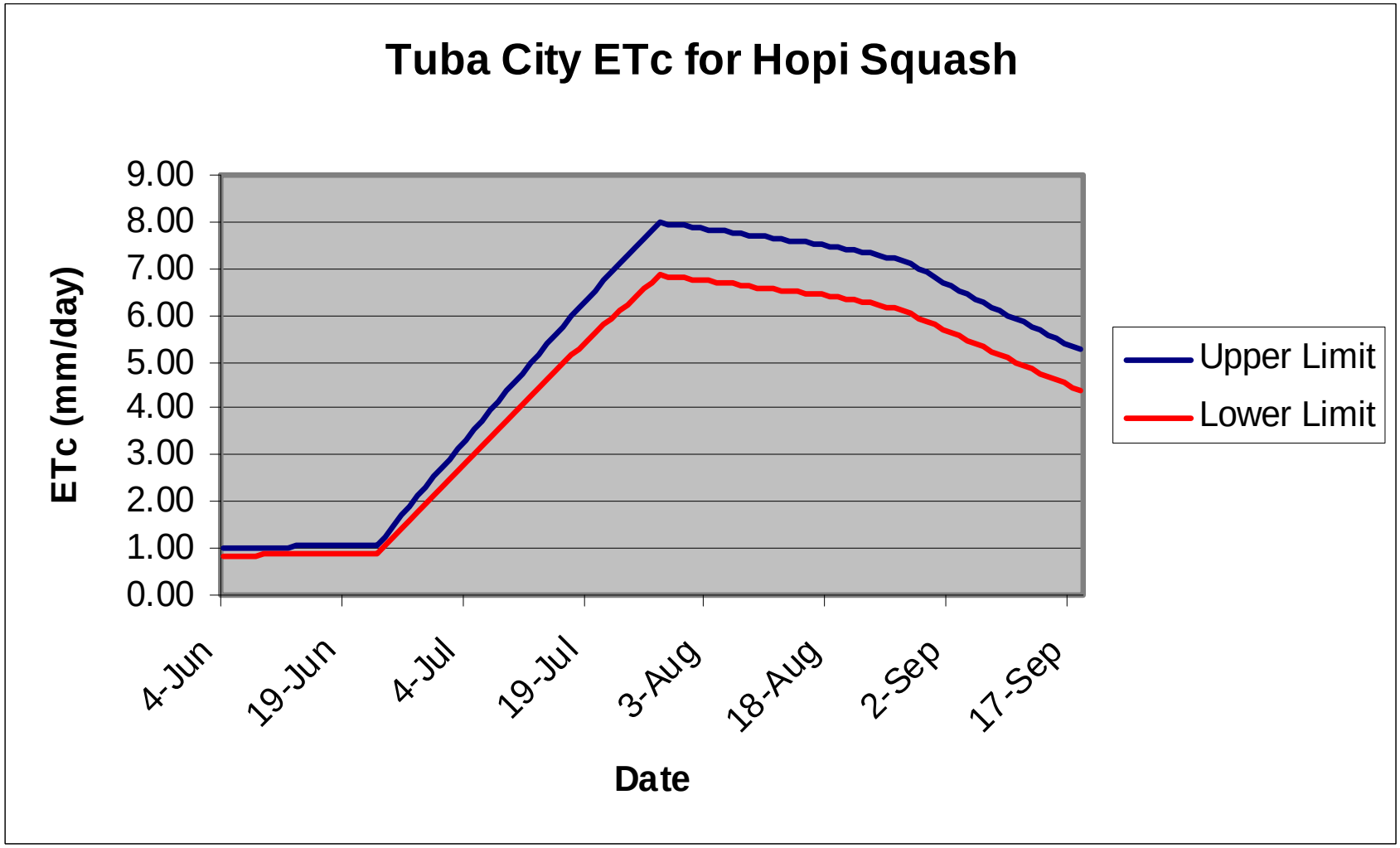
## Figure 2.18: Keams Canyon ETc for Hopi Melons



## Figure 2.19: Tuba City ETc for Hopi Melons




Keams Canyon ETc for Hopi Squash
ETc (mm/day)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1-Jun
16-Jun
1-Jul
16-Jul
31-Jul
15-Aug
30-Aug
14-Sep
Date
Upper Limit
Lower Limit


Tuba City ETc for Hopi Squash
ETc (mm/day)
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
4-Jun
19-Jun
4-Jul
19-Jul
3-Aug
18-Aug
2-Sep
17-Sep
Date
Upper Limit
Lower Limit

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# Appendices

# APPENDIX A

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DEPT OF WATER RESOURCES

**IN THE SUPERIOR COURT OF THE STATE OF ARIZONA**
**IN AND FOR THE COUNTY OF APACHE**

| | |
|---|---|
| IN RE: THE GENERAL ADJUDICATION OF ALL RIGHTS TO USE WATER IN THE LITTLE COLORADO RIVER SYSTEM AND SOURCE | CIVIL NO. 6417<br><br>**THE HOPI TRIBE'S AMENDED STATEMENT OF CLAIMANT** |

| | |
|---|---|
| DESCRIPTIVE SUMMARY: | Amended Statement of Claimant of Hopi Tribe filed pursuant to Court Order dated July 16, 2002 and Minute Entry dated May 9, 2003. |
| NUMBER OF PAGES: | 34 |
| DATE OF FILING: | Original transmitted to Arizona Department of Water |

## I. INTRODUCTION

Pursuant to Paragraph 5 of the Court's Order dated July 16, 2002 and Minute Entry dated May 9, 2003, the Hopi Tribe hereby submits its Amended Statement of Claimant. This

## B. Surface Water for Irrigation

### 1. Past and Present Irrigation

The Hopi Tribe claims the right to divert 49,206 acre-feet of water annually from the five washes and minor tributaries that flow from north to south through the Hopi Reservation to irrigate 38,556 acres as shown in Table 1. The five washes are Moenkopi, Dinnebito, Oraibi, Polacca and Jeddito. On average, the irrigation diversion is 28,700 acre-feet per year. However, the Tribe claims the maximum quantity needed to irrigate all of the past and presently irrigated acreage in order to provide an adequate water supply for irrigation in years) when that water is not available. Table 1 identifies the different types of irrigation and the number of acres in each category, and Table 2 shows the claims by source of supply, i.e. wash. Locations of acreage for past and present irrigation for the Hopi 1882 and 1934 Reservation Areas are shown on Figures 4 and 5. These claims are based on the work of the experts retained by the United States, which is discussed in additional detail in the United States' Amended Statement of Claimant on Behalf of the Hopi Tribe.

from Moenkopi Wash. Location of this project is shown in Figure 6.

### 3. Future Irrigation from the Main Stem of the Little Colorado

The Hopi Tribe claims 21,060 acre-feet annually from the main stem of the Little Colorado River to irrigate 7,400 acres of land on the 1882 Reservation. An off-stream storage reservoir complex of 11,500 acre-feet capacity is required to firm up direct flow water supplies from the main stem of the Little Colorado. Location of the project is shown in Figure 7.

### 4. Evaporative Uses and First Fillings for Irrigation Storage Facilities

The Hopi Tribe claims the right for first-filling and to replace evaporative losses for the projects identified in Section X.B.2 and 3. The Tribe claims 15,700 acre-feet of water for the first time filling of reservoirs and 2,842 acre-feet annually for evaporation from the proposed storage facilities.

## C. Ceremonial and Subsistence Irrigation

The Tribe claims 12,546 acre-feet per year for future irrigation of small family garden plots for ceremonial and subsistence purposes. Such ceremonial and subsistence gardens have historically and contemporaneously been located near the villages. Future gardens would require a total of 3,136 acres of arable land surrounding the villages, as follows: Moenkopi – 754 acres, Hotevilla – 386 acres, Bacavi – 197 acres, Kykotsmovi and Old Oraibi – 647 acres, First Mesa Villages – 542 acres, Second Mesa Villages – 484 acres, Keams Canyon – 126 acres. Subject to Section X.J., the source is groundwater.

## D. Domestic, Commercial, Municipal and Industrial Use (DCMI)

For future domestic, commercial, municipal, and industrial (DCMI) uses of water, the

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**IN THE SUPERIOR COURT OF THE STATE OF ARIZONA**
**IN AND FOR THE COUNTY OF APACHE**

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|---|---|
| IN RE: THE GENERAL ADJUDICATION OF ALL RIGHTS TO USE WATER IN THE LITTLE COLORADO RIVER SYSTEM AND SOURCE | CIVIL NO. 6417<br><br>UNITED STATES' AMENDED STATEMENT OF CLAIMANT ON BEHALF OF THE HOPI TRIBE |

| | |
|---|---|
| DESCRIPTIVE SUMMARY: | Amended Statement of Claimant on behalf of the Hopi Tribe filed pursuant to Minute Entry, dated May 9, 2003. |
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1. *Technical basis for past and present irrigated acreage claim.*

The Hopi Tribe has historically irrigated and continues to irrigate crops on the Hopi Reservation. The past and present irrigated acreage was identified based on interpretation of aerial photos taken since 1934 and field assessment. These identified lands were divided into five irrigation types based on water source and crop as follows:

Perennial Irrigation - Perennial surface water available to the parcel, conveyed by permanent structures.

Seasonal Irrigation - Seasonal surface water available to the parcel and used on planted fields; water is conveyed by structures ranging from temporary and/or permanent spreader dikes to diversion with ditches.

Range Pasture Irrigation - Seasonal surface water available to the parcel and used to improve range for pasture; water is conveyed by structures ranging from temporary and/or permanent spreader dikes to diversions with ditches.

Native Irrigation - Seasonal surface water available to the parcel with minimal water control structures; water arrives at the parcels by strategic placement of the parcel rather than by conveyance of the water.

Spring Irrigation - Perennial groundwater available to the parcels obtained and distributed from a spring.

The Hopi Tribe also crops land that is not irrigated and relies upon precipitation. These precipitation farmed lands were identified, but are not associated with a water right claim.

The seasonal water supplies in the five northern washes for 1950 through 1993 were estimated using the Precipitation Runoff Modeling System (PRMS) created by the United States Geological Survey. The PRMS model estimates daily runoff based on precipitation, temperature, solar radiation, and physical characteristics of the area being modeled. Crop water requirements were estimated using the Modified Jensen-Haise method to determine evapotranspiration (ET)

adjusted by crop coefficients based on crop type, typical planting dates, and cultural cropping practices. The irrigation diversions and irrigation depletions were estimated using a deficit irrigation simulation model that considers the available flows (from PRMS) for irrigation and potential crop ET. The model tracks soil moisture and adjusts crop ET based on soil moisture. A deficit irrigation model was used because full water supplies for the crops are seldom available. The seasonal water supply limits irrigation diversions and depletion. The past and present irrigation claim is for the maximum estimated diversion for irrigation during the period of analysis.

The water supply for perennial and spring irrigation is usually available throughout the irrigation season (April through September). However, because of the nature of springs and the fact that the perennial flows occur only in sections of the washes, a full irrigation supply is not always available. The irrigation supply for these lands was therefore estimated to be 90 percent of the irrigation requirement.

2. *Outline of the past and present irrigation claim*

The following two tables outline the past and present irrigation claim. Table 1, Presently and Historically Irrigated Acreage in the Five Wash Basins through the Hopi Reservation, designates the past and present irrigated acreage divided by wash. Table 2, Estimated Irrigation Depletion and Diversion for Presently and Historically Irrigated Lands on the Hopi Reservation, outlines the irrigation depletion and diversion in both average and maximum years.

In addition, a map labeled Presently and Historically Irrigated Lands is enclosed as Appendix 8 in order to provide an overview of the irrigated acreage based on the GIS coverages created from interpretation of historical photos. The GIS coverages themselves are available for review if ADWR determines such coverages would be helpful.

## Table 1

**Presently and Historically Irrigated Acreage in the five wash basins through Hopi Reservation.**

| Wash | Perennial (acres) | Seasonal (acres) | Range Pasture (acres) | Native (acres) | Spring (acres) | Precipitation Farming (acres) | Total (acres) |
|---|---|---|---|---|---|---|---|
| Moenkopi Main Reservation | 16 | 121 | 334 | 2,002 | 23 | 1 | 2,497 |
| Moenkopi Island | 548 | 0 | 0 | 433 | 8 | 0 | 989 |
| Dinnebito | 0 | 1,375 | 359 | 5,107 | 97 | 333 | 7,271 |
| Oraibi | 0 | 1,653 | 4,052 | 4,910 | 0 | 455 | 11,070 |
| Polacca | 0 | 1,645 | 1,970 | 8,660 | 22 | 252 | 12,549 |
| Jadito | 0 | 1,392 | 807 | 1,926 | 1 | 1 | 4,127 |
| Minor Tributaries | | | | 53 | | | 53 |
| **TOTAL** | **564** | **6,186** | **7,522** | **23,091** | **151** | **1,042** | **38,556** |

Minor tributaries is a small area of the Hopi Reservation drains directly to the Lower Colorado River rather than a major wash.

Precipitation Farming does not have a diversion or depletion from washes.

There is no irrigation from wells on the Hopi Indian Reservation.

## Table 2

**Estimated Irrigation Depletion and Diversion for Presently and Hisortically Irrigated Lands on the Hopi Indian Reservation**

| | Irrigation Depletion | | Irrigation Diversion | |
|---|---|---|---|---|
| Wash | Average (ac ft/yr) | Maximum (ac-ft/yr) | Average (ac-ft/yr) | Maximum (ac-ft/yr) |
| Moenkopi Main Reservation | 2,084 | 2,440 | 2,772 | 3,246 |
| Moenkopi Island | 1,310 | 1,535 | 1,468 | 1,795 |
| Dinnebito | 3,961 | 6,552 | 5,280 | 8,714 |
| Oraibi | 5,384 | 9,865 | 5,384 | 13,120 |
| Polacca | 7,218 | 11,869 | 9,622 | 15,786 |
| Jadito | 2,936 | 4,790 | 3,914 | 6,371 |
| Minor Tributary | 37 | 59 | 49 | 104 |
| **TOTAL** | **22,930** | **37,110** | **28,489** | **49,136** |

# APPENDIX B

Natural Resources Consulting Engineers, Inc.
131 Lincoln Ave, Suite 300
Fort Collins, CO 80524
Phone: (970) 224-1851, Fax: (970) 224-1885

DRAFT MEMORANDUM

Date: October 29, 2007

To: Vanessa Boyd Willard, Esq.
Indian Resources Section
United States Department of Justice
Denver, Colorado

From: L. Niel Allen, Ph.D, P.E.
Natural Resources Consulting Engineers, Inc.

RE: Responses to Arizona Department of Water Resources Questions Regarding Hydrological Modeling on the Hopi Indian Reservation

---

In January 2004, the United States Department of Justice (DOJ) submitted an amended Statement of Claimant for water rights on behalf of the Hopi Tribe to the Superior Court of the State of Arizona in and for the County of Apache. The Statement of Claimant regards the general adjudication of all rights to use water in the Little Colorado River system and sources. As part of the adjudication, the Arizona Department of Water Resources (ADWR) is in the process of preparing a hydrographic survey report of water uses on the Hopi Indian Reservation. ADWR is using the claims submitted by the United States along with other information to prepare the hydrographic survey.

Natural Resources Consulting Engineers, Inc. (NRCE) provided a summary of the estimation of flows in the northern washes of the Little Colorado River to ADWR through the DOJ in June of 2007. In September of 2007, ADWR provided Vanessa Willard, Esq. of the DOJ in Denver, Colorado a list of questions concerning water supply modeling and irrigation water use on the Hopi Indian Reservation. This memorandum provides responses to the numbered questions.

*1. May ADWR obtain a copy of the 2000 NRCE report entitled Historical/Present Irrigation Water Uses of the Navajo and Hopi Indian Reservations within the Northern Washes of the Little Colorado River Basin?*

NRCE has been advised by the DOJ that the 2000 report entitled *Historical/Present Irrigation Water Uses of the Navajo and Hopi Indian Reservations within the Northern Washes of the Little Colorado River Basin* (Report) is not being made available at this time.

*2. Which meteorological stations were used to obtain precipitation and other data needed to estimate crop evapotranspiration (ET)?*

Climate stations selected for use in the study were on the basis of length and continuity of record and location within the study area. The period of analysis was from 1950 through 1993. The National Weather Service stations used in this study were:

- Cameron 1 NNE (#1169)
- Gallup 5 E (#3420)
- Ganado (#3303)
- Keams Canyon (#4586)
- Leupp (#4872)
- Petrified Forest N.P. (#6468)
- Sanders (#7488)
- Sanders 11 ES (#7496)
- Window Rock 4 SW (#9410)

Regression analyses between stations were used to fill in missing temperature and precipitation data so that each site had a full set of data from 1950 through 1993.

The reference ET was estimated in the Precipitation Runoff Model Simulation (PRMS) model using the Modified Jensen-Haise method, which is based on daily temperature and solar radiation data. The daily temperatures for each sub-basin are based on the National Weather Service data. The solar radiation was estimated based on a procedure selected for use in the PRMS model. The method is based on the maximum daily temperature, degree-day relationships for specific months of the year, and a corresponding ratio of actual to potential daily solar radiation as described in the PRMS User's Manual (Leavesley et. al, 1983).

The 869 hydrologic response units (HRUs) were each assigned to the station nearest in elevation to the mean HRU elevation. The station precipitation was then adjusted using a lapse rate and an adjustment due to differences in latitude.

*3. What was the source(s) for the crop coefficient (Kc) values used in the ET calculations, and what crop mix was assumed on the reservation?*

The historically irrigated lands on the Hopi Reservation were categorized based on crop group, irrigation practices, and water source. The two crop groups are fields planted with cultivated crops and range pasture. The two water supplies are seasonal or perennial.

*Seasonal Water Supply*

The seasonal water supplies are based on the PRMS model output. The ET potential for the planted fields was based on the calculated ET for corn. Corn is the principal crop, with other crops such as beans and squash having a similar ET. Crop coefficients for corn were obtained from the United Nations Food and Agricultural Organization (FAO) Publication 24 (Doorenbus and Pruitt, 1977) and University of California Publication 21454 (University of California, 1989). Corn crop coefficients were divided by 1.2 to adjust from a grass-based reference ET method to the alfalfa-based Jensen-Haise method and were subsequently reduced by 30 percent to account for field conditions.

The 30 percent reduction in Kc is used to account for the plant density that is much less than that used to develop published crop coefficients. For example, on the farmed area in the Northern Washes, corn plants are spaced on about 4- to 5-foot rows with spacing of about 3 feet between plant clusters, as compared to typical 2.5-foot row spacing and 0.75- to 1-foot plant spacing along the rows. Another consideration is that once crops become stressed due to lack of soil moisture, plant growth can become stunted, and plants lack the growth and vigor required to transpire water at their potential. The deficit irrigation conditions prevalent on lands irrigated from the Northern Washes often result in low soil moisture conditions that limit the uptake of water by crops.

Crop coefficients for native range were assumed to be the same as for short pasture, as listed in *Consumptive Use of Irrigated Crops in Utah* (Hill, 1994). The following table is an example of cropping dates and crop coefficients used in the deficit irrigation simulation model (DISM). The cropping dates varied between sub-basins.

Example of Cropping Dates and Crop Coefficients

| Crop Type | Cropping Dates[a] | | | | Crop Coefficients[b] | | | |
|---|---|---|---|---|---|---|---|---|
| | A | B | C | E | Kc1 | Kc2 | Kc3 | % |
| Corn[c] | JUN 01 | JUN 18 | JUL 27 | SEP 28 | .16 | .95 | .33 | 90 |
| Native Range | APR 01 | APR 20 | MAY 15 | SEP 15 | .30 | .68 | .40 | 77 |

[a] *Cropping Dates* - A = planting, B = 10 percent ground shading, C = 75 percent ground shading, E = transpiration ceases or harvest. Date D (not listed) is a calculated date that Kc begins to decrease linearly to Kc3 .

[b] *Crop Coefficients* - Kc1 = crop coefficient from date A to B, Kc2 = crop coefficient from C to D, and Kc3 = crop coefficient at date E, % = percent of growing season from A to D. The crop coefficients between dates B and C are a linear interpolation between Kc1 and Kc2, and the crop coefficients between dates D and E are a linear interpolation between Kc2 and Kc3.

[c] Corn - Although several crops are grown on land that has seasonal irrigation, corn is the principal crop. The water requirements of corn are similar to the other crops; therefore, the cropping dates and crop coefficients of corn were used in the DISM.

*Perennial Water Supply*

The perennial irrigation on the Hopi Reservation is about 2 percentage of the total historically irrigated land. The land is cropped, and corn is the major crop. The crop ET for the perennial irrigation was calculated using the methodology described above; however, the Kc values were reduced by 20 percent instead of 30 percent to account for more favorable field conditions in areas irrigated from perennial water supplies in comparison to fields irrigated from seasonal water supplies.

Perennial irrigation indicates water is available for irrigation to meet most of the crop ET needs. Due to annual variability in perennial flows, it was assumed that 90 percent of the net irrigation requirements were met on an annual basis by perennial flows, springs, and seeps. It was also assumed that 95 percent of the net irrigation requirement would be met for irrigated lands that are supplied water from wells.

*4. What period of record for streamgage SW25 was used to calibrate the PRMS model, and can model error summaries be provided?*

Available flow data from station SW25 Peabody for the period of February 1989 through December 1995 were used for calibration. The following table provides a comparison of statistics between measured and predicted data sets. The measured and predicted values are not paired due to the nature of the PRMS model and therefore a regression analysis is not applicable. The data set compares flow rate values over 1 cubic feet per second (cfs).

Statistics of Measured and Predicted Values at Gaging Station SW25 Coal Mine Wash.

| Statistic | Measured | Predicted |
|---|---|---|
| Mean (cfs) | 10.9 | 10.8 |
| Median (cfs) | 3.5 | 5.6 |
| Standard Deviation (cfs) | 22.8 | 15.7 |
| Kurtosis (cfs) | 25 | 22 |
| Skewness (cfs) | 4.6 | 4.1 |
| Range (cfs) | 168 | 124 |
| Minimum (cfs) | 1 | 1 |
| Maximum (cfs) | 169 | 125 |
| Count | 138 | 308 |

*5. Which climate stations were used to assess streamflow conditions for 1950-93 including the station used for model verification at streamgage 9401239?*

See the response to question #2.

*6. Does NRCE's estimated outflow at the mouth of Polacca Wash include outflows from the Oraibi Wash tributary?*

No, all the outflows from the Oraibi, Polacca, and Jadito Washes were calculated before the convergence. Therefore, outflow from Polacca Wash does not include the flow from Oraibi Wash tributary.

As stated in the report: "There are two areas which warrant special attention when examining the results of the natural flow estimation. One area is defined as the region where Oraibi, Polacca, and Jadito washes converge to form Corn Wash. Much of the area at this convergence is devoid of any significant surface drainage features, and thus, flow events are spread out over a large area and much of their volume is lost to seepage and evaporation. Quantifying the extent of these depletions is beyond the intent and scope of the current analysis. Of particular importance in the current study is the hydrology of the washes upstream of this area (i.e. quantifying surface water available for irrigation use within each wash). The diminished flows which actually exit this area do so through Corn Wash, and this study does not attempt to quantify the streamflows ultimately reaching the Little Colorado River from this area."

*7. Was PRMS used to estimate flows at active USGS stream gages along Moenkopi, Dinnebito, Oraibi, Polacca, and Jeddito Washes? If so, can ADWR obtain a copy of these estimates?*

PRMS was not used to estimate flows at active gage locations. A comparison of undepleted flows from Moenkopi wash for the nearest modeled streamflow point (scaled by basin area) to depleted USGS gage flows is presented in the Report. The gages used in this comparison included #09395350 Puerco River near Church Rock, #09395500 Puerco River at Gallup, #09395900 Black Creek near Lupton, #09396500 Puerco River near Adamana, #09401260 Moenkopi Wash At Moenkopi, #09401280 Moenkopi Wash Near Tuba, #09401400 Moenkopi Wash near Tuba City, and #09401500 Moenkopi Wash near Cameron. No gages were available in any of the washes other than Moenkopi and Puerco River except for two recently installed gages in the Dinnebito and Polacca washes (#09401110 Dinnebito Wash near Sand Springs and #09400568 Polacca Wash near Second Mesa). Unfortunately, the limited data available at these two recently installed gages was insufficient enough to draw any conclusions.

This comparison is shown the following table.

Comparison of PRMS estimated flows and USGS Stream Gage Data

| Wash, Gage ID# | PRMS Natural Flow Estimation 1950-1993[1] | | | USGS Gage Data | | | |
|---|---|---|---|---|---|---|---|
| | Drainage Area (sq. miles) | Average Annual Flow (acre-feet) | Adjusted Annual Flow[2] (acre-feet) | Drainage Area (sq. miles) | Period of Record (water years) | Average Record Quality | Average Annual Flow (acre-feet) |
| Moenkopi, 09401500 | 1,891 | 16,245 | 22,873 | 2,662 | 1954-1965 | Good | 9,990 |
| Moenkopi, 09401400 | 1,735 | 15,766 | 22,649 | 2,492 | 1941-1978 | Fair | 11,167 |
| Moenkopi, 09401280 | 1,583 | 14,520 | 17,459 | 1,904 | 1926-1940 | Good/Fair | 16,340 |
| Moenkopi, 09401260 | 1,583 | 14,520 | 14,937 | 1,629 | 1976-1991 | Poor | 7,736 |
| Puerco, 09396500 | 2,580 | 29,067 | 29,898 | 2,654 | 1940-1949 | Poor | 46,759 |
| Puerco, 09395900 | 514 | 6,218 | 5,979 | 494 | 1964-1982 | Fair | 5,978 |
| Puerco, 09395500 | 591 | 7,418 | 7,009 | 558 | 1941-1982 | Poor | 6,849 |
| Puerco, 09395350 | 286 | 3,521 | 2,705 | 220 | 1978-1992 | Poor | 7,037 |

[1] PRMS estimate for location closest to USGS gage location.
[2] Area weighted adjustment of average annual flow to match USGS gage drainage

In the above table, the second column from the right lists the overall data quality based on USGS remarks in the annual water data reports. The data quality remarks are described as follows in USGS (2006): *"The degree of accuracy of the records is stated in the REMARKS in the station description. "Excellent" indicates that about 95 percent of the daily discharges are within 5 percent of the true value; "good" within 10 percent; and "fair," within 15 percent. "Poor" indicates that daily discharges have less than "fair" accuracy. Different accuracies may be*

*attributed to different parts of a given record."* It may be seen from the above table that the USGS data quality is often fair to poor for the gage stations listed. This low data quality increases the uncertainty in comparing the PRMS data to the USGS records.

The main difficulty in using the USGS data in a comparison to the estimated natural flows is that the measured data represents depleted flow values. Even in areas where there are only limited depletions, the measured streamflows also include the effects of changes in hydrologic characteristics such as vegetation and land use. Because statistical characteristics and relationships are best established using longer data sets, an additional difficulty with the USGS data was that many of the gages had only limited data availability.

**References**

Doorenbus, J., and Pruitt, W. O. 1977. *Crop Water Requirements*. 2nd Edition, Irrigation and Drainage Paper No. 24, FAO, Rome. 144 pp.

University of California. 1989. *Using Reference Evapotranspiration and Crop Coefficients to Estimate Crop Evapotranspiration for Agronomic Crops, Grasses, and Vegetable Crops*. Cooperative Extension University of California Division of Agriculture and Natural Resources. Leaflet 21427.

Hill, Robert. W. 1994. *Consumptive Use of Irrigated Crops in Utah*. Utah Agricultural Experiment Station, Project No. 796, Research Report 145. October, 1994.

Leavesley, G.H., Lichty, R.W., Troutman, B.M., and Saindon, L.G. 1983. *Precipitation-Runoff Modeling System: User's Manual*. United States Geological Survey, Water-Resources Investigations Report 83-4238.

U.S. Geological Survey (USGS). *Water Resources Data for Arizona, Water Year 2005*. Prepared by G.G. Fisk, N.R. Duet, E.H. McGuire, W.P. Roberts, N.K. Castillo, and C.F. Smith, Tucson, Arizona, March 2006.

# APPENDIX C

## Estimation of $K_{cb\ mid}$ from effective ground cover ($f_{c\ eff}$)

Where only estimates of the fraction of soil surface effectively covered by vegetation are available, the following approximation for $K_{cb\ mid\ adj}$ can be used:

$$K_{cb\ mid} = K_{c\ min} + \left(K_{cb\ full} - K_{c\ min}\right)\left(\min\left(1,\ 2f_c,\ \left(f_{c\ eff}\right)^{\left(\frac{1}{1+h}\right)}\right)\right) \qquad (98)$$

where
- $K_{cb\ mid}$ estimated basal $K_{cb}$ during the mid-season when plant density and/or leaf area are lower than for full cover conditions,
- $K_{cb\ full}$ estimated basal $K_{cb}$ during the mid-season (at peak plant size or height) for vegetation having full ground cover or LAI > 3 (see Equations 99 and 100),
- $K_{c\ min}$ the minimum $K_c$ for bare soil (in the presence of vegetation) ($K_{c\ min} \approx$ 0.15 - 0.20),
- $f_c$ observed fraction of soil surface that is covered by vegetation as observed from nadir (overhead) [0.01 - 1],
- $f_{c\ eff}$ the effective fraction of soil surface covered or shaded by vegetation [0.01-1] (see Box 18),
- h the plant height [m].

Stomatal conductance and water transport within plants may limit ET under conditions of sparse, tall vegetation. Under these conditions, $K_{cb\ mid}$ is limited by the "$2f_c$" term in Equation 98. Equation 98 applies well to trees and shrubs.

**BOX 18**
**Measuring and estimating $f_{c\ eff}$**

$f_{c\ eff}$ should normally represent the fraction of the soil surface that is shaded by vegetation. This value is generally larger than $f_c$, the actual fraction of the soil surface that is covered by vegetation as observed from directly overhead. The amount of shading represents the amount of solar radiation intercepted by plants for potential conversion into evapotranspiration. The total fraction of shading is a function of the sun angle and the horizontal size and shape of individual plants (or rows) relative to their height.

$f_{c\ eff}$ for 'rectangular' shaped canopies such as most agricultural plant rows can be approximated as:

$$f_{c\ eff} = f_c\left[1 + \frac{HWR}{\tan(\eta)}\right] \leq 1$$

where
- $f_c$ observed fraction of soil surface that is covered by vegetation as observed from nadir (overhead) [0.01 - 1],
- HWR height to width ratio of individual plants or groups of plants when viewed from the east or from the west [ ],
- $\tan(\eta)$ tangent of the mean angle of the sun, $\eta$, above the horizon during the period of maximum evapotranspiration (generally between 11.00 and 15.00 hours) [ ]. For most applications, $\eta$ can be computed at solar noon (12.00 hours).

## Estimation of $K_{cb\ full}$

### *Agricultural crops:*

Non-pristine agricultural crops represent crops that have not developed to their potential due to environmental stresses caused by soil water shortage, fertility, disease, grazing or insect damage or due to low plant density. The value for $K_{cb\ full}$ in Equations 97 and 98 can be taken as the $K_{cb\ mid}$ value listed for any "full-cover" crop ($f_{c\ eff} \sim 1$) in Table 17, after adjusting it for climate (Equation 70):

$$K_{cb\ full} = K_{cb\ mid,Table} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3} \qquad (99)$$

where
- $u_2$ mean value for wind speed at 2 m height during the mid-season [m s$^{-1}$],
- $RH_{min}$ mean value for minimum daily relative humidity during the mid-season [%],
- h mean maximum plant height [m].

### *Natural vegetation and crops not listed in Table 17:*

For natural vegetation, nonfull-cover crops, or for crops not listed in Table 17, $K_{cb\ full}$ can be approximated as a function of climate and mean plant height for areas of vegetation that are greater than a few hectares:

$$K_{cb\ full} = K_{cb,h} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3} \qquad (100)$$

where
- $K_{cb,h}$ $K_{cb\ mid}$ for full cover vegetation (LAI > 3) under sub-humid and calm wind conditions ($RH_{min}$ = 45% and $u_2$ = 2 m s$^{-1}$), (Equation 101),
- $u_2$ mean value for wind speed at 2 m height during the mid-season [m s$^{-1}$],
- $RH_{min}$ mean value for minimum daily relative humidity during the mid-season [%],
- h mean maximum plant height [m].

The value for $K_{cb,h}$ is estimated as:

$$K_{cb,h} = 1.0 + 0.1\,h \qquad \text{for } h \leq 2 \text{ m} \qquad (101)$$

where $K_{cb,h}$ is limited to ≤ 1.20 when h > 2 m. The value of 1.2 represents a general upper limit on $K_{cb\ mid}$ for tall vegetation having full ground cover and LAI > 3 under the sub-humid and calm wind conditions. This limit of 1.2 is adjusted for other climatic conditions in Equation 100. Equations 100 and 101 produce a general approximation for the increase in $K_{cb\ full}$ with plant height and climate. The form of these equations adheres to trends represented in Equation 70.

For small, isolated stand sizes, $K_{cb\ full}$ may need to be increased beyond the value given by Equation 99 or 100, as discussed in Chapter 10.

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Attorneys for the City of Flagstaff

**IN THE SUPERIOR COURT OF THE STATE OF ARIZONA**

**IN AND FOR THE COUNTY OF APACHE**

| | |
|---|---|
| IN RE THE GENERAL ADJUDICATION OF ALL RIGHTS TO USE WATER IN THE LITTLE COLORADO RIVER SYSTEM AND SOURCE | Civil No. 6417<br><br>**CITY OF FLAGSTAFF'S COMMENTS AND JOINDER IN LCR CLAIMANTS' COMMENTS TO ADWR'S PRELIMINARY HYDROGRAPHIC SURVEY REPORT FOR THE HOPI INDIAN RESERVATION**<br><br>(Assigned to the Honorable Eddward P. Ballinger, Jr.) |

Contested Case Name: *In re Hopi Tribe Priority*

HSR Involved: Preliminary Hydrographic Survey Report for the Hopi Indian Reservation.

Descriptive Summary: The City of Flagstaff submits comments and joins in comments submitted by the LCR Claimaints related to the Arizona Department of Water Resources' Preliminary Hydrographic Survey Report for the Hopi Indian Reservation

Statement of Claimant Nos.: City of Flagstaff 39-03-83947, 39-03-83948, 39-03-83949

Date of Filing: Original mailed to the Clerk of the Superior Court for Apache County on June 29, 2009.

Number of Pages: 4

Ballard Spahr Andrews & Ingersoll, LLP
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## INTRODUCTION

The City of Flagstaff (the "City") submits these comments to the Preliminary Hydrographic Survey Report of the Hopi Indian Reservation (the "HSR") submitted to this Court in December 2008, by the Arizona Department of Water Resources ("ADWR"). The City notes that many of the Hopi claims are not addressed in the HSR, and others were excluded or have yet to be analyzed by ADWR due to "legal issues pending before the Court and the Special Master" (See HSR, § 9.3.3). Therefore, these comments are not comprehensive and additional comments may be required if the HSR is revised or when it is finalized. Furthermore, the City joins in certain LCR Claimants' Comments to the HSR for the reasons stated therein.

### I. The final HSR should include the Court's March 2, 2009 order.

On March 2, 2009, after having considered the positions of the parties, this Court declared "that the Hopi Tribe is precluded from asserting water right claims in this adjudication to the extent such claims seek the right to water sources located within the Little Colorado River Basin that neither abut nor traverse Hopi lands." See Minute Entry dated March 2, 2009. In the HSR, ADWR specifically notes the then-current status of this issue as it existed before the Court at the time the HSR was submitted. See id. The HSR states that "until the legal issues before the Court and the Special Master are resolved, ADWR is unable to recommend certain water right attributes." Id. Since the Court has declared that the Hopi Tribe is "precluded from asserting water right claims . . .

located within the Little Colorado River Basin that neither abut nor traverse Hopi lands," such claims should be addressed accordingly in the HSR. The City believes such an approach furthers the interests of judicial economy by ensuring all of the Hopi Tribe's claims are evaluated comprehensively and concurrently. Shelving certain Hopi claims while determining only those claims on the "main reservation" risks unnecessary delays, duplication of work, and lack of certainty for non-Hopi claimants. Moreover, evaluating all of the Hopi Tribe's claims concurrently would satisfy the "comprehensive requirement" of the McCarran Amendment, ensuring that all claims are included in the adjudication. United States v. District Court of Eagle County, 401 U.S. 520, 525 (1971).

## II. Comments by LCR Claimants

The City notes the comments filed by the LCR Claimants to the HSR and specifically joins in paragraphs II – IV for all the reasons stated therein.

## CONCLUSION

The City of Flagstaff respectfully requests that the above comments be included in the HSR prior to its finalization. The City of Flagstaff respectfully requests further that, having joined in certain comments to the HSR submitted by the LCR Claimants, that such comments also be included in the HSR prior to its finalization.

—

—

—

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DATED this 29th day of June, 2009.

BALLARD SPAHR ANDREWS & INGERSOLL, LLP

By: _____

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Attorneys for the City of Flagstaff

ORIGINAL of the foregoing mailed for filing to the Clerk of the Apache County Superior Court this 29 day of June 2009, and a COPY mailed to all persons on the Court-approved mailing list for the Little Colorado River Adjudication Civil No. 6417 dated June 18, 2009.

_____

**Ana M. Marquez**

**From:** Richard Burtell
**Sent:** Wednesday, July 01, 2009 7:47 AM
**To:** 'champson@sonosky.com'
**Cc:** Janet L. Ronald; Glenda S. Winters; Ana M. Marquez
**Subject:** RE: Hopi Tribe Comments on Preliminary Hopi HSR

Hi Colin,

I received both of your emails yesterday (6/30/09) and was able to print out the attachments.

We'll let you know when the Federal Express packet arrives.

Thanks!

Rich

P.S. Scott's been out of the office since Monday.

---

**From:** Colin C. Hampson [mailto:champson@sonosky.com]
**Sent:** Tuesday, June 30, 2009 4:21 PM
**To:** Scott M. Deeny
**Cc:** Richard Burtell
**Subject:** RE: Hopi Tribe Comments on Preliminary Hopi HSR

Scott,

If you could confirm receipt of my two e-mails from a few minutes ago sending the comments and exhibits, I'd appreciate it.

Thanks.

Colin Cloud Hampson
Sonosky, Chambers, Sachse, Endreson & Perry, LLP
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750 B Street, Suite 3130
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* * * * NOTICE * * * *

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-----Original Message-----
**From:** Colin C. Hampson [mailto:champson@sonosky.com]
**Sent:** Tuesday, June 30, 2009 4:11 PM
**To:** 'Scott M. Deeny'
**Cc:** 'Richard Burtell'; 'Harry R. Sachse'; 'SCanty0856@aol.com'; 'Vanessa.Willard@usdoj.gov'; 'Guarino, Guss (ENRD)'; 'Joelynn Roberson'
**Subject:** Hopi Tribe Comments on Preliminary Hopi HSR

Scott,

Attached please find the Hopi Tribe's comments on the Preliminary Hopi Hydrographic Survey Report. The exhibits will be sent by separate e-mail. The original comments and exhibits will be sent by Federal Express.

Regards,

Colin Cloud Hampson
Sonosky, Chambers, Sachse, Endreson & Perry, LLP
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**Kathleen A. Donoghue**

**From:** Colin C. Hampson [champson@sonosky.com]
**Sent:** Tuesday, June 30, 2009 4:11 PM
**To:** Scott M. Deeny
**Cc:** Richard Burtell; 'Harry R. Sachse'; SCanty0856@aol.com; Vanessa.Willard@usdoj.gov; 'Guarino, Guss (ENRD)'; 'Joelynn Roberson'
**Subject:** Hopi Tribe Comments on Preliminary Hopi HSR
**Attachments:** 65pld-Hopi Tribe's comments on Preliminary HSR 6.30.09.pdf

Scott,

Attached please find the Hopi Tribe's comments on the Preliminary Hopi Hydrographic Survey Report. The exhibits will be sent by separate e-mail. The original comments and exhibits will be sent by Federal Express.

Regards,

Colin Cloud Hampson
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DOUGLAS B. L. ENDRESON (DC)°
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MYRA M. MUNSON (AK)°
ANNE D. NOTO (DC)°
MARY J. PAVEL (DC)°
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°NOT ADMITTED IN CA

June 30, 2009

Arizona Department of Water Resources
Attn: Adjudications
3550 N. Central Avenue, Fourth Floor
Phoenix, Arizona 85012

Re: Comments of the Hopi Tribe on the Preliminary Hopi Hydrographic Survey Report

Dear Sir or Madam:

In accordance with the Court's Pretrial Order No. 6 regarding Notice of Hydrographic Survey Reports of July 26, 2000 and Order of March 9, 2009, the Hopi Tribe respectfully submits its comments on the Preliminary Hopi Hydrographic Survey Report dated December 2008 (hereinafter "Preliminary HSR" or "Preliminary Report").

**Comments on the Preliminary Report**

The Hopi Tribe respectfully offers the following specific comments on the Preliminary Report. The comments are provided on a section-by-section and page-by-page basis.

**Chapter 1: Introduction and Scope**

Figure 1-2 should be revised to distinguish between allotments and the 21 "TR" or "Murphy" tracts that are still tribal trust land that are interspersed among the allotments, comprising approximately five acres each, totaling approximately 105 acres. While the Tribe is not aware of the complete history of these tracts, it believes that the federal government surveyed these tracts but never allotted them. *See* Preliminary HSR footnote at 2-24 and text at 2-25.

**Chapter 2: Summary of Adjudication Claims Related to the Hopi Indian Reservation**

The Hopi Tribe intends to file a Second Amended Statement of Claimant which will set out the Tribe's revised claims for water rights.

2.3.2 Water Sources

Footnote 3 on page 2-4 states that the Tribe holds two contract entitlements for Colorado River water for a total of 6,000 AF. The footnote also indicates the Hopi leases one of the entitlements, and that the Hopi claims do not include plans to use the water entitlement on the Reservation. The Hopi Tribe claims the right to import this water to the 1882 Reservation and Moenkopi to satisfy water demands in those locations. The Hopi Tribe's amended claims will address this water.

2.3.3 Priority Date

On page 2-5 the Preliminary HSR discusses the Hopi Tribe's claim to senior priority. The sentence should be revised to read: "*The Tribe's claim of immemorial priority, senior to all claimants, Indian or non-Indian, extends to waters located on and underneath Hopi lands, as well as waters located outside the boundaries of its lands necessary to meet on-reservation demands consistent with the homeland purpose.*"

2.3.4 Past and Present Irrigation Use

On Page 2-5 the Preliminary HSR discusses the Tribe's past and present irrigation use claim. The maximum amount of water available is claimed in order to provide any available water to lands that have been irrigated in the past and present. The Tribe recommends that the sentence beginning with the word "However, . . ." be revised to read: "*However, the Hopi claim a maximum quantity for irrigation of the past and presently irrigated acreage in order to provide water in years when water is available.*"

2.3.8 Stockponds, Springs and Wells

Footnote 5 on page 2-8 states that no capacities are claimed for the recreational lakes identified in Footnote 2 to Table 1 in Appendix 2. However, as noted in Section 2.3.7, the Tribe does identify capacities of the recreational lakes claimed.

2.3.12 Hopi Ranches

The Preliminary HSR states on page 2-10 that the Tribe claims "water for five ranches based on state law," pursuant to the Navajo-Hopi Land Dispute Settlement Act of 1996. On December 11, 2008, the Bureau of Indian Affairs took into trust four of the five ranches referred to in this section. As stated in the Tribe's 2004 Amended Statement of Claimant, the Tribe claims water rights provided for under the 1996 statute, as well as the rights pursuant to state law. The following should be added at the end of the first sentence: "*and the provisions of the Act.*"

2.8.2 Past and Present Domestic, Commercial, Municipal and Light Industrial

Table 2-1 does not compare the Hopi and United States claims accurately. The Hopi and United States' domestic, commercial, municipal and industrial ("DCMI") claims include past, present and future as one 11,211 AF claim. ADWR's breakdown of the springs, wells and stockponds does not accurately reflect past and present DCMI quantities as claimed. Table 2-1 should be revised to delete the DCMI entry and simply note that the United States and Hopi Tribe claim a DCMI amount that includes past, present and future.

2.8.4 Past and Present Livestock

ADWR's breakdown in Table 2-1 of the springs, wells and stockponds does not accurately reflect past and present livestock quantities as claimed. The Preliminary HSR should note that the Tribe claims multiple and continuous fillings of impoundments as unregulated structures. *See* comments regarding Section 7.2.3 below regarding entitlements for stockponds.

2.11 Peabody Western Coal Company Claims

On page 2-25 the Preliminary HSR discusses claims filed by Peabody Western Coal Company (PWCC) for groundwater used on Hopi and Navajo lands. These state law claims on Hopi lands leased by PWCC appear to be for water reserved by the Hopi Tribe under federal law governing Indian reserve rights and are leased to Peabody. Accordingly, they are not subject to appropriation under state law.

2.12 Other Water Uses

On page 2-26 the Preliminary HSR discusses a claim made in 1892 by Mr. Freeman Stewart, presumably a non-Indian, for water for mining and milling purposes from springs located in Blue Canyon on the Hopi Reservation. The Preliminary Report should state whether the claimed use was verified and, if so, has since continued. There is no possible legal basis for a claim for such use on Indian lands, and none apparently has been made in the *Adjudication.*

**Chapter 3: Hopi Reservation Lands**

The Hopi Tribe is concerned about the accuracy of certain information presented in Chapter 3 and the difficulty of accurately conveying the details necessary to understand many complex circumstances, relationships and events discussed there. The Hopi Tribe understands that the Preliminary HSR is not a scholarly paper but is intended to provide the Court and the parties back background information about the Hopi people and their lands. Nevertheless, the Preliminary HSR is produced by the State of Arizona and will be available to the general public who may rely on the information presented in it. It is important to the Hopi people that the information presented about Hopi history, culture and traditions is accurate. There is a vast

literature, both scholarly and general, on Hopi history, culture and tradition, a portion of which is cited in the References.

The Tribe requests that ADWR carefully review Chapter 3, the Tribe's comments (including the Tribe's comments on the Anderson report below) and the relevant literature to ensure that this Chapter is accurate and that every passage in the discussion is necessary for accomplishing the purposes of the HSR.

3.1.1 History to 1540

On page 3-1 the Preliminary HSR states, "[t]he Hopi are a Pueblo people." The Hopi refer to themselves as *Hopisenom*. The Hopi have been described as a "Pueblo people" but have a history that is substantially distinct from the Pueblo peoples of New Mexico. Also, other clans migrated to Hopi from southern Arizona and Mexico, so the Hopi culture has much more extensive historical connections over a wider geographical area. Accordingly, we suggest that the first sentence of the second paragraph be rewritten to state the following: "*The Hopi have been described as a 'Pueblo people' similar in some ways to the Zuni . . .*"

On page 3-2 the Preliminary Report states, "[w]hether the occupants of these earliest sites can be considered ancestors of the Hopi is unclear . . ." In fact, the relationship between modern Hopi and the occupants of the sites described in the Preliminary HSR is clear. The Hopi consider those populations their ancestors. There are Hopi shrines in these areas dating back to this era which the Hopi continue to visit.

The interactions referred to on page 3-2 as "warfare" should more properly described as "conflict" because they involved small raids and minor attacks, not large scale battles. The phrase "or to other developments, such as warfare or social breakdown" should be deleted.

On page 3-3 the Preliminary Report states that Hopi sites supporting Ancestral Puebloan Settlements "were abandoned." However, the Hopi continue to maintain ceremonial ties to those sites and visit them regularly in the course of their religious duties. Accordingly, those sites have not been abandoned. The HSR should be revised to state that the settlements were "*depopulated.*"

On page 3-3 the Preliminary Report describes *Hopitutskwa* in the past tense ("*Hopitutskwa*'s boundary ran"). This is inaccurate because *Hopitutskwa* continues to exist and hold substantial meaning for the Hopi people. "*Hopitutskwa*[] is markedly a sacred landscape, sung of and to in Hopi ceremonial songs, traversed frequently in religious pilgrimages, and re-charged in every season of the calendrical cycle of Hopi ceremonies. Hopis continue to regard their aboriginal lands as under Hopi religious stewardship and cultural sovereignty." Peter M. Whiteley, *The Importance of the Little Colorado River Drainage and its Water Resources to the Hopi* 15-16, 46-58 (2009). Also, the text's use of the term "boundary" does not capture the full meaning to the Hopis of these areas. It is a pilgrimage route which describes the area within the

sacred sites in the LCR Basin regularly visited by Hopis as a part of ceremonies that date back to the Hopi clans' migrations to *Hopitutskwa*. The term "boundary" suggests a terminus of Hopi culture and historic interest, but in some circumstances such interest and relationship extends beyond the pilgrimage route. The Hopi continue to visit, revere and use these lands in accordance with their culture and traditions.

On page 3-3 the Preliminary HSR describes the Hopi claim to *Hopitutskwa* as "based not on current occupancy so much as it was on periodic use and past occupancy (or use) by ancestors of the Hopi," based apparently on a statement found on page 6 of the Anderson report. This statement is inaccurate and involves numerous complex legal issues and should be deleted. For example, the suggestion in the statement that "periodic use" can never amount to occupancy is not consistent with the law. For example, in *Masayesva v. Zah*, 65 F.3d 1445, 1454-1455 (9th Cir. 1995), the Ninth Circuit held that annual religious use by (even a small number of) the Hopi of Hopi shrines outside the 1882 Reservation could be sufficient to establish that the Hopi were "located" on the site within the meaning of the 1934 Act.

Page 3-3 purports to describe the limits of *Hopitutskwa* and refers to Figure 3-1. Figure 3-1 does not coincide with the description provided in the text. For example, the text includes Bill Williams Mountain as a point along the outer edge of *Hopitutskwa*, while it is not included in Figure 3-1. Also, the text states that a "significant part of Grand Canyon" is included in *Hopitutskwa*. It should read "*all of the Grand Canyon, encompassing the entire landscape. . .*"

3.1.3 Mexican Period

On page 3-4 the Preliminary Report refers to "intertribal conflict with the Navajo, Utes, Paiutes, and to a lesser extent, the Apaches" in the Mexican Period between 1821 and 1848. Initial conflicts involved the Utes at the Mesa villages. The Navajo conflicts came later, and conflicts with Apaches were limited. The Anderson report (page 20) finds that "there does not appear to have been any significant conflict between" Hopi and the Southern Paiutes, noting one instance of a conflict reported by Vizcarra. Accordingly, the phrase at the end of the sentence should be revised to read: "*intertribal conflict with the Navajo, Utes, and to a lesser extent, the Apaches and Paiutes.*"

On page 3-4 the Preliminary Report states that Navajo settlements could be found on Black Mesa, the Kaibito Plateau, the Painted Desert and other land surrounding the Hopi Mesas "[b]y early 1800s." Navajo settlements did not appear in these areas until the mid-1800s and remained ephemeral and seasonal into the first third of the 20th century. Peter M. Whiteley, *The Historical Evolution of Navajo Occupancy Areas in the Southwest, with Particular Reference to Black Mesa and the Hopi Washes* 1, 2 (2009). The text should be revised accordingly.

3.1.4 Early Contacts with Americans (1848-1882)

On pages 3-5 and 3-6 the Preliminary HSR discusses the initial Mormon visits in 1858 to Hopi and settlement in Moenkopi Wash near the area now known as Tuba City. The first Mormon settlement was not until 1875. Peter M. Whiteley, *Historic Hopi Use and Occupancy of the Little Colorado Watershed, 1540-1900* 68-69 (2009).

3.1.5 Hopi Agency (1850-1882)

On page 3-6 the Preliminary Report states that Indian Agent John Ward provided the Hopis corn and farming implements in 1865. With centuries of experience farming corn, the Hopi certainly had corn and farming tools by 1865. When Jacob Hamblin and his first party of Mormon explorers in 1858 tried to appeal to Hopis by offering them iron farming tools, they were rebuffed because the Hopis had just received tools from the soldiers at Fort Defiance; even in the 1770's, regular visits were made by Spanish traders to Hopi with tools. Accordingly, the word "*additional*" should be inserted before "corn and farming implements." In addition to the centuries of experience the Hopi had varieties of maize developed over a millennium with an elongated mesocotyl and a single large radicle that were adapted to the arid Hopi environment. New varieties of seed corn which the government attempted to introduce were inferior to the native varieties. T.J. Ferguson, *Hopi Agriculture and Water Use* 30 (2009).

The Preliminary HSR quotes a letter from an Indian agent, A.D. Palmer who reported that on a trip in the spring of 1870 he showed the Hopi how to "clean out and curb their springs and wells" and "the best manner of using their tools and cultivating their cornfields and vegetable patches, and in irrigating where there was sufficient water." While it seems likely that the tools provided by the agent were likely new to the Hopi at the time, and thus instruction on their use was useful to the Hopi, it is unlikely that, after centuries of farming in the area and using its water resources, the Hopis required instruction on cleaning springs and wells and cultivation. In the traditional system, there are specific Katsinas who come around in the springtime to call men to go clean the springs.

The reference in the first sentence on page 3-7 to the Hopi Reservation should be modified to read "*the Hopi Reservation in 1882.*"

3.2 1882 Executive Order Reservation Lands

On page 3-8 it states that the provision of the 1882 Executive Order setting aside the Hopi Reservation for the Hopi for "such other Indians as the Secretary of the Interior may see fit to settle thereon" included the Navajo. This is an incorrect interpretation of the Executive Order. The court in *Healing v. Jones*, 210 F.Supp. 125, 134, 138-139, (D.Ariz. 1962), held that while the Hopi Tribe acquired immediate rights to the 1882 Reservation under the Executive Order, the Navajos (or any other Indians) had no right to the Reservation until "the act of the Secretary on some date subsequent to December 16, 1882" settled them on the Reservation, that is by the

fulfillment of the "future contingency." There was no immediate grant of rights to the Navajo. *Id.* at 139 ("Indians whose rights in the reservation are dependent upon future official acts of discretion can hardly be said to have gained immediate rights by virtue of an executive order which authorizes the exercise of such discretion"). The *Healing* court ruled that settlement occurred in the 1930s. *Id.* at 158. The historical record also supports the contrary conclusion, *e.g.* that, "[f]rom events in the late 1880s involving direct action by the Secretary of the Interior, it is incontrovertible that the 'such other Indians' clause did not refer to Navajos." Whiteley, *Reply Report III* at 8.

On page 3-8 it states that Navajos "settled on the Hopi Mesas" by 1882. This description suggests a greater degree of settlement on the Hopi Mesas than actually occurred. The court in *Healing v. Jones* ruled that Navajos were not settled on the 1882 Reservation until the 1930s. The sentence should be deleted.

3.2.1 District 6 Lands

On page 3-10 it states at the top, "The Hopi and Navajo continued to be unable to resolve their differences." This sentence should be deleted as it doesn't relate to the discussion in the paragraph regarding the establishment of District 6.

3.2.2 Hopi Partitioned Lands

On page 3-13 the Preliminary HSR states that relocation "was slow due to lack of adequate funding and available land." Considering that the Navajo Nation inhabits the largest Indian reservation in the United States comprising 17.2 million acres the conclusion that availability of land seems difficult to support. The Navajo Nation's opposition to relocation was also a significant, likely greater, factor. *See* Anderson report at 84.

On page 3-14 the Preliminary HSR notes that the Hopi-Navajo Land Dispute Settlement Act of 1996 authorizes extensions of the 75-year leases to Navajos residing on Hopi lands pursuant to accommodation agreements. Such extensions, while authorized in the Accommodation Agreement approved by the Act, are not unilateral options to extend but are instead subject to the Hopi Tribe's approval at the time of any such extensions. *See* Pub. L. 104-301 §§ 2(3), 4; Accommodation Agreement § E(2) (set out in S. Rep. 104-363, 104th Cong., 2d Sess. 52 (1996)).

3.3 1934 Act Reservation Lands (including Moenkopi)

On page 3-17 the Preliminary HSR discusses the decision in the 1934 Act case, stating, "The court also attempted to partition water sources equitably so that every grazing area would have access to water." The court awarded the Hopi Tribe a license and/or easement to maintain the ditches running across the Navajo farms in the northern part of Pasture Canyon. *Masayesva v. Zah*, 816 F. Supp. 1387, 1420 n.48, 1424 (D. Ariz. 1992), *aff'd in part, rev'd in part*, 65 F.3d

1445 (9th Cir. 1995). The court granted certain Navajos a license and/or easement to water their livestock in watering troughs if constructed by the Hopi Tribe. *Id.* The court did not address groundwater resources. Indeed, Moenkopi suffers from lack of adequate groundwater resources.

**Chapter 4: Physical Setting**

4.1 Location

BIA Route 2 should be included in the list on page 4-1 of "[m]ajor routes leading to the Reservation" and included in Figure 6-9.

4.2 Topography

Wepo Wash should be included among the "important Hopi washes" listed on page 4-2.

4.3 Climate

On page 4-4 and on Table 4-2 the Preliminary Report indicates that annual surface water evaporation rates on the Hopi Reservation vary from a lower bound estimate of 63.5 inches at Keams Canyon to an upper bound estimate of 80.2 inches at Tuba City. ADWR should confirm whether the rates are for gross or net lake evaporation.

**Chapter 5: Culture**

The Hopi Tribe is very concerned about a number of inaccurate statements in Chapter 5. The Hopi Tribe understands that the Preliminary HSR is not a scholarly paper but is intended to provide the Court and the parties back background information about the Hopi people and their lands. Nevertheless, the Preliminary HSR is produced by the State of Arizona and will be available to the general public who may rely on the information presented in it. It is important to the Hopi people that the information presented about Hopi history, culture and traditions is accurate. There is a vast literature, both scholarly and general, on Hopi history, culture and tradition, a portion of which is cited in the References.

The Tribe requests that ADWR carefully review the Tribe's comments and the relevant literature and make changes to ensure accuracy and that the discussion is necessary in light of the purpose of the HSR.

5.1 Social Organization

On page 5-1 the Preliminary HSR refers to the Village of Tewa, which is also known as Hano. The Tewa-speaking people of First Mesa are of the village of Hano located next to Sichomovi and Walpi. Hano was established by Tano people who came from the Galisteo Basin around 1700 after the Second Pueblo Revolt of 1696. Though they are not recorded historically,

Hopis sometimes distinguish between Tewas who migrated to Sitsom'ovi before the Tano at Hano.

On page 5-2 the Preliminary HSR states that the Oraibi Split resulted in the establishment of two new villages, Hotevilla and Bacavi. It also resulted in the substantial growth of Kykotsmovi which included only a few houses in the 1890s.

On page 5-3 the Preliminary Report discusses the *kikmongwi* of Oraibi who went to Washington D.C. in 1890. The *kikmongwi*'s name was Loololma. It also states that troops were sent to Oraibi in summer of 1891. They were buffalo soldiers from Fort Wingate.

On page 5-4 the Preliminary Report discusses a *kikmongwi* leader of the Friendlies who was sent to Sherman Institute for three years and who, upon his return, sought to push out the Hostiles. That leader was Tawaquaptewa. It also states that the Shungopavi Hostiles were forced out of Oraibi to Bacavi, but, in fact they were forced to return to Shungopavi.

On page 5-5 the Preliminary HSR cites Mischa Titiev's conclusion that the Oraibi Split can be attributed to a social structure that favors small villages and prevents "unity beyond the village level." There is disagreement about the principal forces leading to the Oraibi Split. *See* Anderson at 40-41; Whiteley (1988) and Clemmer (1995). Also, while there have been different views between villages about certain issues over time, such differences have not prevented unity between those villages. In religious and social matters there remains an overarching sense of Hopi unity. *See* Anderson at 39 (describing "cultural solidarity of the Hopi") 40 (quoting another who stated "[p]ractically everyone is related both by kinship and religious ties"). Also, as discussed below, while villages are constituents of the present-day tribal government and retain independence, the government is Reservation-wide. Accordingly, the phrase "no unity beyond the village level" should be deleted.

The last paragraph of Section 5.1 on page 5-5 refers to the "tribal Hopi Council." It should state "*Hopi Tribal Council.*"

5.2 Governance

On page 5-5 the Preliminary Report states in the first paragraph that upon visiting Hopi Mesas the Spaniards reported that Hopi villages were governed by a cacique, one or two captains and a council of elders. In the third sentence the Preliminary HSR surmises that the cacique was the *kikmongwi* and the two captains were likely the war chief and assistant. This statement ventures into a complex area of Hopi culture, tradition and history. Village leadership structures have varied from time to time and village to village. Accordingly, the last part of the sentence following "*kikmongwi*, or village chief . . ." should be deleted.

On page 5-5 the Preliminary HSR states that American observers "were uncertain about whether the villages cooperated with each other or not." There was certainly village cooperation albeit not on all issues at all times.

On page 5-6 the Preliminary HSR states that Oliver LaFarge's constitution gave "the *kikmongwi* power to appoint the representatives to the Tribal Council." In fact, the Constitution did not require appointment of Tribal Council representatives by the *kikmongwi* but allowed each village to choose its means for selecting its representatives. *See* Hopi Constitution of 1936, art. IV, § 4 ("Each village shall decide for itself how it shall choose its representatives" provided that each selection was certified by the *kikmongwi*). The statement should be revised to read: "*LaFarge decided this by reserving powers to the villages and religious leaders to select Council members and address internal village matters.*"

On page 5-7 the Preliminary HSR states that representatives to the Council, under the 1936 Constitution, would be selected "either by appointment by the kikmongwi or by election by its residents." For the reasons described in the paragraph above this phrase should be deleted.

On page 5-7 the Preliminary Report also discusses issues related to the level of participation in the 1936 referendum election on the Hopi Constitution. As noted, the proposed Constitution and the election on its approval vote was controversial at the time and is not a necessary or proper topic for the Preliminary HSR.

On page 5-8 the Preliminary HSR states that the Hopi tribal government is comprised of an executive, legislative and judicial branch. In fact, under the Hopi Constitution the Tribal Council holds all legislative, executive and judicial authority. The Council is authorized to delegate the exercise of these powers as it sees fit in the best interest of the Tribe. For example, the Tribal Council can delegate authority to the Council's Chairman to carry out a broad range of day-to-day executive responsibilities. In addition, the Constitution empowers the Council to establish courts for the resolution of disputes. For example, by Ordinance No. 21 the Tribal Council established the Tribal Court. Finally, the Council can delegate authority for administrative matters to the various departments and programs that comprise the Hopi governmental organization established by the Council. Attached as Exhibit 7 is a copy of the Hopi Constitution.

5.3 Customs

On page 5-9 the Preliminary Report states that Hopi people use wild plants for "personal use" such as for hair washing for ceremony and for basketry. The description should be changed from "personal" to "*ceremonial, religious and medicinal*," and it should emphasize that Hopis use many wild plants for many purposes—personal, social, subsistence, and manufactures as well as ceremonial etc.

On page 5-9 it also states that rabbit hunting was carried out for sport. Hunting has a broader cultural significance than as described as it is tied to the ceremonial cycle and is for subsistence. *Importance of Little Colorado River Watershed* at 108-110. Accordingly, the words "as a sport" should be deleted.

On page 5-9 the Preliminary HSR states that the Hopi "traditional subsistence economy was first supplemented with and then replaced by a cash economy." This is incorrect. A large measure of the subsistence economy remains. Most crops are grown for consumption, not sale.

On page 5-9 the Preliminary HSR refers to the use of burros in the present tense. This discussion needs to be in the past tense, as Hopis do not use burros any more (the last working burro on Third Mesa died in 1981). Today Hopis use cars and pick-up trucks, which has facilitated farming fields further removed from the villages though Hopis were farming a long distance from the villages way before they had motor vehicles.

On page 5-10 the Preliminary HSR concludes that the stock reduction did not adversely affect Hopi income because of efforts to improve and control breeding by fencing pastures. This is incorrect. Stock reduction had devastating impact on Hopi economy. *Importance of Little Colorado River Watershed* at 93; Clemmer, R.O., 1978, *Continuities of Hopi Culture Change, pp 61-62 Hopi Hearings*, 1955, pp 10-17, Whiteley, 1988, 142-43.

Page 5-12 contains a description in the first two full paragraphs of Hopi ceremony that contains substantial inaccuracies and relies on an internet source (Sweat, 2008) that is not authoritative. These two paragraphs should be deleted.

**Chapter 6: Economic Base**

6.1.2 Rangeland

The HSR indicates the ADWR does not have an estimate of useable rangeland in the Moenkopi area. The Hopi Tribe has recently received funding for a range inventory for about 64,000 acres in Moenkopi and plans to complete the study in October 2009. The study results may result in a revised claim for livestock uses.

6.1.3 Minerals and Energy Resources

On page 6-5 the Preliminary HSR indicates the preferred alternative in the November 2008 EIS for the PWCC coal operation in the Black Mesa complex would assume the now shut down coal slurry pipeline would not resume and the Mohave Generating Station (MGS) would not reopen. It should also be noted that the EIS also included a non-preferred Alternative A that did include resumption of the coal slurry pipeline (using C aquifer water piped from near Leupp) and reopening of the MGS. The EIS on page ES-2 notes that, while implementing Alternative A is unlikely, such actions could still occur under certain circumstances.

The Preliminary HSR describes the resources of the Reservation. Renewable energy and wind and solar power should be included in the list of resources. The Hopi Tribe plans to appoint four individuals to an Interim Hopi Regulatory Energy Board to continue the efforts of creating a renewable energy program for its natural resources program.

The Hopi Tribe intends to evaluate possible future development of a Renewable Energy Office (to change the name of current program Hopi Clean Air Partnership Project). The Hopi Tribe will be completing the Feasibility for a Utility-Scale Wind Farm by constructing two 50-meter towers for collecting data on wind resources in the Clear Creek Ranch area. The Hopi Tribe is working with The State of Arizona Energy in development of a Tribal Rural Electrification Program (for those residents who are not able to get on the local electrical grid). The Hopi Tribe plans to install a 30 meter tower close to the villages to assess the wind resource in that area.

All references to "JUA" should be changed to "former JUA."

The Hopi Tribe believes that Morale Uranium Mine near Hopi Buttes mentioned on page 6-7 is outside the HPL and located east of Seba Dalkai, Arizona.

6.1.4 Timber Resources

Page 6-10 of the HSR indicates wood products available from woodlands include railroad ties, but the Tribe does not believe that there is wood that makes good wood ties.

Mistletoe should be included in the list on page 6-11 of the threats to juniper.

6.1.5 Tourism

On page 6-11 the Preliminary HSR states that "some Hopi . . . have a cautious, if not negative, attitude towards tourism today." In fact most Hopis support tourism. In 2005 and 2006 the Tribe conducted a survey on the Reservation which provides evidence that many Hopi do in fact support tourist development on the reservation itself. The survey asked respondents "Do you support development that might bring more tourists to your village?" Out of 724 respondents, 65% said "yes," 18% said "no," and 16% said "not sure/neutral." There was a similar response to the statement that "the Tribal government should promote tourism on the reservation." 67% of the respondents agreed with the statement, 16% disagreed, and 17% were unsure/neutral. Finally, when asked if they would support the building of a new modern museum for the return and display of Hopi cultural arts and crafts on the reservation, 81% said "yes," 10% said "no," and 9% were not sure/neutral. Accordingly, the statement should be revised to read: *"The behavior of early visitors to the Reservation caused concern among some Hopi about tourism, but today a majority of Hopi support development, including a museum, that would bring more tourism to the Reservation."*

6.2.2 Utilities

The HSR refers to the Hopi Tribal Utility Regulatory Authority and a program for renewable electric systems. This can be referred to as the Interim Hopi Regulatory Energy Board.

6.4.1 Demographics

The Tribe will submit revised population projections in its upcoming amended claim. On page 6-24 the Preliminary Report states that the average number of people in a Hopi household has dropped from 4 in 1990 to 2 in 2007. The Tribe conducted a survey on the Reservation in 2005 and 2006 which reached a different conclusion, estimating a current average of 3.6 people per household.

6.4.2 Labor Force

On page 6-25 the Preliminary HSR states, "[m]edian family income is as much as $41,250 in 2007." ADWR should clarify what "as much as" refers to in a median value and the source of data for this figure. It seems unlikely to be accurate. A survey conducted by the Tribe on the Reservation in 2005 and 2006 found a median family income of $22,500. In the SWCA report it indicates for the Hopi Reservation the median family income was $15,875 with a per capita income of $8,637 from the 2000 census data.

**Chapter 7: Water Resources**

7.1.1 Hopi Washes

The Preliminary HSR should include a note in the text and footnote on Table 7-1 and Figure 7-1 that USGS gage 09401265 Pasture Canyon Springs is not listed in the table because ADWR does not consider this gage to be a stream flow gage but rather a spring flow gage which is discussed in the springs section on pages 7-12 and 7-13.

The Preliminary HSR does not identify which PWCC gages were utilized in their analysis. Page 7-3 of the Preliminary HSR indicates USGS and PWCC data were utilized in a regional flow analysis. The Tribe requests that ADWR include a list and location map of the PWCC gages in the final HSR.

On Page 7-5 of the Preliminary HSR ADWR presents a hypothetical scenario for sediment filling on of a reservoir on a Hopi wash. Sediment loads are highly variable, and therefore, the hypothetical scenario is not illustrative at all locations. The analysis should be based on a range of sediment loads based on real data.

The ADWR internal report on surface water quality indicates the sediment load estimates in Table 7-5 and Figure 7-8 were derived from the 1981 USDA report and a 1993 Gebhard-Sarma Group report. USGS has measured some suspended sediment data at their streamflow gages on Dennibito, Oraibi, Polacca, and Jeddito Washes at various times starting in late 1993. It appears that this data may not have been included in the sediment load estimates. This data is available on the USGS website. Furthermore, Table 7-5 and Figure 7-8 should include an additional sediment load site at Moenkopi Wash gage 09401260. This gage and nearby gage 09401250 have several years of sediment load data in the 1970's. The Tribe's water resource experts' preliminary calculations indicate an average of about 450 AF/year of sediment load at/near gage 09401260 assuming a sediment density of about 97 lb/cubic ft. This data would result in significant changes to the estimates in ADWR's scenario for sediment filling of a hypothetical reservoir on Lower Moenkopi Wash.

7.2 Impoundments

The Tribe's Second Amended Statement of Claimant will contain a revised impoundment inventory which will address a number of issues discussed in this section.

7.2.1 Condition

There are also at least five current or historic reservoirs that are or were primarily used for irrigation. Pasture Canyon Reservoir and Lower Lagoon Reservoir (previously unclaimed reservoirs identified by ADWR in Pasture Canyon near Moenkopi) are active reservoirs primarily used for irrigation (Pasture Canyon Reservoir also has incidental recreation use). There was a Middle Reservoir located between Pasture Canyon Reservoir and Lower Lagoon Reservoir that was used for irrigation. Use of Middle Reservoir was discontinued. DW10 Reservoir on Dinnebito Wash and DW11Reservoir on Many Sheep Valley Wash (tributary to Dinnebito Wash) are two historic reservoirs currently breached that were used to store water for historic irrigation further downstream of the dams. DW10 Reservoir was not claimed by either the Tribe or identified by ADWR, while DW11 Reservoir appears to be ADWR unclaimed pond UNC-D-01 but is erroneously labeled in Table C-2 in Appendix C as Big Mountain Dam (which is claimed pond Hopi ID I-7-112). *See* comments in Chapter 8 and 9 for further information on irrigation reservoirs.

7.2.2 Capacity

On page 7-9 the Preliminary HSR states that ADWR did not include the capacity of claimed impoundments that had breached berms because "[i]t was assumed that impoundments with breached berms store relatively little or no water and, therefore, may not be part of the available water resources in the vicinity of the Reservation." This approach is inconsistent with the reserved water rights doctrine which holds that Indian water rights are not lost through non-use. *In re the General Adjudication of All Rights to Use Water in the Gila River System and Source*, 35 P.3d 68, 72 (Ariz. 2001) ("*Gila V*") (a reserved right "retains priority despite non-

use"). The Hopi Tribe has the right to repair breached facilities and to the water necessary to fill them. Accordingly, their original capacity should be included in the Tribe's water rights. This is consistent with ADWR's inclusion of the full capacity of partially silted in impoundments. *See* page 7-9.

The Preliminary HSR capacity of Pasture Canyon Reservoir is listed on page 7-9 and in the Appendix C tables as 202 acre-feet. Based on a past study of this dam, the Tribe's experts calculated the capacity to be 212 acre-feet based on planimetering contour areas on a design drawing and using the conic method commonly used by the U.S. Corp of Engineers. *See* Exhibit 1.

The Preliminary HSR capacity for the Lower Lagoon Reservoir is listed on page 7-9 and in the Appendix C tables as about 51 acre-feet. The Tribe's experts calculated the capacity to be about 121 acre-feet based on planimetering contour areas on design drawings and using the conic method. *See* Exhibit 2.

The Tribe provides comments on the method ADWR used to determine capacity of impoundments in the comments below related to Appendix C. Comments on the capacity of other irrigation reservoirs are set out in the comments on Chapter 8.

7.2.3 Surface Water Depletion

For depletion, on Page 7-10 the Preliminary Report states that 50% of the volume captured by the ponds was depleted, assuming that ponds with surface area of less than one acre fill twice a year and ponds with surface area one acre or larger fill once a year. Depletion is not a proper basis for calculating water right attributes. As explained in ADWR's *Water Entitlements Report* 14-15 (Sept. 1988) prepared for this *Adjudication*, stockponds are considered unregulated structures that are permitted to fill until the water level reaches the spillway, and there is outflow. The entitlement is calculated based on the maximum controlled storage capacity within the associated maximum surface area. Though it should, ADWR does not appear to include depletion (or diversion) in its recommendations for water right attributes in Chapter 9. Furthermore, the proposed calculation of depletion, if it were used, is not appropriate, as it is not consistent with the concept of unregulated flow allowed for stock ponds.

7.3 Springs

The Tribe's amended claims will include a revised inventory of springs.

On page 7-12 the Preliminary HSR notes that 21 springs (18 claimed and 3 unclaimed) are just outside the Reservation boundary along Pasture Canyon. The Tribe has a right to the

flow from these springs as a result of historic use as found by the court in *Masayesva, supra*, at 1420, 1424.[1]

The ADWR total flow of all springs was based only on springs for which discharge measurements were available, and flow was assumed zero if spring was dry, and no value (no flow) if the spring had no measurement data (*see* Table 7-9). This unfairly denies the Hopi Tribe a right to water which there is no question that is available and that Hopis have historically used. Also, such springs should be assumed to have a flow based on reasonable estimates. This comment also applies to Section 8.7.

Some of the springs, though documented as existing, may have been dry when observed by ADWR in 2006 (*see* Appendix D) because 2006 was a drier than average year (as indicated by precipitation data at Keams Canyon and Tuba City) and/or because the spring flow had not yet recovered after PWCC reduced their pumping after shutting the coal slurry pipeline to the Mohave Generating Station at the end of 2005. These springs may flow again in wetter years or may flow as the N-Aquifer levels rise due to the reduced PWCC pumping. The Tribe should be entitled to a right to the flow of those springs should it resume. This comment also applies to Section 8.7.

Some places in the text on pages 7-10 to 7-12 indicate there are 41 unclaimed springs while other places in the text and Table 7-9 indicate the number is 42. On Page 7-11 the Preliminary HSR identifies 5 springs from the D-Aquifer and 103 springs from the T-Aquifer. This may underestimate the number of springs tied to the D-Aquifer. ADWR should review the location of springs in correlation with a geologic map to determine whether the springs tied to the T-Aquifer actually come from the D-Aquifer.

On Page 7-13 in the top paragraph the Preliminary HSR discusses the USGS Pasture Canyon gage. The Tribe notes that this gage does not measure the combined discharge of all upstream springs. There are seeps and springs downstream of the gage, there is likely flow in the subsurface beneath the gage, and there are losses above the gage due to evapotranspiration. The higher historical measurements of spring flow made by the USGS were at a different location.

7.4 Aquifers

Page 7-14 states that ADWR was unable to verify 14 of the claimed wells. In its amended claim, the Tribe will provide verification data for many of these claimed wells. The Tribe will also provide a revised inventory of wells claimed.

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[1] The court awarded the Hopi Tribe a license/easement to maintain the ditches in the northern part of Pasture Canyon.

Page 7-14 of the Preliminary Report references Figures 7-15 and 7-16. Figure 7-15 is not consistent with Figure 7-16. For example, T-Aquifer wells and springs appear near the eastern corner of District 6 on Figures 7-14 and 7-15, but the extent of the T-Aquifer is not shown there on Figure 7-16.

7.4.1 Overview

Page 7-14 of the Preliminary HSR references Figure 7-16 showing the extent and dominant flows of the groundwater aquifers on the Reservation. The flow direction arrow in Figure 7-16 for the N-Aquifer in the southeast corner of the Reservation is inaccurate. It is also inconsistent with the flow directions indicated in Figure 7-23. The dominant flow direction in the vicinity of the villages of First, Second, and Third Mesa is from the north. Any flow from the southeast (as reflected in Figure 7-16) would be weak.

Page 7-15 of the Preliminary Report references Figure 7-17 which appears inaccurate. For example, the depth to water in the N-Aquifer along the northern and western side of Moenkopi District is less than 300 feet, not 1000 to 2000 feet as indicated. If the map reflects the C-Aquifer, it may be correct. Furthermore, Figures 7-17 and 7-18 rely on a report from 1974 based on estimates. Substantial relevant data has been collected since 1974. ADWR's analysis should reflect more recent data.

Page 7-15 of the Preliminary Report references Figure 7-19 showing a conceptual hydrologic model of the region. ADWR should explain why the T-Aquifer is not included.

7.4.5 D Aquifer

Page 7-20 of the Preliminary HSR cites Cooley, 1969 in its discussion of the D-Aquifer. Truini and Longsworth, 2003, is a more is more comprehensive and recent report regarding the D-Aquifer and should be cited rather than Cooley where the two reports address the same topic. Also, the text should address the underlying confining layer.

On Page 7-22 the Preliminary HSR states that the primary drinking water standard for arsenic was also exceeded at two Hopi public water supply wells (Polacca #5 and #6) which were completed in the D-Aquifer. They draw predominantly from the N-Aquifer. *See* Exhibit 6.

The Preliminary Report discusses the estimated storage volume of the D-Aquifer. Such a discussion should also consider and explain that retrievable groundwater is substantially less than the total volume in storage, and the volume of water in storage has little to do in many cases with the potential detrimental effects of pumping.

7.4.6 N Aquifer

On page 7-22 the Preliminary Report states that water can be obtained from the Kayenta Formation. ADWR should note that the Navajo Sandstone is clearly the most important aquifer unit at most locations. The Kayenta Formation generally does not yield significant quantities of water to wells, and at many locations the Wingate Sandstone does not yield appreciable quantities of water or is not present.

The phrase "... at or below the top of the aquifer" on page 7-23 in second paragraph under "Flow Direction" should be modified to read: *"... at or below the top of the Navajo Sandstone."*

Page 7-23 of the Preliminary Report states that the age of water in the N-Aquifer is estimated to be older than 10,000 years where the aquifer is confined and about 35,000 years where it is unconfined. This statement is incorrect and does not accurately reflect the information in Lopes and Hoffman, 1997. The groundwater ages of 10,000 years to 35,000 years relate to confined portions of the N-Aquifer only.

Pages 7-23 through 7-24 of the Preliminary Hopi HSR discuss recharge. The first sentence states that the N-Aquifer has a median recharge of 13,000 acre-feet per year. The range of recharge listed includes estimates based on different N-Aquifer model areas and differences over time. The "median" of these estimates is not informative and could be misleading. The Tribe proposes deleting the reference to a median and revising the first sentence in the first paragraph of the Natural Recharge and Discharge Section as follows: *"Recharge to the N Aquifer overall is estimated to range from 2,600 and 20,248 acre-feet per year. The recharge in the Shonto area, the main recharge area to the confined portion of the N-Aquifer, is estimated by Lopes and Hoffman to be 2,500 to 3,500 acre-feet per year."*

Page 7-24 of the Preliminary HSR references Figures 7-24 and 7-25. ADWR should make clear to the reader that those figures show values assigned to grid cells in a model, and while they are based on some empirical data, they do not necessarily represent actual conditions.

On pages 7-25 and 7-26 the Preliminary Report discusses the estimated storage volume of the N-Aquifer. As noted above with respect to the D-Aquifer, such a discussion should also consider and explain that retrievable groundwater is substantially less than the total volume in storage, and the volume of water in storage has little to do in many cases with the potential detrimental effects of pumping.

The Western-Navajo Hopi N-Aquifer (WNHN) study and model are used throughout this section. This violates the Protective Order dated January 3, 2002, which states:

> IT IS ORDERED that the Hopi/Western Navajo Water Supply Study shall not be used in any judicial proceeding in this Adjudication by any party to this Adjudication or by any representative of a party to this Adjudication.

All references to the model and study, including Figure 7-21 the third bullet and last paragraph on page 7-25 under the "Water in Storage" should be deleted.

On page 7-27 the Preliminary Report discusses measured hydrologic impacts from development. ADWR should point out that the wells that exhibit drawdown in Figure 7-27 are far outside the mining area, while the wells that have exhibited the rising water levels in Figure 7-28 are within the lease area, much closer to the center of pumping. It also would be useful for appropriate context to provide the drawdown portion of observed water levels for wells NAVOBS3 and NAVOBS6, rather than only the recovery portion of the curve. This information would give some indication of the drawdown effects near large pumping centers in the confined portion of the N-Aquifer.

Page 7-27 refers to Figure 7-29 which refers to "Betootkin, Arizona." The correct spelling of that location is Betatakin, Arizona. Also, the statement that "Pasture Canyon Springs appear to have declined by about . . . 10 gpm respectively," should be clarified that the decline is based on values from the current USGS gage which, as discussed above regarding Page 7-13, does not capture the entire flow of all springs in Pasture Canyon.

On page 7-28 the Preliminary HSR makes a recommendation regarding the "best suited" model. This should be deleted. This conclusion is not needed and is inconsistent. For example, the PWCC model does a poorer job than the USGS model simulating observed water levels in the vicinity of the Hopi villages.

**Chapter 8: Water Demands**

8.1 Agriculture

8.1.1 Quantification

The annual irrigated acreage values shown in the Preliminary HSR Figure 8-1 appear to include crop or cultivated land but not irrigated pasture land, and therefore underestimate the quantity of acreage that is irrigated. The source of data for all years of the data in Figure 8-1 except 2005 is Table 9 of the Anderson report. Many of the annual acreage values in this Table 9 come from the 2004 Ferguson report. No mention is made of irrigated pasture. However, the report does mention an <u>additional</u> 5,750 acres of pasture were cultivated to improve forage. Based on the 2004 Hopi and U.S. claims, the range pasture category of irrigation makes up about 20% of the total historic irrigated acreage claim. Accordingly, there appears to be a significant

amount of current or historic irrigated pasture that is not included in the annual acreage values shown in Figure 8-1 of the Preliminary HSR.

The Preliminary HSR on page 8-3 indicates that the ADWR net irrigation requirement (NIR) figures for traditional farming are comparable to the "irrigation depletion" claimed by the United States and Hopi Tribe. It states that the average and maximum depletion claimed (derived from total claimed depletions and total claimed irrigated acres) of 0.61 and 0.99 acre-feet per acre respectively are within the range of the ADWR traditional farming NIR values of 0.35 to 0.86 acre-feet per acre. Depletions, however, are typically more than NIR, and include a portion of conveyance and on-farm losses which do not make it back to the stream as return flow. In the case of traditional farming, there would probably not be much conveyance losses because of the lack of conveyance facilities like canals, but there would be on farm or field irrecoverable losses such as seepage to groundwater which would be depletions. Hence, for traditional farming, depletions should be slightly more than NIR. Although the 0.61 to 0.99 acre-feet per "depletion rate" derived from the United States claim is slightly higher than the ADWR traditional farming NIR, historic irrigation on the Hopi Reservation has included both traditional farming as well as irrigation projects which have higher NIR values and depletions. Therefore, it is not correct to compare the United States reservation wide depletion rates to just traditional farming NIR and ignore historical project NIR.

Depletions and diversions should be determined as a part of the water right attributes.

The Preliminary HSR on page 8-3 indicates the Pasture Canyon service area has a claimed depletion rate of 1.81 acre-feet per acre, which is within the range of the ADWR modern farming NIR values. As pointed out above, depletion rate cannot be compared to NIR. Depletion not only includes NIR but also the portion of conveyance and on-farm irrecoverable losses which are not return flows. In addition, some of the Pasture Canyon service area along Moenkopi Wash also receives supplemental water by pumping from Moenkopi Wash when water is available. This impacts depletions in the Pasture Canyon service area.

The preliminary HSR on page 8-3 indicates that more modern methods of irrigation are being used near Moenkopi, and states that 179 acres are being served by Pasture Canyon Reservoir. This acreage figure is low (*see* comments on Section 8.1.3). In addition, the Hopi also farm part of the Upper Kerley Valley Irrigation Project (downstream of the Pasture Canyon project) which is a modern system of a diversion dam and canals. There are two major siphons which serve two distinct service areas. The second most downstream siphon can be repaired, and irrigation deliveries can resume.

8.1.2 Agriculture, Historic (Pre-1985)

On page 8-5 the Preliminary Report discusses areas previously farmed by Hopi. Hopis farmed in Red Lake to the north ("Red Lake Plateau"). It also states that Hopis previously traveled as much as 45 miles to farm. Such long-distance farming also included fields in Sand

Spring, Burro Spring, Coyote Spring and Talahogan. Hopis continue to travel long distances to farm.

On page 8-5 the Preliminary HSR concludes that the traditional farming acreage per person has dropped from 2.5 acres prior to 1930 to 1.75 acres after 1930 to less than 1 acre in 2005. While this may be true in a general sense, the end of this paragraph speculates as to what the ratio of acres per person may be. Such speculation is unnecessary and misleading. The Tribe proposes deletion of the final two sentences which currently read as follows: "If it were assumed that 8,000 Hopi were living on the Reservation in 2005 and they successfully cropped 5,000 acres that year, the ratio now would be less than 1. The ratio would be even lower if the entire population of the Reservation at the time (about 12,000) were assumed."

Table 8-3 lists past and present irrigation projects on the Hopi Reservation. The Tribe makes the following comments on the Table:

a. The location of some of the irrigation projects is not clear. The HSR should include a map showing the location of the projects. Also, it appears that there are errors. For example, the table indicates the Lower Dinnebito Project lies 18 miles southwest of Hotevilla, but this places it at the Sand Springs project. The Lower Dinnebito project is described in *Arizona v. California* exhibits (and the facilities are still shown on USGS quad maps) as being located where Dinnebito Wash re-enters the Hopi Reservation about 8.5 miles northeast of Hotevilla.

b. While the table shows annual cropped acreage for each project, it does not reflect the maximum historical acreage served by each project.

c. The list of historical irrigation projects is incomplete and fails to note that some projects lie both on Hopi and Navajo land. Historic reports and interpretation of 1934 and 1954 aerial photos document several other historic irrigation projects and a much larger historic project irrigated acreage. Projects omitted from the Preliminary HSR list include: Begashibito 2, Upper Kerley Valley (joint Hopi/Navajo), Oraibi Delta (joint Hopi/Navajo), Polacca Wash (PW) 1, Polacca Wash 35, and Polacca Delta (joint Hopi/Navajo). A comprehensive list and map locating the historic projects will be supplied in the Tribe's Second Amended Statement of Claimant. ADWR should evaluate this information along with aerial photography from the 1930's through the 1950's (shortly after many of the projects were built) to determine the acreage cultivated when these projects were active, with special attention to above-average water years.

On page 8-6 the Preliminary Report discusses dams built by Mormons in Pasture Canyon and states that Navajos were using the irrigation when the government took ownership of Moenkopi. When Mormons built the irrigation system, there were no Navajos living in the area. Later the BIA came in and began farming in the area but didn't use the Pasture Canyon system.

Hopis were farming lands that are now on the Navajo Reservation, including east of Kerley Valley. No Navajos were using lands served by Pasture Canyon irrigation system.

Page 8-6 of the Preliminary HSR refers to a return in 1875 and afterward by Hopi "to fields [in Moenkopi] they had previously farmed before Navajo encroachment" suggesting that Hopi use of land in Moenkopi was not constant. The Anderson report does not support this inference. While it states on page 25 that one scholar concluded that Hopi could not remain there on a full-time basis because of the Navajo, he found that they continued to use the fields during farming seasons.

On page 8-6 the Preliminary HSR refers to the Chambers & Campbell, 1962 report as stating that Pasture Canyon irrigation system was serving an area of approximately 300 acres, but only 40% of this area (120 acres) was being cropped at that time. This did not include acreage farmed above Pasture Canyon Reservoir.

8.1.3 Recent

On page 8-9 it states that 74 fields surveyed were found to obtain their water from springs, and 5 fields were supplied by wells. During dry years, many farmers haul well water to fields, so the number of fields supplied by wells would be much more than 5.

On page 8-9 it states that "reclaimed water [from wastewater treatment plant] from the plant is planned to be used to irrigate Hopi and adjoining Navajo lands." The wastewater treatment plant is now releasing water for irrigation use.

Page 8-9 of the HSR states that flows into Pasture Canyon Reservoir are presumably gauged by the BIA. Inflow into the Reservoir is not gaged. There is no gage measuring inflow to the Reservoir. The structure described in the Preliminary HSR is actually a diversion structure for conveying water to drinkers. As noted above regarding page 7-13, there is a USGS gage further upstream about 1.5 miles above the upper end of the Reservoir, but there are at least four springs between the gage and the Reservoir. The measured flow is also subject to losses from evaporation and transpiration before reaching the reservoir. Measurements by Chambers and Campbell in 1962 and the Tribe's experts in 1992 just above the Reservoir indicate that inflow to the reservoir is larger than the flow at the USGS gage. These data indicate an inflow of 400 acre-feet per year. The inflow could be increased with watershed improvement measures.

Page 8-9 and Figure 8-3 of the preliminary HSR indicates that the Pasture Canyon Reservoir Irrigation Project serves 179 acres. There are some minor differences between Figure 8-3 and the GIS inspected field coverage. For example, Figure 8-3 shows some tracts between Highway 160 and Pasture Canyon Reservoir, while the GIS coverage does not. It is not clear whether Figure 8-3 and the 179-acre value are derived from the GIS coverage for the inspected field study, and if so, why there are differences in some of the tracts. These discrepancies should be explained in the final HSR.

The GIS coverage for the inspected field study provided by ADWR to the Tribe's experts has an outdated and erroneous column for tract (polygon) acres. While the acres column shows a total of 651 acres as on HSR Table 8-4, the true total area of polygons in square meters is shown as 2,467,206.3, which converts to 609.7 acres. It may be that some of the GIS polygons were modified but the acreage of the polygons was not recalculated. This would impact some of the values on Table 8-4. The Tribe's experts recalculated the polygon acreage and found a total of 609.7 acres which matched the square meters total. Using the recalculated polygon acres, the Tribe's experts obtained for the Pasture Canyon Reservoir Irrigation Project about 144 acres irrigated, 25 acres fallow, and 11 acres not irrigated for a total of 180 acres, which is slightly different from the 179 acres listed in the Preliminary HSR. The ADWR 2005 agriculture and riparian study GIS coverage shows a total of about 219 acres (202 acres active agriculture, 15 acres active ag or fallow, and 2 acres active fallow). Preliminary Tribal estimates of this acreage including both active and idle irrigation exceed 240 acres, a figure that will be finalized in the Tribe's amended claim.

The Preliminary HSR on page 8-9 and on Figure 8-3 indicates that there are 55 acres of recent irrigation of traditional farming in the Moenkopi area not served from Pasture Canyon. The Tribe's experts have preliminarily found much more than the 55 acres of non-Pasture Canyon system irrigation. Some of this acreage is on the Hopi south side of Moenkopi Wash within the Upper Kerley Valley Irrigation Project downstream of the Pasture Canyon project. This area was not included in the ADWR 2005 field inspected study, but the upper part of it does show up in the ADWR 2005 agriculture and riparian study. The upper part on the south side is still mostly active and is served by an active flume carrying water across Moenkopi Wash, but most of the lower south side is idle because the flume serving it washed away many years ago and has not been replaced. Another part of this acreage is in isolated tracts which are either served by pumping from Moenkopi Wash or are "traditional farm tracts" served from springs and small side tributaries of Moenkopi Wash upstream of the Pasture Canyon project area. In addition, some of the Pasture Canyon service area adjacent to Moenkopi Wash receives supplemental water pumped from Moenkopi Wash. Therefore not all this farming is traditional, and it exceeds 55 acres. The ADWR 2005 agriculture and riparian study showed about 142 acres of non-project agricultural land along Moenkopi Wash in the Moenkopi area. The exact amount of acreage has not yet finalized by the Tribe but will be reflected in the upcoming amended claim.

On page 8-11, while the Preliminary HSR correctly indicates that the January to April precipitation in 2005 was higher than normal, the primary growing season months of April to October precipitation was lower than normal. For Keams Canyon, the 2005 April to October precipitation was about 5.0 inches while period of record normal is about 6.2 inches. At Tuba City, the 2005 April to October precipitation was at least 4.0 inches compared to period of record normal of about 4.1 inches. At both stations, the May and June precipitation was well below normal with hardly any precipitation. Therefore, while there was good precipitation to plant crops in 2005, the crops may not have developed in May and June unless there was local

irrigation water available. Furthermore, a decade-long draught has likely temporarily reduced the total area farmed.

Four current or historic irrigation reservoirs have been preliminarily identified:

1) Pasture Canyon Reservoir –212 acre-feet capacity

2) Lower Lagoon Reservoir—121 acre-feet capacity

3) DW10 Reservoir (historic)—592 acre-feet capacity

4) DW11 Reservoir (historic)—481 acre-feet capacity

Evaporation loss is not yet calculated, but will be in the Tribe's amended claims. Exhibits 1 through 4 describe the calculations of the capacities of these reservoirs.

8.2 Domestic, Commercial, Municipal and Light Industrial

8.2.2 Historic (Pre-1985)

On page 8-14 the Preliminary HSR estimates historic DCMI use of 300 AFA based on population estimates and 10-20 gpcpd, confirmed by estimates of usage by persons who must haul water. ADWR should confirm that this estimate applies to the time period before the construction of municipal water systems described in initial paragraphs of this Section. If so, then the title should be changed to "Pre-1950." If not, then the estimate is too low because water use by persons using water from municipal water systems would consume greater amounts that those who must haul water.

8.2.3 Recent

For DCMI use, ADWR determined the recent use rate is between 10-43 gpcd, based on 10-40 gpcd rates published in some Hopi references (*see* page 8-13), and 32-43 gpcd rates based on public water system use (292-501 AFA on Table 6-3) and reservation populations on Table 6-7 (*see* page 8-14). The Preliminary HSR compares this 292-501 AFA use to a claimed current use of 716 to 742 gpm (1154 to 1196 AFA) for domestic and municipal wells plus an additional amount for domestic springs (*see* page 8-15). The Tribe makes the following comments:

a. The 32-43 gpcd rates for public water systems listed on page 8-14 are too low because they are apparently based on total population but do not include non-public water sources such as private domestic wells and springs, as acknowledged in the Preliminary HSR on page 8-15. Also, Table 6-3 indicates the amount of use from the spring serving Lower Moenkopi is unknown and hence is not included in the 292-501 AFA public use totals. These low rates of usage are the result of poor infrastructure and overcrowding of housing. It should also be noted

that if the 2004 water demand from Table 6-3 (445.3 AF) is divided by the 2004 on-Reservation population from Taylor in Table 6-7 (8000 people), the result is 49.7 gpcd.

b. ADWR apparently arrived at the 1154 to 1196 AF claimed amounts by summing the entire United States claimed amounts for those wells and springs that included domestic and municipal use. The Preliminary HSR notes that most of these wells and springs are also claimed for stock use, and the claims did not separate amounts for each use of multiple use wells and springs. This will be addressed in the Tribe's amended claims.

8.2.4 Future

On page 8-16 the Preliminary Report states, "The future per capita use assumed in the [Hopi, United States] claims is within the range recently reported for large communities in the region. In 2000, the cities of Williams and Page had an estimated per capita use of 198 and 351 gpcd, respectively. For Flagstaff, per capita water usage was estimated at 120 gpcd in 2005 and 132 gpcd in 2002." First, the assumed future per capita use of 160 gpcd occurs not just in large communities, but in small communities as well (and Page is not a large community with population less than 7,000). Second, this 160 gpcd is conservative in the sense that it is constant over the planning period, i.e., does not increase over time. The Flagstaff figure may be depressed by the significant population of students at NAU. In addition to the data cited by ADWR, it is worth noting that water use in Tuba City is now 146 gpcd, not far below the 160 gpcd benchmark. While Tuba City has better infrastructure and housing conditions than Moenkopi and Kykotsmovi, it still suffers from the infrastructure deficiencies of most American Indian Reservations. Improved water supply, better housing, and economic development will certainly lead to higher levels of water use at Tuba City as well as at Moenkopi, Kykotsmovi, and other parts of the Hopi Reservation.

8.4 Livestock

On page 8-19 the Preliminary HSR states that BIA has authority over Navajo still grazing the HPL. The Tribe enforces grazing regulations pursuant to contract with the Department of Interior.

8.4.3 Recent

The lower quantification limit discussed on page 8-22 of the Preliminary HSR is based on livestock data from the recent drought period which depressed the number of cattle grazed.

In calculating recent livestock use ADWR states on page 8-22 that the capacities of breached stockponds were not counted. *See* footnotes in Table 8-7. As discussed above, this is inconsistent with the reserved rights doctrine which holds that tribal rights are not lost through non-use. *See Gila V, supra.* The Tribe has the right to rebuild the breached impoundments.

It is unclear if ADWR used all verified wells which included stock use, or if ADWR used verified wells whose only claimed use was stock.

8.5 Recreation

8.5.1 Historic

On Preliminary HSR page 8-24 the reference for USDA should be 1981, not 1980.

Table 8-8 indicates the ADWR recreational lake capacities are smaller than both those in the Hopi claim and those published in the 1981 USDA study. This raises the question whether the ADWR capacities of the lakes are calculated based on their existing partially silted-in conditions or are they based on the original unsilted conditions. The capacities should be based on the unsilted condition. Also, Table 8-8 erroneously attributes to the USDA report a finding that Keams Lake is completely silted in. This finding related to "Upper Keams Lake," also known as Lake Maho. The USDA report states with respect to Keams Lake: "Lower Keams Pond is stocked each year with catchable rainbow trout and occasionally with catchable channel catfish. Substantial demand for recreational fishing exists in the area . . . ." This facility continues to be stocked for fishing (as recently as March 2009) and used for recreational purposes.

8.5.2 Recent

As noted above in the comments on Chapter 4, ADWR should confirm whether its evaporation rates are gross or net lake evaporation rates.

8.7 Cultural/Ceremonial

On page 8-27 ADWR argues that the irrigated family gardens would only need 0.35-0.86 acre-feet per acre. These are the crop water duties that ADWR estimated for traditional Hopi agriculture, including dryland farms. The proposed plan for irrigated family garden plots calls for much more intensive irrigation than this using modern irrigation methods. The crop water duties the Tribe will be using in the upcoming amended claim will be much closer to project acreage values. ADWR should correct this mistake.

The comments in Section 7.3 regarding springs with unmeasured flow and springs which have been documented but are currently dry apply to this Section.

8.8 Riparian Evapotranspiration

8.8.1 Historic

Page 8-28 of the Preliminary HSR discusses the introduction of saltceder to the riparian environments on the Hopi Reservation. Russian olive was also introduced from outside the Reservation.

8.8.2 Recent

Page 8-29 mentions species in riparian environments, including cottonwood, willow, Russian olive and saltcedar. Alkali sacaton and camelthor should also be included in this list. Also, ADWR's estimates for annual water demand of the riparian vegetation are based on a study from New Mexico. However, New Mexico is under a different climate regime than the Colorado Plateau. A composite of riparian water use values in the Four Corners states would be more appropriate, with strong consideration for evapotranspiration rates on the Hopi Reservation.

**Chapter 9: ADWR's Analysis of Hopi Water Rights and Proposed Water Right Attributes for Past and Present Water Uses**

Chapter 9 is based on information presented in prior chapters (and appendices) in the Preliminary HSR. Accordingly, the Tribe's comments on previous chapters (and appendices) are incorporated into Chapter 9 and should be applied to its conclusions, proposed water right attributes and supporting discussion. In addition, the Tribe makes comments specific to Chapter 9 below. Furthermore, as noted above, the Tribe intends to file revised claims in the near future.

9.1.1 Agriculture

As discussed above, ADWR's estimates and water rights recommendations on page 9-2 and Table 9-1 of past/present agricultural use (350 to 7921 AFA) for traditional farming and (0 to 1582 AFA) for irrigation projects undercount actual uses principally for the following reasons: (a) some historic irrigation projects are omitted, and (b) irrigated pasture land is omitted. Also, the water rights attributes should include diversion and depletion amounts.

9.1.2 DCMI

The Tribe's DCMI claim includes past, present and future use as a single claim. It did not present a past and present use portion of the claim. Therefore, the Tribe notes that such an approach is inconsistent with the Tribe's claims as filed in the Adjudication.

9.1.4 Livestock

As discussed above, ADWR's estimates and water rights recommendations on pages 9-3 and 9-4 and Table 9-1 underestimate Hopi livestock use for the following principal reasons: (a) stockponds with breached dams or berms were omitted, and (b) depletion was not included in the calculation.

There appears to be a conflict between Table 9-1 which indicates 159 claimed and 18 unclaimed wells for stock purposes, and Table 7-10 which identifies 170 claimed and 18 unclaimed wells for stock use. This conflict may be due to ADWR's allocation of wells claimed for multiple purposes between stock and domestic purposes.

9.1.5 Recreation

As discussed above, ADWR's estimates and water rights recommendations on page 9-4 and Table 9-1 underestimate present Hopi recreational uses principally because ADWR's measurements of capacities of the recreational lakes are less than those claimed and less than those identified in the 1981 USDA study on the LCR basin (*see* Table 8-8).

9.1.6 Ceremonial/Cultural

As discussed above, ADWR's estimates and water rights recommendations on page 9-4 and Table 9-1 underestimate present Hopi ceremonial and cultural uses because ADWR assumes no flow for documented springs with no measured flow. Hopi rights to spring flow should be estimated for documented springs even where there is no measured flow.

9.3 ADWR's Recommended Water Right Attributes

On page 9-12 the Preliminary Report states "Because the Court has not yet determined whether the Hopi are entitled to use surface water sources that do not cross the Reservation, and because the Court has not yet analyzed or quantified proposed future uses, ADWR cannot make a recommendation regarding whether the Hopi federal reserved water right extends to groundwater." This statement is unnecessary and should be deleted.

For the reasons explained above, the Tribe comments that ADWR underestimates the quantity of water used for past and present purposes by the Hopi Tribe.

**Tables and Figures**

Most comments for tables and figures are already included in the comments on the various chapters. Additional comments are set out below.

In Figure 8-3 showing the Pasture Canyon irrigation system, the Hopi Reservation boundary is incorrect, as it seems to exclude the allotment area. In addition, there is additional irrigation not shown in the Hopi portion of the Upper Kerley Irrigation Project, as well as additional current or historic irrigation upstream of the Pasture Canyon area along Moenkopi Wash.

**Appendix A-2: USA Adjudication Claims**

The first 50-60 pages of this appendix appear to be an unorganized mix of 1985, 1994 and 1995 claim material. These pages are followed by the 1985 claim (starting with the cover sheet 39-91441 (US) 11-29-85), the 1994 claim (cover sheet 39-91441 (US) 11-22-94), and then the 2004 claim.

The second and third sheets of Appendix A-2 are Statement of Claimant form 39-91442 filed by the Navajo Nation. It is not clear why they are included here.

The United States 1985 claim is missing part of Table 11, plus all of the tables following Table 11 of the 1985 Stetson Report.

**Appendix A-4: Allotted and Other Lands**

This appendix contains allotment information submitted by the United States in August of 2002, and includes the size, location map, and irrigated acreage of each allotment (and other tracts) located along Moenkopi Wash served from Pasture Canyon. The Appendix omits a later letter submitted in September 5, 2002 by the United States (described in a footnote in the main Preliminary HSR Preliminary Report page 2-24) which clarifies the August 2002 submittal noting that only the "AR" tracts are allotments created by the allotment act while "TR" tracts are not allotments but are tracts still in Tribal trust that were assigned to individuals or families. This appendix should contain a copy of that September 5, 2002 letter.

**Appendix A-5: Other Water Uses**

The first page of this appendix is a map that shows the allotments and Murphy tracts described in the June 3,2008 letter at the end of Appendix A-4. It appears this map is a part of this letter and should be moved to Appendix A-4 following the above mentioned letter. This map is also not one of the two items described in the Preliminary HSR table of contents for Appendix A-5.

**Appendix B: USGS Stream Gages on or near the Hopi Reservation**

USGS gage 09401265 Pasture Canyon Springs is not included in this Appendix because ADWR apparently does not consider this to be a stream gage but rather a gage measuring spring flow. The gage is discussed in the main Preliminary HSR Preliminary Report in section 7.3.2 spring discharge on pages 7-12 and 7-13.

**Appendix C: Impoundments**

Pages C-6 and C-7 describe the ADWR method used to calculate pond capacity. For the ponds with field data, pond capacity was calculated as capacity = (surface area) x (berm height) x 0.4, where capacity is assumed to be ..."the maximum volume of water that could be stored by the impoundment when there is no discharge of water and regardless of the potential loss in storage due to siltation," surface area is the field measured area in acres, berm height is the outside spillway crest or embankment height in feet, and 0.4 is the assumed pond shape factor. For capacity of ponds measured from photo analysis without field measurements, ADWR performed a regression analysis of the field data from 51 measured impoundments to arrive at a equation relating pond capacity to pond area, from which capacity of ponds identified from photos could be estimated from the pond area measured on the photos. Ponds with breached berms were assumed to have no capacity. The Tribe has the following comments on the capacity methodology:

a. ADWR should not have assumed that there is no capacity for ponds with breached berms. Most breached berms or dams can be rebuilt, and the capacity should have been based on the potential rebuilt berm and pond. This would be consistent with the nature of reserved rights.

b. It is not clear what surface area ADWR measured in the field, the existing surface area, or the potential maximum surface area at the top elevation contour of the spillway crest or embankment if there was no spillway. To meet the definition of capacity as the maximum stored volume, the area should have been the maximum pool area at the spillway crest or top of embankment if it had no spillway.

c. Similarly, it is not clear what surface area was measured on the photos, the area at the existing pool level or the maximum pool level at spillway crest or top of embankment. If the pond surface area was measured at maximum pool, how was this done without analyzing the ponds in three dimensions using stereo photo analysis?

d. Based on analysis of ponds visited in the field by both ADWR and the Tribe's retained water resources experts, it appears that the ADWR capacity is generally lower than that of the capacity developed by tribal experts. This appears to be because ADWR's measurements of pond depths were less than those of the Tribe's experts and likely did not account for the usual construction practice of excavating the material for the berm from the pond water storage area.

This common practice was observed by the Tribe's experts in the field on the Hopi Reservation and other reservations in the southwest United States, as well as previous discussions with a stock pond contractor. If there was water and/or silt in the pond so that the original excavation in the pond storage could not be seen, the original pond depth could be easily underestimated without knowledge of common construction practices. It appears that ADWR estimated the depth for capacity calculations as the depth between the spillway and the bottom of the natural drainage. If embankment soil was excavated from the reservoir bottom and not the hillside (as it was in almost all Hopi ponds), then the depth should have been increased to account for the extra excavated depth. Based on field experience, this extra depth is commonly roughly equivalent to the spillway depth, and hence an estimate of the true depth can be estimated by taking the depth from the berm top to the downstream toe of the berm. This would have typically added roughly five feet to the ADWR depth estimate. NRCS criteria shows typical minimum depths should be 12 to 14 feet for the precipitation range on the Hopi Reservation. *See* Exhibit 5. Most ADWR field measured depths are markedly lower than this.

ADWR's regression equation used to estimate pond capacity is inaccurate. The ADWR internal report on the regression analysis indicates the coefficient of correlation r is 0.79, which is below the 0.80 to 1.00 normally used to describe strong correlation. In addition, the regression equation understates such estimates because it relies on data which, as described above, understates capacities of ponds which ADWR measured. The Tribe's experts did not rely on an artificial regression equation to determine capacity, but used stereo aerial photo analysis to estimate the area and depth of each claimed impoundment. The stereo estimated depths and areas were calibrated by actual field visits to many of the ponds.

Appendix C indicates that ADWR used a shape factor of 0.4 to calculate capacity. A shape factor of 0.4 is consistent with NRCS standards. However, the ADWR field sheets show factors of 0.25 to 0.33. ADWR should review its calculations to ensure that it applies a shape factor of 0.4.

The ADWR capacity of the 4 claimed recreational ponds are lower than both the claimed amounts and those listed in the USDA 1981 study and therefore should be re-evaluated. Similarly, the capacities of Pasture Canyon Reservoir and Lower Lagoon Reservoir are lower than those calculated by the tribal experts. *See* previous comments on Chapters 7 and 8.

**Appendix D: Springs**

Tables D-1 and D-2 include a column stating if water quality data are available for a spring. Following that column there are three columns for exceedences of various water quality standards. While this information may be useful, the quality of the water is not a factor in determining if the Hopi Tribe has a reserved right for the water.

The two columns under spring use in Table D-1 are confusing. In almost all instances, the use identified in the "Other Documented" column are already identified in the "Claimed" column. How are they "other" uses?

Table D-2 identifies several potentially unclaimed springs. These springs will be reviewed and may be included in the upcoming amended claim to be submitted. However, it is noted that for one facility only the general location is now known. If this spring is included in the amended claim and final HSR, would it be classified as "unverified"?

**Appendix E: Wells**

The same comments regarding water quality provided for springs also apply to the tables of wells.

The same comments regarding potentially unclaimed springs also apply to potentially unclaimed wells. In addition, some of the unclaimed wells listed in Table E-2 are included in Table E-1.

**Appendix F: ADWR Report on Consumptive Use of Crops**

Why does Figure 2.9 of Appendix F show both a higher and lower curve of GDD for each site if for GDD the only variable in its calculation is mean temperature?

There is some question whether Appendix F Figures 2.12 and 2.13 match the data in Appendix F Tables 2.6 to 2.9.

Is the reference for FAO24 Table 21 the correct table reference for the Kc curve for the DRY scenario?

The Appendix F Table 2-24 compares the ADWR NIR values to those claim values derived by taking average and maximum claimed depletion divided by total claimed acreage. As previously noted in comments on Chapter 8, this is not valid because NIR is not equal to depletions.

It is not clear whether ADWR's methodology accounts for the Hopi practice of planting corn in clumps when the calculating the NIR values for DRY condition.

It appears that ADWR did not develop NIR for irrigated pasture land which is irrigated by water spreading. The Tribe claims 7,522 acres of historic range pasture type irrigation.

**Appendix G-3: 2005 Agriculture & Riparian Lands**

Although the accuracy assessment of the 2005 agriculture study involved 40% of the 514 fields mapped in the field, Table 2 of Appendix G-3 indicates this 40% involved only about 228 acres out of the total 5613 identified agricultural acres (or about 3.9%). ADWR should explain why only 40% of the field mapped irrigation was used in the accuracy assessment, and on what basis the 40% of the fields were selected. It would also help to know generally where this 228 acres was located (was most of it in the Moenkopi area or was it randomly spread across the reservation) and what proportion of the 228 acres is traditional farming versus project irrigation.

The difference between the different categories of active agriculture, active agriculture or fallow, and active fallow should be explained. ADWR should also explain assumptions about crop rotations in defining the category and analyzing the data and whether Hopi crop rotation methods were taken account.

It appears that ADWR did not include irrigated pasture land in the 2005 study. Such lands should have included.

**Appendix G-4: Drainages Derived by ADWR**

In Appendix G-1 and Appendix G-3, the reduced quad map for Moenkopi shows a large blue area in the southeast portion of the quad. What does this area represent, or is this some type of error in generating the stream segments from the Digital Elevation Model (DEM) described in Appendix G-4?

**ADWR Hydrographic Survey Groundwater Report Nelson (2008)**

The comment made above in Chapter 7 that the Western-Navajo Hopi N-Aquifer (WNHN) study and model may not be used in the Preliminary HSR because of the Protective Order dated January 3, 2002 applies to this report where they are cited throughout, including Chapter 6, Figures 3 through 5 and 25 through 28, and the storage estimate at the bottom of the first paragraph on page 8-1. The references to the WHHN study and model and all estimates, analyses or conclusions based on them should be removed from the report.

2.4 D Aquifer Geologic Units

On page 2-3 the report states that the thickness of D-Aquifer ranges from 100 feet in the northwest to 700 in the southeast to 1,300 feet near the center. These measurements appear to be of the thickness of all geologic units that may comprise a portion of the D-Aquifer. The sandstone units that produce water or potentially produce water have significantly less thickness as indicated, for example, by information provided in Truini and Longsworth (2003).

2.5 N Aquifer Geologic Units

On page 2-4 the report describes the thickness of the N-Aquifer as measuring move than 1,200 feet northwest of Black Mesa. These measurements appear to be of the thickness of all geologic units. The units that produce water or potentially produce water have less thickness.

3.5 D Aquifer

The report discusses withdrawals from the D-Aquifer on pages 3-3 and 3-4 but omits withdrawals from Peabody wells. Some PWCC wells are screened across the D-Aquifer and obtain water from both the D- and N-Aquifer when pumped, as detailed in the PWCC modeling reports.

3.6 N Aquifer

On page 3-4 (and elsewhere) the report refers to the geologic unit (e.g. Navajo Sandstone) and is used interchangeably with the term aquifer (e.g. N-Aquifer). The top of the Navajo Sandstone (or other geologic unit) is not the same as the top of the aquifer. Where a water table occurs, the top of the aquifer is the water table, and unsaturated portions of the geologic formation should not be included in thickness computations or referred to as the aquifer. This point, which also has bearing on use of the terms "water table" and "potentiometric surface," should be clarified throughout the text to avoid potential confusion. For example, on page 3-4 in the second paragraph the report states "where the water table was higher than the top of the aquifer." This should be changed to read: "*where the potentiometric surface was higher than the top of the Navajo Sandstone*."

On page 3-5 in the bottom paragraph the report states that the storage coefficient of a confined aquifer is the ratio of the specific storage and saturated thickness. The storage coefficient of a confined aquifer is the *product*, not the ratio, of the specific storage and saturated thickness.

3.7 C Aquifer

On page 3-6 of the report, ADWR should note the poor quality of C-Aquifer water under the Hopi Reservation. It is not potable.

3.8 Paleo-Hydrology

On page 3-7 report discussed recharge. The recharge values in the Shonto area from Lopes and Hoffmann (1996) should be specifically mentioned. They estimated current Shonto area recharge to be about 2,500 to 3,500 ac-ft/yr. This is the main recharge area to the confined portion of the N-Aquifer.

4 Water Use Trends

On page 4-2 the report discusses withdrawals in the periods 1965-1972, 1973-1974, 1985, 1986-2004, 2005. ADWR should explain why these periods were selected.

The top paragraph on page 4-2 states that the PWCC production wells draw from the N-Aquifer. Some of the PWCC production wells are also screened in the D-Aquifer, and obtain a portion of their water from this aquifer. *See also* comment regarding Section 3.5.

6 Groundwater Flow Models

The purpose of the discussion on page 6-1 and subsequent pages that recount the previous simulation results is not clear. The model simulations are outdated and do not appear to be applicable to this Adjudication and were not based on projected demands at issue in this Adjudication. This discussion should be removed.

7 Estimate of Groundwater in Storage.

Chapter 7 estimates storage of the N-Aquifer. The report does not explain the value of such estimates. Such discussion should also consider how much of the estimated storage can actually be efficiently and economically recovered from beneath the Hopi Reservation.

8 Summary and Conclusions

On page 8-1 the report states that mining operations at Peabody ceased and discusses water levels after the cessation. Although use of the slurry has ceased, mining operations have not ceased, and significant quantities of water are still used for mining operations.

On page 8-2 the report recommends that the PWCC model be used for future studies. This recommendation should be removed. The PWCC model is not as accurate as the USGS model in the vicinity of the Hopi Villages. On page 6-7 (bottom of second paragraph) the report quotes one of the model authors as making the recommendation that the model be improved prior to application in the vicinity of the Hopi villages. The observation that the PWCC model extends further southeast than the USGS model is a primary reason not to use it, and it is one of the reasons that the model does a poor job simulating water levels in the vicinity of the Hopi villages. The N-Aquifer southeast of the Hopi Villages is non-existent at many locations. The PWCC model assumes that some pumping from the Polacca area occurs in the D-Aquifer (in part) rather than from the N-Aquifer. Hopi's hydrologists have considered this issue in detail and believe that Polacca pumping is predominately from the N-Aquifer, although there may be some casing leakage at the production well. *See* Exhibit 6.

The summary of simulation results that begins at the bottom of page 8-2 and continues through page 8-5 should be removed. None of these simulations include Hopi or Navajo claims,

nor do they include updated predictive scenarios given current events on the ground. The referenced simulations were all conducted for purpose other than the present adjudication, and therefore there is no basis for reference as to what they do, or do not, imply.

On page 8-4 in Paragraph 5 the report concludes that the USGS and PWCC models overestimate water level declines in the Tuba City area and therefore overstate predicted declines in streamflow and spring discharge. The conclusion may be incorrect and at a minimum should be verified. An overestimation of groundwater declines will not necessarily overestimate reductions in stream flow and spring discharge because: (a) overestimation of water level declines may lead to dry cells during the predictive simulations, at which point the effects of continued pumping on surface water are artificially reduced (i.e. pumping associated with the dry cell location is effectively removed form the simulation), (b) If the overestimation of drawdown is due to a hydraulic conductivity that is too low, then the extent of the simulated cone of depression will also be artificially constrained. This condition may lead to the result that springs and portions of Moenkopi Wash that should experience depletion due to pumping may not, because the extent of the cone of depression is underestimated.

**Fred Anderson Consulting, Historical Research for a Hydrographic Survey Report of the Hopi Reservation (2008)**

The Hopi Tribe has served expert reports on topics addressed in this report in *In re Hopi Priority*. Those reports are: (1) Peter M. Whiteley, *The Importance of the Little Colorado River Drainage and its Water Resources to the Hopi* (2009); (2) Peter M. Whiteley, *Historic Hopi Use and Occupancy of the Little Colorado Watershed, 1540-1900* (2009); (3) Peter M. Whiteley, *The Historical Evolution of Navajo Occupancy Areas in the Southwest, with Particular Reference to Black Mesa and the Hopi Washes* (2009); (4) David J. Weber, *Hopi Land and Water Rights Under Spain and Mexico* (2009); (5) T.J. Ferguson, *Hopi Agriculture and Water Use* (2009); (6) E. Charles Adams, *Hopi Use and Development of Water Resources in the Little Colorado River Drainage Basin of Arizona: an Archaeological Perspective to 1700* (2009); (7) Whiteley, Peter M., Ph.D., *Reply Report I: re: The Myth of Late Arrival of the Navajo in the Southwest, by Alan S. Downer, Ph.D., and Diné Presence in the Little Colorado River Watershed: Pre-Columbian Times to c AD 1800, by Klara Kelley, Ph.D.* (June 2009); (8) Peter M. Whiteley, *Reply Report II: re: Federal Indian Policy and the Diné/Navajos, 1846 to the Present, by Jennifer Nez Denetdale, Ph.D.* (June 2009); (9) Peter M. Whiteley, *Reply Report III: re: two Reports by Historical Research Associates, Inc.: Report I: Water Use and Boundary Disputes in the Little Colorado River Basin, 1860s–1940s; Report II: A Brief Summary of Legislative and Judicial Attempts to Resolve the Hopi-Navajo Land Dispute, 1950s-1990s* (June 2009); and (10) T.J. Ferguson, *Tree Ring Dates and Navajo Settlement in the Little Colorado River Basin of Arizona* (June 2009).

1.1 Prehistoric Period

Anderson states that "some scholars have suggested that the[] early residents were the Hopi's ancestors." Adams states that "the Western Pueblo people of the upper Little Colorado River area, and the Anasazi of the plateau are all believed to be ancestral Pueblo groups and all probably contributed to the ancestry of the Hopi." E. Charles Adams, *Hopi Use and Development of Water Resources in the Little Colorado River Drainage Basin of Arizona: an Archaeological Perspective to 1700* at 20. This is consistent with Hopi oral tradition which firmly establishes the relationship between modern Hopi and the *Hisatsinom* the Hopi ancestors who lived throughout northern Arizona.

1.2.5 Standoff with Spain (1700-1821)

On page 15 the report states that at the time of the Escalante and Garces expedition in 1776 Navajos "were moving onto land surrounding the Hopi mesas." While there is evidence that Navajos were to the east of Hopi at that time (at some distance) there is "no indication of any Navajo presence to the west or north of Hopi country." Whiteley, *The Historical Evolution of Navajo Occupancy Areas in the Southwest, with Particular Reference to Black Mesa and the Hopi Washes* at 23.

1.3.2 Relations with Other Tribes

On page 21 the report states "[b]y the early 1800s, Navajo settlements could be found on Black Mesa, the Kaibito Plateau, the Painted Desert and other lands surrounding the Hopi mesas." Whiteley concludes that it is unlikely that in the early 1800s Navajos were in Black Mesa, noting that Navajos needed to conduct raids from a distance in order to retreat, as far as the Lukachukai Mountains. Whiteley, *The Historical Evolution of Navajo Occupancy Areas in the Southwest, with Particular Reference to Black Mesa and the Hopi Washes* at 45, 55. Tree-ring data suggest a mid-nineteenth century date for Navajo settlement on Black Mesa. Ferguson explains: "tree-ring dates indicate that a few Navajos first occupied Black Mesa in the early 1840s, and this was followed by a movement to areas northwest and southeast of the Hopi Mesas during the early 1860s, when Navajos fled from military campaigns waged by the U.S. Army. More extensive Navajo occupation began on Black Mesa, at the head of the Moenkopi Wash, and along the upper Little Colorado River after the release of Navajos from Fort Sumner in 1868, as the Navajo people began to slowly resettle the areas they had first occupied during the 1860s when they sought to evade capture by the U.S. Army." Ferguson, *Tree Ring Dates and Navajo Settlement in the Little Colorado River Basin of Arizona* at 1-2.

2.1.3 Creation of the Reservation

On page 32 the report discusses the purpose of the establishment of the 1882 Reservation, noting that the language permitting settlement of "other Indians" was boilerplate. Whiteley demonstrates that the original intent of the 1882 Hopi Reservation was, *inter alia*, to protect the

Hopi from Navajo encroachment, and to prevent the latter from trespassing on the rights and resources of the former. Whiteley, *Reply Report III* at 4. Also, its boilerplate language authorizing the settlement of "other Indians" was included as a part of policies then favored by the government to permit deliberate Secretarial removal of Indians to a reservation. *Id.* at 8. However, "[f]rom events in the late 1880s involving direct action by the Secretary of the Interior, it is incontrovertible that the 'such other Indians' clause did not refer to Navajos." *Id.*

2.6.2 Indian Claims Commission

This section discusses the Indian Claims Commission decisions. The Tribe notes that the final judgment of the Claims Commission on Hopi's claims did not rest on the findings and conclusions in that decision discussed in the report. The Hopi Tribe and the United States settled the case while the Tribe's petition for review of the decision cited above was pending before the United States Supreme Court. *See* 429 U.S. 1030 (1976) (order dismissing petition under then Supreme Court Rule 60). The parties expressly stipulated that the judgment would have no preclusive effect, and the Claims Commission entered judgment in accordance with the stipulation. 39 Ind. Cl. Comm. 204, 222 (Dec. 2, 1976) (Findings 7 and 9). The 1970 decision never became final.

3.1.1 Navajo Migrations

On page 58 the report concludes that "[b]y the time the Navajo Reservation was established in 1868, there is no doubt that the Navajo settlement area had expanded to the point where it completed surrounded the Hopi mesas." Whiteley reaches a different result. In his exhaustive review of the contemporaneous accounts of the location of Navajos, Whiteley shows that the westernmost boundary of regular Navajo settlement prior to the establishment of the 1868 Navajo reservation was the Pueblo Colorado wash and the Wide Ruins area to the south, with some stockgrazing northwest of Canyon de Chelly at the Calabasa and Vaca Mountains. Whiteley, *The Historical Evolution of Navajo Occupancy Areas in the Southwest, with Particular Reference to Black Mesa and the Hopi Washes* 71, map accompanying 71. To be sure, during the military campaign against the Navajo during the late 1850s and early 1860s some Navajos moved somewhat further north west, to Skeleton Mesa, the Klethla Valley and Navajo Mountain, as well as onto Black Mesa, and even as far as the Grand Canyon and the San Francisco Mountains, *id.* at 70, 76, but, with the apparent exception of Skeleton mesa and the Klethla Valley, expeditions to these areas showed little signs of Navajo habitation. *Id.* at 760-78. During the final push of the military campaign to subdue the Navajos in 1864, many Navajos did flee to the Hopi washes and mesas, where they resided temporarily while the U.S. military sought to capture them, *Id.* at 85-89, but the short term residence of very few small groups of Navajos does not indicate that the Navajo settlement area surrounded the Hopi mesas. To the contrary, the established line of Navajo settlement consistently along the Chinle wash and the Pueblo Colorado wash. *Id.* at map accompanying p. 6, map accompanying p. 71, which were

well east of Black Mesa. And there appears to have been no Navajo settlements to the west of the mesas, which would be necessary for the Hopi mesas to have been completely surrounded.

3.1.4 Hopi-Navajo Relations after the Navajo War

On page 65 the report states "[m]uch of the reservation was, at the time of its creation, occupied not by Hopis but by Navajos." This is incorrect. To be sure, after the creation of the 1868 Navajo reservation, a significant number of Navajos refused to remain within its boundaries and moved westward, encroaching on historically Hopi areas. Whiteley, *Historic Use and Occupancy of the Little Colorado Watershed, 1540-1900*) at 81. *See also* Whiteley, *Historical Evolution of Navajo Occupancy Areas* at 92. But as late as 1876, the Navajo population remained mainly to the east of the Hopi people. Whiteley, *Historic Use and Occupancy of the Little Colorado Watershed, 1540-1900* at 79. And the Navajos that did move into Hopi areas, such as Black Mesa, did so on a largely seasonal basis. Whiteley, *Historical Evolution of Navajo Occupancy Areas* at 90-91. Moreover, Navajo movement onto the southern parts of the Hopi Reservation of 1882 did not occur until the 1890s, *see* Whiteley, *Historical Evolution of Navajo Occupancy Areas* at 92.

4.5 Federal Irrigation and Agricultural Projects

4.5.1 Early Projects

On page 127 the report states, "[i]n the 1930s several irrigation projects were built on the Hopi washes. The Hardrocks, or Lower Oraibi Wash, project was built as a Navajo farm unit in the 1930s but never used. In 1942 it was turned over to the Hopi. It included a masonry dam, gates, and ditches to serve up to three hundred irrigable acres. Neither Ferguson nor Whiteley indicated that this land was ever actually irrigated by Hopis (IIS 1943; IIS 1944:4)." In fact, Laura Thompson reported that Hardrock was farmed by Hopis. Ferguson explains: "In 1946, in a report prepared for Indian Service administrators, Laura Thompson reported there were 7,130 acres under cultivation. A total of 6,967 acres were cultivated using floodwater and dry farming techniques, while 163 acres were irrigated, including 11 acres of irrigated village gardens, 5 acres of irrigated school gardens, and 147 acres in Irrigation Division Projects at Hardrock, Jeddito, and Phillips Farms." Ferguson, *Hopi Agriculture and Water Use* at 172.

On page 129 the report states: "Moenkopi was farmed by Hopis in the past, but not permanently occupied." Moenkopi was seasonally occupied during the growing season in the 19th century, and probably earlier. By the late 19th century, the Hopis established a permanent settlement at Moenkopi. *See* Ferguson, *Hopi Agriculture and Water Use* at 133.

**Conclusion**

The Hopi Tribe will provide ADWR new information regarding its claims and the matters addressed in the Preliminary HSR as it becomes available. The Tribe reserves the right to supplement information provided to date prior to issuance of the final HSR.

The Hopi Tribe looks forward to working with ADWR as the Adjudication proceeds. Please do not hesitate to contact us with any questions regarding these comments.

Sincerely,

Harry R. Sachse
Colin Cloud Hampson
A. Scott Canty

65pkd-

**Kathleen A. Donoghue**

**From:** Colin C. Hampson [champson@sonosky.com]
**Sent:** Tuesday, June 30, 2009 4:14 PM
**To:** Scott M. Deeny
**Cc:** Richard Burtell; 'Harry R. Sachse'; SCanty0856@aol.com; Vanessa.Willard@usdoj.gov; 'Guarino, Guss (ENRD)'; 'Joelynn Roberson'
**Subject:** RE: Hopi Tribe Comments on Preliminary Hopi HSR - Exhibits
**Attachments:** Hopi Comments on Prelim Hopi HSR - Exhs 1-7 (complete set).pdf

Scott,

Attached are the exhibits to the Hopi Tribe's comments on the Preliminary HSR.

Regards,

Colin Cloud Hampson
Sonosky, Chambers, Sachse, Endreson & Perry, LLP
Symphony Towers
750 B Street, Suite 3130
San Diego, CA 92101
(619) 546-5585
(619) 546-5603 (direct)
(619) 546-5584 (fax)
(619) 855-7050 (cell)

# EXHIBIT 1

ELEV. CAPACITY [illegible] FOR CONIC METHOD

SITE: [illegible] CANYON RESERVOIR NR TUCA CITY

| ELEV. (FEET) | AREA (AC) | CAPACITY (AF) | TOTAL DEPTH (FEET) | CONE DEPTH (FEET) |
|---|---|---|---|---|
| [illegible] | 1 ** | 0.0 | 0.0 | 1.6 |
| [illegible] | [illegible] ** | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] ** | [illegible] | [illegible] | 8.4 |
| [illegible] | [illegible] * | 121.[illegible] | [illegible] | 44.7 |
| [illegible] | [illegible] * | [illegible] | [illegible] | [illegible] |

Notes:

- * Area shown on 1975 "Phase 2 Part 3 Improvements to Pasture Canyon Reservoir" drawings by L. H. Bell & Assoc. Areas approx. verified OK by HKM measurements from contour map shown in the above drawings.
- ** Areas determined by estimating contours below el. 4882 on contour map referenced above and then planimetering these estimated contours.
- NWS el. = 4885 = spillway crest el.

[illegible]

ELEVATION-AREA-CAPACITY USING THE CONIC METHOD

SITE: UPPER PASTURE CANYON RESERVOIR NR TUBA CITY

| ELEV. (FEET) | CALC. AREA (AC) | CALC. CAPACITY (AF) |
|---|---|---|
| 4872.0 | 1.00 | (0.0) |
| 4872.5 | 1.71 | 0.7 |
| 4873.0 | 2.41 | 1.7 |
| 4873.5 | 3.71 | [illegible] |
| 4874.0 | 5.00 | 5.3 |
| 4874.5 | 5.79 | 8.2 |
| 4875.0 | 6.65 | 11.[illegible] |
| 4875.5 | 7.56 | 14.8 |
| 4876.0 | 8.53 | 18.9 |
| 4876.5 | 9.56 | 23.4 |
| 4877.0 | 10.65 | 28.4 |
| 4877.5 | 11.79 | 34.0 |
| 4878.0 | 13.00 | 40.2 |
| 4878.5 | 14.60 | 47.1 |
| 4879.0 | 16.30 | 54.5 |
| 4879.5 | 18.09 | 63.5 |
| 4880.0 | 19.97 | 73.0 |
| 4880.5 | 21.93 | 83.4 |
| 4881.0 | 24.01 | 94.9 |
| 4881.5 | 26.18 | 107.5 |
| 4882.0 | 28.43 | 121.[illegible] |
| 4882.5 | 29.07 | 135.5 |
| 4883.0 | 29.71 | 150.[illegible] |
| 4883.5 | 30.37 | 165.2 |
| 4884.0 | 31.03 | 180.8 |
| 4884.5 | 31.70 | 196.2 |
| 4885.0 | 32.37 | 212.2 |

PLANIMETER SHEET--HKM ASSOCIATES

Job No. 3M137.169 By DRC Date 6/25/92

Job Name Hopi - Pasture Canyon - 1

Description of Areas Upper Pasture Canyon Res

Scale of map/drawing 1" = 100' blueline, 1" = 50 on my Xerox copy

Planimeter Type

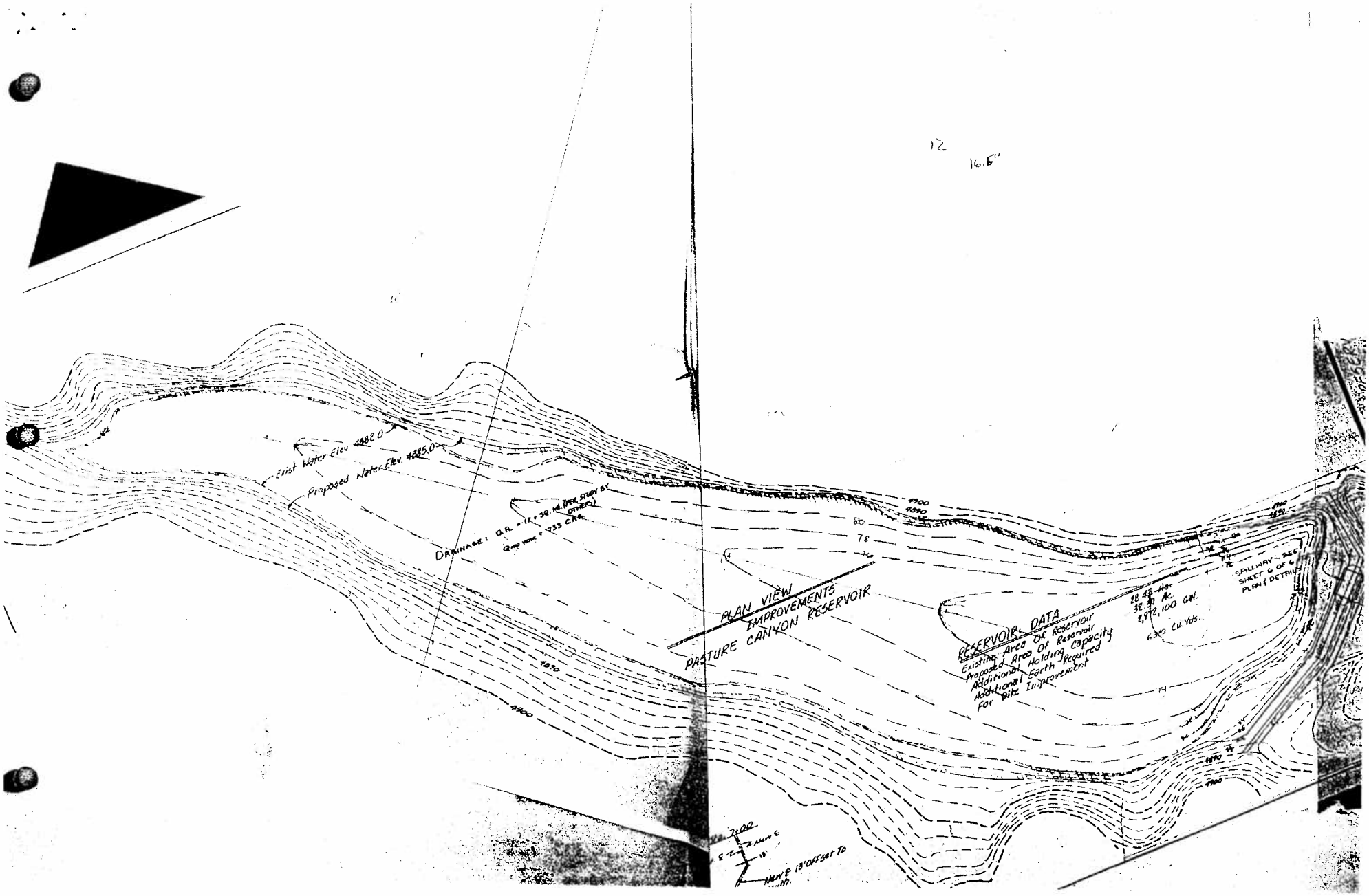
Conversion Constant/Factor $\left(\frac{100\,ft}{in}\right)^2 \times \frac{9\,in^2}{1571} \times \frac{ac}{43560\,ft^2} = .001315$

$\left(\frac{200}{in}\right)^2 \times \frac{9}{1571} \times \frac{ac}{43560} = .005261$

| Description | Cummulative Planimeter Readings 1x around | 2x around | 3x around | average | Called out Area on Area Drawing | |
|---|---|---|---|---|---|---|
| Calibration: 3"x3" | 1574 | 3142 | 4710 | 1571 | | |
| 100 ft/" Blueline Drawing: | | | | | | |
| - Ck Calib - more 3"x3" | 2.067 ac | (3x100)²/43560 | 2.066 ac | | | |
| - Pool Area, EL 4882 | 28.61 | 57.24 | 85.86 | 28.62 | 28.43 | |
| EL 4885 | 32.21 | 62.41 | 96.06 | 32.22 | 32.37 | |
| Note: 4884 & 4886 Contour not entirely shown on drawing | | | | | | |
| 200'/" Drawing | | | | | | |
| Ck Calib - More 3"x3" | 8.21 ac | (2x200)²/43560 | = 8.26 | | | |
| EL 4882 | 28.61 | 57.37 | 85.96 | 28.65 | | |
| This is essentially the same as above | | | | | | |
| Measure assumed interpolated contours | | | | | | |
| 4872 | 1.98 | 2.78 | 4.14 | 1.38 | say 1 ac | |
| 4874 | 4.54 | 9.15 | 13.71 | 4.57 | say 5 ac | |
| 4876 | | | | | | |
| 4878 | 13.4 | 26.94 | 40.40 | 13.46 | say 13 ac | |
| 4880 | | | | | | |

Conclusion: Use areas called out on drawings for EL 4882 & 4885
Use interpolated areas for contours below 4882 w.s.

| | |
|---|---|
| 4872 | say 1 ac |
| 4874 | say 5 ac |
| 4878 | say 13 ac |
| 4882 | 28.43 |
| 4885 | 32.37 |


PLAN VIEW
IMPROVEMENTS
PASTURE CANYON RESERVOIR
Exist. Water Elev. 4882.0
Proposed Water Elev. 4885.0
DRAINAGE: D.A. = 18.4 SQ. MI. (PER STUDY BY OTHERS)
Q100 MAX = 733 CFS
RESERVOIR DATA
Existing Area Of Reservoir 18.48 Ac.
Proposed Area Of Reservoir 32.81 Ac.
Additional Holding Capacity 2,972,100 Gal.
Additional Earth Required For Site Improvement 6,300 Cu. Yds.
SPILLWAY - SEE SHEET 6 OF 6 PLAN & DETAILS
4900
4890
4880
4870
4860
78
74
76
MAX. 13' OFFSET TO

# EXHIBIT 2

ELEVATION-AREA-CAPACITY USING THE CONIC METHOD

SITE: LAGOON RESERVOIR USING MEASURED AREAS FROM DESIGN DRWS

| INPUT ELEV. (FEET) | INPUT AREA (AC) | CAPACITY (AF) | TOTAL DEPTH (FEET) | CONE DEPTH (FEET) |
|---|---|---|---|---|
| [illegible] | [illegible] | 0.0 | 0.0 | 0.0 |
| [illegible] | [illegible] | 1.9 | 0.5 | 50.8 |
| [illegible] | [illegible] | 29.3 | 1.0 | 70.1 |
| [illegible] | [illegible] | [illegible] | [illegible] | 57.9 |
| [illegible] | [illegible] | [illegible] | 5.5 | 40.1 |
| [illegible] | 15.1 | 105.5 | 8.5 | 41.2 |
| [illegible] | [illegible] | [illegible] | 10.5 | 31.2 |
| [illegible] | 18.0 | [illegible] | 12.5 | 31.8 |
| [illegible] Top of Dam | [illegible] | [illegible] | 12.5 | 0.0 |



ELEVATION-AREA-CAPACITY USING THE CONIC METHOD

SITE: LAGOON RESERVOIR USING MEASURED AREAS FROM DESIGN DRWS

| ELEV. (FEET) | CALC. AREA (AC) | CALC. CAPACITY (AF) | |
|---|---|---|---|
| 4791.5 | 0.0 | 0.0 | |
| 4792.0 | 11.2 | 1.5 | |
| 4792.5 | 11.4 | 7.5 | |
| 4793.0 | 11.6 | 13.3 | |
| 4793.5 | 11.9 | 19.2 | |
| 4794.0 | 12.1 | 25.2 | |
| 4794.5 | 12.3 | 31.3 | |
| 4795.0 | 12.4 | 37.4 | |
| 4795.5 | 12.6 | 43.7 | |
| 4796.0 | 12.8 | 50.1 | |
| 4796.5 | 13.0 | 56.5 | |
| 4797.0 | 13.2 | 63.1 | |
| 4797.5 | 13.5 | 69.8 | |
| 4798.0 | 13.7 | 76.6 | |
| 4798.5 | 14.0 | 83.5 | |
| 4799.0 | 14.4 | 90.6 | |
| 4799.5 | 14.7 | 97.9 | |
| 4800.0 | 15.1 | 105.3 | NWS elev.? |
| 4800.5 | 15.5 | 113.0 | |
| 4801.0 | 15.8 | 120.8 | Overflow Pipe Invert |
| 4801.5 | 16.2 | 128.8 | |
| 4802.0 | 16.6 | 137.0 | |
| 4802.5 | 17.1 | 145.5 | |
| 4803.0 | 17.7 | 154.2 | |
| 4803.5 | 18.2 | 163.1 | |
| 4804.0 | 18.8 | 172.4 | |
| 4804.5 | 19.4 | 182.0 | |
| 4805.0 | 20.0 | 191.8 | |

PLANIMETER SHEET--HKM ASSOCIATES

Job No. 3M137164 By _____ Date _____

Job Name Hopi - Irr. Stor. Reservoirs nr Moenkopi

Description of Areas Areas for elev-area-cap

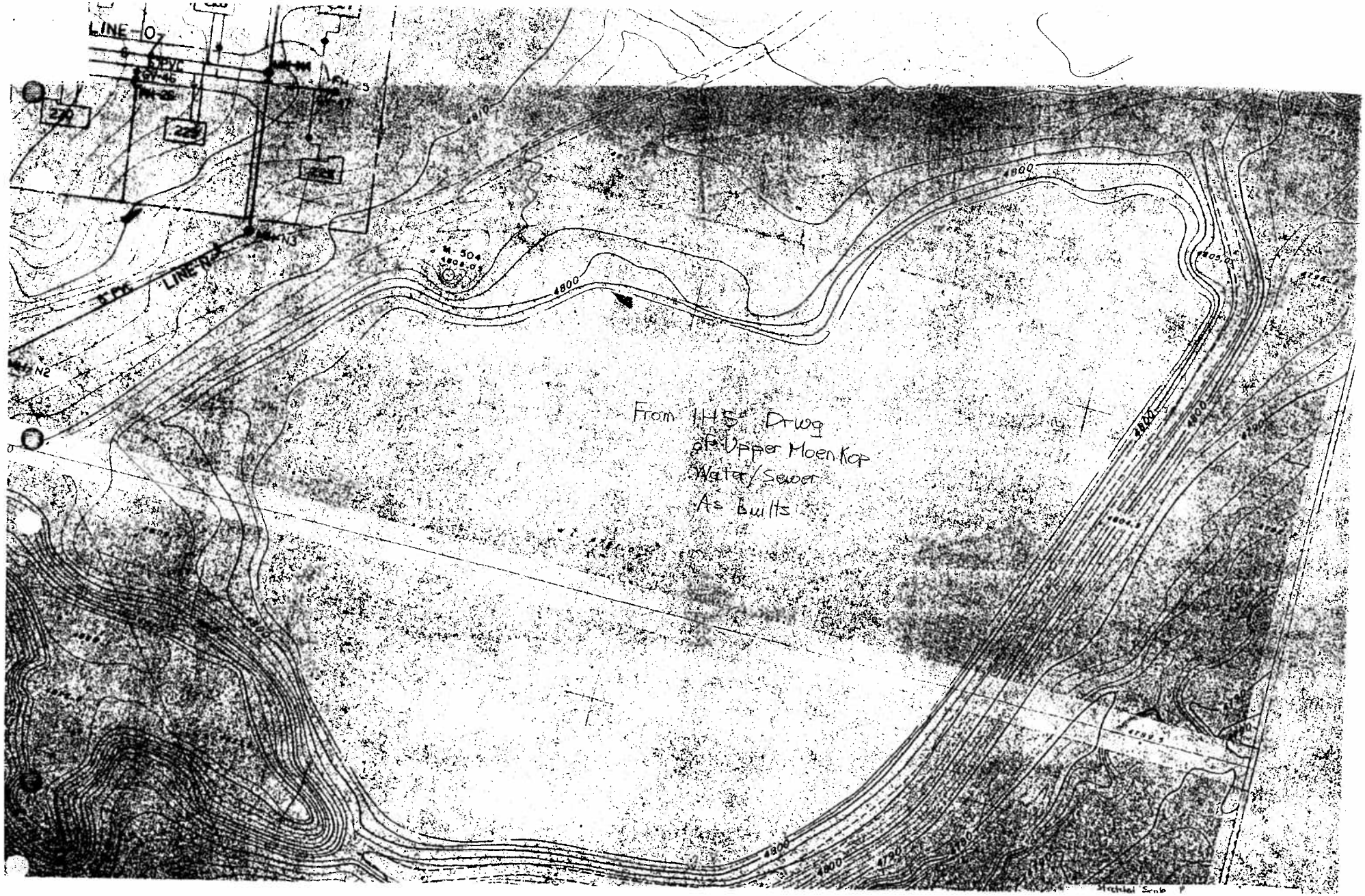
Scale of map/drawing See below

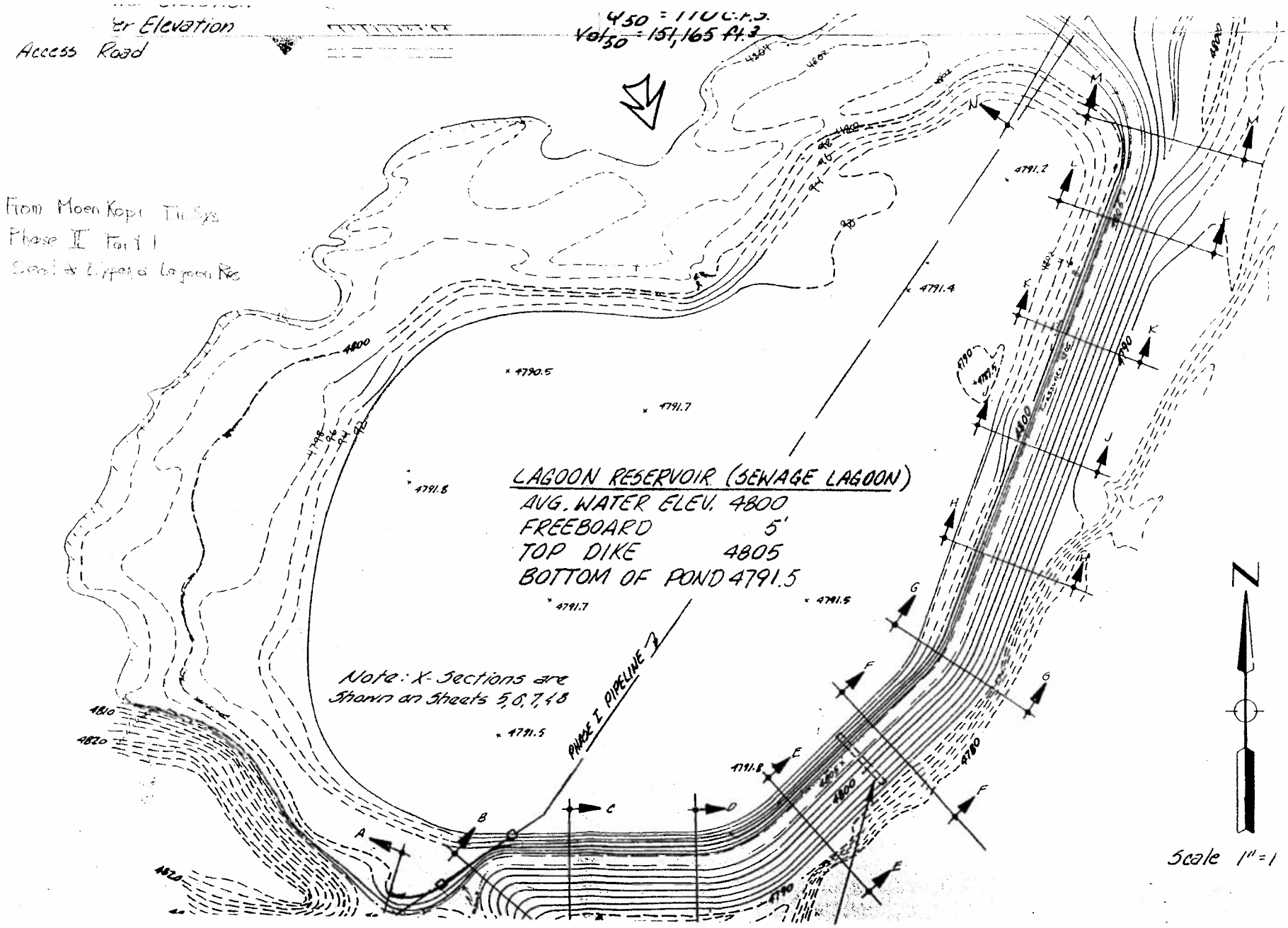
Planimeter Type basico

Conversion Constant/Factor 1" = 100' Const = $\left(\frac{100'}{in}\right)^2 \left(\frac{9in}{1573}\right) \times \frac{ac}{43560}$ = .001313 ac/read

1" = 9156' " $\left(\frac{9156'}{in}\right)^2 \times \frac{9in}{1573} \times \frac{ac}{43560}$ = .001250 ac/read

| Description | Planimeter Readings 1x | 2x | 3x | average = 2x/3 | Design Drwg Area | IHS Drwg |
|---|---|---|---|---|---|---|
| Calibration: 3"x3" sq. ck 1" sq | 1573 .2274ac | 3146 100%x.2274 = .227 | 4718 | 1573 | | |
| Lagoon Reservoir | Scale 1" = 100' - Design Drwg | | | | | |
| 4796.5 = Design bottom | | | | | 0 | |
| 4792 | 1.11 | 2.237 | 3.355 | 1.118 | 1.12 | |
| 94 | 1.20 | 2.415 | 3.624 | 1.208 | 1.21 | |
| 96 | 1.279 | 2.559 | 3.838 | 1.279 | 1.28 | |
| 98 | 1.370 | 2.741 | 4.112 | 1.371 | 1.37 | 1.46 |
| 4800 | 1.508 | 3.017 | 4.525 | 1.508 | 1.51 | 1.55 |
| 02 | 1.664 | 3.326 | 4.990 | 1.663 | 1.66 | 1.67 |
| 04 | 1.885 | 3.769 | 5.653 | 1.884 | 1.88 | |
| 4805 Top berm | 2.002 | 4.003 | 6.005 | 2.002 | 2.00 | |
| Lagoon Reservoir | Scale 1" = 100' (Stretched (1" = 9156') - IHS Drwg | | | | | |
| 4797 w/L | 1.385 | 2.770 | 4.154 | 1.385 | | |
| 4798 | 1.462 | 2.925 | 4.387 | 1.462 | | |
| 4800 | 1.548 | 3.093 | 4.640 | 1.547 | | |
| 4802 | 1.668 | 3.335 | 5.003 | 1.668 | | |


LINE O
LINE N
N2
N3
4800
4810
4790
From 1"=5' Drwg
of Upper Moenkopi
Water/Sewer
As Builts


Elevation
Access Road
450 = 110 c.f.s.
Vol 50 = 151,165 A.F.
From Moen Kopi Tie Sys
Phase II Part 1
Sewal & Lipari Lagoon Res
LAGOON RESERVOIR (SEWAGE LAGOON)
AVG. WATER ELEV. 4800
FREEBOARD 5'
TOP DIKE 4805
BOTTOM OF POND 4791.5
Note: X-Sections are Shown on Sheets 5,6,7,8
PHASE I PIPELINE
4790.5
4791.7
4791.8
4791.4
4791.2
4791.5
4800
4810
4820
A
B
C
D
E
F
G
H
J
K
L
M
N
Scale 1" = 1

# EXHIBIT 3

[illegible]

[illegible]

| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
|---|---|---|---|---|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

Many Sheep

Valley

# PLANIMETER SHEET — HKM ENGINEERING INC.

Job # ______________________ By ______________________ Date ______________________

Job Name ____________________________________________________________

Description of Areas ____________________________________________________________

Scale of map/drawing ____________________________________________________________

Planimeter type ____________________________________________________________

Conversion Constant/Factor ____________________________________________________________

| Description | Cummulative Planimeter Readings | | | Average Reading | Area |
|---|---|---|---|---|---|
| | 1x around | 2x around | 3x around | | |

# EXHIBIT 4

ELEVATION-AREA-CAPACITY USING THE CONIC METHOD

SITE: Historic Dam on Dinnebito Wash at HIA Site DW10

| INPUT ELEV. (FEET) | INPUT AREA (AC) | CAPACITY (AF) | TOTAL DEPTH (FEET) | CONE DEPTH (FEET) | INC HT TO NEXT ELEV | -ELEV + DEPTH | INC HT + +DEPTH | AREA * DEPTH | NEXT AREA |
|---|---|---|---|---|---|---|---|---|---|
| 6125 | 0 | 0 | 0.0 | 0.0 | 15.0 | -6125.0 | 15.0 | 0.0 | 8.4 |
| 6140 | 8.4 | 42.0 | 15.0 | 13.2 | 20.0 | -6126.8 | 33.2 | 111.1 | 53.0 |
| 6160 | 53 | 592.0 | 35.0 | 16.0 | 10.0 | -6144.0 | 26.0 | 847.6 | 140.0 |
| 6170 | 140 | 1,522.5 | 45.0 | 0.0 | 0.0 | -6170.0 | 0.0 | 0.0 | 0.0 |

Note: Countour 6170 estimated between contours 6160 & 6180

H:\03\M616102\HSRReview\DW10AreaCap.xls

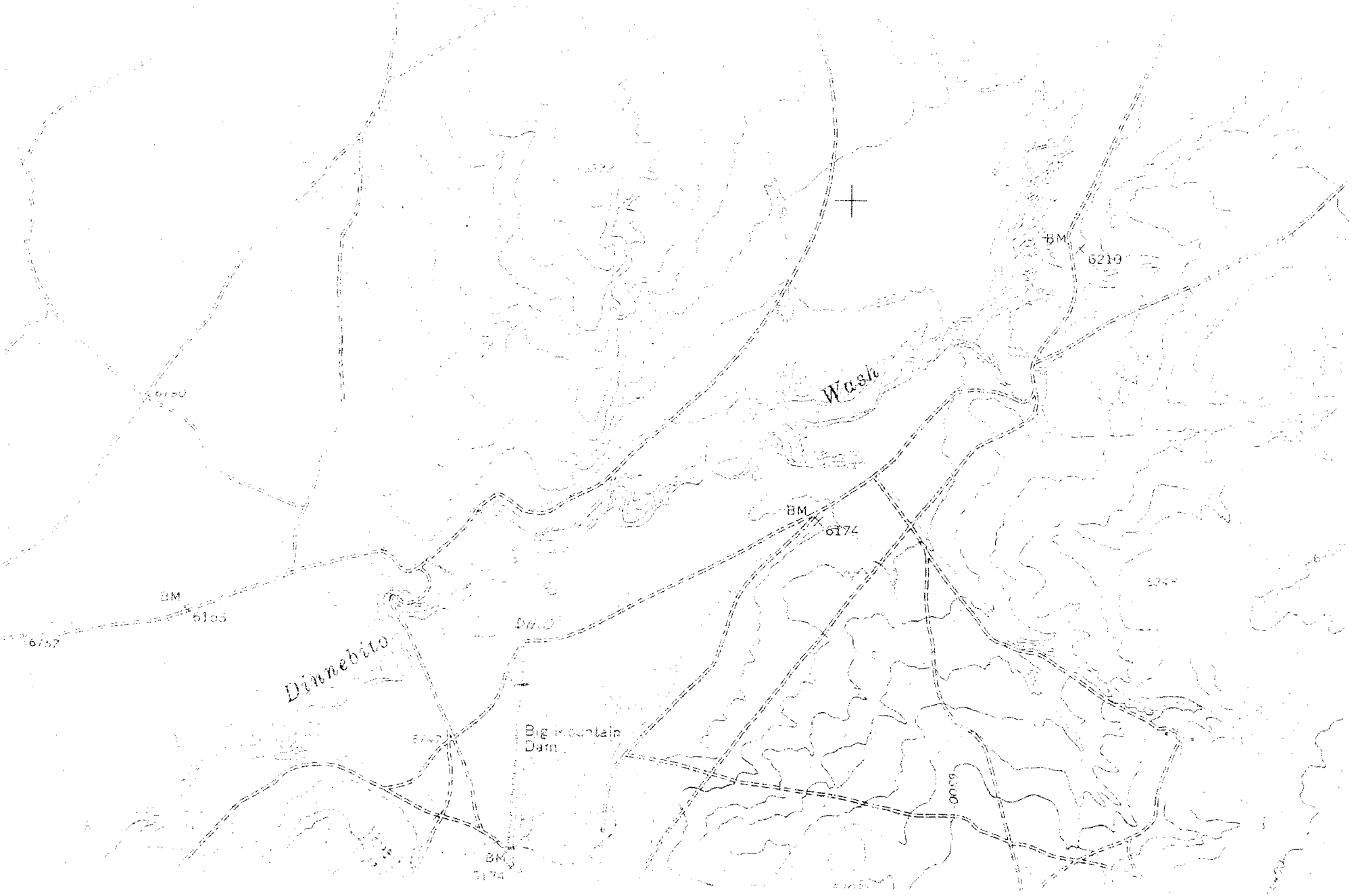
5/5/2009

ELEVATION-AREA-CAPACITY USING THE CONIC METHOD

SITE: Historic Dam on Dinnebito Wash at HIA Site DW10

| ELEV. (FEET) | CALC. AREA (AC) | CALC. CAPACITY (AF) |
|---|---|---|
| 6125.0 | 0.0 | 0.0 |
| 6126.0 | 0.0 | 0.0 |
| 6127.0 | 0.1 | 0.1 |
| 6128.0 | 0.3 | 0.3 |
| 6129.0 | 0.6 | 0.8 |
| 6130.0 | 0.9 | 1.6 |
| 6131.0 | 1.3 | 2.7 |
| 6132.0 | 1.8 | 4.3 |
| 6133.0 | 2.4 | 6.4 |
| 6134.0 | 3.0 | 9.1 |
| 6135.0 | 3.7 | 12.4 |
| 6136.0 | 4.5 | 16.6 |
| 6137.0 | 5.4 | 21.5 |
| 6138.0 | 6.3 | 27.3 |
| 6139.0 | 7.3 | 34.1 |
| 6140.0 | 8.4 | 42.0 |
| 6141.0 | 9.7 | 51.1 |
| 6142.0 | 11.1 | 61.5 |
| 6143.0 | 12.6 | 73.3 |
| 6144.0 | 14.2 | 86.8 |
| 6145.0 | 15.9 | 101.9 |
| 6146.0 | 17.7 | 118.7 |
| 6147.0 | 19.6 | 137.4 |
| 6148.0 | 21.6 | 158.0 |
| 6149.0 | 23.7 | 180.7 |
| 6150.0 | 25.9 | 205.5 |
| 6151.0 | 28.2 | 232.5 |
| 6152.0 | 30.6 | 261.9 |
| 6153.0 | 33.0 | 293.7 |
| 6154.0 | 35.6 | 328.0 |
| 6155.0 | 38.2 | 364.9 |
| 6156.0 | 41.0 | 404.5 |
| 6157.0 | 43.9 | 446.9 |
| 6158.0 | 46.8 | 492.3 |
| 6159.0 | 49.9 | 540.6 |
| 6160.0 | 53.0 | 592.0 ← |
| 6161.0 | 59.8 | 648.4 |
| 6162.0 | 67.1 | 711.8 |
| 6163.0 | 74.7 | 782.7 |
| 6164.0 | 82.8 | 861.4 |
| 6165.0 | 91.3 | 948.5 |
| 6166.0 | 100.2 | 1,044.2 |
| 6167.0 | 109.5 | 1,149.1 |
| 6168.0 | 119.3 | 1,263.5 |
| 6169.0 | 129.4 | 1,387.8 |
| 6170.0 | 140.0 | 1,522.5 |

5/5/2009


BM
6210
Wash
BM
6174
BM
5165
6757
Dinnebito
Big Mountain
Dam
6500
BM
5174

# EXHIBIT 5

# CHAPTER 11. PONDS AND RESERVOIRS

Compiled by: George M. Renfro, Agricultural Engineer, SCS, Fort Worth, Tex.

## Contents

## PART I - GENERAL


| | Page |
|---|---|
| Definition | 11-1 |
| Uses for Water on the Farm | 11-1 |
| Water for Livestock | 11-1 |
| Irrigation Storage | 11-2 |
| Regulation of Irrigation Streams | 11-2 |
| Field and Orchard Spraying | 11-3 |
| Fish Production | 11-3 |
| Fire Protection | 11-4 |
| Recreation | 11-4 |
| Waterfowl and other Wildlife | 11-6 |
| Multiple Uses | 11-6 |
| Legal Requirements | 11-6 |
| Types of Ponds and Reservoirs | 11-6 |
| Selecting the Pond Site | 11-7 |
| Preliminary Site Studies | 11-8 |
| Adequacy of the Drainage Area | 11-8 |
| Minimum Pond Depth | 11-8 |
| Drainage Area Protection | 11-9 |
| Adequacy of Pond Capacity | 11-9 |
| Engineering Surveys | 11-9 |


## PART II - EMBANKMENT PONDS


| | |
|---|---|
| Geologic Investigations | 11-12 |
| Soils in the Ponded Area | 11-12 |
| Studies of Foundation Conditions | 11-12 |
| Availability of Suitable Fill Material | 11-13 |
| Soils in the Spillway Area | 11-13 |
| Records of Soils Investigations | 11-13 |
| Spillway Requirements | 11-13 |
| Trickle Tubes | 11-13 |

A check should be made to insure that no buried pipelines or cables exist in the construction area. These might be broken or punctured by the excavating equipment, resulting not only in damage to the utility but in injury to the operator of the equipment as well. Where such a site must be used, the utility owners should be contacted prior to foundation investigation or construction.

## 5. PRELIMINARY SITE STUDIES

In addition to the considerations mentioned for the selection of a pond location, there are other physical characteristics of the drainage area and the pond site which should be investigated before the final selection is made.

### ADEQUACY OF THE DRAINAGE AREA

Where surface runoff is the main source of water supply, the contributing drainage area should be large enough to yield sufficient runoff to maintain the water supply in the pond during all periods of intended use. The drainage area should not be so large, however, as to require large and expensive overflow structures to bypass runoff safely.

The amount of runoff that can be expected annually from a watershed of a given area depends on so many factors that no set rule can be given for its determination. The physical characteristics of the watershed that have a direct effect on the yield of water are land slopes, soil infiltration, vegetal cover and surface storage. Storm characteristics such as the amount, intensity and duration of rainfall also affect water yield. All of these characteristics vary widely throughout the United States.

Exhibit 11-1 can be used as a general guide for estimating the size of a watershed required for each acre-foot of capacity in a pond or reservoir to maintain normal pool level, if more precise local data is not available. The map does not apply when ponds are used for irrigation.

### MINIMUM POND DEPTH

For a permanent water supply, it is necessary to provide sufficient water depth to meet the intended use and to offset seepage and evaporation losses. These losses vary in different sections of the country and also from year to year in any section. Table 11-3 shows recommended minimum depths of water for farm ponds, assuming normal seepage and evaporation losses. Greater depths are desirable where a year-round water supply is essential or where seepage losses may exceed three inches per month. See State Standards and Specifications for local minimum depths.

Table 11-3. Recommended minimum depths of ponds and reservoirs

| Climate | Annual Rainfall (inches) | Minimum Water Depth Over 25 percent of the Area (feet) |
|---|---|---|
| Superhumid | Over 60 | 6 |
| Humid | 40 - 60 | 8 |
| Subhumid - Moist | 30 - 40 | 9 |
| Subhumid - Dry | 20 - 30 | 10 |
| Semiarid | 10 - 20 | 12 |
| Arid | Under 10 | 14 |

DRAINAGE AREA PROTECTION

To maintain the required depth and capacity of a farm pond, it is necessary that the inflow be reasonably free from sediment. The best protection is adequate erosion control on the contributing drainage area. Land under a cover of permanent vegetation, such as trees or grasses, makes the most desirable drainage area. If such an area is not available, cultivated areas that are protected by necessary conservation practices, such as terracing, contour tillage, strip-cropping, conservation cropping systems, vegetated desilting areas, and other soil-improvement practices, may be utilized as a last resort. Allowance should be made for the expected sedimentation during the effective life of the structure.

ADEQUACY OF POND CAPACITY

To insure that the water stored in a farm pond will be adequate to satisfy the intended uses, a reasonable estimate of the pond capacity should be made. The following is a simple method of estimating capacity.

The pond-full water elevation is established and the waterline is staked at this elevation. The widths of the valley at this elevation are measured at regular intervals and these measurements are used to compute the pond-full surface area in acres. The surface area is multiplied by 0.40 times the maximum water depth at the dam. For example, a pond with a surface area of 3.2 acres and a depth of 12.5 feet at the dam would have an approximate capacity of 0.4 x 12.5 x 3.2 = 16.0 ac.ft. (1 acre-foot = 325,857 gallons). If a more accurate answer is required, the surface area at successive intervals of elevation may be determined and the average end-area method may be used to compute the volume.

## 6. ENGINEERING SURVEYS

Once the location of the pond or reservoir has been determined, sufficient engineering surveys should be made so that the dam, spillway and other features of the pond can be planned.

Surveys for embankment-type ponds normally will consist of a profile of the centerline of the dam, a profile of the centerline of the earth

# EXHIBIT 6

# MEMORANDUM

TO: Paul Clark, OSM

FROM: Neil Blandford and Chris Wolf

DATE: June 20, 2006

SUBJECT: Summary of Well Completion Data for Polacca Wells No. 5 and 6

Water supply wells for the Village of Polacca were investigated by Daniel B. Stephens & Associates, Inc (DBS&A) to determine the source of elevated total dissolved solids (TDS) and the lithology of water producing zones. DBS&A reviewed existing records and conducted a borehole geophysics analysis (DBS&A, 1998b). The primary issues investigated were the quality of well completion and sources of water in the well. The primary aquifer at Polacca is the Navajo Sandstone aquifer system (N-aquifer). The Dakota Sandstone aquifer system (D-aquifer) is stratigraphically higher and is shallower than the N-aquifer. The N-aquifer produces high-quality (low-TDS) water, but the D-aquifer contains poorer quality groundwater and is typically "cased off" to prevent mixing of water between the aquifers.

## Well Completion

Polacca wells No. 5 and 6 were installed in 1986 within 500 feet of each other. The wells are telescoped from a 10-inch casing to an 8-inch casing. The 10-inch casing is grouted in the annular space. The 8-inch casing has no annular seal, so it is essentially hanging in an open borehole. Completion details presented herein (Table 1 and the attached well completion diagram) are primarily based upon a video log run in 1997. Some of the entries in Table 1 are queried because suspended materials in the water column obscured the view of the well casing in the video log.

**Table 1. Polacca Supply Wells Nos. 5 and 6 Completion Details**
**Hopi Tribe, Arizona**

| Detail | Polacca No. 5 | Polacca No. 6 |
|---|---|---|
| Total depth (ft bgs) | 910 | 915 |
| Casing diameter (inches) | 10 | 10 |
| Casing reduction (ft bgs) | 636 | 626 |
| Screen diameter (inches) | 8 | 8 |
| Screen interval (ft bgs) | 825(?)–910 | 715–717, 760–915 |

ft bgs = Feet below ground surface

## Lithologic Interpretation

The U.S. Geological Survey (USGS) originally had designated the Polacca wells as D-aquifer wells (USGS, 1997a), but subsequently reinterpreted the stratigraphy and decided that the Polacca wells were N-aquifer wells based on a geophysical log from the Mishongovi Well west of Polacca (USGS, 1997b). The USGS also provided a lithologic profile to the Hopi Tribe indicating that the Navajo Sandstone was 215 feet thick and exposed in Polacca No. 4 (USGS, 1997c). DBS&A confirmed the N-aquifer status of nearby Polacca wells No. 5 and 6 during a water quality and geophysical investigation (DBS&A, 1998b).

**Table 2. Lithology of Polacca Wells Nos. 5 and 6**
**Hopi Tribe, Arizona**

| Formation | Top of Formation (ft bgs) | Bottom of Formation (ft bgs) | Thickness (feet) |
|---|---|---|---|
| Valley Fill | 0 | 30 | 30 |
| Mancos Shale | 30 | ? | ? |
| Dakota Sandstone | ? | 338 | ? |
| Cow Springs Sandstone | 338 | 542 | 204 |
| Entrada Sandstone | 542 | 692 | 150 |
| Carmel Formation | 692 | 771 | 79 |
| Navajo Sandstone | 771 | 910+ | 139+ |

ft bgs = Feet below ground surface

## Water Quality Issues

Based on our geophysical investigation of Polacca wells No. 5 and 6, DBS&A concluded that both wells predominantly produce water from the N-aquifer (DBS&A, 1998b). After these wells were completed, it was noticed that water obtained from well No. 6 was poorer quality (higher TDS) than that obtained from well No. 5. Because the differences in water quality are not related to geologic structures such as faults (as determined from the good correlation of gamma-neutron logs run in each well), it was suspected that the marked differences in water quality might be attributable to poor well completion that could allow for vertical mixing of poor water quality from the D-aquifer to mix with the better quality water of the N-aquifer. Because the 10-inch casing and associated annular seal was intended to seal off the D-aquifer, the grout competency of this zone was investigated using a cement bond log for each well.

Polacca well No. 6 appears to have a poor cement seal based upon the cement bond log. The cement bond log indicated a poor seal from about 400 feet below ground surface (ft bgs) to the reduction point at 626 ft bgs, thereby indicating the strong potential for the downward leakage of water along the annulus. The cement bond log for Polacca well No. 5 indicated a better seal, and downward leakage from above the reduction point at 636 ft bgs was not suspected.

DBS&A concluded that two mechanisms are allowing the mixing of D-aquifer and N-aquifer water in Polacca well No. 6. The first mechanism is downward seepage from the Entrada Sandstone exposed below the reduction point at top of the 8-inch casing. Below the reduction point there is no annular seal, so any water from the D-aquifer from a leaking cement seal or that exposed in the adjacent open borehole will be able to reach the perforated section of the casing deeper in the borehole. The second mechanism is vertical seepage along the annular space from zones of D-aquifer above the casing reduction point.

While working at the Hopi High School, DBS&A observed that water quality became better (TDS decreased) as pumping progressed. This same trend is probably true at Polacca wells No. 5 and 6 because the High School well is completed in a similar manner. The majority of water pumped from each well is believed to be from the N-aquifer, although a minor volume of the flow would be expected to travel through the annular space behind the casing and contribute to the produced water.

**References**

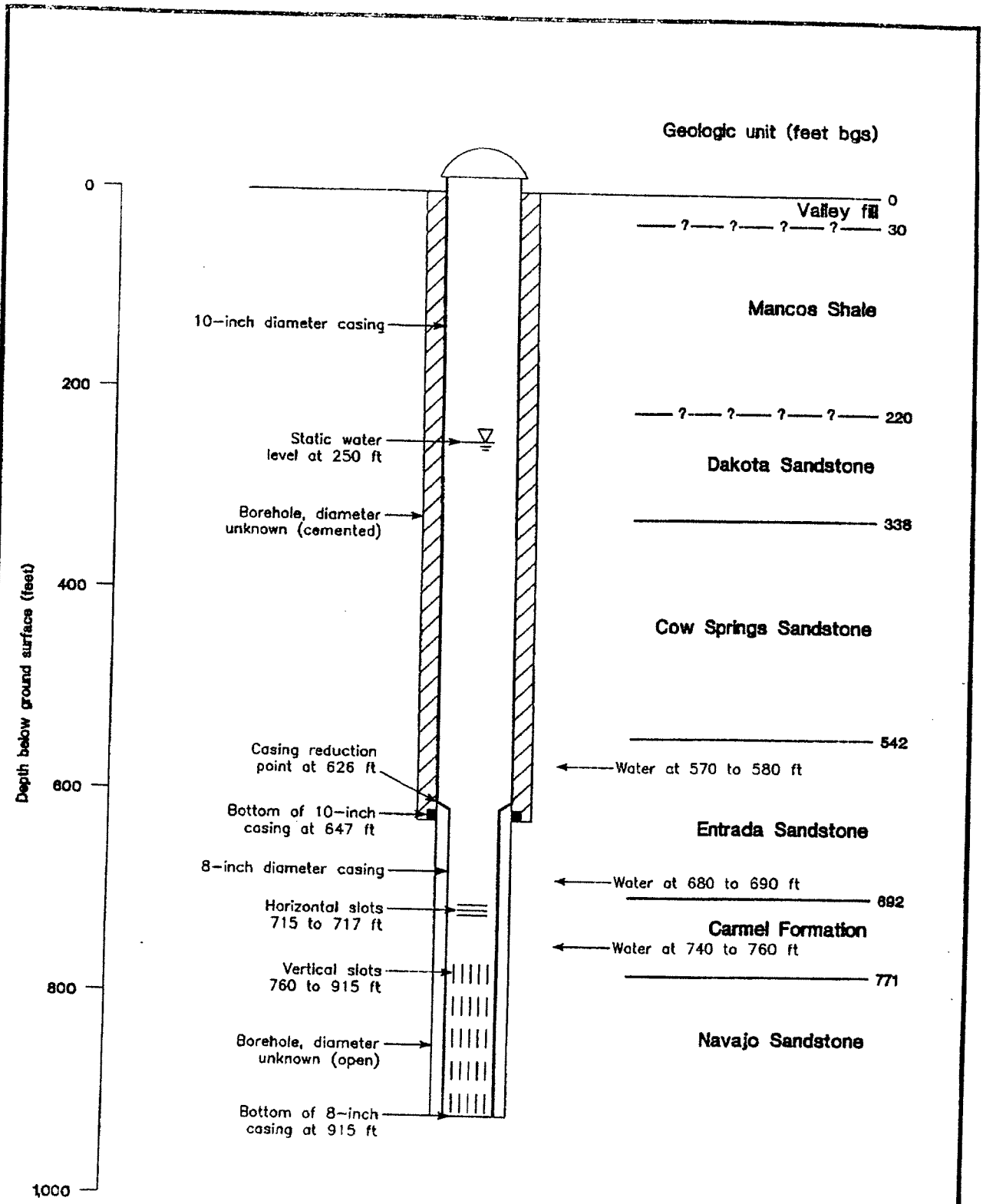
Daniel B. Stephens & Associates, Inc. (DBS&A). 1998a. *Geophysical evaluation of Civic Center and Keams Canyon #2 wells*. Prepared for the First Mesa Consolidated Villages Water Program, Polacca, Arizona. January 14, 1998.

DBS&A. 1998b. *Geophysical evaluation of Polacca Wells #5 and #6*. Prepared for the Hopi Water Resources Department, Kykotsmovi, Arizona. April 24, 1998.

U.S. Geological Survey (USGS). 1997a. Letter from G. Litton to Nat Nutongla, Hopi Water Resources Department, regarding Proposed site for the Hopi hospital, Polacca, Arizona. Water Resources Division, Flagstaff, Arizona. January 2, 1997.

USGS. 1997b. Letter from G. Litton to Nat Nutongla, Hopi Water Resources Department, regarding Proposed site for the Hopi hospital, Polacca, Arizona. Water Resources Division, Flagstaff, Arizona. February 5, 1997

USGS. 1997c. Letter from G. Litton to Nat Nutongla, Hopi Water Resources Department, regarding Lithologic profile along Hwy 264 from Hotevilla to Keams Canyon, Arizona. Water Resources Division, Flagstaff, Arizona. August 20, 1997




bgs = below ground surface

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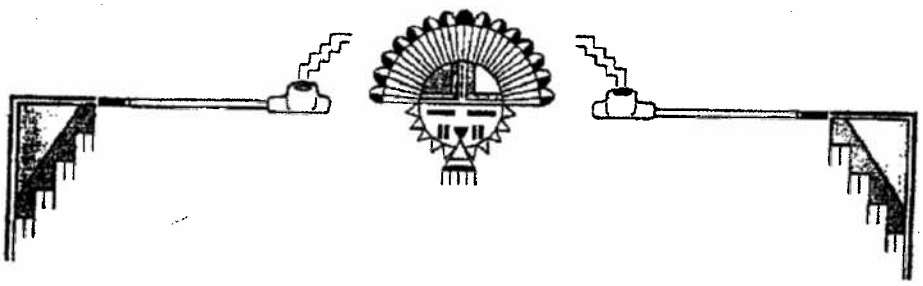
HOPI TRIBE

**Polacca Well #6 Construction Details**

DANIEL B. STEPHENS & ASSOCIATES, INC.
1-14-98
JN 7081

# EXHIBIT 7

Office of General Counsel



# Constitution and By-laws of the Hopi Tribe

Approved December 19, 1936
and as Amended on
August 1, 1969
February 14, 1980
December 7, 1993

RECEIVED
BY GENERAL COUNSEL
MAR 21 1994
AM PM
7 8 9 10 11 12 1 2 3 4 5 6

United States
Department of the Interior
Office of Indian Affairs

## PREAMBLE

This Constitution, to be known as the Constitution and By-Laws of the Hopi Tribe, is adopted by the self-governing Hopi and Tewa Villages of Arizona to provide a way of working together for peace and agreement between the villages, and of preserving the good things of Hopi life, and to provide a way of organizing to deal with modern problems, with the United States Government and with the outside world generally.

## ARTICLE I - JURISDICTION

The authority of the Tribe under this Constitution shall cover the Hopi villages and such land as shall be determined by the Hopi Tribal Council in agreement with the United States Government and the Navajo Tribe, and such lands as may be added thereto in future. The Hopi Tribal Council is hereby authorized to negotiate with the proper officials to reach such agreement, and to accept it by a majority vote.

## ARTICLE II - MEMBERSHIP

SECTION 1. The following persons shall be enrolled members of the Hopi Tribe:

All persons whose names appear on the Census Roll of the Hopi Tribe as of December 31, 1937, as corrected and adopted by the Hopi Tribal Council; PROVIDED, That subsequent corrections may be made to said roll by the Hopi Tribal Council at any time with the approval of the Secretary of Interior.

SECTION 2. After the effective date of this Constitution, the following persons shall be eligible for enrolled membership in the Hopi Tribe.

(a) All persons of a one-fourth (1/4) degree Hopi Indian blood or more, or one-fourth (1/4) degree Tewa Indian blood or more, or one-fourth (1/4) degree Hopi-Tewa Indian blood or more combined, born after December 31, 1937, who are not enrolled with any other Indian Tribe.

(b) For the purpose of determining enrolled membership, Hopi Indian blood, Tewa Indian blood, and Hopi - Tewa Indian blood shall mean biological lineal descent from any Hopi or Tewa Indian person whose name appears on the Corrected Membership Roll of the Hopi Tribe as defined in Section 1.

SECTION 3. Persons Already Enrolled. All persons properly enrolled as members of the Hopi Tribe as of the effective date of this Constitution shall continue to be members.

SECTION 4. Village Membership. Village membership shall be determined by the individual Hopi Villages.

SECTION 5. Hopi Enrollment Ordinance. The Hopi Tribal Council shall adopt, and from time to time may amend, an enrollment ordinance not inconsistent with this Article, setting forth the manner in which this Article shall be implemented and administered.

## ARTICLE III - ORGANIZATION

SECTION 1. The Hopi Tribe is a union of self-governing villages sharing common interests and working for the common welfare of all. It consists of the following recognized villages:

First Mesa (consolidated villages of Walpi, Shitchumovi, and Tewa).

Mishongnovi.

Sipaulavi.

Shungopavi.

Oraibi.

Kyakotsmovi.

Bakabi.

Hotevilla.

Moenkopi.

SECTION 2. The following powers which the Tribe now has under existing law or which have been given by the Act of June 18, 1934, (48 Stat. 984), and acts amendatory thereof or supplemental thereto, are reserved to the individual villages:

(a) To appoint guardians for orphan children and incompetent members.

(b) To adjust family disputes and regulate family relations of members of the villages.

(c) To regulate the inheritance of property of the members of the villages.

(d) To assign farming land, subject to the provisions of Article VII.

SECTION 3. Each village shall decide for itself how it shall be organized. Until a village shall decide to organize in another manner, it shall be considered as being under the traditional Hopi organization, and the Kikmongwi of such village shall be recognized as its leader.

SECTION 4. Any village which does not possess the traditional Hopi self-government, or which wishes to make a change in that government or add something to it, may adopt a Village Constitution in the following manner: A Constitution, consistent with this Constitution and

By-Laws, shall be drawn up, and made known to all the voting members of such village, and a copy shall be given to the Superintendent of the Hopi jurisdiction. Upon the request of the Kikmongwi of such village, or of 25% of the voting members thereof, for an election on such Constitution, the Superintendent shall make sure that all members have had ample opportunity to study the proposed Constitution. He shall then call a special meeting of the voting members of such village, for the purpose of voting on the adoption of the proposed Constitution, and shall see that there is a fair vote. If at such referendum, not less than half of the voting members of the village cast their votes, and if a majority of those voting accepts the proposed Constitution, it shall then become the Constitution of that village, and only officials chosen according to its provisions shall be recognized.

The village Constitution shall clearly say how the Council representatives and other village officials shall be chosen, as well as the official who shall perform the duties placed upon the Kikmongwi in this Constitution. Such village Constitution may be amended or abolished in the same manner as provided for its adoption.

## ARTICLE IV - THE TRIBAL COUNCIL

SECTION 1. The Hopi Tribal Council shall consist of a Chairman, Vice Chairman, and representatives from the various villages. The number of representatives from each village shall be determined accordingly to its population, as follows: villages of 50 to 250 population, one (1) representative; villages of 251 to 500 population, two (2) representatives; villages of 501 to 750 population, three (3) representatives; villages of over 750 population, four (4) representatives.

The representation in the first Tribal Council shall be as follows:

| | |
|---|---|
| First Mesa | 4 |
| Mishongnovi | 2 |
| Sipaulavi | 1 |
| Shungopavi | 2 |
| Oraibi | 1 |
| Kyakotsmovi | 2 |
| Bakabi | 1 |
| Hotevilla | 2 |
| Moenkopi | 2 |

SECTION 2. The term of office of the representatives shall be two (2) years, except that at the first election or choosing of representatives following the adoption of this section, approximately one-half of the representatives shall serve for a term of one (1) year. The determination as to which representatives shall serve for one (1) year shall be made by the Tribal Council and announced to each village Kikmongwi or Governor on or before the first day of October 1969. Representatives may serve any number of terms in succession or otherwise.

SECTION 3. Each representative must be a member of the village which he represents. He must be twenty-five (25) years or more of age, and must have lived in the Hopi jurisdiction for not less than two (2) years before taking office, and must be able to speak the Hopi language fluently.

SECTION 4. Each village shall decide for itself how it shall choose its representatives, subject to the provisions of Section 5. Representatives shall be recognized by the Council only if they are certified by the Kikmongwi of their respective villages. Certifications may be made in writing or in person.

SECTION 5. One (1) representative of the Village of Moenkopi shall be selected from the Lower District, and certified by the Kikimongwi of Moenkopi, and one (1) representative shall be selected by the Upper district, and certified by the Official whom that District may appoint, or who may be specified in a village Constitution adopted under the provisions of Article III, Section 4. This section may be repealed, with the consent of the Tribal Council, by vote of a two-thirds majority at a meeting of the voting members of Moenkopi Village called and held subject to the provisions of Article III, Section 4.

SECTION 6. No business shall be done unless at least a majority of the members are present.

SECTION 7. The Chairman and Vice-Chairman shall be elected by secret ballot by all members of the Hopi Tribe. The Tribal Council shall choose from its own members or from other members of the Tribe, a secretary, treasurer, sergeant-at-arms and interpreters and such other officers and committees as it may determine necessary, subject to the provisions of the By-Laws, Article I.

SECTION 8. All members of the Hopi Tribe eighteen (18) years of age or over shall be qualified to vote in any election or referendum other than village elections and referendums under such rules and regulations as may be prescribed by the Hopi Tribal Council .

SECTION 9. The Chairman and Vice Chairman shall serve for a term of four (4) years. Candidates for the offices of Chairman and Vice Chairman shall be members of the Hopi Tribe, twenty-five (25) years of age or older and must be able to speak the Hopi language fluently. Each candidate for either of said offices must also have lived on the Hopi Reservation for not less than two years immediately preceding his announcement of such candidacy.

SECTION 10. Candidates for the offices of Chairman and Vice Chairman may declare their candidacy by filing with the tribal Secretary or tribal Chairman or Vice Chairman a petition signed by at least ten (10) adult members of the tribe at least 15 days before the date set for the election. It shall be the duty of the Secretary to post the names of the qualified candidates for both the primary and final elections in a public place in each village at least ten (10) days prior to the election.

SECTION 11. A primary election shall be held on the first Wednesday in November in 1969 and on the first Wednesday in November in every fourth year thereafter, PROVIDED. That, no primary election shall be held in the years when there shall be no more than two (2) candidates for either of the offices of Chairman and Vice Chairman. The two (2) candidates in a primary election receiving the highest number of votes for each of said offices of Chairman and Vice Chairman shall have their names entered in the final election. In the event there are not more than two (2) candidates for either of such offices those candidates with no more than one (1) competing candidate shall have their names entered in the final election without the necessity of a primary election.

SECTION 12. The general election shall be held on the third Wednesday in November 1969 and on the third Wednesday in every fourth year thereafter.

SECTION 13. Inauguration of the Chairman and Vice Chairman shall take place at the first regular Tribal Council meeting following their election.

## ARTICLE V - VACANCIES AND REMOVAL FROM OFFICE

SECTION 1. Any Chairman, Vice Chairman, representative or other officer found guilty in a tribal or other court of a misdemeanor involving dishonesty, of a felony, or of drunkenness, shall be automatically removed from office and the Council shall refuse to recognize him.

SECTION 2. Any officer or representative may be removed from office for serious neglect of duty, by a vote of not less than two-thirds of the Council, after the officer to be so removed has been given full opportunity to hear the charges against him and to defend himself before the Council.

SECTION 3. Vacancies occurring for any reason among the representatives shall be filled for the rest of the term by the village concerned, in the same manner as a representative from that village is ordinarily chosen.

Vacancies occurring for any reason among the officers appointed by the Council shall be filled by the Council.

Vacancies occurring for any reason in the offices of Chairman and Vice Chairman or in the office of any other officer shall be filled for the rest of the term in the same manner as those officers are ordinarily chosen.

## ARTICLE VI - POWERS OF THE TRIBAL COUNCIL

SECTION 1. The Hopi Tribal Council shall have the following powers which the Tribe now has under existing law or which have been given to the Tribe by the Act of June 18, 1934. The Tribal Council shall exercise these powers subject to the terms of this Constitution and to the Constitution and Statutes of the United States.

(a) To represent and speak for the Hopi Tribe in all matters for the welfare of the Tribe, and to negotiate with the Federal, State, and local governments, and with the councils or governments of other tribes.

(b) To employ lawyers, the choice of lawyers and fixing of fees to be subject to the approval of the Secretary of the Interior so long as required by Federal law.

(c) To prevent the sale, disposition, lease or encumbrance of tribal lands, or other tribal property.

(d) To advise with the Secretary of the Interior and other governmental agencies upon all appropriation estimates or Federal projects for the benefit of the Tribe, before the submission of such estimates to the Office of Management and Budget or to Congress.

(e) To raise and take care of a tribal council fund by accepting grants or gifts from any person, State, or the United States Government, or by charging persons doing business within the Reservation reasonable license fees.

(f) To use such Tribal Council fund for the welfare of the Tribe, and for salaries or authorized expenses of tribal officers. All payments from the Tribal Council fund shall be a matter of public record at all times.

(g) To make ordinances to protect the peace and welfare of the Tribe, and to set up courts for the settlement of claims and disputes, and for the trial and punishment of Indians within the jurisdiction charged with offenses against such ordinances.

(h) To act as a court to hear and settle claims or disputes between villages in the manner provided in Article VIII.

(i) To provide by ordinance for removal or exclusion from the jurisdictionof any non-members whose presence may be harmful to the members of the Tribe.

(j) To regulate the activities of voluntary cooperative associations of members of the Tribe for business purposes.

(k) To protect the arts, crafts, traditions, and ceremonies of the Hopi Indians.

(l) To delegate any of the powers of the Council to committees or officers, keeping the right to review any action taken.

(m) To request a charter of incorporation to be issued as provided in the Act of June 18, 1934.

(n) To adopt resolutions providing the way in which the Tribal Council itself shall do its business.

SECTION 2. Any resolution or ordinance which, by the terms of this Constitution, is subject to review by the Secretary of the Interior, shall be given to the Superintendent of the jurisdiction, who shall, within ten (10) days thereafter, approve or disapprove the same.

If the Superintendent shall approve any ordinance or resolution, it shall thereupon become effective, but the Superintendent shall send a copy of the same, bearing his endorsement, to the Secretary of the Interior, who may, within ninety (90) days from the date of enactment, veto said ordinance or resolution for any reason by notifying the Tribal Council of his decision.

If the Superintendent shall refuse to approve any ordinance or resolution submitted to him, within ten (10) days after enactment, he shall report his reasons to the Tribal Council. If the Tribal Council thinks these reasons are not sufficient, it may, by a majority vote, refer the ordinance or resolution to the Secretary of the Interior, who may, within ninety (90) days from the date of its enactment, approve the same in writing, whereupon the said ordinance or resolution shall become effective.

SECTION 3. The Hopi Tribal Council may exercise such further powers as may in the future be delegated to it by the members of the Tribe or by the Secretary of the Interior, or any other duly authorized official or agency of the State or Federal Government.

SECTION 4. Any rights and powers which the Hopi Tribe of Indians now has, but which are not expressly mentioned in this Constitution, shall not be lost or limited by this Article, but may be exercised by the members of the Hopi Tribe of Indians through the adoption of appropriate by-laws and constitutional amendments.

## ARTICLE VII - LAND

SECTION 1. Assignment of use of farming land within the traditional clan holdings of the Villages of First Mesa, Mishongnovi, Sipaulavi, and Shungopavi, and within the established village holdings of the Villages of Kyakotsmovi, Bakabi, Oraibi, Hotevilla, and Moenkopi, as in effect at the time of approval of this Constitution, shall be made by each village according to its established custom, or such rules as it may lay down under a village Constitution adopted according to the provisions of Article III, Section 4. Unoccupied land beyond the clan and village holdings mentioned shall be open to the use of any member of the Tribe, under the supervision

of the Tribal Council. Nothing in this Article shall permit depriving a member of the Tribe of farming land actually occupied and beneficially used by him at the time of approval of this Constitution, but where an individual is occupying or using land which belongs to another by agreement with the owner, that land shall continue to belong to that owner.

SECTION 2. In order to improve and preserve the range, range land shall be supervised by the Tribal Council in cooperation with the various United States Government agencies.

SECTION 3. All springs shall be considered the property of the Tribe, and no individual or group of individuals shall be allowed to prevent the reasonable use of any spring by members of the Tribe generally, but the individual who develops a spring, or on whose land it is, shall have the first use of it.

SECTION 4. The administration of this Article shall be subject to the provisions of Section 6 of the Act of June 18, 1934.

## ARTICLE VIII - DISPUTES BETWEEN VILLAGES

SECTION 1. When a dispute arises between villages over any matter, the Kikmongwi of any village party to the dispute may inform the Chairman of the Tribal Council of the nature of the dispute, and ask him to call a special meeting of the Council to settle the matter.

The Chairman shall thereupon call a special meeting of the Council, to be held on the eighth day from the day of such request, at which meeting he, and the Council representatives or other persons chosen by each village party to the dispute to speak for it before the Council, may summon all witnesses having evidence to give in the matter, and may examine them.

When the Council has heard all the evidence and examined the witnesses to its satisfaction, it shall hold a secret meeting which shall not be attended by the representatives of the villages party to the dispute, and after full and careful consideration and discussion, shall vote on a decision. Such decision shall become effective when it is carried by a majority of the Council members present. The Council shall keep a record of the evidence and the reasons for its decision.

SECTION 2. If both the Chairman and the Vice Chairman are representatives of villages party to the dispute, the Council shall elect a temporary Chairman to serve for the duration of the trial.

SECTION 3. If any village party to the dispute feels that the decision of the Council in such case is unjust, the Kikmongwi of that village may notify the Superintendent within ten (10) days and the decision of the Council shall then be subject to review by the Secretary of the Interior, within ninety (90) days thereafter, in the manner provided in Article VI, Section 2.

## ARTICLE IX - BILL OF RIGHTS

SECTION 1. All resident members of the Tribe shall be given equal opportunities to share in the economic resources and activities of the jurisdiction.

SECTION 2. All members of the Tribe shall be free to worship in their own way, to speak and write their opinion, and to meet together.

## ARTICLE X - AMENDMENT

Any representative may propose an amendment to this Constitution and By-Laws at any meeting of the Council. Such proposed amendment may be discussed at that meeting, but no vote shall be taken on it until the next following meeting of the Council. If the Council shall then approve such proposed amendment by a majority vote, it shall request the Secretary of the Interior to call a referendum for accepting or rejecting such amendment. It shall then be the duty of the Secretary of the Interior to call such referendum, at which the proposed amendment may be adopted subject to the Secretary's approval. in the same manner as provided for the adoption and approval of this Constitution and By-Laws.

## ARTICLE XI - TAXATION

SECTION 1. The Hopi Tribal Council shall, subject to the express limitations contained in this Constitution and the laws of the United States, have the power to impose duties, fees, taxes, and assessments on any person, corporation or association residing or doing business within the Hopi Reservation, PROVIDED, That the Tribal Council shall not have the power to impose a personal income tax.

SECTION 2. No tax imposed by the Tribal Council under Section 1 of this Article shall become effective unless approved by a majority vote of the eligible voters of the Hopi Tribe voting in a referendum called for that purpose pursuant to Section 8 of Article IV of this Constitution.

# BY-LAWS OF THE HOPI TRIBE

## ARTICLE I - DUTIES AND QUALIFICATIONS OF OFFICERS

SECTION 1. The Chairman shall preside over all meetings of the Tribal Council. He shall perform all duties of a Chairman fairly and impartially, and exercise any authority delegated to him by the Council.

He shall vote only in case of a tie.

SECTION 2. The Vice Chairman shall help the Chairman in his duties when called upon to do so, and in the absence of the Chairman shall act as Chairman with all the attendant powers and duties.

SECTION 3. The representatives shall perform the duties of the Council, set forth in this Constitution and By-Laws. They shall inform the people of their villages of the matters discussed and the actions taken, and they shall fairly and truly represent the people of their villages.

SECTION 4. The Secretary shall write all tribal correspondence, as authorized by the Council, and shall keep an accurate record of all action of regular and special meetings of the Council. He shall keep a copy of such records in good order and available to the general public and shall send another copy of them, following each meeting of the Council, to the Superintendent of the jurisdiction. He shall have a vote in the Council only if he is a regular representative.

The Secretary must be a resident member of the Hopi Tribe, and must be able to speak the Hopi language fluently, and to read and write English well.

SECTION 5. The Treasurer shall receive, receipt for, and take care of all funds in the custody of the Council, and deposit them in a bank or elsewhere as directed by the Council. He shall make payments therefrom only when authorized by a resolution of the Council, and in the manner authorized. He shall keep a faithful record of such funds, and shall report fully on receipts, payments, and amounts in hand at all regular meetings of the Council and whenever requested to do so by the Council. His accounts shall be open to public inspection.

He shall have a vote in the Council only if he is a regular representative.

The Treasurer may be required by the Council to give a bond satisfactory to the Council and to the Commissioner of Indian Affairs.

The Treasurer must be a resident member of the Hopi Tribe, and must be able to speak the Hopi language fluently and to read and write English well.

SECTION 6. The interpreter or interpreters shall be resident members of the Hopi Tribe, and shall be able to interpret fluently and accurately in the Hopi, English, and Navajo languages, and shall do so whenever requested by the Council. Interpreters shall have a vote in the Council only when they are regular representatives.

SECTION 7. The Sergeant-at-Arms, at the orders of the Chairman, shall enforce order in the Council, and shall summon all persons required to appear before the Council, and deliver notices of special meetings, and perform such other duties as may be required of him by the Council. The Sergeant-at-Arms shall be a resident member of the Hopi Tribe, and must be able to speak Hopi fluently, and to speak English.

SECTION 8. The qualifications and duties of all committees and officers appointed by the Council shall be clearly defined by resolution of the Tribal Council at the time the positions are created. Such committees or officers shall report to the Council whenever required.

## ARTICLE II - MEETINGS OF THE COUNCIL

SECTION 1. Regular meetings of the Tribal Council shall be held on the first day of December, March, June, and September, at such places as shall be determined by the Council.

SECTION 2. Within sixteen (16) days after this Constitution goes into effect, the villages shall choose their representatives for the first term of one (1) year, and on the sixteenth day the first meeting of the Council shall be held at Oraibi Day School.

SECTION 3. Special meetings of the Council shall be called by the Chairman in his discretion or at the request of four (4) representatives, or in the case of a dispute between villages, as provided in Article VIII of the Constitution. Notice of special meetings shall be delivered to each representative not less than eight (8) days before such meeting, together with a statement of the business to be discussed thereat.

SECTION 4. All members of the Hopi Tribe may attend any meeting of the Council, but they may not speak, except by invitation of the Council. Non-members may be invited by the Council to attend any meeting and to address it.

SECTION 5. The Council may employ, or may request the Superintendent of the jurisdiction to furnish, a clerk trained in shorthand, to take down verbatim minutes of any meeting.

SECTION 6. When the Council desires advise of, or consultation with, any officer of the Federal Government, it may invite him to attend any meeting and may give him the privilege of the floor.

## ARTICLE III - ORDINANCES AND RESOLUTIONS

All ordinances and resolutions shall be recorded and available at all times for the information and education of the Tribe. Copies of all ordinances shall be posted from time to time in a public place in each village.

## ARTICLE IV - EAGLE HUNTING TERRITORIES AND SHRINES

The Tribal Council shall negotiate with the United States Government agencies concerned, and with other tribes and other persons concerned, in order to secure protection of the right of the Hopi Tribe to hunt for eagles in its traditional territories, and to secure adequate protection for its outlying, established shrines.

## ARTICLE V - ALL-PUEBLO COUNCIL

The Tribal Council may appoint delegates to speak for the Tribe at the All-Pueblo Council, and to report to the Council and the Tribe on all proceedings thereof.

## ARTICLE VI - ADOPTION OF CONSTITUTION AND BY-LAWS

This Constitution and By-Laws, when ratified by a majority vote of the adult members of the Hopi Tribe voting at a referendum called for that purpose by the Secretary of the Interior, PROVIDED, That at least thirty percent (30%) of those entitled to vote shall vote at such referendum, shall be submitted to the Secretary of the Interior, and if approved, shall take effect from the date of approval.

## CERTIFICATION OF ADOPTION

Pursuant to an order, approved September 30, 1936, by the Secretary of the Interior, the attached Constitution and By-laws was submitted for ratification to the Hopi Tribe residing on the Hopi Reservation, and was on October 24, 1936, duly adopted by a vote of 651 for, and 104 against, in an election in which over 30 percent of those entitled to vote cast their ballots, in accordance with section 16 of the Indina Reorganization Act of June 18, 1934, (48 Stat. 984), as amended by the Act of June 15, 1935 (49 Stat. 378).

George Coochise, *Chairman of Election Board.*

Albert Yava, *Secretary of Election Board.*

A. G. Hutton, *Superintendent.*

I, Harold L. Ickes, the Secretary of the Interior of the Unites States of America, by virture of the authority granted me by the act of June 18, 1934 (48 Stat. 984), as amended, do hereby approve the attached Constitution and By-laws of the Hopi Tribe.

All rules and regulations heretofore promulgated by the Interior Department or by the Office of Indian Affairs, so far as they may be incompatible with any of the provisions of the said Constitution and By-laws are hereby declared inapplicable to these Indians.

All officers and employees of the Interior Department are ordered to abide by the provisions of the said Constitution and By-laws.

Approval recommended December 14, 1936.

John Collier, *Commissioner of Indian Affairs.*

Harold L. Ickes, *Secretary of the Interior.* [Seal]

Washington, D.C., December 19, 1936

AMENDMENT
CONSTITUTION AND BYLAWS
of the
HOPI TRIBE
ARIZONA

AUG - 1 1968

AMENDMENT I

Section 3 of Article II, Membership, shall be deleted in its entirety.

The first sentance of Article IV, The Tribal Council, shall be amended to read:

> Section 1. The Hopi Tribal Council shall consist of a chairman, vice chairman and representatives from the various villages.

Section 2 of Article IV, The Tribal Council, shall be amended in its entirety to read as follows:

> Sec. 2. The term of office of the representatives shall be two years, except that at the first election or choosing of representatives following the adoption of this section, approximately one-half of the representatives shall serve for a term of one year. The determination as to which representatives shall serve for one year shall be made by the tribal council and announced to each village Kickmongwi or Governor on or before the first day of October 1969. Representatives may serve any number of terms in succession or otherwise.

Section 7 of Article IV, The Tribal Council, shall be amended to read as follows:

> Sec. 7. The chairman and vice chairman shall be elected by secret ballot by all members of the Hopi Tribe. The tribal council shall choose from its own members or from other members of the tribe, a secretary, treasurer, sergeant-at-arms and interpreters and such other officers and committees as it may determine necessary, subject to the provisions of the Bylaws, Article I.

Article IV, The Tribal Council, shall be amended by adding to it Sections 8, 9, 10, 11, 12 and 13 as follows:

Sec. 8. All members of the Hopi Tribe twenty-one years of age or over shall be qualified to vote in any election or referendum, other than village elections and referendums under such rules and regulations as may be prescribed by the Hopi Tribal Council and approved by the Secretary of the Interior.

Sec. 9. The chairman and vice chairman shall each serve for a term of four years. Candidates for the offices of chairman and vice chairman shall be members of the Hopi Tribe, twenty-five years of age or older and must be able to speak the Hopi language fluently. Each candidate for either of said offices must also have lived on the Hopi Reservation for not less than two years immediately preceding his announcement of such candidacy.

Sec. 10. Candidates for the offices of chairman and vice chairman may declare their candidacy by filing with the tribal secretary or tribal chairman or vice chairman a petition signed by at least ten adult members of the tribe at least 15 days before the date set for the election. It shall be the duty of the secretary to post the names of the qualified candidates for both the primary and final elections in a public place in each village at least ten days prior to the election.

Sec. 11. A primary election shall be held on the first Wednesday in November in 1969 and on the first Wednesday in November in every fourth year thereafter, provided that, no primary election shall be held in the years when there shall be no more than two candidates for either of the offices of chairman and vice chairman.

The two candidates in a primary election receiving the highest number of votes for each of said offices of chairman and vice chairman shall have their names entered in the final election. In the event there are not more than two candidates for either of such offices those candidates with no more than one competing candidate shall have their names entered in the final election without the necessity of a primary election.

Sec. 12. The general election shall be held on the third Wednesday in November 1969 and on the third Wednesday in November in every fourth year thereafter.

Sec. 13. Inauguration of the chairman and vice chairman shall take place at the first regular tribal council meeting following their election.

AMENDMENT
CONSTITUTION AND BYLAWS
of the
HOPI TRIBE
ARIZONA

AMENDMENT II

Article V, Vacancies and Removal from Office, shall be amended as follows:

Section 1. Any chairman, vice chairman, representative or other officer found guilty in a tribal or other court of a misdemeanor involving dishonesty, of a felony, or of drunkenness, shall be automatically removed from office, and the council shall refuse to recognize him.

Section 3, paragraph 3 shall be added as follows:

Vacancies occurring for any reason in the offices of chairman and vice chairman or in the office of any other officer shall be filled for the rest of the term in the same manner as those officers are ordinarily chosen.

APPROVAL

I, Harrison Loesch, Assistant Secretary of the Interior of the United States of America, by virtue of the authority granted to me by the Act of June 18, 1934 (48 Stat. 984), as amended, do hereby approve the attached Amendments I and II to the Constitution and Bylaws of the Hopi Tribe of Arizona.

Approval Recommended:

Acting Commissioner of Indian Affairs

Harrison Loesch

Assistant Secretary of the Interior

Washington, D. C.

Date: AUG - 1 1969

AMENDMENT
CONSTITUTION AND BYLAWS
OF THE
HOPI TRIBE OF ARIZONA

Amendment III

Article II, Membership, Section 1, subsections 1(a), 1(b) and 1(c) shall be amended as follows:

Section 1. Membership in the Hopi Tribe shall be as follows:

(a) All persons whose names appear on the census roll of the Hopi Tribe as of December 31, 1937, provided that corrections may be made at any time to said roll by the Tribal Council, subject to the approval of the Secretary of the Interior.

(b) All children born after December 31, 1937, whose father and mother are both members of the Hopi Tribe.

(c) All children born after December 31, 1937, whose mother is a member of the Hopi Tribe, and whose father is a member of some other tribe.

Article II, Section 1, subsection 1(d) is not being amended.

CERTIFICATES OF RESULTS OF ELECTION

Pursuant to an election authorized by the Phoenix Area Office on June 26, 1979, the attached Amendment III to the Constitution and By-laws of the Hopi Tribe, was submitted to the qualified voters of the Hopi Tribe of Arizona and was on January 30, 1980, duly adopted by a vote of 607 (number) for and 74 (number) against, in an election in which at least 30 per cent of the 977 (number) entitled to vote cast their ballots in accordance with Section 16 of the Indian Reorganization Act of June 13, 1934, (48 Stat. 984) as amended by the Act of June 15, 1934, (49 Stat. 378).

Alph H. Secakuku, Chairman
Election Board

Samuel P. Shing, Member
Election Board

Thomas Balenquah, Member
Election Board

APPROVAL

Amendment No. III

I, Curtis Geiogomah, Deputy Phoenix Area Director, Bureau of Indian Affairs, by virtue of the authority delegated to the Commissioner of Indian Affairs by the Act of June 18, 1934 (48 Stat. 984), as amended, and redelegated to me, do hereby approve the foregoing Amendment No. III to the Constitution and Bylaws of the Hopi Tribe of Arizona; provided that nothing in this approval shall be construed as authorizing any action under the Constitution and Bylaws that would be contrary to Federal Law.

Curtis Geiogomah
Deputy Phoenix Area Director
Bureau of Indian Affairs

Phoenix, Arizona

Date: FEB 14 1980

AMENDMENT
CONSTITUTION AND BYLAWS
OF THE
HOPI TRIBE OF ARIZONA

AMENDMENT NO. A

ARTICLE II - MEMBERSHIP shall be amended in its entirety to read as follows:

ARTICLE II - MEMBERSHIP

Section 1. The following persons shall be enrolled members of the Hopi Tribe.

All persons whose names appear on the Census Roll of the Hopi Tribe as of December 31, 1937, as corrected and adopted by the Hopi Tribal Council; PROVIDED, That subsequent corrections may be made to said roll by the Hopi Tribal Council at any time with the approval of the Secretary of the Interior.

Section 2. After the effective date of this amendment, the following persons shall be eligible for enrolled membership in the Hopi Tribe.

(a) All persons of one-fourth (1/4) degree Hopi Indian blood or more, or one-fourth (1/4) degree Tewa Indian blood or more, or one-fourth (1/4) degree Hopi-Tewa Indian blood or more combined, born after December 31, 1937, who are not enrolled with any other Indian Tribe.

(b) For the purpose of determining enrolled membership, Hopi Indian blood, Tewa Indian blood, and Hopi-Tewa Indian blood shall mean biological lineal descent from any Hopi or Tewa Indian person whose name appears on the Corrected Membership Roll of the Hopi Tribe as defined in Section 1.

Section 3. Persons Already Enrolled. All persons properly enrolled as members of the Hopi Tribe as of the effective date of this amendment shall continue to be members.

Section 4. Village Membership. Village membership shall be determined by the individual Hopi Villages.

Section 5. Hopi Enrollment Ordinance. The Hopi Tribal Council shall adopt, and from time to time may amend, an enrollment ordinance not inconsistent with this Article, setting forth the manner in which this Article shall be implemented and administered.

**Having been duly adopted and approved, Proposed Amendment A is hereby designated as Amendment No. IV to the Constitution and Bylaws of the Hopi Tribe of Arizona.**

CERTIFICATE OF RESULTS OF ELECTION

Pursuant to a Secretarial election authorized by the Assistant Secretary - Indian Affairs on September 8, 1993, Amendment No. A to the Constitution and Bylaws of the Hopi Tribe of Arizona was submitted to the qualified voters of the Hopi Tribe, and was on Dec. 7, 1993, duly adopted/rejected by a vote of 364 for, and 134 against, and 9 cast ballots found spoiled or mutilated, in an election in which at least thirty percent (30%) of the 776 members entitled to vote, cast their ballots in accordance with Section 16 of the Indian Reorganization Act of June 18, 1934 (48 Stat. 984), as amended.

Davis F. Pecusa
Chairman, Election Board

Herrin Lolayumptewa
Election Board Member

Beverly J. Thomas
Election Board Member

Betty Thunder Hawk
Election Board Member

Robert C. Sakiestewa Sr
Election Board Member

Date: 12/07/93

APPROVAL

I, Ada E. Deer, Assistant Secretary - Indian Affairs, by virtue of the authority granted to the Secretary of the Interior by the Act of June 18, 1934 (48 Stat. 984), as amended, and delegated to me by 230 D. M. 2.4, do hereby approve Amendment A, hereinafter known as Amendment No. IV, to the Constitution and Bylaws of the Hopi Tribe of Arizona. This Amendment is effective as of this date; PROVIDED, That nothing in this approval shall be construed as authorizing any action under this document that would be contrary to Federal law.

Ada E. Deer
Assistant Secretary - Indian Affairs

Washington, D. C.

Date: [illegible]

AMENDMENT
CONSTITUTION AND BYLAWS
OF THE
HOPI TRIBE OF ARIZONA

AMENDMENT B

Section 8 of ARTICLE IV - THE TRIBAL COUNCIL shall be amended to read as follows:

> Section 8. All members of the Hopi Tribe eighteen (18) years of age or over shall be qualified to vote in any election or referendum other than village elections and referendums under such rules and regulations as may be prescribed by the Hopi Tribal Council.

Having been duly adopted and approved, Proposed Amendment B is hereby designated as Amendment No. V to the Constitution and Bylaws of the Hopi Tribe of Arizona.

CERTIFICATE OF RESULTS OF ELECTION

Pursuant to a Secretarial election authorized by the Assistant Secretary - Indian Affairs on September 8, 1993, Amendment B to the Constitution and Bylaws of the Hopi Tribe of Arizona was submitted to the qualified voters of the Hopi Tribe, and was on Dec. 7, 1993, duly adopted/rejected by a vote of 343 for, and 154 against, and 0 cast ballots found spoiled or mutilated, in an election in which at least thirty percent (30%) of the 776 members entitled to vote, cast their ballots in accordance with Section 16 of the Indian Reorganization Act of June 18, 1934 (48 Stat. 984), as amended.

Davis F. Pecusa
Chairman, Election Board

Henry Sleyumptewa
Election Board Member

Bernard D. Thomas
Election Board Member

Betty Thunder Hawk
Election Board Member

Robert C. Sakiestewa Sr
Election Board Member

Date: 12/07/93

APPROVAL

I, Ada E. Deer, Assistant Secretary - Indian Affairs, by virtue of the authority granted to the Secretary of the Interior by the Act of June 18, 1934 (48 Stat. 984), as amended, and delegated to me by 230 D.M. 2.4, do hereby approve Amendment B, hereinafter known as Amendment No. V, to the Constitution and Bylaws of the Hopi Tribe of Arizona. This Amendment is effective as of this date; PROVIDED, That nothing in this approval shall be construed as authorizing any action under this document that would be contrary to Federal law.

Ada E. Deer
Assistant Secretary - Indian Affairs

Washington, D. C.

Date

AMENDMENT
CONSTITUTION AND BYLAWS
OF THE
HOPI TRIBE OF ARIZONA

AMENDMENT C

Section 1(e) of ARTICLE VI - POWERS OF THE TRIBAL COUNCIL shall be amended to eliminate Secretarial approval to read as follows:

(e) To raise and take care of a tribal council fund by accepting grants or gifts from any person, State, or the United States Government, or by charging persons doing business within the Reservation reasonable license fees.

**Having been duly adopted and approved, Proposed Amendment C is hereby designated as Amendment No. VI to the Constitution and Bylaws of the Hopi Tribe of Arizona.**

CERTIFICATE OF RESULTS OF ELECTION

Pursuant to a Secretarial election authorized by the Assistant Secretary - Indian Affairs on September 8, 1993, Amendment C to the Constitution and Bylaws of the Hopi Tribe of Arizona was submitted to the qualified voters of the Hopi Tribe, and was on Dec. 7, 1993, duly adopted/rejected by a vote of 325 for, and 169 against, and 0 cast ballots found spoiled or mutilated, in an election in which at least thirty percent (30%) of the 776 members entitled to vote, cast their ballots in accordance with Section 16 of the Indian Reorganization Act of June 18, 1934 (48 Stat. 984), as amended.

Dennis F. Pecusa
Chairman, Election Board

Harris Talayumptewa
Election Board Member

Beverly J. Thomas
Election Board Member

Betty Thunder Hawk
Election Board Member

Robert C. Sakiestewa Jr.
Election Board Member

Date: 12/07/93

APPROVAL

I, Ada E. Deer, Assistant Secretary - Indian Affairs, by virtue of the authority granted to the Secretary of the Interior by the Act of June 18, 1934 (48 Stat. 984), as amended, and delegated to me by 230 D.M. 2.4, do hereby approve Amendment C, hereinafter known as Amendment No. VI, to the Constitution and Bylaws of the Hopi Tribe of Arizona. This Amendment is effective as of this date; PROVIDED, That nothing in this approval shall be construed as authorizing any action under this document that would be contrary to Federal law.

Ada E. Deer

Ada E. Deer
Assistant Secretary - Indian Affairs

Washington, D. C.

Date: DEC [illegible] 1993

AMENDMENT
CONSTITUTION AND BYLAWS
OF THE
HOPI TRIBE OF ARIZONA

AMENDMENT D

Section 1(g) of ARTICLE VI - POWERS OF THE TRIBAL COUNCIL shall be amended to eliminate Secretarial approval to read as follows:

(g) To make ordinances to protect the peace and welfare of the Tribe, and to set up courts for the settlement of claims and disputes, and for the trial and punishment of Indians within the jurisdiction charged with offenses against such ordinances.

Having been duly adopted and approved, Proposed Amendment D is hereby designated as Amendment No. VII to the Constitution and Bylaws of the Hopi Tribe of Arizona.

CERTIFICATE OF RESULTS OF ELECTION

Pursuant to a Secretarial election authorized by the Assistant Secretary - Indian Affairs on September 8, 1993, Amendment D to the Constitution and Bylaws of the Hopi Tribe of Arizona was submitted to the qualified voters of the Hopi Tribe, and was on Dec. 7, 1993, duly adopted/rejected by a vote of 311 for, and 178 against, and 0 cast ballots found spoiled or mutilated, in an election in which at least thirty percent (30%) of the 776 members entitled to vote, cast their ballots in accordance with Section 16 of the Indian Reorganization Act of June 18, 1934 (48 Stat. 984), as amended.

Dennis J. Peecksy
Chairman, Election Board

Henri Talayumptewa
Election Board Member

Beverly J. Thomas
Election Board Member

Betty Thunder Hawk
Election Board Member

Robert C. Sakiestewa Sr.
Election Board Member

Date: 12/07/93

APPROVAL

I, Ada E. Deer, Assistant Secretary - Indian Affairs, by virtue of the authority granted to the Secretary of the Interior by the Act of June 18, 1934 (48 Stat. 984), as amended, and delegated to me by 230 D. M. 2.4, do hereby approve Amendment D, hereinafter known as Amendment No. VII, to the Constitution and Bylaws of the Hopi Tribe of Arizona. This Amendment is effective as of this date; PROVIDED, That nothing in this approval shall be construed as authorizing any action under this document that would be contrary to Federal law.

Ada E. Deer
Assistant Secretary - Indian Affairs

Washington, D. C.

Date: DEC 30 1993

AMENDMENT
CONSTITUTION AND BYLAWS
OF THE
HOPI TRIBE OF ARIZONA

AMENDMENT E

Section 1 (j) of ARTICLE VI - POWERS OF THE TRIBAL COUNCIL shall be amended to eliminate Secretarial approval to read as follows:

(j) To provide by ordinance for removal or exclusion from the jurisdiction of any non-members whose presence may be harmful to the members of the Tribe.

**Having been duly adopted and approved, Proposed Amendment E is hereby designated as Amendment No. VIII to the Constitution and Bylaws of the Hopi Tribe of Arizona.**

CERTIFICATE OF RESULTS OF ELECTION

Pursuant to a Secretarial election authorized by the Assistant Secretary - Indian Affairs on September 8, 1993, Amendment E to the Constitution and Bylaws of the Hopi Tribe of Arizona was submitted to the qualified voters of the Hopi Tribe, and was on Dec. 7, 1993, duly adopted/rejected by a vote of 329 for, and 162 against, and 0 cast ballots found spoiled or mutilated, in an election in which at least thirty percent (30%) of the 776 members entitled to vote, cast their ballots in accordance with Section 16 of the Indian Reorganization Act of June 18, 1934 (48 Stat. 984), as amended.

Chairman, Election Board

Election Board Member

Election Board Member

Election Board Member

Election Board Member

Date: 12/07/93

APPROVAL

I, Ada E. Deer, Assistant Secretary - Indian Affairs, by virtue of the authority granted to the Secretary of the Interior by the Act of June 18, 1934 (48 Stat. 984), as amended, and delegated to me by 230 D.M. 2.4, do hereby approve Amendment E, hereinafter known as Amendment No. VIII, to the Constitution and Bylaws of the Hopi Tribe of Arizona. This Amendment is effective as of this date; PROVIDED, That nothing in this approval shall be construed as authorizing any action under this document that would be contrary to Federal law.

Ada E. Deer

Ada E. Deer
Assistant Secretary - Indian Affairs

Washington, D. C.

Date: DEC 30 1993

AMENDMENT
CONSTITUTION AND BYLAWS
OF THE
HOPI TRIBE OF ARIZONA

AMENDMENT F

Section 1(b) of ARTICLE VI - POWERS OF THE TRIBAL COUNCIL shall be amended to read as follows:

(b) To employ lawyers, the choice of lawyers and fixing of fees to be subject to the approval of the Secretary of the Interior so long as required by Federal law.

Having been duly adopted and approved, Proposed Amendment F is hereby designated as Amendment No. IX to the Constitution and Bylaws of the Hopi Tribe of Arizona.

CERTIFICATE OF RESULTS OF ELECTION

Pursuant to a Secretarial election authorized by the Assistant Secretary - Indian Affairs on September 8, 1993, Amendment F to the Constitution and Bylaws of the Hopi Tribe of Arizona was submitted to the qualified voters of the Hopi Tribe, and was on Dec. 7, 1993, duly adopted/rejected by a vote of 344 for, and 144 against, and 0 cast ballots found spoiled or mutilated, in an election in which at least thirty percent (30%) of the 776 members entitled to vote, cast their ballots in accordance with Section 16 of the Indian Reorganization Act of June 18, 1934 (48 Stat. 984), as amended.

Davis F. Pecena
Chairman, Election Board

Verna Talayumptewa
Election Board Member

Beverly J. Thomas
Election Board Member

Betty Thunder Hawk
Election Board Member

Robert C. Sakiestewa Sr
Election Board Member

Date: 12/07/93

APPROVAL

I, Ada E. Deer, Assistant Secretary - Indian Affairs, by virtue of the authority granted to the Secretary of the Interior by the Act of June 18, 1934 (48 Stat. 984), as amended, and delegated to me by 230 D.M. 2.4, do hereby approve Amendment F, hereinafter known as Amendment No. IX, to the Constitution and Bylaws of the Hopi Tribe of Arizona. This Amendment is effective as of this date; PROVIDED, That nothing in this approval shall be construed as authorizing any action under this document that would be contrary to Federal law.

Ada E. Deer
Assistant Secretary - Indian Affairs

Washington, D. C.

Date: DEC 30 1993

AMENDMENT
CONSTITUTION AND BYLAWS
OF THE
HOPI TRIBE OF ARIZONA

AMENDMENT G

The Constitution and Bylaws of the Hopi Tribe shall be amended by adding a new article entitled ARTICLE XI - TAXATION to read as follows:

ARTICLE XI - TAXATION

Section 1. The Hopi Tribal Council shall, subject to the express limitations contained in this Constitution and the laws of the United States, have the power to impose duties, fees, taxes, and assessments on any person, corporation or association residing or doing business within the Hopi Reservation, PROVIDED, That the Tribal Council shall not have the power to impose a personal income tax.

Section 2. No tax imposed by the Tribal Council under Section 1 of this Article shall become effective unless approved by a majority vote of the eligible voters of the Hopi Tribe voting in a referendum called for that purpose pursuant to Section 8 of Article IV of this Constitution.

**Having been duly adopted and approved, Proposed Amendment G is hereby designated as Amendment No. X to the Constitution and Bylaws of the Hopi Tribe of Arizona.**

CERTIFICATE OF RESULTS OF ELECTION

Pursuant to a Secretarial election authorized by the Assistant Secretary - Indian Affairs on September 8, 1993, Amendment G to the Constitution and Bylaws of the Hopi Tribe of Arizona was submitted to the qualified voters of the Hopi Tribe, and was on Dec. 7, 1993, duly adopted/rejected by a vote of 278 for, and 213 against, and 0 cast ballots found spoiled or mutilated, in an election in which at least thirty percent (30%) of the 776 members entitled to vote, cast their ballots in accordance with Section 16 of the Indian Reorganization Act of June 18, 1934 (48 Stat. 984), as amended.

Chairman, Election Board

Election Board Member

Election Board Member

Election Board Member

Election Board Member

Date: 12/07/93

APPROVAL

I, Ada E. Deer, Assistant Secretary - Indian Affairs, by virtue of the authority granted to the Secretary of the Interior by the Act of June 18, 1934 (48 Stat. 984), as amended, and delegated to me by 230 D. M. 2.4, do hereby approve Amendment G, hereinafter known as Amendment No. X, to the Constitution and Bylaws of the Hopi Tribe of Arizona. This Amendment is effective as of this date; PROVIDED, That nothing in this approval shall be construed as authorizing any action under this document that would be contrary to Federal law.

Ada E. Deer
Assistant Secretary - Indian Affairs

Washington, D. C.

Date: DEC 30 1993

McElroy, Meyer, Walker & Condon
ATTORNEYS AT LAW

Scott B. McElroy
Elizabeth Meyer
Alice E. Walker
M. Catherine Condon
O. Conner
Phoebe Anne Gratson

Daniel E. Steuer
Gregg de Bie

RECEIVED
JUN 30 2009
ADJUDICATIONS

*Via Overnight Courier*

June 29, 2009

Herb Guenther, Director
Arizona Department of Water Resources
Attn: Adjudication
3550 N. Central Avenue, 4th Floor
Phoenix, Arizona 85012

Re: Navajo Nation Comments on the Preliminary Hydrographic Survey Report for the Hopi Indian Reservation

Dear Mr. Guenther:

On behalf of the Navajo Nation, we file the following comments.

## I. INTRODUCTION

On December 31, 2008, the Arizona Department of Water Resources ("ADWR") released a *Preliminary Hydrographic Survey Report for the Hopi Indian Reservation* ("PHSR") pursuant to A.R.S. § 45-256, as part of the proceedings in the adjudication of water rights in the Little Colorado River ("LCR") basin, entitled *In re the General Adjudication of All Rights to Use Water in the Little Colorado River System and Source*, No. 6417, pending in the Apache County Superior Court ("LCR adjudication"). Comments on the PHSR were initially due on March 31, 2009, PHSR § 1.4, at 1-7,[1] but that deadline was later extended by the Court to June 30, 2009. *Order Granting Expedited Joint Motion for Extension of Time to Submit Comments on the Preliminary Hydrographic Survey Report for the Hopi Reservation* (Mar. 9, 2009). The Navajo Nation now timely files its comments on the PHSR. The Navajo Nation first offers general comments on the PHSR and the role the PHSR plays in this adjudication, followed by comments that reference specific sections of the PHSR, as directed by the ADWR. *See* § 1.4, at 1-7.

[1] For simplicity, all future citations to the PHSR will only provide section and page number references.

1007 Pearl Street, Suite 220 Boulder, Colorado 80302 www.mmwclaw.com 303-442-2021 Fax 303-444-3490
A Professional Corporation

## II. PROCEDURAL BACKGROUND

Through the preparation of a PHSR, the ADWR provides "technical assistance" to the Court on aspects of the adjudication "with respect to which [ADWR] possesses hydrological or other expertise." A.R.S. § 45-256(A). The PHSR plays a critical role in the adjudication of water rights in Arizona by providing an underpinning for defining and resolving the complex issues raised by competing claims to water. *See id.* The establishment of that common foundation benefits the Court and the parties by facilitating the development of the factual record required to address the disputed claims to water rights. Thus, Arizona law mandates that the PHSR must "list all information that is obtained by [ADWR] and that reasonably relates to the water right claim or use investigated." *Id.* § 45-256(B).

Expanding on this mandate, the Court directed ADWR to "include hydrological and technical information about available surface water and groundwater supplies and resources to meet each claim" as well as "comprehensive and detailed information about historic, current and existing water uses." *Minute Entry* at 7 (July 16, 2002). The Court also directed that the PHSR include "ADWR's proposed water right attributes . . . for historic, current and existing water uses [but not] to report proposed water right attributes for proposed future water uses." *Id.* at 8 (quoting *Pre-Trial Order No. 2 Re: Content of HSRs* at 2 (Aug. 15, 1988)). The Court, however, explicitly instructed ADWR to not analyze "the feasibility, profitability or practicability of future uses of water" and to not "report proposed water right attributes for proposed future uses." *Id.* at 8-9. ADWR was nevertheless charged with providing "adequate descriptive and technical information about proposed future uses" to "'serve as a basis for evaluating claims of future uses.'" *Id.* at 8-9. The Court required ADWR to "use all available relevant technical reports and try to find the most recent reports or the ones having the most recent data or information." *Id.* at 9. The Court also encouraged the parties "to provide technical and other information to ADWR during the course of preparing the Hopi HSR." *Id.* at 10. The Court recognized that "[s]ome of the factors to be considered by ADWR as a result of this order require that ADWR undertake economic analysis and consider proposed uses of water within the Hopi Tribal lands that may not be known to ADWR." *Id.* at 11. Thus, the Court declared that it "expects that the Hopi Tribe and the United States will provide ADWR, on a cooperative and ongoing basis, with information and supporting documentation relating to the Tribe's current and future land and water use planning within the area affected by the Hopi HSR." *Id.*

The Court also explicitly directed ADWR to prepare the PHSR with an evaluation of the factors listed in *In re the General Adjudication of All Rights to Use Water in the Gila River System and Source*, 201 Ariz. 307, 35 P.3d 68 (2001) ("*Gila V*"). *Minute Entry* at 6 (July 16, 2002). Accordingly, the PHSR purports to include an analysis of "the tribe's history; tribal culture; geography, topography, and natural resources of the tribal lands, including groundwater availability; the tribe's economic base; past water use; and the tribe's present and projected population." § 1.3, at 1-4; *see also Gila V*, 201 Ariz. at 318-19, 35 P.3d at 79-80. The Court directed ADWR to use the *Gila V* factors in order to comply with A.R.S. § 45-256(B) in

reporting the proposed water rights attributes and examining all relevant details of the water rights claims. *Minute Entry* at 6 (July 16, 2002). Those factors, "which are not intended to be exclusive," were adopted by the Arizona Supreme Court because a "'fact-intensive inquir[y] . . . made on a reservation-by-reservation basis' . . . is the only way federally reserved rights can be tailored to meet each reservation's minimal need." *Gila V*, 201 Ariz. at 318, 35 P.3d at 79 (quoting *In re the General Adjudication of All Rights to Use Water in the Gila River System and Source*, 195 Ariz. 411, 420, 989 P.2d 739, 748 (1999) ("*Gila III*")). The *Gila V* court explained that only by examining these factors and any other relevant information can the lower court adequately determine the feasibility of proposed uses and the amount of water needed to fulfill the homeland purpose of the reservation. *Id.* at 320, 35 P.3d at 81.

## III. GENERAL COMMENTS ON THE PHSR AND THE LITIGATION PROCESS

In light of the above process and framework, as a general matter the Navajo Nation asserts that there is no way to properly evaluate – and, ultimately, to litigate – the validity of the claims of the Hopi Tribe, and the United States' claims on behalf of the Hopi Tribe,[2] based on the information presented in those claims and as analyzed in the PHSR. The Hopi Tribe claimed water rights based on historical and present use as well as water for proposed future uses. *See generally* § 2.3, at 2-3 to 2-11. But while A.R.S. § 45-256(B) mandates that objections to the final Hydrographic Survey Report ("final HSR") "specifically address [ADWR's] recommendations regarding the particular water right claim or use investigated," ADWR may not make any such recommendation for claimed future uses by the Hopi Tribe. *Minute Entry* at 8 (July 16, 2002). It is, therefore, unclear how the litigating parties are to bring the proposed future uses claimed by the Hopi Tribe to issue before the Court.

It is also unclear how the *Gila V* factors integrate with the statutory scheme and the pretrial orders of the Court, and thus how litigation of even the water rights claims based on existing and historical uses will proceed. For example, pursuant to the Court's order and *Gila V*, ADWR analyzed the Hopi Tribe's history and cultural practices in the PHSR. *See* § 3, at 3-1 to 3-18, and § 5, at 5-1 to 5-14. However, those topics are beyond ADWR's special expertise in water matters, *see* A.R.S. § 45-256(A), and as such the PHSR offers no real guidance to the Court with respect to those topics. Moreover, if the Navajo Nation disagrees with any of ADWR's analysis of those topics, the Navajo Nation may offer comments but there is no mechanism to formally object to that analysis. As noted above, A.R.S. § 45-256(B) only permits objections to "specifically address [ADWR's] recommendations regarding the particular water right claim." According to the statute, objections that do not comply with that directive – that do

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[2] Because of their similarities, the Navajo Nation will hereafter refer to both the Hopi Tribe's claims and the United States' claims on behalf of the Hopi Tribe as the "Hopi claims," except where differentiation between the Hopi Tribe's claims and the United States' claims is relevant.

not specifically relate to a particular recommendation by ADWR – shall be "summarily dismiss[ed] with prejudice." *Id.* It is unclear how or if ADWR used its analysis of the *Gila V* factors as the basis for the recommendations in the PHSR. It is also unclear how that information might be used as the basis for litigation over the Hopi Tribe's claims for future uses. However, because ADWR possess no special expertise on such topics as tribal history and culture, and because no mechanism exists to object to any analysis of the *Gila V* factors in the final HSR, that analysis should not be given any evidentiary credence in future litigation over the Hopi claims.

This confusion regarding the future course of the litigation must be resolved. The confusion appears to be the result of applying a statutory process that was designed for litigation of non-Indian uses in a prior appropriation system to Indian water rights that operate differently. While the Navajo Nation commends ADWR's efforts to comply with the Court's directive in the drafting of the PHSR, the Navajo Nation asserts that the current process does not facilitate the resolution of the complex issues raised in this adjudication. The Navajo Nation recognizes that ADWR may be unable to resolve this problem, yet confusion over how this process will move forward nonetheless exists.

In addition to the confusion that exists over the process of litigating the Hopi claims, the PHSR also fails in a number of other respects. In conducting its fact-intensive inquiry pursuant to *Gila V* and the Court's direction, ADWR essentially ignored the single most important fact relating to the Hopi claims: the existence and competing water uses of the Navajo Nation. Just as the Hopi Reservation was set aside to serve as the permanent homeland of the Hopi Tribe, so too was the Navajo Reservation set aside as the permanent homeland of the Navajo Nation. *Gila V*, 201 Ariz. at 315, 35 P.3d at 76 ("We therefore hold that the purpose of a federal Indian reservation is to serve as a 'permanent home and abiding place' to the Native American people living there."). The Hopi Tribe and the Navajo Nation share – and compete for – most of the water present on the Hopi Reservation, yet the PHSR fails to give this fact any consideration, and instead analyzes the Hopi claims in a vacuum, thereby failing to adequately provide all facts "that reasonably relate[] to the water right claim or use investigated." A.R.S. § 45-256(B). Given this failure of the PHSR to recognize the Navajo Reservation's status as a permanent homeland for the Navajo people, and, therefore, to adequately explain all of the relevant facts of the Hopi claims or its past, present and future water usage, it is impossible to see how the Court or the parties can rely on the PHSR as the factual foundation for litigating the Hopi claims. It is entirely unclear how the Court could use this PHSR, and any objections to it, and move directly to a case that quantifies and prioritizes the Hopi Tribe's water rights in the LCR basin, without any consideration of the Navajo Nation's competing water uses or the Navajo Reservation's purpose as a permanent homeland for the Navajo people. *See Gila V*, 201 Ariz. at 315, 35 P.3d at 76.

Litigating this case based on the PHSR as it currently exists is also made more difficult by the fact that the Hopi Tribe has not yet identified the sources of water that would satisfy

certain of the claims which it asserts, and the PHSR does little to analyze this failure to identify water sources for the Hopi claims. For example, the PHSR does not identify the source aquifer associated with the Hopi Tribe's claim for groundwater to serve its proposed future uses, nor does the PHSR indicate the location of pumping wells for the Hopi Tribe's proposed major uses, such as a power plant. While the Court instructed ADWR to not analyze "the feasibility, profitability or practicability of future uses of water," ADWR was still charged with providing information that is "adequate to . . . 'serve as a basis for evaluating claims of future uses.'" *Minute Entry* at 9 (July 16, 2002) (quoting *Pre-Trial Order No. 2 Re: Content of HSRs* at 2 (Aug. 15, 1988)). The PHSR, however, lacks sufficient detail about the Hopi claims for future uses to serve as the basis for evaluating those claims.

Even if one could ignore the Navajo Nation's competing water uses or the Navajo Reservation's unmistakable homeland purpose when considering the Hopi claims, the PHSR also does not adequately explain the unique nature and limitations of the Hopi Tribe's water uses described in the PHSR. Much of the irrigation practiced by the Hopi Tribe can be defined as dry land farming or "native irrigation," and the washes themselves are often dry. *See generally* § 8.1, at 8-1 to 8-12. These native irrigation fields are strategically placed by Hopi farmers in areas that receive runoff and maximize stored soil moisture;[3] "water arrives at the parcels by strategic placement of the parcel rather than by conveyance of the water." *United States' Amended Statement of Claimant on Behalf of the Hopi Tribe* at 8 (Jan. 29, 2004). This type of agriculture is far different than modern agricultural systems in which regional supplies concentrated in a stream channel can be diverted and conveyed to agricultural fields. While such modern systems may be amenable to administration by water managers, the native irrigation system that strategically relies on localized water supplies that are unique to the particular field situation cannot be similarly subject to water-rights administration. Thus, the notion that native irrigation water rights on the Hopi Reservation can be aggregated and transferred from one location on the Reservation to another is extremely problematic and ignores the physical reality of water uses in the LCR basin. Such water uses should be considered *in situ*. Furthermore, these *in situ* uses are *sui generis* and do not fit traditional models of agriculture and crop water usage, yet the PHSR does not adequately address this fact.[4] The final HSR should adequately reflect and analyze the unique nature of these Hopi Tribe water uses.

The PHSR also appears to rely at least in part on a study prepared by HDR Engineering, Inc., entitled *Western Navajo-Hopi Water Supply Needs, Alternatives and Impacts* (2003) ("HDR study"). Although it is unclear to what extent ADWR relied upon the HDR study, the PHSR lists

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[3] Typical geomorphological locations of farmed fields include, but are not limited to, the base of sand dunes, within arroyos and floodplains adjacent to streams, gentle slopes below rock escarpments, and alluvial fans.

[4] See the Navajo Nation's comments on Chapter 8 of the PHSR for a further discussion of this issue.

this study among its references, at R-5, and Figure 7-21 cites the HDR study as its source. The HDR study was the subject of a protective order by the Court, prohibiting its use "in any judicial proceeding in this Adjudication by any party to this Adjudication." *Protective Order* at 1 (Dec. 31, 2001). While ADWR is not a party to this adjudication, the PHSR provides the factual record upon which the adjudication is based. *See* A.R.S. § 45-256. Thus, parties that rely on the PHSR might indirectly be using the HDR study. At a minimum, the final HSR should note the protective order and include a discussion regarding the use of the HDR study.

Lastly, as a general housekeeping comment, the appendices of the PHSR – which were only available electronically – were not globally paginated, making the task of locating pages within these appendices extremely problematic. For example, Appendix F contains a document prepared by ADWR. While this document is numbered internally, it is not globally numbered as "Appendix F-page #" nor do any of the pages of the text, tables or figures indicate that it is part of Appendix F. Thus, the task of locating a document in the appendices, or of determining which appendix a particular page is located in, is very difficult. ADWR should include global pagination for all included documents in the final HSR.

## IV. COMMENTS ON SPECIFIC SECTIONS OF THE PHSR

## CHAPTER 2: SUMMARY OF ADJUDICATION CLAIMS RELATED TO THE HOPI INDIAN RESERVATION

### 2.6 2004 UNITED STATES CLAIMS ON BEHALF OF THE HOPI

#### Section 2.6.6 Present and Future Domestic, Commercial, Municipal and Industrial Use

The total water demand of 11,211 acre-feet per year ("AFA") for future domestic, commercial, municipal and industrial ("DCMI") use described in this section is based on 160 gallons per capita per day ("gpcd") for a population of 62,512. However, ADWR later notes that some of this domestic demand is included more than once. § 2.8, at 2-20. The Hopi Tribe's water claim for 1,083 AFA for future tourism, § 2.9.6, at 2-24, should already be accounted for in the DCMI value. The final HSR should more clearly reflect this fact.

### 2.9 SUMMARY AND COMPARISON OF HOPI AND UNITED STATES 2004 CLAIMS FOR FUTURE USES

#### 2.9.1 Future Agriculture (Irrigation)

The Hopi Tribe claims 3,000 AFA for future irrigation for the Moenkopi Irrigation Project from Moenkopi Wash. This claim may overlap with historic irrigation. The final HSR should address whether the proposed future irrigation use includes any waters already claimed for historic irrigation.

## CHAPTER 3: HOPI RESERVATION LANDS

### 3.3 1934 ACT RESERVATION LANDS (MOENKOPI)

The PHSR overstates the holding of *Sekaquaptewa v. MacDonald*, 448 F. Supp. 1183 (D. Ariz. 1978), *aff'd in part, rev'd in part*, 619 f.2d 801 (9th Cir. 1980). In that case, the court held that the Hopi Tribe received rights to land it occupied or used at the time of the passage of the Act of June 14, 1934, 48 Stat. 960 ("1934 Act"). The court declared that the 1934 Act "protect[ed] the rights and interests of the Hopi tribe to the land they were occupying and using . . . . Inasmuch as the 1934 Act did not attempt to separate Hopi and Navajo property interests, the Hopi tribe and the Navajo tribe each received an undivided one-half interest *in these lands*." *Sekaquaptewa*, 448 F. Supp. at 1196 (emphasis added). The court did not hold that the Hopi Tribe "received an undivided one-half interest in the 1934 Act Reservation," as stated in the PHSR. § 3.3, at 3-15. Indeed, on appeal the Ninth Circuit explicitly upheld the district court on this point, declaring that the 1934 Act "cannot be read to convey to the Hopis a one-half interest in the Reservation." *Sekaquaptewa v. MacDonald*, 619 F.2d 801, 806 (9th Cir. 1980). It should also be noted that the Ninth Circuit overturned the district court on a related point, holding that for lands that the Hopi Tribe "exclusively possessed, occupied, or used in 1934," the Hopi Tribe was not limited by the 1934 Act to "an undivided one-half interest," but rather received exclusive rights to those lands. *Id.* at 808. The final HSR should more accurately state the holding of the *Sekaquaptewa* cases.

## CHAPTER 6: ECONOMIC BASE

### 6.2 INFRASTRUCTURE AND PUBLIC SERVICES

#### 6.2.2 Utilities

The PHSR indicates that Hopi Tribe's public water systems serve approximately 12,000 residents. Table 6-3, however, presents the factual background for that assertion, and appears to double count many people. Large student populations are indicated as being served by these water systems, and these students are almost certainly included in the counts for their home communities. Similarly, workers at tribal offices and many businesses are indicated as being served by these water systems; the population of people served by each system as stated in the PHSR far outstrips the likely number of residents served. Hopi tribal workers are almost certainly also included in the counts for their homes. The final HSR must more carefully analyze the populations being served by the Hopi Tribe's public water systems.

## 6.4 HUMAN RESOURCES

### 6.4.1 Demographics

In its amended claims, the Hopi Tribe claims future DCMI water for a population that will stabilize at 62,512 in 2175. Table 6-7. Neither the PHSR nor the Hopi claims provide sufficient documentation and methodology to support this assertion. Projecting a population 166 years into the future is, simply stated, highly questionable from a demography standpoint. Indeed, the United States Census Bureau has expressed great reservations about projecting populations even 100 years into the future, yet the PHSR does not even suggest that the Hopi Tribe's population projection of 166 years is problematic. *See* FREDERICK W. HOLLMANN ET AL., U.S. CENSUS BUREAU, METHODOLOGY AND ASSUMPTIONS FOR THE POPULATION PROJECTIONS OF THE UNITED STATES: 1999 TO 2100 (2000), http://www.census.gov/population/www/documentation/twps0038/twps0038.html ("The boldest decision was undoubtedly the one to extend the series to the year 2100. In making this decision, we were fully aware of the precarious nature of any population projection that is three human generations past the existing population base.").[5] In this respect, the PHSR fails to meet the Court's directive to analyze "the tribe's present and projected population." § 1.3, at 1-4; *see also Gila V*, 201 Ariz. at 319, 35 P.3d at 80. The final HSR must, therefore, include an adequate analysis of the Hopi Tribe's population figures.

For this section on Hopi Tribe demographics, the PHSR relies on data compiled by SWCA Environmental Consultants ("SWCA") in a report prepared for ADWR.[6] § 6.4.1, at 6-22. The SWCA 2008 report declares that a variety of statistics exist for the Hopi Tribe, but where these statistics differ, SWCA utilized the figures generated by the department or entity "closest to the source of the data" in question. SWCA 2008 at 1. However, SWCA did not appear to give any consideration to the quality of the data in question nor to the credibility of the source closest to the data. SWCA notes, for example, that the 2000 census counted 6,815 persons on the Hopi Reservation (the actual count was 6,946, of whom 6,573 were American Indians), but the Hopi Tribe, in an update to its comprehensive development plan, declared the census total an undercount and substituted a figure of 10,571 as its benchmark for 2000. Without any attempt to evaluate the accuracy of the Hopi Tribe's number, SWCA utilized 10,571 as the population of the Hopi Reservation in 2000 because the Hopi Tribe, the source of the numbers, is closest to its people.

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[5] Even though national projections draw from a larger database and are, therefore, more reliable, the Census Bureau still calculated a low, middle and high value, recognizing that projecting a century into the future is problematic.

[6] *Socioeconomic Study in Support of a Hydrographic Survey Report for the Hopi Indian Reservation* (2008). This report is referenced in the PHSR as "SWCA 2008." Thus, it is similarly referenced as such here.

Similarly, SWCA cites a 2006 study of water sources and contamination on the Hopi Reservation completed by Tetra Tech, Inc., *Source Water Assessment for Communities and Villages of the Hopi Reservation*, in which a 2006 population of 13,000 is claimed for the reservation. Again, without any critical evaluation, SWCA inserts 13,000 as the Hopi Reservation population in 2006. In the 2006 Tetra Tech report, a 93-page document prepared by water treatment experts, there are two sentences stating that 13,000 is the estimated population for the Hopi Reservation in 2006, without any indication of the source of this number nor the method by which it was derived. Besides appearing in the SWCA 2008 report, the PHSR also cites the Tetra Tech report in Table 6-7, but inexplicably reduces the Tetra Tech estimate to 12,000. In a footnote for this number, ADWR states that it represents an estimated number of persons served by public water systems on the Hopi Reservation, although no such explanation or documentation exists in the Tetra Tech report.

The update to the Hopi Tribe's comprehensive development plan, *Hopi Tunatya at 2000: The Hopi Strategic Land Use and Development Plan* (2001), which as noted above was cited in the SWCA 2008 report, was prepared by the Hopi Office of Community Planning and Economic Development and referenced in the PHSR as "Hopi (2001)." Although this document was relied on by SWCA – and thus by the PHSR – it is rife with errors. For example, on page 24, the Hopi (2001) report indicates that from 1999 to 2000, Hopi tribal enrollment grew from 10,704 to 10,870, an increase of 166 new members, which the report states is an increase of 4.75%; it is actually an increase of 1.6%. On the following page, the report notes that the 1980 census was the first census that reported populations for Indian Reservations, when a special subject report dealing with American Indians was published following the 1970 census. The Hopi Reservation total count of Indians in 1970 was 4,404 persons living in 765 households according to the Census Bureau. Inexplicably, the Hopi (2001) report indicates a total 10,757 people as the 1970 census count on the Reservation, even though the report also indicates that no reservation totals were tabulated by the Census Bureau prior to the 1980 census. For the same reason, it is unclear where the count of 9,360 persons on the Hopi Reservation in 1960 came from, though it is presented with authority in Hopi (2001).

The Hopi (2001) report also cites the 1980 and 1990 census counts of Indian persons on the Hopi Reservation as 6,606 in 1980 and 7,061 in 1990. The report does not mention, however, that following the 1977 partition of the Joint Use Area into Hopi Partitioned Lands ("HPL") and Navajo Partitioned Lands ("NPL"), the Navajo people who were counted on the Hopi Tribe's side of the line were counted as Indians living on the Hopi Reservation in 1980 and 1990. Fred Anderson, who completed a historical research report under contract to ADWR in 2008, states that 1,763 Navajos were counted in the HPL in 1980. *Historical Research for Hydrographic Survey Report of the Hopi Reservation* at 169 tbl.8. Thus, the actual count of Hopis in the pre-partition District 6 in 1980 was 4,843. The PHSR, however, ignores this information in the Anderson report. The bottom line is that SWCA, acting as ADWR's consultant, accepted highly questionable data from the Hopi Tribe because the Hopi Tribe is "closest to the source of the data," and ADWR in turn uncritically used the information passed

along by SWCA in the PHSR. Pursuant to the Court's mandate to ADWR to analyze the present and projected future population of the Hopi Tribe, the final HSR must include independent verification of data and methodologically sound calculations.

## CHAPTER 7: WATER RESOURCES

### 7.1 STREAMS

#### 7.1.1 Hopi Washes

The PHSR indicates several hydrologic factors affecting Hopi Reservation streamflows, determining that some of these factors have only "minor" effect. The PHSR does not include a definition for "minor" nor does it indicate whether the same definition extends to all surface water channels; what is a minor effect on the mainstem of the LCR might not be a minor effect on a tributary to one of the washes. The final HSR should explain what constitutes a "minor" effect for each surface water channel.

The PHSR indicates that a formerly perennial reach of Jeddito Wash has become ephemeral in recent years. ADWR attributes this change to the "occurrence of wet and dry periods over the region." § 7.1.1, at 7-3. The PHSR does not, however, provide sufficient background information to support this explanation. The final HSR should include a more detailed explanation for why this change is attributed solely to climate variations.

The PHSR provides no explanation for why the time period of 1981 to 2006 is used. Moreover, a number of the values presented in Table 7-3, from which the data on page 7-4 is derived, are inconsistent with some of the values shown in Figure 7.6. For example, in Table 7-3, Point I-13 has a mean flow of 3,830 AFA and a median of 4,540 AFA, while in Figure 7-6 it has a mean flow of 3,810 AFA and a median flow of 4,510 AFA. Other points have similar discrepancies. The final HSR should correct or explain these inconsistencies.

Table 7-3 also contains values that defy common sense. In Table 7-3, the mean flows are almost always less than the median flows. For example, the mean flow at I-13 is 3,830 AFA while the median flow is 4,540 AFA. Generally speaking, one would expect the mean flows to be higher because the mean is heavily influenced by a relatively small number of very high flow periods. A review of USGS gaging data presented in the table below shows that the means are larger than the medians, and it indicates that the ADWR results are highly suspect.

USGS Gage Data in the Moenkopi Area

| USGS Station | Period | Mean | Median |
|---|---|---|---|
| 9401260 Moenkopi at Moenkopi | 1981 to 2006[7] | 7,397 | 6,391 |
| 9401400 Moenkopi near Tuba City | 1941 to 1978 | 11,048 | 9,373 |
| 9401280 Moenkopi near Tuba City | 1927 to 1940 | 16,879 | 9,988 |

Letter from John Leeper, Civil Engineer, to Ms. Bidtah Becker, Esq. (June 26, 2009), Attachment 1.

This problem is compounded in subsequent analyses in the PHSR because ADWR developed extended records of streamflow for the gages for periods with short and/or missing records, and for a common "base period" from 1981 to 2006. Only gage number 0941260 had a complete record for the base period, and for several of the gages with missing data, ADWR used gage number 0941260 as the "Index Station" for computation of "synthetic data" (estimates of flows for periods of missing data) for the base period. These synthetic flows for the base period were then used by ADWR in a regional watershed analysis to generate flow estimates at 21 ungaged locations on the Hopi Reservation boundaries (13 inflow points and 8 outflow points). Table 7-3 in the PHSR presents the final results for the estimated mean and median annual flows from this regional analysis at the 21 ungaged locations, and in 17 of 21 cases the median flows are higher than the mean flows. In several cases, the median flow is more than twice as high as the mean flow. These projections are not only nonsensical but are inconsistent with the observed annual flows at the gaged locations, indicated in Table 7-1 of the PHSR, where only one gage – number 0941260 – exhibited a median higher than the mean, and for that one gage the median flow is less than 5% higher than the mean flow. ADWR should reexamine the data and either correct the final HSR or adequately explain the highly unusual results.

Table 7-3 further shows that the reported mean outflow at O-8 is approximately 4,710 AFA. This site is very close to the USGS gage which reports that the mean flow from 1981 through 2006 is more than 6,300 AFA. The PHSR should address this discrepancy. The PHSR also does not address the fact that the USGS gage data already reflect the effects of the current Navajo Nation and Hopi Tribe depletions upstream from the existing irrigation. It is not clear how ADWR addresses the Navajo Nation demands upstream from the Hopi Tribe. The final HSR should reflect ADWR's evaluation of the impact of upstream Navajo Nation irrigation.

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[7] The complete data set for this gage is from 1977 to 2008. For that period, the mean is 7,261 AFA and the median is 6,272 AFA.

Footnote 5 of Table 7-3 has a huge impact on the interpretation of this table and the subsequent description of the water supply on page 7-4 and other sections. The footnote indicates that some "outflows become inflows again over relatively short distances." The PHSR appears to aggregate the flows at O-7 and O-8, which essentially describe the same physical water supply that leaves the western border of the Hopi Reservation (O-7), enters the eastern boundary of Moenkopi (I-13), and then leaves the western border of Moenkopi (O-8). The interpretation on Page 7-4 implies that the "Total Outflows" is the measure of the water supply available when it is not. Table 7-3 presents the difference between the "total outflows" and the "total inflows" which creates an even more misleading characterization of the water supply that may be generated on the Hopi Reservation. The lack of analysis of the natural undepleted flows versus the depleted flows makes it difficult to uses these results in a meaningful way. The final HSR should address these discrepancies.

Please see the comments from the Navajo Nation Department of Water Resources for a lengthier discussion of the regional stream flow analysis, Attachment 1.

## 7.2 IMPOUNDMENTS

### 7.2.2 Capacity, and Appendix C

The PHSR includes estimations of the capacity of impoundments on the Hopi Reservation. These capacities were derived using formulas provided in Appendix C, at C-6. The PHSR does not, however, indicate the basis for these formulas, making it impossible to assess the validity of ADWR's impoundment capacity estimations. The final HSR should include a detailed explanation of the basis for its impoundment capacity formulas.

### 7.2.3 Surface Water Depletion

The PHSR indicates that ADWR utilized certain assumptions when calculating surface water depletions. The basis for these assumptions is unclear, and the PHSR does not include nor reference any hydrologic analysis to assess the validity of these assumptions. The final HSR should explain the hydrological basis for these assumptions.

## 7.4 AQUIFERS

### 7.4.6 N Aquifer

The PHSR notes the drawdown likely to occur as a result of increased pumping of wells in the N-Aquifer, as represented in Table 7-14. That table, however, uses information derived from the Final Black Mesa Project Environmental Impact Statement ("Black Mesa EIS"), and impacts are predicted only through 2025. Given the Hopi Tribe's projected population estimate of over 62,000 people in 2175, Table 6-7, the effect on springs, streamflow and water levels in

wells will no doubt increase significantly beyond that predicted in Table 7-14. Assuming the population projections are correct, which the Navajo Nation does not admit, *see* Comment re § 6.4.1, *supra*, the final HSR should reflect this fact.

## CHAPTER 8: WATER DEMANDS

### 8.1 AGRICULTURE

#### 8.1.1 Quantification

ADWR estimates that the net irrigation requirement for crops grown following traditional Hopi farming practices is 0.35 to 0.86 acre-feet per acre. The net amount reflects the difference between the crop water requirement and the estimated rainfall but does not include the effect of riparian salvage. In other words, the crops grown according to traditional Hopi farming techniques may actually deplete less water than the native vegetation that they are replacing. Traditional Hopi farming practices are extremely opportunistic in terms of the location of planting and how water is conserved. Thus, a standard irrigation system model may not be the best analog for these fields. For example, rainfall can be collected from a larger area and concentrated close to a single cluster of plants. These techniques magnify the impact of the rainfall. It is unreasonable to substitute a standard irrigation model on this type of farming system. Please see the attached technical memo for a lengthier discussion of this issue. Letter from Jim McCord, Ph.D., P.E., AMEC, to Ms. Bidtah Becker, Esq. (June 28, 2009), Attachment 2. The final HSR should analyze the net irrigation requirement for traditional Hopi farming practices with a more appropriate model.

Also, while ADWR calculated consumptive use for five different crops grown on the Hopi Reservation, it did not calculate consumptive use for range pasturage, as indicated in § 1-5 of Appendix F to the PHSR. The Natural Resource Consulting Engineers ("NRCE") report prepared in support of the United States' claims on behalf of the Hopi Tribe did calculate consumptive use for corn and range pasturage but not for other crops, as indicated in Appendix B to Appendix F to the PHSR. Thus, direct comparison of the ADWR and NRCE estimates of crop water use is impossible. The final HSR should explicitly compute per-acre crop water use for the same crop mix and same irrigation categories as did NRCE to facilitate checking and validation.

Calculating the crop coefficient Kc values for DRY conditions required adjustments by ADWR beyond the more standard application for modern irrigated agriculture. Standard Kc values could not be used for the dry conditions since the much of the agriculture is dryland farming and does not express a micro-climate similar to modern day agriculture. In addition, the crop coefficient must account for increase in spacing of crops as compared to modern agricultural practices. While this adjustment is likely well justified, ADWR fails to consider another adjustment to account for the fact that the widely spaced plantings will lead to a greater

water use per "plant cluster" due to each cluster being exposed to lower relative humidity. Please see the attached technical memo for a lengthier discussion of this issue, Attachment 2. The final HSR should include a detailed analysis of Kc as there are many variables used in determining this value and the methodology is unique and has not been repeated. At a minimum, ADWR should conduct a sensitivity analysis of the variables that would help better identify and quantify uncertainties in the Kc estimates.

To develop the final crop water use estimates, ADWR takes the average of ETc values calculated for Tuba City and Keams Canyon weather data and averages these values for the final ETc values. These final values are used to calculate the net irrigation water requirement. Temperature and precipitation values from the Tuba City and Keams Canyon stations are significantly different. ADWR should also weigh ETc values for irrigated crops based on proximity to each weather station. The final HSR should then include a sensitivity analysis to compare ETc values computed both ways.

ADWR estimates effective precipitation, which is subtracted from the ETc to obtain the net crop irrigation requirement. ADWR estimates that 52 - 89% of ETc is met by from annual precipitation at the Keams Canyon station, implying that 11 - 48% of ETc is acquired from surface water. The Tuba City estimate assumes that a smaller percentage of ETc is met by effective precipitation. ADWR averaged the values of effective annual rainfall to calculate the final net irrigation requirements. ADWR calculated effective precipitation from total annual rainfall rather than using the more common standard of the amount of rainfall during the growing season. ADWR adopted this alternative since the Hopi Tribe's fields are geographically situated so as to maximize effective precipitation by taking advantage of deeply stored soil moisture. While this assumption may be valid for dryland crops irrigated via the Hopi Tribe's traditional methods, for crops grown using modern-day irrigation in leveled fields, the standard approach of using only growing season precipitation might be more appropriate. The final HSR should include a sensitivity analysis to assess the impacts of ADWR's effective precipitation assumptions.

The irrigation water claim in the PHSR report has been determined based on the assumption that 643 acres were farmed using modern day irrigation practices (non-deficit irrigation, or "NDI") and that the remaining acreage was irrigated using native irrigation techniques (DRY). This is inconsistent with the definition of irrigation types as included in the Hopi Tribe's Amended Statement of Claimant, found in Appendix A of the PHSR. The 2004 Hopi Tribe claim defines"native irrigation" as lacking the use of structures for diversion. Based on irrigation types defined in the Hopi Tribe's claim, it appears that there is a range of variability in crop densities rather than only two types, NDI and DRY. The final HSR should explicitly provide some comparison between the NDI and DRY definitions and the irrigation types identified in the Hopi Tribe's claim.

The PHSR reports that crops grown in the Moenkopi area, served by the Pasture Canyon irrigation system, have a depletion rate of 1.81 acre-feet per acre. The PHSR also reports that the diversion rate for the same irrigation system is 2.01 acre-feet per acre, resulting in irrigation efficiency of 90%. This is an extremely high value compared to most modern flood irrigation systems. ADWR should reexamine these values and either correct or explain the anomalous result in the final HSR.

### 8.1.2 Historic (Pre-1985) and 8.1.3 Recent

ADWR reports that the Hopi Tribe and the United States "indicate that actual diversions for irrigation on the Reservation have averaged about 29,000 AFA, but are claiming the larger amount [49,200 AFA] to provide an adequate water supply during years when *less* water is available." § 8.1.2, at 8-7 (emphasis added); *see* § 8.1.3, at 8-10. It is very unlikely that the actual average diversion, even including native irrigation, was 29,000 AFA. The average water supply as described in the PHSR appears to be much less, possibly around 13,900 AFA. Any modeling results that might support a conclusion of higher diversions were not made available to ADWR. *See, e.g.*, § 8.1.1, at 8-3 ("ADWR's request for a copy of the surface water model [used by the United States 'to simulate the quantity of surface water depleted by irrigation of Hopi fields'] was denied."). In addition, some of the water diverted for native irrigation may not have reached the downstream gages used to create this analysis. The water supply on the Hopi Reservation is not fungible, but instead is highly sensitive to specific locations and practices. Simply aggregating the total acreage and the total water duty implies that there is an aggregate volume of water that can be moved around with impunity, and this is not the case. The final HSR should reflect this reality.

Also, the PHSR indicates that the Hopi Tribe is claiming larger amounts of water to provide adequate water during years when *less* water is available. This statement appears to be worded incorrectly. The final HSR should presumably indicate that more water is being claimed for the few years when *more* water is actually available.

### 8.1.4 Future

The PHSR uses the term "net irrigation demand" to apparently indicate the consumptive use demand of a crop which is not satisfied by precipitation. At other points in the report and accompanying documentation, ADWR appears to use the terms "net irrigation water requirement" and "supplemental irrigation demand" synonymously with "net irrigation demand." The final HSR should explicitly define and if necessary distinguish all of these terms at the beginning of the report.

The PHSR suggests that "there is enough surface water physically available for these projects." § 8.1.4, at 8-12. This statement is based on the 190,000 AFA in the LCR. However, no demonstration has been made that the water in the LCR is practically or legally available.

Without the LCR mainstem water, there may not be enough surface water available. The final HSR should reflect this.

## 8.3 HEAVY INDUSTRIAL

### 8.3.2 Recent and 8.3.3 Future

The Black Mesa EIS preferred alternative proposes to operate the Black Mesa Complex coal mines into 2026 without supplying the Mohave Generating Station, i.e. with no slurry water use. Proposed water use is estimated at 1,236 AFA for ongoing operations at the Kayenta mine, up to 505 AFA for reclamation and public use from 2026 to 2028, and 444 AFA from 2029 to 2038 for post-reclamation and public use. § 8.3.3, at 8-17. The Black Mesa EIS reports a past average usage of 3,100 AFA of N-Aquifer water for slurry of coal to the Mohave Generating Station and 1,300 AFA for other mine-related uses, for a total of 4,400 AFA. Based on the foregoing, it appears that Hopi claims for ground water at Black Mesa may be overstated in terms of both historic and future uses. This conclusion is based on the fact that seven of the eight Peabody water supply wells are on Navajo Reservation land and the claimed future 5,600 AFA for slurry to the Mohave Generating Station is nearly twice what has been required to operate the pipeline in the past. The final HSR should reflect this.

Proposed future development areas and well locations are shown on Map F from Appendix A of the PHSR. Proposed N-Aquifer wells for these developments are located further south and west than the existing Peabody wells. While studies to date have found little impact to springs and streams on the Hopi Reservation, moving the wells to the south and west closer to Hopi Reservation springs and stream segments could result in future impacts to these features. The final HSR should provide some analysis on the potential effects of these proposed wells.

The Hopi Tribe claims 6,000 AFA of groundwater for the Black Mesa Mine and another 19,000 AFA of groundwater (or off-reservation water sources) for new industrial uses; the water source for these projects is not identified beyond "groundwater." The PHSR notes a proposed 1,200 megawatt coal-fired power plant that would use 15,000 AFA and a proposed coal liquefaction plant and 300-megawatt power generating station.[8] The PHSR reports that both projects were previously abandoned due to the lack of a sustainable water supply. While ADWR was instructed to not analyze "the feasibility, profitability or practicability of future uses of water," ADWR was still charged with providing information that is "adequate to . . . 'serve as a basis for evaluating claims of future uses.'" *Minute Entry* at 9 (July 16, 2002) (quoting *Pre-Trial Order No. 2 Re: Content of HSRs* at 2 (Aug. 15, 1988)). In describing these projects, the PHSR does not provide sufficient information to evaluate the proposed future uses. These projects are very speculative, and no substantive material is provided to evaluate whether they are feasible or

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[8] The PHSR does not make clear if the coal liquefaction plant and 300-megawatt power generating station account for all of the remaining 4,000 AFA claimed for future industrial use.

practical. Moreover, it is likely that the lack of a sustainable water supply is only one reason among many that led to their abandonment. For example, air quality concerns, transmission limitations, and widespread public resistance all may have factored into the fate of these projects. The final HSR should include more information on the proposed projects in order for the HSR to meet ADWR's obligation to provide information that is "adequate to . . . 'serve as a basis for evaluating claims of future uses.'" *Id.*

## 8.4 LIVESTOCK

### 8.4.2 Historic

The PHSR uses the phrase "[a]t the time of the Navajo migration" without explaining the reference. Also, the PHSR states that "[u]p to this point" there had been little development of livestock water sources, without identifying exactly what point in time is being indicated. The final HSR should explain these references.

## 8.6 TOURISM

The PHSR presents water demands for tourist purposes. This type of demand should be included as part of the 160 gpcd DCMI claim to avoid being double counted. *See* § 2.6.6, at 2-16. For example, the City of Flagstaff provides for thousands of tourists as part of its municipal demands. Facilities like the Tuuvi Travel Center should be included in the DCMI claim. While the PHSR later indicates that ADWR assumes that the Hopi Tribe's tourism claims are included in its DCMI claims, § 9.1.2, at 9-2 n.2, it does so in a footnote and not in its primary presentation of the Hopi claims. The final HSR should clearly reflect that the Hopi claims for water for tourist purposes should be subsumed within the DCMI amount.

### 8.6.3 Future

The PHSR notes that the Hopi Tribe claims 1,038 AFA for two resorts, one recently opened in Moenkopi (Tuuvi Travel Center) and a future resort in Keams Canyon. The claimed amounts for these uses are 522 AFA and 516 AFA, respectively. The Tuuvi Travel Center includes two fast food restaurants, a convenience store, smoke shop, gas station and car wash. A planned 72-acre development would include a 100-room motel and conference center, office complex and bank. Using the ADWR Generic Demand Calculator, a similar project in the Phoenix Active Management Area ("AMA") would have an annual water demand of less than 200 AFA, as follows:

| Item | Units | Use Rate | Demand (AFA) |
|---|---|---|---|
| Commercial | 72 acres | 2.25 ac-ft/ac | 162 |
| Hotel | 100 du | 57 gpcd<br>2 c/du | 12.7 |
| Pool | 5,000 $ft^2$ | See ADWR guidance | 0.8 |
| Turf | 2 ac | 4.9 ac-ft/ac | 11.6 |
| **Total Demand** | | | **187.1** |

gpcd – gallons per capita per day
c/du – capita per dwelling unit (room)

No information is provided for the proposed Keams Canyon resort.[9] Based on the comparison with the ADWR Generic Demand Calculator for the Phoenix AMA, the Hopi Tribe claimed amounts for these two resorts are at least twice what a similar project in the Phoenix AMA would require. The final HSR should note that fact. Of course, as described above, these projects should be included in the Hopi Tribe's DCMI claims.

## 8.7 CULTURAL/CEREMONIAL

### 8.7.2 Future

The PHSR indicates that the Hopi Tribe claims water for future irrigation demands for 3,136 acres for gardens and a 4.0 acre-feet per acre water duty for these gardens. ADWR correctly notes that the water duty should be far less. However, the PHSR ignores the fact that the water supplied to these gardens would increase the shortages for the future irrigation projects, possibly reducing their viability. Another consideration ignored in the PHSR is that many homeowners use water for outside landscaping and gardens, and such outside water use is typically included within DCMI demands. The final HSR should either integrate the garden water demand into future irrigation analysis or consider the garden water demand to be part of the DCMI demand.

## 8.8 RIPARIAN EVAPOTRANSPIRATION

### 8.8.3 Future

The PHSR reports that Arizona Water Protection Fund projects will be removing Russian olive and salt cedar along the washes. While this is important work and should be commended, replacing the exotic vegetation with native vegetation may not result in a significant change in the overall water budget. The final HSR should reflect this reality.

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[9] The PHSR indicates that ADWR is unaware of any plans for a resort in Keams Canyon, but does identify plans for a motel, restaurant, conference center and museum/cultural center at Tawaivi. § 8.6.3, at 8-26.

# CHAPTER 9: ADWR'S ANALYSIS OF HOPI WATER RIGHTS AND PROPOSED WATER RIGHT ATTRIBUTES FOR PAST AND PRESENT WATER USES

## 9.1 SUMMARY OF ADWR'S EVALUATION OF PAST AND PRESENT TRIBAL WATER USES

### 9.1.4 Livestock

The PHSR includes impoundments in the livestock category, and its quantification of water use for these impoundments is based strictly on storage capacity, as indicated in Tables 9-1 and 9-2. Because this quantification is based solely on the volume of water that the impoundments can hold, ADWR does not explicitly take into account surface water depletions due to evaporation, infiltration, and stock use in determining how much water the Hopi Tribe uses for livestock. ADWR should perform independent, physically-based hydrologic analyses to test the empirical equations for depletion to impoundments, and the final HSR should reflect that.

## 9.2 COMPARISON OF QUANTITIES OF WATER FOR PAST AND PRESENT USES CLAIMED BY THE HOPI AND UNITED STATES TO QUANTITIES OF WATER DETERMINED BY ADWR

### 9.2.1 Agriculture

The PHSR describes the Hopi Tribe's claim of composite irrigated acreage of 38,556 acres. ADWR reported convincing evidence of only 25,261 acres, and estimates a total of 9,503 AFA for agriculture purposes in any year. While this analysis is much more accurate than the analyses presented by the Hopi Tribe and the United States, it still appears to be too high. The PHSR uses an "estimated crop water demand," § 9.2.1, at 9-6, but the final HSR should instead consider the specific farming practices used on all of the lands in question.

## 9.3 ADWR'S RECOMMENDED WATER RIGHT ATTRIBUTES FOR PAST AND PRESENT WATER USES ON THE HOPI RESERVATION

### 9.3.2 ADWR's Recommended Water Right Attributes and 9.3.3 Legal Issues Pending Before the Court and Special Master

The PHSR indicates that the question of whether the Hopi Tribe may receive water rights to streams that do not traverse or abut the Hopi Reservation is currently pending before the Court. On March 2, 2009, the Court ruled that "that the Hopi Tribe is precluded from asserting water right claims in this adjudication to the extent such claims seek the right to water sources located within the Little Colorado River Basin that neither abut nor traverse Hopi lands."

*Minute Entry* at 2 (Mar. 2, 2009). The final HSR should be amended to reflect the Court's ruling.

The PHSR indicates that water reserved for an Indian tribe to meet the homeland purpose, once recognized, may be diverted and used anywhere on the Reservation. ADWR bases this statement on *Gila V*, 201 Ariz. at 313, 35 P.3d at 74. Not only does the PHSR take this pronouncement out of its legal context, but it also ignores the well-established "no harm" rule of water law. *See generally* DAVID H. GETCHES, WATER LAW IN A NUTSHELL at 173-75 (4th ed. 2009) (changes in use of a water right may not injure other water users). Moreover, the PHSR's statement fails to take into account the unique nature and limitations of the Hopi Tribe's water uses described in the PHSR. As noted previously, much of the irrigation practiced by the Hopi Tribe can be defined as dry land farming or "native irrigation," and the washes themselves are often dry. Fields being irrigated in this manner are chosen specifically for their location; water arrives at these fields by virtue of their placement, not by conveyance of water to the fields. *United States' Amended Statement of Claimant on Behalf of the Hopi Tribe* at 8. Thus, the notion that "native irrigation" water rights on the Reservation can be aggregated and transferred from one location on the Reservation to another is extremely problematic and unrealistic. Such water uses should be considered *in situ*. The final HSR should reflect this.

Sincerely,

Scott B. McElroy
SBM/dav
cc: Bidtah N. Becker

Enc.:

Letter from John Leeper, Civil Engineer, to Ms. Bidtah Becker, Esq. (June 26, 2009), Attachment 1.

Letter from Jim McCord, Ph.D., P.E., AMEC, to Ms. Bidtah Becker, Esq. (June 28, 2009), Attachment 2

# THE NAVAJO NATION
## DEPARTMENT OF WATER RESOURCES
### WATER MANAGEMENT BRANCH

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JOE SHIRLEY, JR.
PRESIDENT

BEN SHELLY
VICE PRESIDENT


June 26, 2009

RECEIVED
JUN 26 2009
DEPARTMENT OF JUSTICE
WATER RIGHTS UNIT

Ms. Bidtah Becker, Esq.
Water Rights Unit
Navajo Department of Justice
P.O. Box 2010
Window Rock, AZ 86515

SUBJECT: **Comments on the *Preliminary Hydrographic Report for the Hopi Indian Reservation, In re The General Adjudication of the Little Colorado River System and Source*, December 2008**

Dear Bidtah,

The objective of this memorandum is to provide Navajo Nation Department of Water Resources' comments on the Regional Stream Flow analysis (Pages 7- 1 through 7-6, Streams - Regional Stream Flow Analysis) in the *Preliminary Hydrographic Report for the Hopi Indian Reservation, In re The General Adjudication of the Little Colorado River System and Source*, December 2008..

The Arizona Department of Water Resources (ADWR) made a substantial effort to estimate the volume of water that flows into the Hopi Reservation and the volume of water that flows out of the Hopi Reservation. Table 7.3 presents the final numerical conclusions of the ADWR hydrologic analysis. Table 1 in this memorandum present selected values from ADWR's Table 7-3 *Estimated Stream Inflows and Outflows on the Hopi Indian Reservation* for the base period 1981 through 2006 and values from nearby gaged sites for the same base period.

The lack of gaged data along with the complexity of the flow regimes, make it very difficult to accurately estimate these inflows and outflows. There is no single correct or incorrect method for generating these estimates. ADWR went to great lengths to develop an appropriate methodology. Much of this methodology is described in *Stream Flow Characteristics of the Hopi Reservation* January 2008. However, in spite of the significant effort made by ADWR, the overarching concern is that several of the key technical decisions made by ADWR may have resulted in misleading values.



**Attachment 1**

1. Estimated mean flows are frequently less than estimated median flows

The ADWR estimate stream inflows and outflows in Table 7-3 are very unusual. In this region the mean (average) runoff volume is almost always greater than the median runoff volume. (The median flow is the flow that is available 50 percent of the time.) An inspection of more than 20 locally gaged sites verifies this observation. Intuitively this result does make sense because the average is influenced by a relatively small number of very large events. However, the ADWR estimated mean flows are frequently less than ADWR estimated median flows.

The values cited in the first paragraph on Page 7- 4 are derived from Table 7-3 *Estimated Stream Inflows and Outflows on the Hopi Indian Reservation.* Table 7-3 includes mean and median stream flows for a number of sites that are intended to reflect the points of inflow to, and the outflow from, the Hopi Reservation. For example, as presented by ADWR, the estimated mean flow at Point I-1 is 650 AFA while the median flow is 1,440 AFA. The total average inflow at all of the estimated points is 6,820 AFA while the estimated median inflow is 10,800 AFA. For this basin, this result would be very unlikely. This finding indicates that the ADWR results may be suspect.

2. The measurements at the Moenkopi Gage USGS #09401260 are unusual

The USGS Moenkopi Gage #09401260 calender year data appear to be the exception to the rule that the regional stream flow averages are greater than the regional medians. In this respect, this gage differs from every other gaging site on the Moenkopi Wash. NRCE Incorporated reports in its October 29, 2007 response to ADWR that the average record quality at this gage is poor. Even so, no clear explanation for this possible anomaly is apparent. Accurately measuring flows in the local sandy stream channels is very difficult. It is as much art as science. There are theoretically possibilities that could account for this anomalus result. For instance, it is theoretically possible that at large flows the rating curves underestimate the actual flows. This problem could result in the larger flows that should have raised the overall average having less statistical impact.

Another possibility is that the flows passing the gage occasionally become isolated from the gage's transducer. If this ever occurred, the gage would record a zero flow while the actual flow would be somewhat greater. This problem could result in some unknown number of relatively small flows that should have raised the overall average result in a lower reported average. Another possibility is sediment clogging the gage's transducer resulting in a recorded flow when actually there is no flow. Based on a field trip to this site on June 10, 2009 either problem appeared possible. Due to limited resources, unless there is an obvious problem with the data stream, the USGS only visits the site every six weeks. So these types of problems could go uncorrected for weeks.

Table 1.1 ADWR Points and Nearby Gaged Sites for the ADWR Base Period (1988 to 2006)

| Site Label | Estimated Average AFA | Estimated Mean AFA |
|---|---|---|
| ADWR I-1 | 650 | 1,440 |
| | | |
| ADWR I-2 | 350 | 514 |
| PWCC SW25 + SW26 +SW 155 | 2226 | 1187 |
| | | |
| ADWR I-13 | 3810 | 4510 |
| USGS 0901260 | 7610 | 7780 |
| ADWR O-8 | 4620 | 4140 |
| | | |
| USGS 090583 | 305 | 230 |
| ADWR O-3 | 191 | 208 |
| | | |
| USGS 090568 | 305 | 230 |
| ADWR O-4 | 1,250 | 1,520 |
| | | |
| USGS 090562 | 1520 | 880 |
| ADWR O-5 | 1610 | 1560 |
| | | |
| USGS 09401110 | 2260 | 1740 |
| ADWR O-6 | 1780 | 2460 |

In order to extend the USGS Gage #09401260 record ADWR appended the gage records from USGS Gages #09401280 and #09401250 to it. Because of the influence of the other two gages, the extended record resulted in an average flow greater than the median flow. However, simply appending these records together may introduce error. ADWR Figure 7.1 shows that USGS Gages #09401260 and #09401280 are in the same location. However, ADWR Figure 7.5 shows that USGS Gage #09401280 is several miles downstream from USGS Gage #09401260. This confusion is understandable because the USGS published incorrect location information for USGS Gage #09401280 that indicated that they were in the same location. The reality is that the USGS Gage #09401280 was several miles downstream. Its watershed was 17 percent greater in area, it included flows from Pasture Canyon, and it was influenced by upstream irrigation diversions. Some of these USGS gage values are shown in Table 2.

Another very unexpected result is shown in Table 1. During the base period the average estimated ADWR flow upstream from USGS Gage #090126 is 3,810 AFA while the average estimated flow downstream from USGS Gage #09401260 is 4,620 AFA. However, the flow at #09401260 during the base period is 7,610 AFA. This result indicates that the estimated flow data is not well calibrated.

Table 2. USGS Gage Data in the Moenkopi Area

| USGS Station | Period | Mean | Median |
|---|---|---|---|
| 9401260 Moenkopi at Moenkopi | 1977 to 2008 | 7,261 | 6,272 |
| 9401260 Moenkopi at Moenkopi | 1981 to 2006 | 7,397 | 6,391 |
| 9440140 Moenkopi nr Tuba City | 1941 to 1978 | 11,048 | 9,373 |
| 9401280 Moenkopi Near Tuba City | 1927 to 1940 | 16,879 | 9,988 |

3. ADWR made no attempt to census outliers

ADWR made no attempt to identify or censor outliers. It is understandable that ADWR would rely on the source data as they are without any screening that would bias the results. However, some greater screening might have eliminated data sets that resulted in suspect results.

4. Oraibe, Polacca and Dinnebito Washes data were filled with PWCC FL15 data

ADWR ran an extensive series of Pearson correlations among the gaged sites in the study area. One result is that Peabody Western Coal Company (PWCC) FL15, a gaged site on Yellow Water Wash, showed a high correlation with sites on Oraibe (USGS Gage #09400562), Polacca (USGS Gage #09400568) and Dinnebito (USGS Gage #09401110). The Pearson correlation coefficient values were 0.93, 0.94 and 0.83 respectively. Based on these high correlations, ADWR used the FL15 data in the formula for filling in the flow records for these washes during the base period.

The use of this data in this manner is completely understandable. However, the results are again suspect. As shown in Table 1, the estimated means are again less than the estimated medians. This result is surprising because between 1987 and 2002 the PWCC sites have an annual mean that is 30 percent greater than the median. In addition, the original USGS records show that the annual means for these three closest USGS gages are also approximately 30 percent greater than the medians.

Although the data collected at FL15 may have a high correlation, several aspects of that site may have made it a poor choice for this purpose. The FL15 watershed is 42.1 square miles and the stream length is 13 miles. However, Oraibe is 666 square miles and the stream length is 107 miles, Polacca is 908 square miles and the stream length is 80 miles, and Dinnebito is 491 square miles and the stream length is 89 miles. Furthermore, the data collected by PWCC may not have been mean daily values. The Peabody data may be more similar to peak discharge measurements.

One interesting comparison is that correlation coefficient between FL15 and the downstream USGS Gage #09401260 is 0.20. Evidently one is to assume that FL15 is a better hydrologic indicator for Oraibe, Polacca and Dinnebito than it is for the watershed that it is in. Another interesting comparison is that the correlation coefficient between FL15 and Jeditto Wash, which is close to the other three washes is only 0.06. The apparent correlations between FL15 and the three washes may be spurious.

5. ADWR's selected base period may not be representative

ADWR indicated that the base period was driven by the availability of data. Consequently the inflow and outflow results may not be representative. For instance, it is possible that this base period reflects a drier period. For instance, the average flow of the Little Colorado River at Cameron between 1948 and 2006 was more than 220 cfs while the average flow during the ADWR base period was less than 200 cfs. This is roughly a 10 percent difference.

6. ADWR Text Includes Numeric Discrepancies

Several of the values presented in Table 7.3 are inconsistent with some of the values shown in Figure 7.6 *Stream Inflows and Outflows on the Hopi Indian Reservation*. For instance in Table 7-3, Point I-1 has a mean flow of 659 AFA and a median of 1,440 AFA, while in Figure 7-6 it has a mean flow of 690 AFA and a median flow of 1,520 AFA And Point I-13 has a mean flow of 3,830 AFA and a median of 4,540 AFA, while in Figure 7-6 it has a mean flow of 3,810 AFA and a median flow of 4,510 AFA. Other points have similar discrepancies.

7. Impacts of existing uses on the inflows and outflows

Another issue that ADWR does not address is that the USGS gage data already reflect the effects of the current Navajo and Hopi depletions upstream from the existing irrigation. It is not clear how ADWR addresses the Navajo depletions upstream from Hopi. The impact of Navajo irrigation appears to have been ignored. The inflows and outflows values are not comparable to estimates of the natural flows.

8. Possible misinterpretation of the inflow and outflow results

Table 7-3 includes a footnote that has a huge impact on the interpretation of this table and the subsequent description of the water supply on Page 7-4 and other sections. That footnote indicates that some "outflows become inflows again over relatively short distances." It might make sense to aggregate the separate discrete flows from the five major washes to generate an estimate of the total aggregate water supply flowing onto, or off of, the Hopi Reservation. But, it is absurd to aggregate the flows at O-7 and O-8 which essentially describe the same physical water supply that leaves the western border of the Hopi Reservation (O-7), enters the eastern boundary of Moenkopi (I-13), and then leaves the western border of Moenkopi (O-8). The interpretation on Page 7-4 implies that the "Total Outflows" is the measure of the water supply available when it is not. Table 7-3 presents the difference between the "total outflows" and the "total inflows" which create an even more misleading characterization of the water supply that may be generated on the Hopi Reservation. The lack of analysis of the natural undepleted flows verses the depleted flows, makes it difficult to uses these results in a meaningful way.

Thank you for the opportunity to provide these comments. If you have any further questions please contact me at (928) 729-4004.

Sincerely

THE NAVAJO NATION

John Leeper, Civil Engineer
Water Management Branch
Department of Water Resources

(Formerly)

HYDROSPHERE
Resource Consultants

amec

28 June 2009

Ms. Bidtah Becker, Esq.
Water Rights Unit
Navajo Nation Department of Justice
P.O. Box 2010
Window Rock, AZ 86515

Re: Comments on Agricultural Water Use Estimates in Preliminary Hydrologic Survey Report of Hopi Claims in Little Colorado River Basin Adjudication by the Arizona Department of Water Resources

Dear Bidtah:

This letter report summarizes my comments to date on behalf of the Navajo Nation regarding the above-referenced adjudication court filing.

## SCOPE OF AMEC REVIEW

In our review of the Preliminary HSR, AMEC is focusing on hydrology issues related to claims, water supplies, and demands (in Chapters 2, 7, 8, and 9), and we offer no critical evaluation of ADWR's summary of Hopi Reservation lands, physical setting, the Hopi Tribe culture, and its economic base (addressed in Chapters 3, 4, 5, and 6). In this letter report, my technical review and comments focus in particular on the agricultural water-use category. I reviewed two broad aspects of the agricultural claims and the ADWR assessment of those claims:

a) The crop water use per acre for the various agricultural systems employed by the Hopi, and
b) The quantification of the historically irrigated acreage.

For simplicity in my citation of references herein, I employ the same reference list compiled by the ADWR in the PHSR.

*Privileged & Confidential Attorney – Client Work Product*

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**Attachment 2**

## AGRICULTURAL WATER DEMANDS

The PHSR was reviewed in conjunction with its associated appendices (as well as available references therein) for subject matter concerning agricultural land use and associated consumptive use values. This section provides a summary of my review with associated comments noted that either require further attention, or items that are not congruent with referenced material. Overall conclusions and suggestions for further analysis are made at the end of this section.

In Chapter 8 of the PHSR (and detailed in Appendix F), ADWR estimated agricultural water demands on the Hopi reservation by characterizing:

- the types of crops being grown,
- the net irrigation requirement of the crops (crop consumptive use demand less the effective precipitation),
- the efficiency of the irrigation system; and
- the cropped acreage.

### *Crop Mix and Water Demands*

The ADWR notes (PHSR Table 8-1, details in Appendix F) that corn has been the most common crop grown, followed by orchards, beans, melons, and squash.

- Corn: 81.2%
- Orchards: 8.1%
- Beans: 6.7%
- Melons: 2.3% (note: usually grown in home gardens)
- Squash: 1.7% (note: usually grown in home gardens)

The ADWR calculated consumptive use for these 5 different types of crops, but did not calculate consumptive use for range pasture (Section 1.5 Appendix F to the HSR, Consumptive Use of Crops Grown on the Hopi Indian Reservation ADWR 20008). According to the Hopi claim summarized in the PHSR (and included as part of Appendix A of the PHSR), range pasture occupied a significant acreage, 19.5% of all Hopi-identified historically farmed lands, or 7,522 acres (Section 2.3.4 HSR). In comparison, an NRCE memo (National Resource Consulting Engineers, 2007; attached as Appendix B to Appendix F of the PHSR) in support of US claim on behalf of Hopi Tribe calculated consumptive use for corn and range pasture but not for individual types of crops (Answer to Question 3 in Appendix B to Appendix F, Consumptive Use of Crops Grown on the Hopi Indian Reservation ADWR 20008). This prevents direct comparison of ADWR and NRCE estimates of crop water use. *The ADWR should augment the existing analyses by explicitly computing per-acre crop water use for the same crop mix and same irrigation categories as did NRCE to facilitate checking and validation.*

The majority of historical agricultural fields use dryland farming techniques (Appendix F, page 1-2). Dryland fields are strategically placed by the Hopi in areas that receive runoff and maximize stored soil moisture. Typical geomorphological locations of dry farmed fields include, but are not limited to, the base of sand dunes, within arroyos and floodplains adjacent to streams, gentle slopes below rock escarpments, and alluvial fans. This type of "Native" or "ak chin" agriculture is far different than modern agricultural systems in which regional water supplies concentrated in a stream channel can be diverted and conveyed to agricultural fields. While such modern systems may be amenable to administration by water managers, the Native system that strategically relies on localized water supplies that are unique to the particular field situation and location can not be similarly subject to water-rights administration. Rather, the estimated crop consumptive use for the Native systems provide an indication of the potential crop water depletions to total water yield of the wash watersheds.

The ADWR report calculates a lower and upper confidence interval for "Native" or dry land farming and "modern day" or non-deficit irrigation farming, entitled "DRY" and "NDI" respectively (Appendix F, pages 1-4, 2-1).

Water demand for any particular crop mix involves calculating the "reference" evapotranspiration (ETo) and multiplying that by a "crop coefficient" ($K_c$). to yield a crop-specific estimate of evapotranspiration, ETc.

As described in Appendix F of the PHSR (Section 2.1), three models were considered to compute ETo. These models are:

- FAO-24 Blaney-Criddle: not used for final CU calculations because there was no local calibration
- 1985 Hargreaves-Samani: not used for final CU calculations because it has been shown to be less accurate in windy areas unless local calibration is available.
- FAO-56 Modified Penman-Monteith: This method incorporates winds into the ETo calculation and was therefore chosen to calculate final ETo values for the Hopi Reservation. This method is largely equivalent with the "ASCE Reference" method (ASCE-EWRI, 2005).

Even beyond the advantages of the FAO-56 method described above, it is currently the most widely accepted method for estimating crop water use (Allen et al., 1998). While in general I support ADWR's selection of the FAO-56 method for estimating crop water use on the Hopi reservation, its application to "native" Hopi farming systems is outside the range of conditions for which it was developed, imparting a large unquantified uncertainty to those estimates. The ADWR (Appendix F, Sections 1.3 and 1.4) explicitly recognizes the uncertainty in crop water use estimates due to the lack of availability of needed meteorological data, and attempts to account for that uncertainty by computing a range of CU values "that bracket the actual CU rates for crops on the Reservation." They also attempt to make adjustments to the crop coefficients to address how Native cropping systems deviate from NDI "modern" irrigated systems (Appendix

F, Section 2.2); this adjustment for Native agriculture is based on effective ground cover and according to ADWR this adjustment method was reviewed and approved by Dr. Richard Allen (Appendix F, page 2-8), one of the co-authors of both the FAO-56 and the ASCE Reference methods.

The three models were run using the Ref-ET program developed at University of Idaho, using input data compiled by the ADWR from WRCC and the Hopi Water Resources Program. Default values were developed using FAO-56. The Penman-Monteith model requires as input: air temperature, wind speed, air humidity, and solar radiation data. Of these, only air temperature had a satisfactory period of record (>10 years). All other variables were estimated, interpolated, or calculated.

- Solar Radiation was calculated by using the difference between maximum and minimum air temperatures on any given day. An adjustment coefficient of 0.16 was used as recommended for interior, non-coastal regions.
- Dew Point (Tdew) for NDI. There appears to be a typographical error on p. 2-5 of Appendix F, Section 2.1.3.4 where ADWR imply that an increase in relative humidity would lead to a *decrease* in Tdew; this is the exact opposite of what one would expect and therefore the ADWR must have meant the increase in humidity over an NDI-cropped field would lead to an *increase* in Tdew; if this is *not* a typographical error, the ADWR needs to clarify what they mean here. In this same section, the ADWR next notes that they employed the ASCE Reference method of Walter et al. (2005) to estimate Tdew from Tmin. This methodology was chosen because much of the data for which it was developed for ASCE are specifically taken from Arizona. *This methodology described to estimate Tdew from Tmin appears reasonable for NDI crop water use estimation.*
- Dew Point (Tdry) for DRY. Because of the large data gaps in relative humidity measurements the Method Of Variance Extension, Type 1, or MOVE1, was used by the ADWR to create a relationship between Tmin and Tdew for each month to extend the record of relative humidity data. They further note that no Tdew correction is needed for

small size and sparse cropping pattern for the DRY fields. *I recommend that the ADWR provide a "Tdew sensitivity" chart or table to illustrate the difference that results in the calculated ETo from adjusting the Tdew for two equivalent time series of climatic input data.*

Calculating the crop coefficients Kc values for DRY conditions required adjustments beyond the more standard application for modern irrigated agriculture. Standard Kc values could not be used for the DRY Native agriculture conditions since the much of the agriculture is dryland farming and does not express a micro-climate similar to modern day agriculture[2]. In addition, the crop coefficient needs to account for increase in spacing of crops as compared to modern agricultural practices. This adjustment is likely well justified, however, it is unclear whether this adjustment also accounts for the fact that the widely spaced plantings will lead to a greater water use per "plant cluster" due to each cluster being exposed to lower relative humidity. A *more detailed summary of the ADWR's method to compute Kc is recommended*[3] *as there are many variables used in determining this value, and the methodology is unique and has not been repeated. At a minimum, ADWR should consider a sensitivity analysis of the various variables that would help better identify and quantity uncertainties in the Kc estimates.* For example, ADWR notes (Appendix F, pages 2-8 and 2-9) that use of a single growing degree-day (GDD) curve irrespective of planting date leads to anomalous results, but I could not find an illustration of how using different GDD curves for different corn plantings may affect results. See Table 2.11 of Appendix F for ETc values for each crop under each condition.

To develop the final crop water use estimates, ADWR takes the average of ETc values calculated for Tuba City and Keams Canyon weather data and averages these values for the final ETc values. These final values are used to calculate NIWR. Temperature and precipitation values

[2] In modern-day irrigated agriculture with an adequate water supply, the micro-climate within an irrigated field is characterized by a high relative humidity compared to the background ambient conditions expected for the arid and semi-arid Hopi reservation lands.

from these two stations are significantly different. *An alternative, and perhaps better, approach would be to weight ETc values for irrigated crops based on proximity to each weather station. The ADWR should include a sensitivity analysis to compare ETc values computed both ways.*

***Effective Precipitation***

Finally, ADWR needed to estimate effective precipitation, which is subtracted from the ETc to obtain the net crop irrigation requirement. Keams Canyon and Tuba City annual and effective precipitation values calculated by the ADWR are shown in the table below.

| Location | Annual Rainfall | Effective Precipitation |
|---|---|---|
| Keams Canyon | 9.97 | 6.48 |
| Tuba City | 8.19 | 5.48 |

As described in Appendix F (Section 2.4), ADWR estimates that 52 - 89% of ETc is met by from annual precipitation. This implies that from 11 to 48% of ETc is acquired from surface water. Note that this value is for the Keams Station. The Tuba City estimate assumes a smaller percentage of ETc met by effective precipitation. ADWR averaged the values of effective annual rainfall when calculating the final net irrigation requirements (0.57 ft). The ADWR calculated effective precipitation from total annual rainfall rather than using the more common standard of the amount of rainfall during the growing season. ADWR adopted this alternative since the Hopi fields are geographically situated as to maximize effective precipitation by taking advantage of deeply stored soil moisture. *While this assumption may be valid for dryland crops irrigated via the Hopi's unique traditional methods, for crops grown using modern-day irrigation in leveled fields (NDI), the standard approach of using only growing season precipitation may be preferred. ADWR should perform a sensitivity analysis to assess the impacts of their effective precipitation assumptions.*

With the calculated ETc and estimated effective precipitation, the net Crop Irrigation Requirement can be computed for by NDI and DRY conditions. Lower and upper limits for NDI

[3] The current presentation of Kc methods in Section 2.2 of Appendix F is quite detailed, however, it

and DRY irrigation methods as calculated by ADWR are listed in the table below (from Table 2.14 of Appendix F).

| Irrigation Method | Lower Limit (ft/ac) | Higher Limit (ft/ac) |
|---|---|---|
| NDI | 1.72 | 2.46 |
| DRY | 0.35 | 0.86 |

These values were calculated assuming the consumptive use for Hopi agricultural fields is 0.92 - 1.43 ft/acre and 2.29-3.03 ft/acre if water was not a limiting factor. Effective precipitation was estimated to be 0.57 ft per year as described above.

Working for the US on behalf of the Hopi tribe, NRCE conducted a consumptive use study using the Jensen-Haise model to calculate ET. The ADWR did not use this method because it is a solar radiation based model and according to Allen et al (1998) "radiation methods show good results in humid climates...but performance in arid conditions is erratic and tends to underestimate evapotranspiration." The NRCE report entitled 'Historical/Present Irrigation water uses of the Navajo and Hopi Indian Reservation within the Northern Washes of the Little Colorado River Basin' is not being made available at this time, so the methodology used to calculate consumptive use is unknown. According to Table 2.14 of Appendix F, the net crop irrigation demand for dryland "native agriculture" calculated by NRCE to support the Hopi claim.

| Average (ft/acre) | Maximum (ft/acre) |
|---|---|
| 0.61 | 0.99 |

The irrigation water demand in the ADWR report has been determined based on the assumption that 643 acres were farmed using modern day irrigation practices (non-deficit irrigation, or NDI) and that the remaining acreage was irrigated using native irrigation techniques (DRY). This is inconsistent with the definition of irrigation types as defined in the Hopi Claim submitted to

---

proceeds in a narrative fashion that makes it difficult to evaluate, let alone reproduce, ADWR's findings.

ADWR on 2/2/2004 (Appendix A of HSR). As defined in the 2004 Hopi claim, claimant defines an irrigation type entitled "native irrigation" as lacking the use of structures for diversion. Based on irrigation types defined in this claim it appears that there is a range of variability in crop densities rather than only two types, NDI and DRY. *The ADWR should explicitly provide some sort of cross-walk between their NDI and DRY definitions and the irrigation types identified in the Hopi claim.*

In summary, ADWR determined a net Crop Irrigation Requirement (CIR) of 0.35 to .86 acre-feet per acre for traditional farming practices and 1.72 to 2.46 acre-ft per acre for modern farming practices, compared to the claims of the Hopi (and the US on behalf of the Hopi) of 0.61 - 0.99 acre-feet per acre for traditional farming, and 1.81 acre-ft per acre for modern practices. In general, the ADWR approach that relies on the FAO-56 method should yield results superior to the Jensen – Haise method employed to develop the Hopi claim.

Agriculture in the Moenkopi Area uses more modern irrigated agricultural methods. A reservoir has been constructed along Pasture Canyon to capture spring discharge, and releases from the reservoir are used to irrigate 179 acres near Moenkopi Wash. The United States reported 2.01 acre-feet per acre are diverted for these parcels. Combining this diversion amount with the estimate of 1.81 acre-ft per acre depletion indicates a 90% irrigation efficiency. This efficiency is extremely high compared to most modern flood irrigation systems. *The ADWR should comment on this issue and determine whether such an assumed irrigation efficiency is defensible.*

## Past and Present Agricultural Acreage

The last piece of the puzzle for estimating past and present agricultural water diversions and depletions is the amount of acreage cultivated annually. ADWR estimates that 63% of the reservation land (over 1 million acres) have soils that could potentially grow crops, if irrigated. Consultants working on behalf of the Hopi used aerial and satellite photography to identify all lands that had been historically or are currently being farmed. They estimated that 38,556 acres

have been historically farmed on the Hopi reservation in 8,210 individual agricultural fields; it is important to note this is NOT what is currently being farmed.

ADWR reviewed the same photography and determined only 25,261 acres show convincing or partial evidence of farming (PHSR Appendix G). ADWR reduced the 8,210 individual agricultural fields to 2,214 by joining fields that bordered each other and reviewed 76% of the total claimed area. In their formal review, ADWR determined that:

- 11% of agricultural lands identified by Hopi consultants was found to have complete evidence of agricultural activity
- 55% was found to have partial evidence of agricultural activity in one or more years
- 34% was found to have either questionable or no evidence of agricultural activity.
- In their verification review of agricultural acreage, ADWR also undertook a topographic drainage analysis (ADWR, 2008m) to determine that surface water drainages pass through or in close proximity of most fields, and can provide a source of water.

Historic and recent data indicate that since the 1870s the total acreage farmed by the Hopi in any given year has not exceeded 9,330 acres (Table 9-1 of PHSR), and has typically ranged between 3,500 and 6,500 acres as shown in Figure 8-1 of PHSR. (Note that ADWR recorded this value as 2,000 to 7,000 acres in the ADWR report 'Identification of Recent (2005) Agricultural and Riparian Lands on the Hopi Reservation').

The ADWR annual water demand for irrigation is calculated assuming an annual farmed acreage of 1,000 – 9,853 acres. This is a very different approach than the Hopi and the U.S. are using, who are claiming water for all land that has at any point in time been farmed, 38,556 acres. This value of acreage claimed on ehalf of the Hopi Tribe should be compared to the historical agricultural water use quantities summarized in Table 9-1 of the PHSR and the following information:

- The annually cropped acreages summarized in Figure 8-1.

- In 2005 ADWR identified a total of 5,613 acres of agricultural lands on the Reservation (PHSR Appendix G). Approximately 63% of this acreage was classified as actively farmed, 6% were left fallow during the growing season and the remaining 31% either active or fallow. Accounting for potential errors, the ADWR estimates that the total area of agricultural lands on the Reservation in 2005 is estimated to have ranged between 5,570 and 6,506 acres.

### Future Agricultural Water Use

In section 8.1.4 of the PHSR, the ADWR notes that the Hopi, but not the US on their behalf, claim water for future crop irrigation beyond the historical and current uses. Those future claims include new garden plots near the Hopi villages (these uses are claimed under ceremonial / cultural uses and are suggested to be supplied by groundwater) as well as new agricultural irrigation projects supplied by surface flows in Moenkopi Wash and the mainstem LCR.

With regard to the future irrigation projects fed by surface supplies, the ADWR crop water use values for NDI should be used to estimate crop water use on a per acre basis. The ADWR correctly notes that the magnitude of the Hopi claim for the future Moenkopi Wash project appears to exceed the sustainable water yield of the wash.

With regard to the village garden plots claimed for future ceremonial / cultural uses, the ADWR notes (Section 8.7.2 of the PHSR) that the crop water use for these fields should use values computed using the DRY per-acre water use numbers. When using the DRY water use values and a reasonable value for irrigation system efficiency, the total expected water use for these cultural garden fields should be a half or lass than the amount claimed by the Hopis.

## ADWR SUMMARY AND CONCLUSIONS

As summarized in Table 9-1, ADWR calculated the quantity of water used each year by the Hopi for agriculture by multiplying the range of farmed acreages in a given year (Appendix G) by the

averaged weighted consumptive use values summarized above (Appendix F). Based on these calculations, ADWR determined that traditional farming used from 350 to 7,921 AFA, and irrigation projects used from 0 to 1,582 AFA, which results in a net irrigation demand of 350 AFA to 9,503 AFA for agricultural purposes in any one year (Table 9-1). These estimates of historical agricultural water use developed by the ADWR are much smaller than the Hopi claim of approximately 28,000 to 49,000 af/yr. Based on my review of the PHSR, the ADWR's conclusions of historical water use summarized in Chapter 9 are more defensible than the historical agricultural water use claimed by the Hopi and the US on their behalf.

As described above, for future agricultural claims, the ADWR draws defensible conclusions that: (i) the Moenkopi Wash surface water yield is less than the projected demands for the claimed future irrigation project in the Wash, and (ii) the expected water use for the new ceremonial / cultural garden plots adjacent to the Hopi villages is far less than the amount claimed by the Hopis for this use.

After reviewing my comments above, please do not hesitate to call me (505-835-3026) or email (jim.mccord@amec.com) if you have any questions.

Sincerely,

by: James J. McCord

Jim McCord, Ph.D., P.E.

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March 30, 2009

Arizona Department of Water Resources
Adjudications Section
3550 North Central Avenue, 4th Floor
Phoenix, AZ 85012

**RE: PRELIMINARY HYDROGRAPHIC SURVEY REPORT FOR THE HOPI INDIAN RESERVATION**

Dear Sirs:

Peabody Western Coal Company (PWCC) has reviewed the preliminary Hydrographic Survey Report for the Hopi Indian Reservation (Hopi Preliminary Report) released on December 31, 2008 for inspection and comment. PWCC's comments on the Hopi Preliminary Report are provided in the following sections.

Chapter 6: Economic Base

1. Page 6-5, Second Paragraph: The Office of Surface Mining Reclamation and Enforcement (OSM) issued the LOM Permit to PWCC on December 22, 2008. This fact should be included in this paragraph.

Tables

1. Table 7-4: Table 7-4 indicates surface water sampled at CG85 exceeded numerous trace element standards associated with Primary and Secondary Drinking Water quality standards, as well as several trace element standards for Livestock Water. Water samples collected by PWCC at CG85 were collected from runoff events that typically featured very high concentrations of suspended sediment. These samples were analyzed by a contract laboratory using both the dissolved and total analytical method. The total method typically results in high concentrations of trace elements for un-filtered samples collected from water with high sediment loads, as the acid digestion process breaks down the suspended silts and clays. PWCC's review of the data collected at CG85 indicates trace elements analyzed using the dissolved method were very low concentrations, and most met all of the standards compared in Table 7-4. PWCC recommends using the dissolved analyses collected at CG85 for comparing water quality standards as shown in Table 7-4, and questions whether samples collected at the other sampling sites had high suspended solids concentrations and which analytical method was used for the trace elements compared against the standards.

Appendix C

1. Table C-1: Table C-1 shows PWCC's sediment pond WW-9 has a claimed capacity of 21.21 acre-feet, and the ADWR regression analysis indicates a capacity of 2.53 acre-feet. There are two ponds in series at the location of pond WW-9, WW-9#1, and WW-9#2, both with a combined capacity of 21.21 acre-feet. Also, PWCC believes the pond associated with Hopi Claim No. 1-3-302 is a pre-existing stock pond within the PWCC leasehold and is not a PWCC permanent or temporary sediment pond.

2. Table C-2: The ponds associated with ADWR ID No.'s UNC-M-14 through UNC-M-17 are pre-existing stock ponds within the PWCC leasehold and are not PWCC permanent or temporary sediment ponds.

Appendix D

1. Sand Spring is a developed spring located on southwestern portion of the PWCC leasehold, and review of the springs in Tables D-1 and D-2 indicate this spring has not been identified. The coordinates to Sand Spring are 551960 (easting) and 4029066.8 (northing).

2. Table D-1: PWCC believes the spring listed as Hopi Claim No. S-3-226 no longer exists, as recent site investigations have yielded no evidence of its existence.

Appendix E

1. Table E-1: Table E-1 lists Hopi Claim No. W-3-8, and indicates the ADWR could not find the well. PWCC is aware of the location of this well, as it is within sight of the coordinates provided in Table E-1. PWCC is willing to provide assistance to the ADWR finding the location of this well in the future.

If you have any questions or require additional information, please do not hesitate to contact me via phone at (928) 913-9218 or via email (jcochran@peabodyenergy.com).

Sincerely,

John Cochran

John Cochran
Manager Environmental Hydrology
Peabody Investments Corporation

C: Gary Wendt (PWCC)
Jim Ohlman (PWCC)

*SALT RIVER PROJECT*
*P.O. Box 52025*
*Phoenix, AZ 85072-2025*

June 30, 2009

Arizona Department of Water Resources
Adjudications Section
3550 North Central Avenue, 4th floor
Phoenix, Arizona 85012

RE: Comments of SRP on the Preliminary Hydrographic Survey Report for the Hopi Indian Reservation

To Whom it Concerns,

Attached please find the document titled, SRP Comments to the Preliminary Hydrographic Survey Report for the Hopi Indian Reservation. We hope that these comments provide useful information and suggestions to the Department in preparation of the final Hydrographic Survey Report.

Thank you for your consideration of our comments.

Very truly yours,

Dave Roberts, Manager
SRP Water Rights and Contracts
PAB110
P.O. Box 52025
Phoenix, AZ 85072-2025

Attachment

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JUN 30 2009
7:10 am KD
LEGAL
DEPT OF WATER RESOURCES

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# SALT RIVER PROJECT COMMENTS
# ON THE
# PRELIMINARY HYDROGRAPHIC SURVEY REPORT FOR THE
# HOPI INDIAN RESERVATION

**June 30, 2009**

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# SALT RIVER PROJECT COMMENTS
# ON THE
# PRELIMINARY HYDROGRAPHIC SURVEY REPORT FOR THE
# HOPI INDIAN RESERVATION

## JUNE 30, 2009

The Salt River Project Agricultural Improvement and Power District, referred to herein as the Salt River Project or SRP, submits the following comments on the Preliminary Hydrographic Survey Report for the Hopi Indian Reservation (HSR) published by the Arizona Department of Water Resources (Department) on December 31, 2008. SRP's interest in this preliminary HSR and subsequent proceedings are primarily due to the potential precedents for HSRs on other federal and Indian Reservations, which may have a direct impact on SRP water rights. Following receipt of comments and any changes in the preliminary HSR, the Department will publish a final HSR, which will trigger the formal objection process. The intent of SRP's comments is to suggest changes that are needed before final publication. These changes are intended to enhance understanding of the HSR, minimize objections, and reduce the need to introduce evidence at subsequent hearings, thereby expediting the resolution of these claims.

In general, SRP concurs with the Department's approach for all procedures that are not specifically addressed below. However, SRP reserves the right to comment on or object to additional items if further review results in the identification of other problems or concerns.

# I. Comments on Overall Scope of the HSR.

## A. Overall Content and Support

The preliminary HSR is a significant improvement over past HSRs. The Department compiled a large amount of useful information, which is well-documented and well-cited.

### *1. Issue*

The preliminary HSR heavily relies on internal and consultant reports; the reports are referenced throughout.

### *2. Recommendation*

Internal and consultant reports should be readily available for review when the draft is published and throughout the comment period. These could all be posted on the Department's website. Likewise, the reports should be readily available when the final HSR is published, including any revisions or additional reports that were developed after publication of the draft HSR.

# II. Comments on Specific Sections of the HSR

## A. Riparian Evapotranspiration

### *1. Issue*

Although acknowledging that claims were not made for water use by riparian vegetation, the Department conducted an analysis of this naturally occurring consumption of water (Section 8.8). It is not clear how estimates of riparian evapotranspiration are relevant to the adjudication of these or other water rights.

### *2. Recommendation*

Unless the Department establishes the relevance of the riparian evapotranspiration estimates to the adjudication of Hopi or other water rights, SRP recommends that the evaluation of riparian evapotranspiration be removed from the final HSR.

## B. Net Irrigation Demand For Rain-fed Crops

### *1. Issue*

The Department includes 7,921 acre-feet per annum (AFA) for cropped acreage under "Traditional Hopi Farming" as part of its recommended quantity of 19,896 AFA for water use on the Reservation (Sections 9.1.1 and 9.3.2, and Table 9-1). This quantity includes estimated crop consumptive use for areas that are "dryland farmed" (Section 9.1.1 and Table 8-2; Appendix F, Section 1.2). Dryland agriculture is not entitled to a water right.

### *2. Recommendation*

Crop consumptive use estimates for dryland acreage without a diversion from a water source should not be included in the quantity of use recommended for a water right.

## C. Evaporation Estimates

### *1. Issues*

The Department uses estimates of gross evaporation to report historical demands and recommended water right attributes for evaporation from recreation and multi-purpose lakes and reservoirs (Sections 8.5.2 and 9.2.5).

The period of record used for evaporation estimates is not clear (pp. 4-4 and 8-25; ADWR 2008f).

### *2. Recommendations*

The Department should use net evaporation, which is gross evaporation minus precipitation, to estimate evaporation losses from lakes and reservoirs.

The Department does not specify the period of record used to estimate evaporation. To calculate net evaporation as recommended above, the same period of record should be used for both gross evaporation and precipitation.

## D. Pre-history and History

Hopi pre-history and history appear in *Chapter 3: Hopi Reservations Lands*, *Chapter 5: Culture*, and throughout the report in the chapter sub-sections labeled *Historic.* The two chapters and the sub-sections are reviewed separately below.

### Chapter 3: Hopi Reservation Lands

Overall, **Chapter 3** provides a solid, general history of the Hopi Reservation lands. The account begins with the pre-reservation period which discusses pre-1540 evidence by charting the early record as documented during the Spanish, Mexican and early U.S. periods (1540 to 1882). Hopi population and settlement patterns were drawn from the early writings which were reiterated in later writings. The history of Hopi Reservation lands, beginning with the 1882 Executive Order, is well presented. The description of post-Executive Order history clearly describes the complexity of Hopi land evolutions through the many designations, enactments, court proceedings, and allotments. The author has provided information and data based on research findings and, for the most part, steered away from offering interpretation of the findings.

1. ***Issue***

   The quote, "one historian stated that 'the cultural remains present a clear, uninterrupted, logical development culminating in the life... Hopi Mesas today." (Section 3.1.1, History to 1540, p. 3-2)

2. ***Recommendation***

   Remove conclusion drawn by "one historian" and replace with data/information the historian used to reach said conclusion.

3. ***Issue***

   The Hopi Tribe claims Pueblo water rights under the Treaty of Guadalupe Hidalgo (Section 9.3.2, p. 9-11). (The Treaty of Guadalupe Hidalgo is mentioned in Section 3.1.4, p. 3-5).

4. ***Recommendation***

   Given that there is a legal issue about whether the Hopi Tribe holds 1848 water rights under the Treaty of Guadalupe Hidalgo (Section 9.3.3, p. 9-14), it would be helpful

for the Treaty citations to be included in the text (9 Stat. 922; Feb. 2, 1848) and for the Treaty itself to be appended to the HSR.

## III. Specific Comments and Questions

* All citations in the HSR need to be checked for format consistency throughout the report. Some are listed below.

| Page | Section; Line | Comment |
|---|---|---|
| | | |
| 2-20 | 2.8.1, line 5 | "Wash" should be capitalized. |
| 3-9 | 3.2.1 1st paragraph | Citation should be on its on line (See example – p. 3-11). |
| 3-11 | | Citations for the two inset quotes and the endnote – treat as other citations with parentheses. |
| 3-17 | 1st paragraph | Citation – 2006 Intergovernmental Compact appears twice in paragraph. 1st time in does not provide location, 2nd time it is not in parentheses. |
| 4-3 | Precipitation; lines 3 and 5 | Insert "average" before "annual" |
| 4-4 | Surface Water Evaporation; line 1 | Insert "average" before "annual" |
| 4-5 | 4.5.1; lines 11-13 | It is not correct to state that "Soils series consist of soil families with similar color, texture, structure and composition (NRCS, 2007b)." Soil families are a broader classification than soil series (ADWR 2008f, Section 2.1). Suggest rewording as follows: "Soils series consist of soils with similar color, texture, structure and composition (NRCS, 2007b)." |
| 5-2 | 1st paragraph | Citation should follow the quote. (See example – p. 3-11). |
| 5-5 | 1st paragraph | Reference to Mischa Titiev - Does this work appear in the bibliography? |
| 5-8 | 1st & 2nd paragraphs | Citations are missing page number(s). |
| 5-9 | 2nd paragraph | Suggest moving paragraph farther down in the section to be adjacent to other paragraphs on domesticated animals. |
| | All Chapter 6, 7 | Citations are missing page number(s). |
| 8-4 | Last paragraph | Citation is missing page number(s). |
| 8-5 | 1st & 2nd paragraphs | Citations are missing page number(s). |
| 8-6 | 1st & 2nd paragraphs | Citations are missing page number(s). |
| 8-14 | 1st & 3rd paragraphs | Citations are missing page number(s). |
| 8-17 | 1st paragraph | Citation missing. |
| 8-19 | 8.4.2 intro paragraph | Andersen citation – move parenthesis to before Andersen from before 2008 |
| 8-24 | 8.5.1 intro paragraph | Citation is missing page number(s). |

| Page | Section; Line | Comment |
|---|---|---|
| 8-27 | 8.7.1 | Documentation / report for this information is missing. |
| 8-28 | 8.8.1 | Citation is missing page number(s). |

VBW
*Denver Field Office*
*1961 Stout Street*
*8th Floor*
*Denver, CO 80294*

**United States Department of Justice**
Environment and Natural Resources Division
*Telephone (303) 844-1372*
*Facsimile (303) 844-1350*

June 29, 2009

**Via Federal Express**

Arizona Department of Water Resources
Attn: Adjudications
3550 N. Central Ave, 4th Floor
Phoenix, AZ 85012

Re: United States' comments on the Preliminary Hydrographic Survey Report for the Hopi Indian Reservation

Dear Sir or Madam,

Pursuant to A.R.S. § 45-256(H) and in accordance with the Court's Pretrial Order No. 6 re: Notice of Hydrographic Survey Reports, dated July 26, 2000, the United States of America ("United States") respectfully submits its comments on the Preliminary Hydrographic Survey Report for the Hopi Indian Reservation ("Preliminary HSR"). The comments are provided below by section consistent with the presentation in the Preliminary HSR. Language presented in italics below reflects the United States' proposed revisions to the Preliminary HSR.

## Chapter 1: Introduction and Scope

### 1.1: Introduction

p. 1-2, footnote 1 – The information regarding the San Juan Southern Paiute Tribe should be clarified to note that they are a federally recognized tribe although they do not currently have a land base. It should be noted that the San Juan Southern Paiute lands are located generally northwest of Moenkopi village. The proposed revision would replace Section 1.1, footnote 1:

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*"The lands occupied by the San Juan Southern Paiute Tribe are not depicted on Figure 1-1. The San Juan Southern Paiute Tribe is a federally recognized Indian Tribe but does not currently have a reservation. The lands occupied by the San Juan Southern Paiute Tribe are generally located northwest of Moenkopi Village and may form the basis of a future San Juan Southern Paiute Reservation."*

### 1.3: Scope

p. 1-4, ¶ 2– The *Gila V* statement of law should recognize that "[t]he method utilized in arriving at such an amount, however, must satisfy both present and future needs of the reservation as a livable homeland." *In re the General Adjudication of All Rights to Use Water in the Gila River System and Source*, 201 Ariz. 307, 35 P.3d 68, 77 (2001). The proposed revision for Section 1.3, ¶ 2, 2nd Sent. follows:

*"Under Gila V, the water rights for the Hopi Reservation are to be quantified by determining the amount necessary to satisfy both the present and future needs that serve the purpose of the reservation, i.e. as a permanent home and abiding place, also referred to as homeland purposes. Gila V, 35 P.3d at 76-77."*

## Chapter 2: Summary of Adjudication Claims

As a general matter, the United States intends to file a Second Amended Statement of Claimant on behalf of the Hopi Tribe that will set out revised water right claims.

### 2.3.4: Past and Present Irrigation Use

p. 2-5, ¶ 1, last sentence – The maximum amount of water available is claimed in order to provide any available water to lands that have been irrigated in the past and present. The proposed revision for Section 2.3.4, ¶ 1 follows:

*"However, the Hopi claim a maximum quantity for irrigation of the past and presently irrigated acreage in order to provide water in years when water is available. In other words, for those years with higher than average water availability, the maximum quantity claim ensures that the Hopi will be able to increase their farming acreage at the times that increased water is available. Such an approach is consistent with Hopi historic practice.*

### 2.5: 1994 United States Claim

p. 2-12,– The summary of the 1994 United States Amended Claim needs to clarify that the numbers provided in the HSR are for Hopi only. The proposed revision for Section 2.5, ¶ 1 follows:

*"On November 22, 1994, pursuant to court order, the United States, on its own behalf and as trustee for the Navajo Nation, the Hopi Tribe, the White Mountain Apache Tribe and the Zuni Pueblo, filed amended SOCs on behalf of Indian Lands in the Little Colorado River Basin, including SOC No. 39-91441 (See Appendix A-2). The 1994 United States Amendment separated the water claimed by tribe. The claimed water uses for the Hopi Tribe set forth in the amendment are set forth below, and are based on 'current or recent' (as of 1994) as well as 'future additional' uses, which respective amounts are indicated parenthetically after the total."*

**2.6.4: Past and Present Irrigation Use**

p. 2-15, ¶ 1 on this page, last sentence – The maximum amount of water available is claimed in order to provide any available water to lands that have been irrigated in the past and present. The proposed revision for Section 2.6.4, ¶ 1 follows:

*"This information is presented in Table 2 of the United States claim, which includes an average irrigation diversion of 28,489 AFA. The United States claims the maximum diversion amount in order to provide irrigation on larger areas of historically irrigated land in years when water is available. (see also Sec. 2.3.4)"*

**2.8: Summary and Comparison of Hopi and United States 2004 Claims and 2005 Supplemental Information for Past and Present Uses**

p. 2-18,– HSR Table 2-1 claims to compare the Hopi and United States claims but does not compare them accurately. The Hopi and United States' domestic, commercial, municipal and industrial ("DCMI") claims included past, present and future DCMI claims as one 11,211 AF claim. ADWR's breakdown of the springs, wells and stockponds does not accurately reflect past and present DCMI quantities as claimed. The proposed revision for Table 2-1 is to <u>*delete*</u> the DCMI entry and simply note that the US and Hopi Tribe claim a DCMI amount that includes past, present and future and that the separation of the time-dependant components of the DCMI claim has not been performed.

**2.12: Other Water Uses**

p. 2-26, - The first sentence of Section 2.12 may create some confusion as it does not specify that it is addressing non-Hopi uses. The proposed revision for Section 2.12, 1st Sent. follows:

*"The Department is aware of two parcels of land that may lie within the Hopi Reservation on which water may have been claimed or used by persons or groups other than the Hopi Tribe or its members."*

## Chapter 3: Hopi Reservation Lands

### 3.1.5: Hopi Agency (1850-1882)

pp. 3-6 through 3-7,– This Section 3.1.5 charts generally the administrative history of Hopis under American authority, but glosses over much of the background behind the issuance of the 1882 Executive Order which set aside the "Moqui," i.e. Hopi reservation. The proposed revision is to add the following paragraph, to be inserted after the fourth paragraph of this section:

*"Efforts to set aside a reservation for the Hopi spanned the careers of all of these Indian agents. Prior to 1882, these agents' concern focused on the lack of a reservation to protect the Hopis from threat of encroachments by non-Indian cattlemen, the proximity of the Mormons at Moenkopi, the presence of the Navajos and the resulting competition over land and water. All of these issues led periodically to recommendations by some Indian agents to move the Hopis from their villages to the Little Colorado River in order to secure a reliable water source"*

### 3.2: 1882 Executive Order Reservation Lands

p. 3-8, , ¶ 1 – This Section provides an instructive description of Jesse Fleming's depiction of proposed Hopi Reservation boundaries but lacks the underlying reasoning for his decision to exclude Moenkopi and fails to mention another government official's recommendation that Moenkopi be included as part of the Hopi Reservation. The proposed revision is to substitute the following text in lieu of the 5th sentence beginning "*As instructed…*":

*"His proposal did not include the Moenkopi area, occupied by approximately 100 Hopi in 1882, because Fleming felt that the inclusion of the non-Indians at Moenkopi could complicate the administration of the reservation. It should be noted that contemporary to Fleming's survey of the land was the work of another government official, Charles H. Howard. Inspector Howard was in the process of making his own reservation proposal, one to include the Moenkopi area within a Hopi reservation, when the 1882 Executive Order was issued."*

p. 3-8, ¶ 2 – Historical evidence does not support the statement that Navajos settled on the Hopi Mesas, but rather that the Navajo occupied lands between the Hopi mesas at times. The proposed revision is to substitute the following sentence for the third sentence in Sec. 3.2, ¶ 2:

*"Some Navajo used lands between the Hopi Mesas and within the boundaries of the 1882 Executive Order Reservation for raising livestock and building homes."*

### 3.3: 1934 Act Reservation Lands (Moenkopi)

pp. 3-14 through 3-15, ¶ 1 – The description of the 1900 Executive Order lands as opposed to the 1934 Navajo Boundary Extension Act should be clarified. The proposed revision is to redraft Sec. 3.3, ¶ 1 & the first sentence of ¶ 2 as follows:

"*In addition to lands within the 1882 Executive Order Reservation, there are Hopi lands within the surrounding Navajo Reservation. The Navajo Reservation was initially created by Treaty of June 1, 1868, 15 Stat. 667, and was expanded through various executive orders. For example, the Executive Order, dated January 8, 1900, incorporated the lands immediately west of the 1882 Executive Order Reservation extending to the Little Colorado River and Colorado River into the Navajo Reservation, including Upper and Lower Moenkopi villages as well as surrounding areas to which the Hopi claimed an exclusive interest. This land is often referred to as the 1900 Extension. See Figure 3-2.* (keep footnote 13 the same) *The 1900 Executive Order did not mention the Navajo or any other Indians, but the consensus of the government officials was that the lands were withdrawn in anticipation of the areas being allotted to the Indians. Certain Moenkopi lands were allotted and occupied by both Hopis and Navajos prior to the issuance of the 1900 Executive Order.*

*In 1934, Congress passed legislation that confirmed the boundaries of the Navajo Reservation resulting from the additions made by the prior executive orders. Act of June 14, 1934, Ch. 521, 48 Stat. 960. In addition to confirming the boundaries of the Navajo Reservation, the 1934 Act permanently ...*"

### 3.4: Allotted Lands

pp. 3-17 through 3-18,– This Section needs some additional information to clarify that the Dawes Act authorized allotment of lands from the unappropriated public domain as well as from reservation lands. This is important because the Hopi allotments were withdrawn from the public domain, not from the 1882 Executive Order Reservation, and allotted to Hopi individuals. This clarification is important because the Hopi allotments occurred prior to the 1900 Executive Order but were part of the lands covered by the 1900 Executive Order that were added to the Navajo Reservation as a result of the passage of the 1934 Navajo boundary extension bill. The proposed revision is to substitute the following text in lieu of ¶ 1 and 1st Sent of ¶ 2 :

"*Under the Indian General Allotment Act of 1887, also known as Dawes Severalty Act, the President was authorized to allot reservation lands to individual Indians when advantageous for "agricultural and grazing purposes." Act of February 8, 1887, ch. 119, § 1, 24 Stat. 338. The Act authorized the allotment of lands within the boundaries of Indian reservations as well as from lands on unappropriated public domain to Indians not residing upon a reservation or for those with no tribal reservation. The allotment program ended in 1934 as part of the Indian Reorganization Act. 48 Stat. at 984.*

*The allotments to Hopi Tribal members were established in the late 1800s and were allotted from the public domain at Moenkopi, located outside the exterior boundaries of the 1882 Hopi Reservation. The surrounding area was subsequently*

*withdrawn by the January 8, 1900 Executive Order. This withdrawal became a permanent addition to the Navajo reservation as the result of the passage of the 1934 Navajo boundary extension bill. These allotted lands are depicted on Figure 1-2 ..."*

## Chapter 4: Physical Setting

The United States has no comments on this section.

## Chapter 5: Culture

The United States has no comments on this section.

## Chapter 6: Economic Base

### 6.1.1: Arable Land

p. 6-2, Sec. ¶ 4 – The use of the term "irrigated" in the last sentence appears to be an error and should be changed to "arable" as follows:

*"The other 37% of Reservation lands or approximately 597,758 acres had soil types that were not found to be arable during the NRCS survey and, therefore, were not given an Irrigated Capability Class by NRCS."*

### 6.4: Human Resources

As a general matter, the United States intends to update its population projections for the Hopi Tribe in its Second Amended Statement of Claimant.

The United States finds that Section 6.4 reveals a number of data gaps and, with some data, a level of inter-year variation that on its face puts to question the data's accuracy. While the United States understands that accurate and consistent data on Reservation demography, employment and general economics is sometimes unavailable, we feel that this section demands closer examination of data and explanation of possible sources of error. Given the number and specificity of the United States' concerns, proposed revisions for Section 6.4 have been made in the table below.

| Data | Location in Report | Issue | Proposed Revision |
|---|---|---|---|
| "approximately 12,000" | 6.4.1., p. 6-22, Population, ¶ 1 | The SWCA study cites a 2006 Tetra Tech study that estimates the population at 13,000. Therefore, the basis of "approximately 12,000" is not clear. Perhaps it is due to the discrepancies in population numbers discussed in the SWCA document (including the Tetra Tech study) or from another source. Regardless, this discrepancy should be corrected or explained. | *Include a footnote citing the source(s) of the "12,000" estimate or change the estimate to "13,000" to reflect the Tetra Tech data referenced in the SWCA document.* |
| "In 2000, about 94% of the Reservation population was determined to be American Indian with Whites making up most of the remainder." | 6.4.1., p. 6-22, Population, ¶ 2 | This sentence requires two changes. First, the current wording suggests that someone other than the census respondent had a role in determining the race of the respondent when the census is actually a self identification process. Second, the source of the 94% American Indian appears to be based on incorrect numbers. Table 6-7 reports a Reservation population of 6,315 in 2000 based on Census data. However, according to the US Census file, the Reservation and off-reservation trust land population in 2000 was 6,946, of which 6,633 identified themselves as American Indian alone or American Indian in combination with other races. | *Change "was determined to be..." to "identified themselves as..."*<br><br>*Change 94% to 95%*<br><br>*Change Table 6-7 entry of 6,315 to accurately reflect the Census 2000 population of Indians on the Reservation as 6,633.* |
| "This equates to an annual growth rate of up to 2.2%" | 6.4.1., p. 6-22, Population, ¶ 3 | The growth rate is incorrect because it should be based on the correct Census data and should go through the entire 175 year period. Using the correct initial 2000 population of 6,946, the annual growth rate is 1.26 percent for the full 175 year period and 2.05 percent for the first 100 years. Even based on an initial population of 6,315 cited in Table 6-7, which the US believes to be incorrect, the respective annual growth rates would only be 2.14 percent for 100 years and 1.32 percent for the 175 year time. | *Change to "This equates to an annual growth rate of 2.1% over 100 years and 1.3% over 175 years."* |

| | | | |
|---|---|---|---|
| "Average persons per household on the Reservation have dropped from nearly 4 in 1990 to about 2 in 2007" | 6.4.1., p. 6-24, ¶ 2 | Combining the data from Tables 6-7 and 6-8 demonstrates that if anything the average persons per household on the Reservation has increased and certainly has not decreased by half. For example, these tables show that the number of housing units during this time frame went from 2,476 to 3,061 while the population went from approximately 8,000 to approximately 12,000. The estimate of 4 persons per household is rightly calculated using the 1990 statistics and the occupancy rate of 75% given in Table 6-8. Even if we were to assume 100% occupancy for 2007, we should still have an average number of persons per household in excess of 3.9. Furthermore, the claim of a dramatic decrease in average number of persons per household is puzzling as the rest of the paragraph focuses on the difficulties in overcrowding. It should be noted that the SWCA report discards the lower number and adopts 4 persons per domestic unit as its basis for estimating future housing needs. | *Change to "The average number of persons per household on the Reservation is estimated to have remained around 4 from 1990 to 2007."* |
| "The unemployment rate over this period varied from 10.9% in 2006 to 62% in 1999. Hopi unemployment is relatively high and variable compared to Arizona as a whole, where rates since 1990 have remained at or below 6.2%." | 6.4.2., Employment, p. 6-24, ¶ 1 and Table 6-9 | The statement that the unemployment rate varied from 62% to 10.9% between 1999 and 2006 suggests a wildly varying status of employment on the Reservation. In fact this variation seems to be a result of relying on multiple sources that calculate unemployment differently. | *Change to "Reservation unemployment data vary tremendously based on the source of data. For example, estimates range from 10% to 62% between 1999 and 2007. In 2008, the TDR and Hopi tribe reported the unemployment rate as 29.8% and 35.6% respectively. Despite disagreement on precise statistics, all sources agree that Hopi unemployment is relatively high and variable compared to Arizona as a whole, where rates since 1990 have remained at or below 6.2%."* |

| | | | |
|---|---|---|---|
| "Outlying communities such as Flagstaff, Page, Winslow, Holbrook, and Gallup will probably continue to provide only limited employment opportunities for Reservation residents." | 6.4.2., Employment, p. 6-25, ¶ 1 | This statement should be clarified as many Hopi live in these outlying communities during the week precisely for employment reasons and then return to the Reservation on weekends and for ceremonies. This sentence appears to be taken directly from the SWCA report, only the HSR added the word "only." It should be noted that the SWCA Report states that the Hopi Tribe has purchased land in Holbrook, Winslow, Flagstaff, and Sedona to create "economic enterprises." This seems to imply that the Tribe intends for these areas to offer greater employment opportunities in the future. | *Change to "Outlying communities such as Flagstaff, Page, Winslow, Holbrook, and Gallup will continue providing limited employment opportunities for Reservation residents, however, these opportunities may increase due to the Hopi Tribe's purchase of property in those communities with plans for economic enterprises."* |
| "The median family income on the Reservation has increased from $15,875 in 1999 to as much as $41,250 in 2007." | 6.4.2., Income, ¶ 2 and Table 6-9 | This suggests that there has been a tremendous and unexplained infusion of wealth on the Reservation during this period. Furthermore, the footnote on Table 6-9 addressing the median income in 2007 indicates that while the projected median family income is $41,250, "households that were queried were found to have a median income of only $9,600." Given the lack of verification of this data and the inexplicable nature of the dramatic increase, the United States is opposed to it inclusion in the Report. Finally, the difference in income data from the Reservation and Moenkopi should be included in the Report in order to capture key socioeconomic issues. | *Change to "The median family income in 1999 was $15,875. More current estimates have indicated an increase but remain unconfirmed. The income for residents living in Moenkopi in 2005 was substantially higher than for those living on the Reservation, likely due to the larger job market and better income opportunities."* |

## Chapter 7: Water Resources

### 7.1.1: Hopi Washes, Flow Conditions and Regional Flow Analysis

pp. 7-1 through 7-4,– This discussion is a summary of the information presented in *Streamflow Characteristics of the Hopi Indian Reservation* (ADWR, 2008b) ("ADWR Streamflow Report"). Accordingly, the United State's provides detailed comments on the ADWR Streamflow Report in **Attachment 1**. As a general matter and for purposes of commenting on the Preliminary HSR rather than its supporting documentation, there are three primary shortfalls with the methods described in the ADWR Streamflow Report. First, the methods used to determine perennial streams are too restrictive and result in misclassifications. Second, the filling/extension of annual streamflows uses models built from either too short of periods (as short as four data points) or with inadequate explanation of the variance to use for record extension. Third, these filled annual data are used to produce models of ungaged locations using questionable statistical techniques including correlated predictor variables from a non-representative period. The result is a compounding of errors in the final results. *For all of these reasons, the United States requests that ADWR reevaluate their methodology for estimation of undepleted wash flows consistent with the United States' comments in* ***Attachment 1****.*

### 7.2: Impoundments

pp. 7-7,– As a general matter, the impoundment information presented by the Preliminary HSR has some errors which the United States will address when it files its amended statement of claimant on behalf of the Hopi Tribe. For example, the difference in the number and/or size of each individual impoundment and verification of the 4 impoundments that ADWR could not verify will be addressed in the amended statement of claimant rather than through these comments.

### 7.2.1: Condition

pp. 7-7 through 7-8 – ADWR identified breached and silted-in impoundments, but either did not include a storage quantity or included a limited storage quantity for such impoundments. The claim submitted by the United State is based on past and present use and thus includes impoundments that are breached and silted-in. The breached and silted-in impoundments can be repaired and/or the silt removed, therefore, the United States will claim the storage quantities based on original construction capacities. It should be noted that the United States' Second Amended Statement of Claimant will include updated storage quantities for these impoundments.

### 7.3: Springs

pp. 7-10– As a general matter, the springs information presented by the Preliminary HSR has some errors which the United States will correct when it files its Second Amended Statement of Claimant on behalf of the Hopi Tribe. For example, the

difference in the number and /or size of each individual spring will be addressed in the amended statement of claimant rather than through these comments.

### 7.3.1: Characteristics

p. 7-11– This section states that ADWR verified the location of 328 of the overall 360 springs claimed. Therefore, ADWR was unable to verify 32 springs. In its amended claim, the United States will provide verification data for many of the 32 springs plus additional unclaimed springs.

### 7.4: Aquifers

As a general matter, the information about wells presented by the Preliminary HSR has some errors which the United States will correct when it files its Second Amended Statement of Claimant on behalf of the Hopi Tribe. For example, the difference in the number and/or size of each individual well will be addressed in the amended statement of claimant rather than through these comments.

On p. 7-14 this section also states that ADWR was unable to verify 14 of the claimed wells. In its amended claim, the United States will provide verification data for many of these claimed wells.

### 7.4.2: Aquivers, Alluvial/Coluvial Aquifer

Colluvial water may be entirely distinct from alluvial water, as suggested by the mapped occurrence of landslide debris by Cooley et al (1969, their Plate 2), which is different than the alluvium mapped in Figure 7-16. Calling it a single aquifer appears inappropriate.

This section expands on the limited concept of alluvial water provided by Cooley et al (1969, Plate 2) to nearly the entire area mapped as Quaternary alluvium (Figure 7-16). Truini and Longsworth (2003) and Richards et al (2000) did not indicate that additional information existed regarding the saturated conditions of this mapped unit. *Therefore, the map should be limited to the alluvial areas that Cooley et al identified as being water bearing unless ADWR has additional information not cited that would justify including the larger areas shown.*

p. 7-16, ¶ 3 – The reference to Section 8.6 should instead be to Section 8.8.

### 7.4.3: Bidahochi Aquifer

This section refers to the "underlying T Aquifer" which insinuates that the T Aquifer underlies the entire Bidahochi Aquifer. On the contrary, much of the Hopi Buttes portion of the Bidahochi directly overlies Mancos Shale, lower Jurassic rocks, and Triassic rocks. It appears that only the northeast area of the Bidahochi Aquifer directly overlies the T aquifer in the Roberts Mesa area. (Plate 1, Sheet 4 in Cooley et al, 1969).

The United States proposes that the following sentences be added to the end of the "Occurrence" paragraph on p. 7-17:

*"In many places, the Bidahochi Aquifer directly overlies Mancos Shale, lower Jurassic rocks, and Triassic rocks. It overlies the T Aquifer in the northeast area near Roberts Mesa."*

**7.4.6: N Aquifer, Occurrence**

The last paragraph on page 7-22 states that water is obtained from sandstones in the Kayenta Formation. This is incorrect. As shown in Figure 4-9, the Kayenta Formation is non-water bearing, a fact which is evident where the Kayenta Formation outcrops in the Dinnebito, Polacca and Moenkopi Washes in the form of springs emanating from the top of the Kayenta/base of Navajo Sandstone. The United States proposes that reference to the Kayenta Formation be deleted from the 2nd sentence, last ¶, p. 7-22 and be revised as follows:

*"The Navajo Sandstone is the primary water-bearing unit, with water also obtained from underlying sandstones in the Lukachukai Member of the Wingate Sandstone. (Figure 4-9)"*

**7.4.6: N Aquifer, Natural Recharge and Discharge**

p. 7-23,– The 1st sentence states that the N Aquifer has a median recharge of 13,000 AFA. The range of recharge listed includes estimates based on different N aquifer model areas and differences over time. The "median" of these estimates is not informative and could be misleading. The United States proposes deleting the reference to a median and revising the 1st sentence of this section as follows:

*"Recharge to the N Aquifer is estimated to range from 2,600 and 20,248 AFA."*

p. 7-24, 2nd ¶ – The 1st sentence of this paragraph states that the Jeddito Wash, among others, is fed by the N Aquifer. This is incorrect because there is no indication that Jeddito Wash receives water fed by the N aquifer. The perennial reach mapped by Hack (1942), and by Cooley et al (1969, their Plate 2) lies mostly adjacent to D aquifer rocks or Mancos Shale. The USGS N aquifer model boundary runs north of Jeddito Wash because the Navajo Sandstone thins to extinction along that boundary. The United States proposes deleting Jeddito Wash and revising the sentence as follows:

*"Perennial and intermittent stream reaches historically and currently observed along Moenkopi, Dinnebito, Oraibi and Polacca Washes are also believed to have been fed by the N Aquifer (Figure 7-5)."*

**7.4.6: N Aquifer, Water in Storage**

pp. 7-25 through 7-26¶ – The calculated ratio of total N aquifer pumping to total volume in storage (0.1%, page 7-26) is misleading because it infers that existing pumping has a negligible impact on N aquifer groundwater resources. As the various groundwater modeling results have shown, this inference is incorrect because the ratio is neither a measure of groundwater availability nor is it an indicator that pumping impacts on the groundwater resources are negligible. *The United States proposes deletion of the last sentence of this section.*

**7.4.6: N Aquifer, Well Development**

p. 7-26 – The Truini and Macy (2007) report provides N aquifer pumping totals through year 2005, not 2002. The United States proposes that 2002 be changed to 2005 in the 3rd sentence, 3rd ¶ as follows:

"*Over 218,000 acre-feet of water have been pumped from the N Aquifer over the period from 1965 to 2005 and, since 1972, annual withdrawals have steadily risen from 4,300 acre-feet in 1972 to 8,000 acre-feet in 2005 (Truini and Macy, 2007).*"

**7.4.6: N Aquifer, Measured Hydrologic Impacts from Development**

p. 7-27¶ – The United States proposes that the last sentence, 1st ¶, be revised to change "municipal well" to "Hopi Reservation boundary" as follows:
"*A municipal well (PM2) near Keams Canyon showed a water-level decline of 196.2 feet, a USGS monitoring well (BM2) northeast of the leasehold showed a change of -87.8 feet, and a USGS monitoring well (BM6) between the leasehold and the Hopi Reservation boundary showed a change of -161.7 feet.*"

**7.4.6: N Aquifer, Future Hydrologic Impacts from Development**

pp. 7-28 through 7-29¶ – The HSR recognizes its limitations as to future uses on p. 1-5. Based on these limitations, the United States proposes that this section be renamed and changed to simply list the models that exist rather than recommending the use of one model over another for calculating future uses. Comparing various models and recommending one over others was not an objective of the HSR and is not appropriate in light of the specific limitations imposed on ADWR in opining on future uses. Such recommendations should be left to the hyrdologists that will present evidence regarding future uses without prejudicing the court and parties regarding which model is preferred by ADWR for simplistic reasons listed on p. 7-28. For example, although the PWCC model is indeed more complex than the others listed, predictions made by that model did not significantly differ from the much simpler USGS N aquifer model, given the uncertainties in modeled hydrologic properties. Increased model accuracy is not a natural result of model complexity. The United States proposes that this section be changed as follows:

"*Available Models to Evaluate Future Hydrologic Impacts from Development*
*Three numeric groundwater flow models have been developed to simulate existing hydrologic impacts from well development in the N Aquifer and predict future impacts. A detailed review and comparison of the models is presented in ADWR (2008h). (delete remainder of this section)*"

Moreover, any discussion of the HDR model developed by the Western Navajo-Hopi Water Supply Study, 2004, should be deleted pursuant to the Protective Order, dated January 3, 2002, which states the following:

> IT IS ORDERED that the Hopi/Western Navajo Water Supply Study shall not be used in any judicial proceeding in this Adjudication by any party to this Adjudication or by any representative of a party to this Adjudication.

## Chapter 8: Water Demands

### 8.1.1: Agriculture, Quantification

The United States' approach to quantification of the historic and present irrigation claim on behalf of the Hopi Tribe has significant differences from ADWR's approach to quantification in this section of the HSR. A detailed explanation of these differences, including suggested changes to ADWR's approach, is provided below in **Attachment 2 - United States' Comments on HSR Appendix F: *Consumptive Use of Crops Grown on the Hopi Indian Reservation* (ADWR, Dec. 2007).** A summary of comments and proposed revisions is provided here.

ADWR summarizes its approach to quantification by stating that it "estimated agricultural water demands on the Reservation utilizing the following commonly used factors: 1) the type of crops being grown; 2) the net irrigation requirement of the crops (i.e., the amount of water needed to supplement local precipitation); 3) the efficiency of the irrigation system; and 4) the cropped average." HSR, p. 8-2. The United States provides comments on this section according to each subject outlined above:

1. Type of crops being grown – The United States generally agrees with ADWR's conclusion that corn has been the most common crop, followed by orchards, beans, melons and squash, among other items.

2. Net irrigation requirement of crops in traditional agriculture/native irrigation – ADWR provided a range from 0.35 to 0.86 acre-feet per acre for crop water irrigation demands. This estimate is lower than the United States' claimed depletion of 0.61 to 0.99 acre-feet per acre. Some of the difference between the net irrigation requirements for crops can be explained by the different approaches, i.e., the United States' claim is based on modeling of the water supply to simulate the quantity of surface water depleted by irrigation whereas ADWR did not analyze water supply. However, even under ADWR's approach, a number of important factors such as climate data, crop spacing, growing

season, soil moisture accounting, crop coefficients, and effective precipitation were not properly addressed and need to be considered in any final analysis. *The United States' proposed changes to ADWR's analysis on these topics are outlined in detail in* ***Attachment 2***. It should be noted that this discussion of the net irrigation of crops refers to crops under traditional farming methods rather than project irrigation systems.

3. Efficiency of the irrigation system – ADWR's treatment of irrigation efficiency, on p. 8-3, ¶ 2, is inconclusive and unhelpful. The United States estimated conveyance seepage and evaporation water uses for seasonal and range pasture irrigation as 16% of irrigation diversion. Generally, seasonal and range pasture irrigation have structures that convey water a short distance to the parcels. Since native farming uses few structures, and irrigated parcels are very near the water source, it is reasonable to assume that conveyance and distribution water uses are small. These values are appropriate based on diversion into dry unlined canals (ditches). The intermittent use of the ditches does not allow for steady-state seepage conditions, which would result in less loss. ADWR could adopt the United States' estimate of 16% of the irrigation diversion going to inefficiency losses composed of deep percolation and evaporation from conveyance facilities or provide support for other conveyance efficiency value. The field level (on-farm) efficiency estimated by the United States is from the irrigation model output based on irrigation water entering the field through the diversion, deep percolation in the soil moisture budget, and a runoff estimate. ADWR should also include estimates of field-level efficiencies to determine irrigation diversion requirements.

The last sentence on p. 8-3, "[c]omparison of the depletion and diversion rates indicates an irrigation efficiency of 90%," should be deleted because it is incorrect. The 90 percent is actually the percentage of diverted water that does not return to the surface flows. To the extent that this 90% may be based on NRCE's October 29, 2007 memorandum, it does not represent the irrigation efficiency. There, the 90% represents the fact that the full water requirements of crops irrigated with a perennial water supply would not be met on an annual basis because even perennial flows are not constant from year to year. Thus, the claim was reduced to 90 percent of crop irrigation requirement to account for water supply shortages. It was also assumed that with well irrigation 95 percent of the irrigation requirement would be met on an average annual basis. The reduction in this irrigation requirement is to account for typical irrigation management and cropping conditions.

4. Cropped Acreage – On pp. 8-4 and 8-10, ADWR concludes that the maximum cropped acreage in one year on the Hopi Reservation has been 9,330 acres but has typically ranged between 3,500 and 6,500 acres. In its Second Amended Statement of Claimant, the United States intends to provide an updated photo interpretation analysis that will improve its estimate of the irrigated acreage on the Hopi Reservation in a certain time period.

It should be noted that ADWR's estimate of a maximum of 9,330 acres irrigated at one time is likely an underestimate for several reasons. First, to the extent that the

estimate is based on the Anderson Report and historical documents relied on therein, those historical documents represent a sporadic collection of materials gathered over a large period of time and cannot accurately reflect a single irrigated acreage. While the historical documents are helpful in generally identifying irrigated lands, they should not be viewed as a comprehensive inventory of all irrigated lands.

The second reason that ADWR's estimate likely undercounts acreage is the flaws associated with ADWR's photo interpretation outlined in HSR Appendix C. ADWR's photo analysis is flawed for the following reasons: 1) it was based on images scanned from aerial photos rather than negatives of the photos; 2) it lacks stereoscopic analysis; 3) it incorrectly assumes "digitizing errors" in its evaluation of United States' interpretation; 4) it is based on a misleading classification scheme; 5) it inappropriately collapses small fields into larger fields; and 6) it failed to identify clear categories of irrigation such as orchards and range pasture. **Attachment 3** provides a detailed critique of the ADWR photo interpretation.

Despite the flaws in ADWR's photo interpretation effort, the United States supports the premise that photo interpretation methodology is the most important source of information necessary to estimate irrigated acreage during a certain time period, particularly when used in conjunction with historical documents such as those cited in the Anderson Report. For these reasons, the United States' Second Amended Statement of Claimant will provide an updated photo interpretation of irrigated acreage for a certain time period.

### 8.1.2: Historic (Pre-1985)

The last paragraph observes that Hopi farming in the number of acres per person has decreased. While this is true in a general sense, the end of this paragraph speculates as to what the current ratio of acreage per person may be. Such speculation is unnecessary and misleading because it is based on certain assumptions that lack a basis, i.e.: 8,000 Hopis on the Reservation farming 5,000 acres. The HSR does not provide sufficient information to support these population and acreage numbers; therefore, the United States proposes deletion of the final two sentences which currently read as follows:

"*If it were assumed that 8,000 Hopi were living on the Reservation in 2005 and they successfully cropped 5,000 acres that year, the ratio now would be less than 1. The ratio would be even lower if the entire population of the Reservation at the time (about 12,000) were assumed.*"

### 8.1.2: Historic (Pre-1985), <u>Irrigation Projects</u>

p. 8-6 and Table 8-3 – The list of historical irrigation projects is incomplete because historic reports and interpretation of aerial photos document several other historic irrigation projects as well as a much larger historic project irrigated acreage. Some of the projects omitted from the Preliminary HSR list include Begashibito 2, Upper

Kerley Valley (joint Hopi/Navajo), Dinnebito Wash (DW)10, Oraibi Delta (joint Hopi/Navajo), Polacca Wash (PW) 1, Polacca Wash 35, and Polacca Delta (joint Hopi/Navajo). A comprehensive list and map locating the historic projects will be provided in the upcoming Second Amended Statement of Claimant.

**8.1.2: Historic (Pre-1985), Claims**

pp. 8-7 through 8-8 – As mentioned above, the maximum amount of water diverted and total acreage claimed by the United States and Hopi Tribe will be updated when the amended statements of claimant are filed in the future with updated information. Therefore, the number of AFA (49,200) and amount of acreage (37,514) listed in the 1st ¶ will change.

ADWR's photographic analysis of irrigated acres, Preliminary HSR Appendix G-1, is inaccurate in many instances for two primary reasons. First, ADWR used scanned photos rather than prints from original negatives. Second, ADWR did not employ stereoscopic analysis of the photos. For these reasons, ADWR's conclusions that 11% of acreage had complete evidence of agriculture, 55% of acreage had partial evidence of agriculture, and 34% of acres were questionable or lacked evidence of agriculture is incorrect and wholly unreliable. Moreover, ADWR's classification scheme listed at the bottom of p. 8-7 is misleading. For example, based the explanation in Appendix G-1, the "Questionable" category should be labeled "Cannot be Determined." A complete set of comments regarding HSR Appendix G-1 is provided herewith in **Attachment 3**. *In light of the United States' view that ADWR's photographic analysis underestimates the number of irrigated acres, the United States proposes that ADWR not rely on this photo interpretation and rely on the acreage provided in the United States' amended claim that will be filed in the near future.*

**Sec. 8.1.3 Recent**

The Preliminary HSR indicates that the Pasture Canyon Reservoir Irrigation Project serves 179 acres. There are some minor differences between the tracts in Figure 8-3 and the GIS coverage for the ADWR 2005 inspected field study. For example, Fig.8-3 shows some tracts between Highway 160 and Pasture Canyon Reservoir, while the GIS coverage does not. The United States requests that ADWR clarify the basis for Figure 8-3. The United States intends to update the acreage for the Pasture Canyon Reservoir Irrigation Project in its Second Amended Statement of Claimant because it appears that ADWR's approach underestimates the total acreage under irrigation.

The Preliminary HSR on page 8-9 and on Figure 8-3 indicates that there are 55 acres of recent irrigation of traditional farming in the Moenkopi area not served from Pasture Canyon. The United States believes there are more than the 55 acres of non-Pasture Canyon system irrigation. Some of this acreage is on the Hopi south side of Moenkopi Wash within the Upper Kerley Valley Irrigation Project downstream of the Pasture Canyon project. The Upper Kerley Valley Irrigation Project is a modern system

of a diversion dam and canals. There are two major siphons which serve two distinct service areas. One of the siphons is currently not in operation but could be repaired. Another part of this acreage is in isolated tracts which are either served by pumping from Moenkopi Wash or are "traditional farm tracts" served from springs and small side tributaries of Moenkopi Wash upstream of the Pasture Canyon project area. In addition, some of the Pasture Canyon service area adjacent to Moenkopi Wash receives supplemental water pumped from Moenkopi Wash. 8.2.4, Domestic, Commercial, Municipal and Light Industrial, Future

p. 8-15 – The 2nd sentence states that the growth rate is 2.2%. The 2.2% growth rate reflects the first 100 years only. The growth rate to the stable population of 62,512 in 2175 is actually 1.26%. The United States proposed the following revision:

*"This claim assumes that the population of the Reservation grows annually at 1.26% and stabilizes in 2175 at 62,512."*

**Sec. 8.4.1, Livestock, Quantification**

p. 8-19 – The United States' claim for livestock is referenced as a use in the wells, springs, and impoundments claim and quantification. The United States does not have a specific identifiable quantity of water use for livestock. However, ADWR calculated upper and lower limit quantifications for livestock use. ADWR assumes that a cow or horse need 12 gallons per day (gpd) and sheep need 1.5 gpd. The livestock water used by Daniel B. Stephens and Associates in the Hopi Drought Plan of 19.5 gpd per animal unit is a more suitable number because it includes the losses and other inefficiencies associated with livestock water. *For these reasons, the United States proposes that ADWR use the 19.5 gpd instead of 6-12 gpd.*

**8.8, Riparian Evapotransporation**

The discussion of riparian evapotranspiration (ET) is not necessary as it is not part of either the Hopi or US claims. Moreover, the analysis appears to have significant flaws as explained below.

ADWR calculated ET by multiplying 14,000 acres of riparian vegetation times a demand of 2.3 to 4.4 acre-feet per acre, and subtracting a portion provided by local precipitation. The total ranges between 23,100 and 56,400 AFA. Both values are extraordinarily large, up to 7 times greater than total modeled ET in the USGS N aquifer model, more than 5 times greater than the total aquifer discharge to streams on the Hopi Reservation, and between 2 and 4 times as much as the average yearly streamflow in the five Hopi Washes (Section 7.1.1).

It is likely that the supply of water to the alluvium is grossly inadequate for this amount of ET to occur. Additionally, winter periods, when ET is negligible, should show a cumulative increase in base flow in washes of between 32 and 78 cubic feet per second during a winter month (or a large rise in the alluvial aquifer water table), if this

calculation was correct. However, the wintertime increase in base flow in these washes is only a small fraction of this amount, and there is no evidence that alluvial storage could increase by this amount. For these reasons, this amount of ET is not justified based on alluvial aquifer water balance considerations.

Likely errors are in how the acreage was calculated, and in the assumption that the riparian vegetation evapotranspires at its potential rate. The measured 14,000 acres is undoubtedly not at 100 percent plant density, and probably not even half that, on average. Lower plant density, for example 20 percent, would reduce this ET calculation by a factor of 5. Equally as important is that riparian vegetation may be significantly water stressed over most of the year, and actual ET over a year may be much less than the demand listed above.

*For these reasons, the United States proposes that ADWR delete this section.*

**Chapter 9: Analysis**

Chapter 9 provides a summary of the information presented in prior chapters in the Preliminary HSR. Accordingly, the United States comments on previous chapters are incorporated into Chapter 9 and should be applied to the relevant issues below. In addition, the United States summarizes certain comments for Chapter 9 below.

**9.1.1, Agriculture**

p. 9-2, and Table 9-1 – ADWR underestimates the water amounts used by the Hopi Tribe for traditional irrigation (350 to 7,921 AFY) and project irrigation (0 to 1,582 AFY) for several reasons that were explained in detail above and are summarized below. The United States intends to provide updated acreage amounts in its Second Amended Statement of Claimant and requests that ADWR consider adopting that updated acreage at that time. The primary reasons that ADWR's methodology underestimates the water use for historic and present agriculture are:

1. ADWR's estimate of traditional irrigation cropped acreage is too low because:
    a. Historical documents in the Anderson Report are helpful but do not represent a comprehensive record of irrigated acreage;
    b. ADWR's photo interpretation underestimates irrigated acreage because it was based on images scanned from aerial photos rather than negatives of the photos and lacks stereoscopic analysis; and
    c. ADWR's photo interpretation failed to identify clear categories of irrigation such as orchards and range pasture.

2. ADWR's estimate of crop water demand for traditional irrigation is low because:
    a. it does not acknowledge the importance of water availability, as calculated through the United States PRMS model, to estimate water diversions; and
    b. it does not include critical data components in its analysis including, but not limited to, climate data analysis, proper crop spacing, appropriate crop growing season estimates, soil moisture accounting, crop coefficients,

realistic effective precipitation, accurate cropped area and crop evapotransporation, deep percolation and conveyance losses measurements.

3. ADWR underestimates the acreage irrigated from historic and recent projects. The United States intends to provide an updated estimate of cropped acreage within projects in its Second Amended Statement of Claimant.

**9.1.2: DCMI**

The United States' claim includes past, present and future use within the DCMI category as a single claim. It did not separate the time-dependant components of the claim nor did it present a past and present use portion of the claim distinct from the future use portion of the claim. *Therefore, the United States does not provide comments on ADWR's attempt to separate the claim in this manner other than to note that such an approach is inconsistent with the claims as filed in the adjudication.*

**9.1.3: Heavy Industrial**

The United States intends to provide an updated mining claim in its Second Amended Statement of Claimant.

**9.1.4: Livestock**

The United States intends to provide an updated livestock claim in its Second Amended Statement of Claimant.

**9.2: Comparison of Quantities of Water for Past and Present Uses Claimed by the Hopi and United States to Quantities of Water Determined by ADWR**

Overall, ADWR accurately describes the differences between the 2004 claims and ADWR's determination. It should be noted that the United States intends to file a Second Amended Statement of Claimant which will update certain categories of information, such as providing an updated agricultural acreage for a single period rather than just a composite of acreage. The comparison presented in this Section will necessarily change in light of the amended claims.

**9.3.2: ADWR's Recommended Water Right Attributes, Quantity of Use**

p. 9-12, Water Source – The second sentence in the second paragraph is unnecessary and should be *deleted*. For convenience, the sentence proposed for deletion reads "Because the Court has not yet determined whether the Hopi are entitled to use surface water sources that do not cross the Reservation, and because the Court has not yet analyzed or quantified proposed future uses, ADWR cannot make a recommendation regarding whether the Hopi federal reserved water right extends to groundwater."

p. 9-12, Quantity of Use - For the reasons explained above, the United States comments that ADWR underestimates the quantity of water used for past and present purposes by the Hopi Tribe.

Please do not hesitate to contact either Vanessa Willard at (303) 844-1353 or Guss Guarino at (303) 844-1343 if you have questions regarding these comments and enclosures.

Sincerely,

Vanessa Boyd Williard
Andrew "Guss" Guarino

Enclosures

cc (w/enclosures) via US Mail:

Chris Banet, BIA
Grant Vaughn, Solicitor's Office
Colin Hampson, Counsel for Hopi Tribe
Scott McElroy, Counsel for Navajo Nation

## ATTACHMENT 1 – United States' Comments on *Streamflow Characteristics of the Hopi Indian Reservation* (ADWR, 2008b) ("ADWR Streamflow Report")

ADWR (2008b) was examined in detail; it reviews four general attributes of streamflows on the Hopi Reservation: Streamflows at Gaging Stations, Temporal Streamflow Patterns, and Spatial Streamflow Patterns. Each is described in further detail below.

### Streamflows at Gaging Stations

ADWR attempted to characterize streamflows by their magnitude and frequency and categorize them as perennial, intermittent, or ephemeral. This categorization was based upon Meinzer (1923) which listed perennial flows as 100% of days showing flows, intermittent as 10%-90%, and ephemeral as below 10%. There are many attempted categorizations of streamflows between perennial, intermittent, and ephemeral. For example, the State of Idaho defines intermittent streams as such (Rea and Skinner, 2009):

> Intermittent Waters. A stream, reach, or water body which naturally has a period of zero (0) flow for at least one (1) week during most years. Where flow records are available, a stream with a $7Q_2$ hydrologically-based unregulated flow of less than one-tenth (0.1) cubic feet per second (cfs) is considered intermittent. Streams with natural perennial pools containing significant aquatic life uses are not intermittent. (IDAPA 58.01.02.010.45)

Hedman and Oesterkamp (1982) define the break between intermittent and perennial as 80% and Hewlett (1982) defines it at 90%. Clearly, the Meinzer definition of "intermittent" would misidentify a number of perennial stream reaches, including on Moenkopi Wash and the Little Colorado River.

A comparison of some of the gages between calculated values and reported (ADWR) reveals slight differences in streamflows (see Table 1 below).

**Table 1: Comparison of gage flow summaries between NRCE and ADWR.**

| Gage | Number | 9400568 | 9400583 | 9401110 | 9401260 | 9401400 |
|---|---|---|---|---|---|---|
| | Name | Polacca | Jadito | Dinnebito | Moenkopi | Moenkopi Near Tuba City |
| Minimum (acre-feet/year) | ADWR (2008g) | -- | -- | -- | -- | -- |
| | ADWR HSR | 194 | 14 | 312 | 1,376 | 2,181 |
| | NRCE | 194 | 13 | 311 | 1,373 | 2,188 |
| Mean (acre-feet/year) | ADWR (2008g) | 2,320 | 298 | 2,790 | 7,290 | 11,200 |
| | ADWR HSR | 2,319 | 298 | 2,787 | 7,292 | 11,165 |
| | NRCE | 2,312 | 298 | 2,787 | 7,282 | 11,167 |
| Median (acre-feet/year) | ADWR (2008g) | 2,130 | 145 | 2,300 | 7,470 | 8,830 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | **ADWR HSR** | 2,126 | 145 | 2,297 | 7,462 | 8,838 |
| | **NRCE** | 2,128 | 145 | 2,294 | 7,471 | 8,845 |
| **Maximum (acre-feet/year)** | **ADWR (2008g)** | -- | -- | -- | -- | -- |
| | **ADWR HSR** | 6,151 | 1,427 | 6,687 | 14,779 | 44,482 |
| | **NRCE** | 6, 070 | 1,425 | 6,703 | 14,739 | 44,580 |

### Temporal Streamflow Patterns

The temporal streamflow pattern section attempted to identify likely trends in streamflows over a long period. ADWR used maintenance of variance extension (MOVE) to extend annual streamflows through 1926. Comments on individual analyses are listed below.

USGS 9402000

ADWR lists a 13-year record as the calibration period for this model. It is not clear whether this period is long enough to develop a robust model. The periods in question may not contain representative dry, normal, and wet periods that are required to properly calibrate a model.

USGS 9401260

ADWR correlated annual rainfall and runoff between Tuba City and the streamflow gage on Moenkopi Wash. The reported correlation coefficient was 0.17 for the model used to extend this gage for annual flows. Because of the extremely low amount of variance explained by this model, it is unlikely that it represents the annual streamflows well. Similarly, they use a model reconstruction for the period 1940 through 1973 based on four overlapping annual streamflows. While the reported correlation coefficient is relatively high, this is clearly not a robust model. The period of overlap was also from 1974-1977, so most likely represents only a small portion of hydrologic conditions.

USGS 9400562 Oraibi Wash, 9400568 Polacca Wash, 9401110 Dinnebito Wash, 941400 Moenkopi Wash

These gages use relationships built from between four and six years of data. Again, they are unlikely to represent a range of hydrologic conditions and are not robust models.

9400583 Jeddito Wash

Over an 11-year concurrent period, the model explained only 25% of the variance in annual streamflows. This is not adequate to use for filling and extension of gage records.

Peabody Coal Company records

Similar problems exist with the models developed for the Peabody gages. These either show a short period of record, inadequate explanation of variability, or both.

### Long-term flow variability

ADWR uses Meko et al. (2007) and Meko and St. George (in prep.) to examine the long-term variability of flow in the Colorado and Little Colorado River basins. NRCE was unable to obtain a copy of Meko and St. George, so these data were not reviewed.

Meko et al. use tree ring data from various locations in the Colorado River basin to synthesize an annual hydrograph to 762 at the Lee's Ferry gage. However, none of these tree rings were contained within the Little Colorado basin, so this provides little insight into the streamflows in the Hopi Reservation. In fact, examination of Figure 7-11 shows little correlation between the extended Moenkopi Wash data and the extended Lee's Ferry record for the period beginning in 1927.

It should be also noted that tree ring reconstructions tend to underestimate years of high streamflows, so it is possible that comparisons with tree ring reconstructions are biased toward lower streamflows.

## Spatial Streamflow Patterns

In the spatial streamflow patterns section, ADWR attempted to estimate mean and median annual runoff at various points throughout the Hopi Indian Reservation. ADWR used multiple regression analysis to create models between their extended gage records described in the Temporal Streamflow Patterns section and various basin characteristics. These models were then transferred to other ungaged points in the basin and runoff was estimated.

The ADWR models used a calibration period of 1981-2006. These data were filled at 13 gages and measured at one gage. As mentioned previously by ADWR, the Colorado River basin may see significant persistence of trends including drought or wet periods. It is quite possible that this 25-year period is not representative of the total record. If their trend analysis is correct, the runoff on the Reservation has recently been declining. This could indicate that the most recent period represents a relatively dry period.

The model was developed using a number of basin characteristics including drainage area, stream gage elevation, stream length, stream slope, forested area, barren area, mined area, Quaternary deposit area, and mean annual precipitation. They point out that there is a significant correlation between variables, which promotes error in multivariate models. ADWR used a multivariate model using stream gage elevation, forested area, and barren area to predict mean and median annual runoff.

Three potential problems arise from the use of these models. First, while there may be a significant correlation between gage elevation and runoff, it is not clear that this is a causal link that can be explained through any physical reasoning. Similar problems can be seen with the other variables used.

The second problem arises with the multivariate regression method used. As mentioned previously, there is substantial correlation between predictor variables used. A common method of removing collinearity is to use principal components analysis (PCA). PCA transforms related variables into orthogonal components (Haan, 1977) and would have been appropriate in this situation.

Finally, the model was produced using depleted streamflows. The model represents undepleted streamflows at the Reservation boundary but does not take into account the fact that the predictive model was built using gaged (depleted) streamflows. Hence, this is not a viable model of undepleted flows available for irrigation at the Reservation boundary.

**Attachment 1 References**

ADWR, 2008a. Streamflow Characteristics of the Hopi Indian Reservation. Internal report prepared in support of Preliminary Hopi HSR, January 2008.

ADWR, 2008b. Surface Water Quality of the Hopi Indian Reservation. Internal report prepared in support of Preliminary Hopi HSR, March 2008.

Haan, C.T. 1977. *Statistical Methods in Hydrology.* The Iowa State University Press, Ames, IA.

Hedman, E.R., and W.R. Osterkamp. 1982. Streamflow Characteristics Related to Channel Geometry of Streams in Western United States. USGS Water-Supply Paper 2193. 17 p.

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Meko, D.M. and St. George, S., in preparation. Tree-ring reconstruction of Little Colorado River Annual Flows. University of Arizona, Tree Ring Laboratory.

Meko, D.M., Woodhouse, C.A., Baisan, C.A., Knight, T., Lukas, J.J., Hughes, M.K., and Slazer, M.W., 2007. Medieval Drought in the Upper Colorado River Basin. Geophysical Research Letters, v. 34, L10705.

Rea, Alan, and Skinner, K.D., 2009, Estimated perennial streams of Idaho and related geospatial datasets: U.S. Geological Survey Data Series 412, p. 32.

**ATTACHMENT 2 - United States' Comments on HSR Appendix F: *Consumptive Use of Crops Grown on the Hopi Indian Reservation* (ADWR, Dec. 2007)**

The differences between the analysis of irrigation conducted by the United States in support of its irrigation claim on behalf of the Hopi Tribe and the agricultural analysis conducted by ADWR for the HSR are substantial. A large portion of the difference results from the difference in irrigated acreage and a smaller portion results from the different methodologies of estimating crop irrigation water requirements.

The United States' approach is superior because it is more thorough and includes a number of important factors that the HSR analysis ignored. Therefore, the United States recommends that ADWR revise its report, *Consumptive Use of Crops Grown on the Hopi Indian Reservation* (ADWR, Dec. 2007), to account for the following factors:

1) **Climate data analysis** should include all available data (not just two stations), adjust for location, utilize the method that best estimates solar radiation in the region, and perform an exceedance probability analysis based on daily ET (rather than using mean climatic data);
2) Proper **Crop Spacing** measurements;
3) **Crop Growing Season** should be tailored to subbasins and elevations (rather than simply using high and low values of 170 and 115 days for corn);
4) **Soil Moisture Accounting** should be included;
5) **Crop Coefficients** should be determined using the proper method to estimate water use when adjusting for non-standard conditions where crops do not reach effective cover;
6) Realistic **Effective Precipitation** estimates;
7) **Calculation of overall consumptive use should include:**

   ***a)*** *Cropped Area* ***with all historic acres cropped because Indian water rights are not lost through non-use; and***

   ***b) revised*** *Cropped ET* ***calculation;***
8) **Deep Percolation Losses** should be included;
9) **Conveyance Losses**, such as evaporation and seepage, should be included;
10) Acknowledge the importance of **Water Availability**, such as calculated through the PRMS model, to estimate diversions.

These factors are discussed in detail below. The following analysis compares and comments on the methods used by ADWR versus those used by the United States in estimating irrigation water use on the Hopi Reservation.

## Differences in Treatment of Climate Data

ADWR's climate analysis is inadequate for two reasons. First, the HSR uses limited climate data and does not attempt to adjust these data for location. This is an important process and calculations are easily performed. ADWR did not use the full climate record available at the Keams Canyon station. As Shown in Figure 1 below, ADWR's method of radiation calculation is not the best method available for the region, overestimating measured radiation at the Flagstaff station.

Second, ADWR uses only mean climatic data to calculate evapotranspiration. Irrigation requirements will be highest during drought seasons that have higher than average temperatures and lower than average precipitation. A more comprehensive analysis should be performed by estimating daily ET and performing an exceedence probability analysis. The United States analysis rectifies these two inadequacies as explained below.

## Temperature and Precipitation Records

The United States used nine stations in the generation of climatic data for calculations of depletions. These stations are shown below in Table 1. The selection of stations was based upon climate record and proximity to the basin. The closest station was used and lapsed to each hydrologic response unit (HRU) in the PRMS model, developing refined precipitation and temperature records for the ET analysis.

**Table 1: Summary of climate stations used in the hydrologic modeling.**

| Station ID | Station Name | County | State | Latitude | Longitude | Elevation (feet) | Period |
|---|---|---|---|---|---|---|---|
| 1169 | Cameron 1 NNE | Coconino | AZ | N35:53:00 | W111:24:00 | 4,165 | 1962-1992 |
| 3103* | Flagstaff Pulliam AP | Coconino | AZ | N35:09:00 | W111:40:00 | 7003 | 1950-2006 |
| 3303 | Ganado | Apache | AZ | N35:42:59 | W109:33:58 | 6,340 | 1929-2006 |
| 3420 | Gallup 5 E | McKinley | NM | N35:32:00 | W108:39:00 | 6,604 | 1918-1979 |
| 4586 | Keams Canyon | Navajo | AZ | N35:48:40 | W110:11:30 | 6,205 | 1894-2006 |
| 4872 | Leupp | Coconino | AZ | N35:17:00 | W110:58:00 | 4,705 | 1914-1981 |
| 6468 | Bellemont NWFO | Coconino | AZ | N35:13:48 | W111:49:17 | 7,152 | 1999-2006 |
| 7488 | Sanders | Apache | AZ | N35:13:26 | W109:19:20 | 5,853 | 1949-2006 |
| 7496 | Sanders 11 ESE | Apache | AZ | N35:10:00 | W109:10:00 | 6,250 | 1961-1986 |
| 9410 | Window Rock 4 SW | Apache | AZ | N35:37:01 | W109:07:28 | 6,920 | 1937-1999 |

*Station was used only for solar radiation data; not included in precipitation or temperature calculation.

**Table 1 (Continued): Summary of climate stations used in the hydrologic modeling.**

| Station ID | Station Name | Elev. (ft) | Annual Avg. Prcp (in) | Annual Avg. Tmax (F) | Annual Avg. Tmin (F) | State | USGS HUC | USGS HUC Name |
|---|---|---|---|---|---|---|---|---|
| 1169 | Cameron 1 NNE | 4164 | 5.59 | 73.9 | 42.0 | AZ | 15020016 | Lower Little Colorado |
| 3303 | Ganado | 6340 | 12.32 | 64.9 | 33.7 | AZ | 15020011 | Cottonwood Wash |
| 3420 | Gallup 5 E | 6604 | 9.18 | 66.9 | 31.7 | NM | 15020012 | Cottonwood Wash |
| 4586 | Keams Canyon | 6205 | 10.60 | 66.4 | 34.6 | AZ | 15020013 | Polacca Wash |
| 4872 | Leupp | 4705 | 6.49 | 72.2 | 35.2 | AZ | | |
| 6468 | Petrified Forest | 5444 | 9.37 | 70.7 | 39.0 | AZ | 15020007 | Lower Puerco |
| 7488 | Sanders | 5853 | 11.26 | 68.9 | 35.2 | AZ | | |
| 7496 | Sanders 11 ESE | 6250 | 12.37 | 67.3 | 31.3 | AZ | | |
| 9410 | Window Rock 4 SW | 6920 | 11.67 | 64.0 | 32.6 | AZ | 15020006 | Upper Puerco |

ADWR used only two stations: 8792 Tuba City and 4586 Keams Canyon. ADWR used a period of record from 1900 to 2006 for Tuba City and 1948-2006 for Keams Canyon. However, the record extends to 1894 for both stations. Using the entire set of data would provide better average data. Precipitation and temperature were assumed to be relatively uniform across cropped areas and these records were not refined for geographical location. ADWR states that:

> "data from additional met stations on the Reservation with a significant period of record may improve ET estimates". (Appendix F to the HSR, page 3-1)

The United States used the daily data over the period of analysis which accounts for differences in temperature that occur over time. The United States then filled missing data using a regression analysis between weather stations. ADWR methodology relied only on mean data. The ADWR methodology does not take into account the temperature and precipitation differences that result from the elevation changes across the Reservation. Since mean data was used by ADWR the missing data was not filled.

## Solar Radiation

Daily solar radiation was calculated by the United States as a function of day of the year, the dew point temperature (*Tdew*), and the total sky cover (*Tskc*), using equations from Dingman (1994). These values were adjusted within PRMS for aspect, elevation, and slope. ADWR used the Hargreaves Method. The United States compared measured radation at Flagstaff to the Dingman and Hargreaves method as presented in Figure 1. The Hargreaves method overestimates radiation in this comparison.

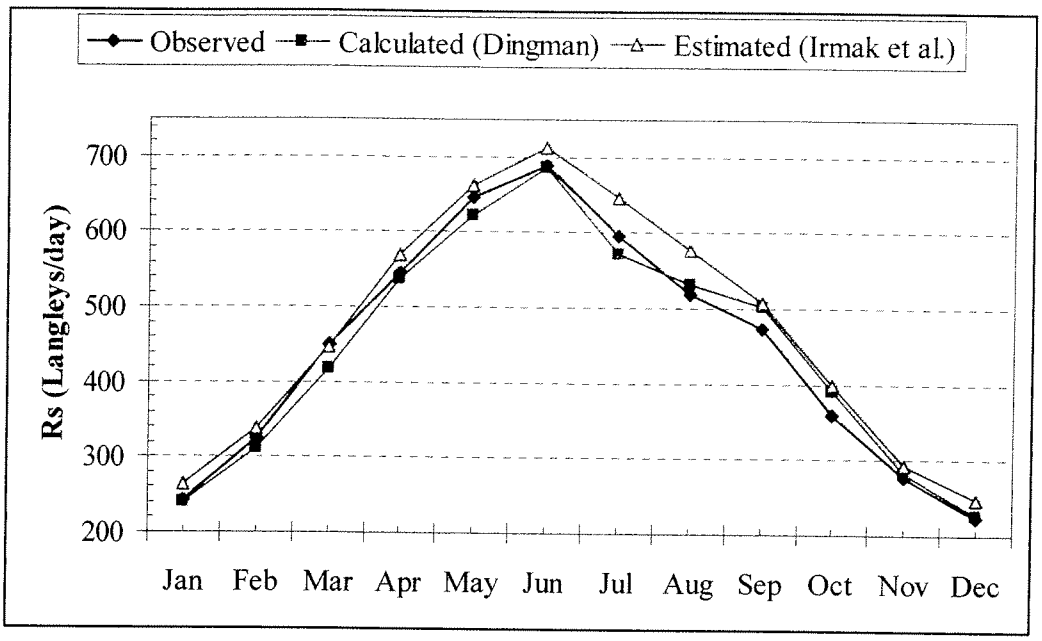


**Figure 1**: Average monthly solar radiation based on data from NCDC SA station 3103.

## Wind Speed

Wind speed was not considered by the United States, as the method of ET calculation did not require wind speed data. ADWR estimated the wind speed to be between 3 and 5 meters per second.

## Differences in Crop Evapotranspiration and Consumptive Use Determinations

The largest differences in crop ET between the HSR and the United States' claim are due to crop coefficient estimates. For example, the United States used very different peak crop coefficient estimates than the HSR. It should be noted that Table 2.1 of Appendix F the HSR is incorrect; the growing season should be April 7-September 24 for a 170-day growing season.

As listed in Table 2, the HSR peak coefficient is considerably lower than the already-reduced estimates by the United States. ADWR justifies this by estimating crop spacings at a minimum of 8-12 feet and a maximum of 15-20 feet. However, ADWR's own photos show this spacing to be unreasonable (see photo figures in Appendix F in ADWR Hopi HSR). Figure 2 shows a typical field; for scale the tire tracks at the left of the photo should be no more than 12" wide. Clearly crop spacing is not 8-12 feet.

**Table 2: Comparison of U.S. and ADWR cropping dates and coefficients.**

| | Crop Type | Cropping Dates[a] | | | | Crop Coefficient[b] | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | E | Kc1 | Kc2 | Kc3 | % |
| U.S. | Corn | 1-Jun | 18-Jun | 27-Jul | 28-Sep | 0.16 | 0.95 | 0.33 | 90 |
| U.S. | Native Range | 1-Apr | 20-Apr | 15-May | 15-Sep | .30 | .68 | .40 | 77 |
| ADWR (Upper) | Corn | 7-Apr | 7-May | 26-Jun | 24-Sep | 0.12 | 0.36 | 0.19 | |
| ADWR (Lower) | Corn | 15-May | 4-Jun | 9-Jul | 7-Sep | 0.12 | 0.36 | 0.19 | |

[a] *Cropping Dates*: A = planting, B = 10% ground shading, C = 75% ground shading, E = transpiration ceases or harvest. Date D (not listed) is a calculated date at which Kc begins to decrease linearly to Kc3.
[b] *Crop Coefficients*: Kc1 = crop coefficient from date A to B, Kc2 = crop coefficient from C to D, and Kc3 = crop coefficient at date E, % = percent of growing season from A to D. The crop coefficients between dates B and C are a linear interpolation between Kc1 and Kc2, and the crop coefficients between dates D and E are a linear interpolation between Kc2 and Kc3.

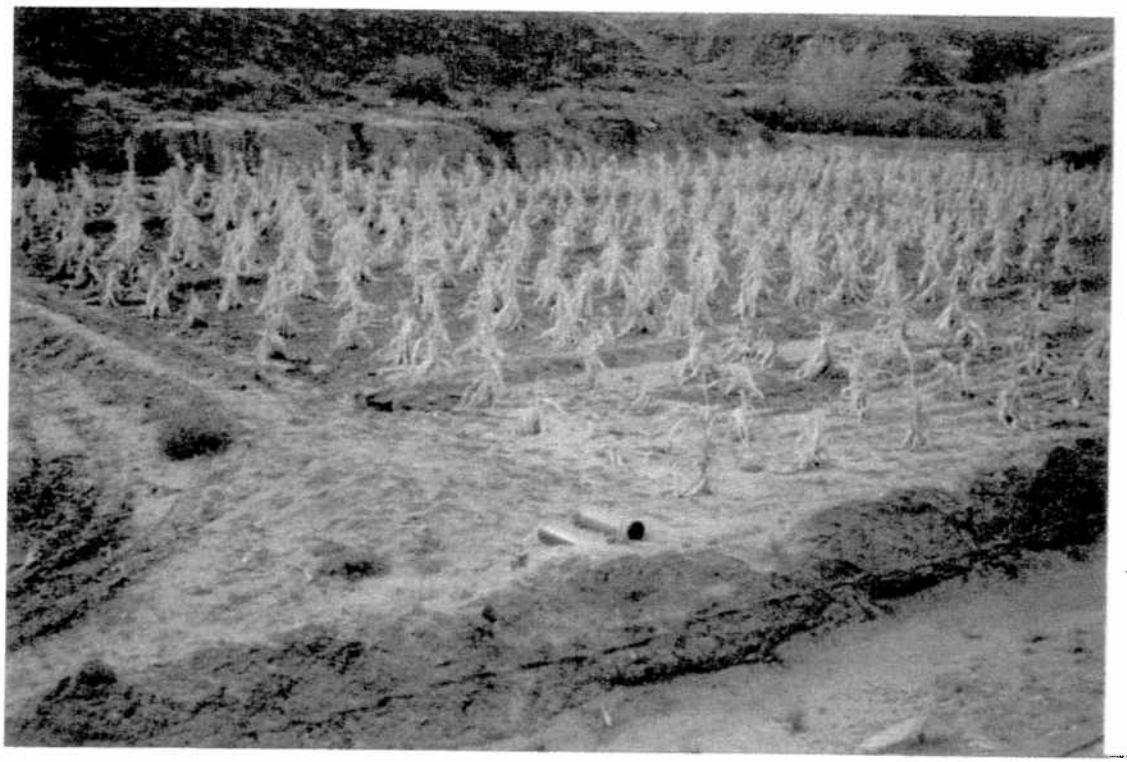

**Figure 2: Example of corn spacing on the Hopi Reservation.**

## Crop Growing Season

The United States used different cropping dates for individual subbasins based upon elevation. While cropping dates vary from year to year, the cropping dates were estimated by one set of cropping dates for each subbasin. The cropping dates provide adequate results due to the soil moisture budget accounting which allows irrigation before planting. ADWR used cropping dates to produce a high and low value of 170 and 115 days, respectively for corn.

**Soil Moisture Accounting**

ADWR did not use a soil moisture accounting approach to account for reductions in crop water use due to low soil moisture. The United States used a daily soil moisture accounting model. ADWR recognized the need for this:

> "To model actual growing conditions on the Hopi Reservation (DRY), a daily soil moisture budget would be helpful to ETc estimations. Due to infrequent watering, readily available water within the soil declines to the point of zero which causes the ETc to also approach zero. In other words, when there is no moisture in the soil, the plant does not transpire. To correct Kc for such conditions, soil moisture needs to be quantified. Because these data could not be obtained, an alternative approach to correcting Kc was used.". (2008 ADWR HSR, Appendix F page 2-8).

**Crop Coefficients (Detail)**

Both the United States and ADWR used the methods outlined in Food and Agriculture Organization of the United Nations, Publication 56 (FAO, 1998) to estimate crop coefficients. Both claims adjusted the crop coefficients (Kc) to represent the less than ideal growing conditions observed on the Hopi Reservation. ADWR estimated the plant spacing at 8-12 feet between rows and clumps of plants. ADWR estimated the peak crop coefficient for corn at 0.36, using a method described in FAO 56. However, the methodology is applicable to adjustments in the basal crop coefficients, not the Kc mean. Kc basal only includes plant transpiration and evaporation beneath the vegetation canopy; therefore, if effective cover is never obtained the soil evaporation component needs to be included. Additional water use or demands are needed to account for the evaporation from the soil surface during and after a precipitation events or irrigations. The combined or average (evaporation and transpiration) Kc for the crop is 1.0 for the day of a rain decreases over the following days depending on the soil type. Similarly, upon irrigation the Kc combined is also increased to account for soil evaporation. For crops with a small percentage of effective cover the soil evaporation is a significant contributor to crop ET.

The proper method for estimation of water use when adjusting for non-standard conditions is described in the FAO 56 manual and Part 623 Irrigation of the National Engineering Handbook (NEH, 1993). Figure 3 is an illustration from the National Engineering Handbook Part 623, Chapter 2, page 2-90. If the crop coefficient is less than 1.0 due to less than 100 percent effective cover than the average coefficient is greater that the basal crop coefficient. This is particularly important because most crops grown on the Hopi Reservation never reach effective cover due to the crop spacing.

Figure 2-23 Comparison of basal and average crop coefficients for the average crop coefficient example

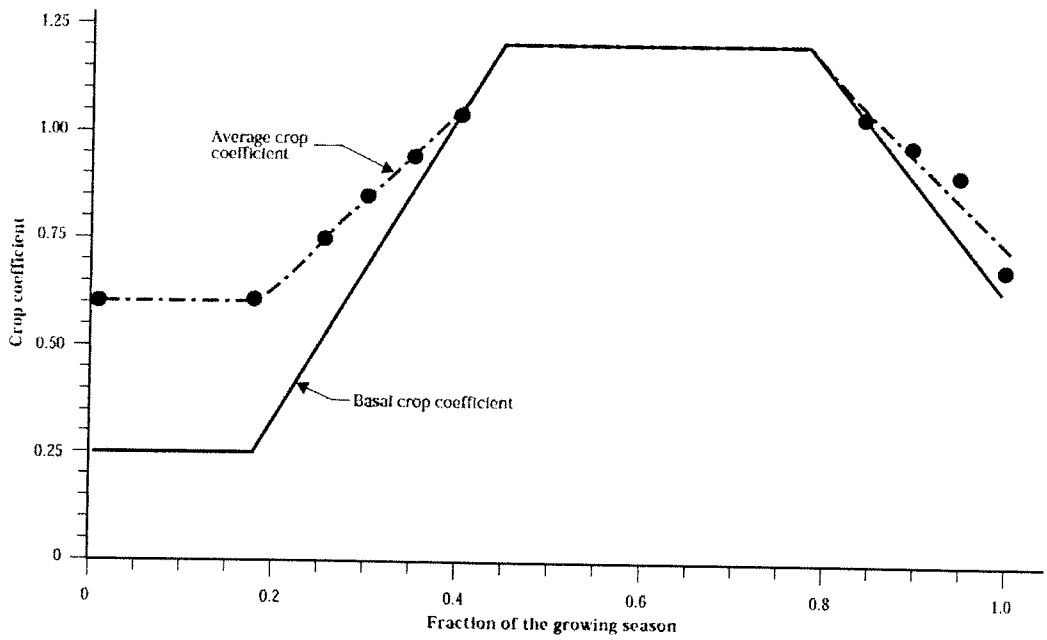


**Figure 3. Example of Basal and Average Crop Coefficients from National Engineering Handbook.**

ADWR made an adjustment for "DRY" referred to as dry land, based primarily on the crop spacing of corn. ADWR's definition of dry land is crops grown without irrigation. While precipitation farming was a land use category, the United States did not estimate a water requirement for the precipitation farming.

The United States made an adjustment in the Kc for crops irrigated from seasonal water supplies based on a variety of non-quantified conditions. It used the water use of corn for lands with seasonal and native irrigation. The United States's peak crop coefficient was 0.95 (vs. 0.36 as determined by ADWR). The United States estimated plant spacing at 4-5 feet between rows and 3 feet between clumps of plants based on photographs taken during a field visit. In addition to the Kc adjustment, the soil water budget reduces the crop ET further when the soil water limits crop ET.

## Reference Evapotranspiration

The United States estimated reference ET using the Jensen-Haise method (1963). This method uses mean daily air temperature and solar radiation to estimate ET. Temperature and radiation are adjusted within the model by HRU, representing elevation, slope, and aspect. The United States estimates ET on a daily basis using climatic data.

ADWR used the Penman-Monteith method described in FAO (1998) via the Ref-ET program to calculate reference ET. ET is calculated based upon mean long-term daily data rather than actual year-to-year daily data.

The Jensen-Haise method is used in the PRMS model. The United States conducted analysis to determine the sensitivity of reference ET to irrigation depletion. It was found that the estimated water supply was the most significant factor in the determination of crop water use. Under the deficit irrigation conditions the reference ET methodology made little difference in irrigation depletion.

**Potential Crop ET**

Both the United States and ADWR calculated potential crop ET as reference ET multiplied by the crop coefficient. As stated in the discussion on crop coefficients, it appears that ADWR neglected to consider the evaporation portion of the crop ET when adjusting the Kc for crops grown in non-standard conditions.

**Effective Precipitation**

Effective precipitation is calculated by the United States using daily time step and a soil moisture accounting model. The daily precipitation was based upon recorded precipitation adjusted based on location and elevation. The United States also neglected precipitation events less than 0.05 inches, these small precipitation events do not provide a significant source of water for plants and the storms as often accompanied by winds that increase ET. Additionally, the United States used only 67 percent of winter moisture as being available for soil moisture storage. During the winter there is evaporation from wet soil surfaces and snow which was not modeled for the fields. On an annual basis, the United States estimated that effective precipitation ranges from about 55 to 60 percent of total precipitation.

ADWR estimated that 81 and 85 percent of the long-term annual average precipitation is effective for Keams Canyon and Tuba City, respectively. ADWR estimated that over 90 percent of the growing season precipitation is effective. These estimates were applied to both dry land farmed and non-deficit irrigated lands. In addition to the high effective percentages, the long-term average precipitation the irrigation water claim would be insufficient over 50 percent of the years.

**Consumptive Use and Irrigation Requirement**

Two main differences result in the large discrepancy between the United States' Claim and the HSR: cropped area and the crop ET. Tables 3-5 provide summaries of the United States' irrigation claim and the ADWR's estimate of net irrigation requirements. The HSR cropped area is considerably lower, at a maximum of 9,853 acres and a minimum of 1,000 acres, compared to a total cropped area in the United States' Claim of 37,514 acres.

Likewise, for net irrigation requirements, ADWR estimates a low end of 4.2 inches per year and a high end of 10.32 inches per year for traditional farming (dry land), and low end of 20.64 inches per year and a high end of 29.52 inches per year for irrigation projects (non-deficit irrigation). The United States did not provide estimate of net irrigation requirements in their Hopi claim. However, the weighted irrigation averaged 7.33 inches per year with a maximum of 11.87 inches per year and the irrigation diversion averaged 9.11 inches per year with a maximum diversion of 15.72 inches per year. ADWR's maximum net irrigation requirement is 9,502 acre-feet per year verses the United State's maximum irrigation depletion claim of 37,110 acre-feet per year. ADWR's minimum net irrigation requirement is 305 acre-feet per year. The United States' claim did not report a minimum irrigation depletion. ADWR's only estimated net irrigation which does not include irrigation efficiencies or losses.

**Table 3: United States Estimates of Acreage, Irrigation Depletion, and Irriagtion Diversion.**

| Wash | Acreage | Irrigation Depletion | | Irrigation Diversion | |
|---|---|---|---|---|---|
| | | Average (ac-ft/yr) | Maximum (ac-ft/yr) | Average (ac-ft/yr) | Maximum (ac-ft/yr) |
| Moenkopi Main Reservation | 2,496 | 2,084 | 2,440 | 2,772 | 3,246 |
| Moenkopi Island | 989 | 1,310 | 1,535 | 1,468 | 1,795 |
| Dinnebito | 6,938 | 3,961 | 6,552 | 5,280 | 8,714 |
| Oraibi | 10,615 | 5,384 | 9,865 | 5,384 | 13,120 |
| Polacca | 12,297 | 7,218 | 11,869 | 9,622 | 15,786 |
| Jadito | 4,126 | 2,936 | 4,790 | 3,914 | 6,371 |
| Minor Tributaries | 53 | 37 | 59 | 49 | 104 |
| **TOTAL** | **37,514** | **22,930** | **37,110** | **28,489** | **49,136** |

**Table 4: United States' Esitmate of Irrigation Depletion and Diversion Rate.**

| Wash | Irrigation Depletion | | Irrigation Diversion | |
|---|---|---|---|---|
| | Average (in/yr) | Maximum (in/yr) | Average (in/yr) | Maximum (in/yr) |
| Moenkopi Main Reservation | 10.02 | 11.73 | 13.33 | 15.60 |
| Moenkopi Island | 15.90 | 18.62 | 17.81 | 21.79 |
| Dinnebito | 6.85 | 11.33 | 9.13 | 15.07 |
| Oraibi | 6.09 | 11.15 | 6.09 | 14.83 |
| Polacca | 7.04 | 11.58 | 9.39 | 15.40 |
| Jadito | 8.54 | 13.93 | 11.38 | 18.53 |
| Minor Tributaries | 8.31 | 13.45 | 11.06 | 23.51 |
| **Weighted Average** | **7.33** | **11.87** | **9.11** | **15.72** |

**Table 5: Summary of ADWR's Cropped Acreage and Net Irrigation Demand.**

| Irrigation Practice | Area Type | Acreage | Lower Limit Net Irrigation CU (in/yr) | Upper Limit Net Irrigation CU (in/yr) | Total Net Irrigation CU (Lower Limit) (ac-ft/yr) | Total Net Irrigation CU (Upper Limit) (ac-ft/yr) |
|---|---|---|---|---|---|---|
| Traditional Farms Dry Land | Maximum | 9,210 | 4.2 | 10.32 | 3,224 | 7,921 |
| | Minimum | 1,000 | 4.2 | 10.32 | 350 | 860 |
| Irrigation Projects Non-Deficit | Maximum | 643 | 20.64 | 29.52 | 1,106 | 1,582 |
| | Minimum | 0 | 20.64 | 29.52 | 0 | 0 |
| Total | Maximum | 9,853 | | | 4,329 | **9,502** |
| | Minimum | 1,000 | | | **350** | 860 |

Table Notes: Acreage from Table 9-1 ADWR HSR 2008
Irrigation CU from Appendix F, ADWR HSR 2008, Table 2.13 and 2.14

## Other Factors Governing Water Use

*Deep Percolation Losses from Irrigation Applications*

The United States uses the daily soil moisture accounting to calculate deep percolation losses. Deep percolation occurs after a field's soil moisture reaches field capacity. ADWR does not account for any deep percolation.

*Conveyance inefficiency—Evaporation and Deep Percolation Losses*

The United States estimates 16% of the irrigation diversion goes to conveyance inefficiency losses. These losses include deep percolation and evaporation from conveyance facilities that do not return to the surface flows. ADWR ignores these losses.

*Water availability*

The United States conducted a detailed accounting of available flow. This is performed by estimating streamflows in the washes using the PRMS hydrologic model, routing them through the channel network, and estimating diversions on a daily basis. ADWR does not estimate water availability; instead they reduce crop coefficients to limit the claim.

**Attachment 2 References**

(FAO, 1998) Food and Agriculture Organization of the United Nations (FAO), *Crop Evapotranspiration, Guidelines for computing crop water requirements,* FAO Irrigation ad Drainage Paper No. 56, Rome, Italy, 1998.

(Jensen and Haise, 1963) *Estimating Evapotranspiration From Solar Radiation* by Jensen, M.E. and Haise, H.R. In Proceedings of the American Society of Civil Engineers, Journal of Irrigation and Drainage, vol. 89, no. IR4.

(NEH, 1993) U.S. Department of Agriculture, Soil Conservation Service (SCS), *National Engineering Handbook*, Chapter 2, Irrigation Water Requirements, 1993.

**ATTACHMENT 3 - United States' Comments on HSR Appendix G-1: Verification of Claimed Agricultural Lands on the Hopi Indian Reservation (Dianne Yunker)**

The United States provides the following detailed comments regarding ADWR's photographic review of irrigated acres. These comments can be divided in the following categories and are addressed in detail below:

1) ADWR's aerial photo data is faulty because it consists of digital images scanned from aerial photos rather than images created from negatives;

2) ADWR's analysis erred because it did not employ stereoscopic analysis;

3) "Digitizing errors" identified by ADWR are not errors but results of the unioning process that are removed once a Dissolve function is applied to the data;

4) ADWR's classification scheme is misleading and ambiguous;

5) ADWR's decision to collapse small fields into larger fields for random review leads to errors; and

6) ADWR's analysis overlooks critical irrigated lands such as orchards and range lands.

**Aerial Photographic Data and Process used by ADWR**

The aerial photographic data used by ADWR as the basis for their critique are not comparable to the aerial photos used by the United States. The photo analyses which support the United States' claim were accomplished using stereo aerial chemical photographic contact prints and enlargements made from original negatives, while ADWR used only digital images scanned from aerial photos and did not employ stereo photo analysis.

Stereoscopic analysis is vitally important in mapping agricultural fields and determining their water uses for many reasons. Stereoscopic photo analysis allows the topography of the landscape and therefore the sources of water supplied to fields to be identified and classified by the photo analyst.

In addition, things on the ground are often expressed very differently on the left vs. the right frames of a stereo pair because of variation in photographic exposure due to vignetting, and because of the effects of lens aberration in photos, which depends largely on an objects' distance from the principal point (the point in the middle of an aerial photo, directly below the central lens axis). By viewing the stereo pair with a stereoscope, the photo analyst sees entities on the land surface on both of the frames of the pair, with clarity and definition almost always unattainable by viewing a monoscopic image.

There are other problems associated with relying solely on digital images scanned from aerial photos to identify ground features such as those important in identifying agricultural water use. When images are scanned there is a fundamental tradeoff between spatial resolution and file size. If, for instance, a 10" x 10" black-and-white contact print is scanned at 3200 dpi resolution, which is a common maximum optical resolution for many recent flat-bed scanner models, a file about 1 gigabyte in size results, much too large to be used without difficulty in ArcGIS. A scan of the same print at 800 dpi produces a file about 70 megabytes in size, much more reasonable for use in ArcGIS. There is no indication in ADWR's report of what file sizes they used for viewing scanned aerial data in ArcGIS, but depending upon the scale of the images they had scanned for them, files of workable size were clearly of too low resolution to show some features clearly. The quality of scans produced by different scanners, even at the same dpi resolution, can vary significantly as well. The fact that about 15% of the "joined fields" ADWR inspected were classified as "questionable," indicating the images were of poor quality, show ADWR had significant concerns regarding the usefulness of their digital images.

Viewing images with magnifying, optical stereoscopes as well as digitally on a computer, infers many advantages over digital viewing alone.

Photographic data from the mid-1930's are especially important in the Hopi water claim because they are the only source from which maps of early Twentieth Century Hopi agricultural water use can be made.

The 1930's aerial photographic data ADWR used were obtained from the Arizona State University Library's Map Collection. This collection contains monoscopic mosaics of most of the state of Arizona, which were created by overlaying portions of 10" x 10" contact prints made from negatives flown at an approximate scale of 1:28,000 by Fairchild Aerial Surveys in 1935-1937. At the time these mosaics were made, the aerial contact prints were manually overlain using a network of metal aerotriangulation templets and pasted together, then rephotographed and printed. They were then printed on paper from the third-generation photographic negatives, making them a fourth-generation photographic product (the original negatives are the first generation, and contact prints made from them are the second generation). Each time another photographic generation is made, contrast increases (i.e. the light-to-dark range of the photographic image is decreased), and spatial definition of details in the photo product is decreased. The fourth-generation mosaics were printed at a reduced scale of 1:62,500 so they would cover the same area, at the same scale, as a USGS 15-minute quad sheet. These mosaics were scanned for ADWR at the ASU Library.

The United States worked with 1:28,000 scale contact prints from the 1930's Fairchild aerial photographs, many of them originals printed at that time by Fairchild and archived by the BIA. The lower resolution of the scanned versions of the 4$^{th}$, or perhaps later, generation mosaics, reduced in scale to 1:62,500, is probably responsible for ADWR's

inability to identify fields from these images, and classifying so many areas with agricultural fields as "No."

**Comments on "Digitizing Errors"**

The GIS shapefile analyzed by ADWR is the first generation of a fields database created with a unioning process. This unioned fields shapefile can be thought of simply as comprising three different years of field shapes superimposed and collapsed upon one another. The boundaries of all original fields are retained in this data. It is, therefore, not surprising that myriad small polygons, or slivers of the original field shapes, occur in the database. These are not "very small claimed fields" or " residual errors from digitizing" as described on page 3 of Appendix G-1, but are instead artifacts of the unioning process that are removed once a Dissolve function is applied to the data. This is, in fact, the process ADWR used in beginning to evaluate the data.

**The ADWR's Classification Scheme and Decision Flow**

Two categories in the ADWR's classification scheme are markedly ambiguous. The "Questionable" category has a name which is misleadingly and conveys an unwarranted connotation. The "Questionable" classification is given to a "joined field" if, "...due to poor image quality, it was difficult to determine if agriculture had actually occurred in an area (Yunker, page 8)." A better name for this class would be "Cannot be Determined," or "We Can't Tell Due to the Quality of the Digital Data We're Using." If a determination cannot be made, it apparently means a conclusion cannot be reached as to whether the joined field they are inspecting is "Complete," or "Partial," or "No."

The "Partial" category is also ambiguous and misleading. No mention is made in the report of any mapping being done to determine how much of a "joined field" classified as "Partial" is devoid of agricultural activity or not, "in a given year." The "Partial" class and the enumeration of the acreages defined as being "Partial," purposefully or not, conveys the connotation that since the whole unioned area wasn't being farmed on a single photo date, the United States interpretations are incorrect. Since the GIS data *is* unioned, it would be expected that one would find some places in a unioned field area that are not being farmed in any single year.

**The "Fields Selected for Review" Procedure used by ADWR**

One of the first steps in reviewing the GIS database criticized by ADWR was to dissolve the boundaries of individual agricultural fields, reducing "... the number of claimed fields to verify from 8,121 to 2,214 (Yunker, page 3)." The new "fields," as they are referred to in Appendix G-1, are actually collections of contiguous agricultural fields. After this was done, "... ADWR randomly reviewed about 25% of the resulting fields, which covered between 0 and 10 acres, about 50% of the fields that covered between 10 and 100 acres, and 100% of the fields that covered more than 100 acres (Yunker, page 6). No mention is given in appendix G-1 as to how the fields were selected randomly, and it needs to be determined how the "random" selection was made. "Randomly" is just as

likely, in our opinion, to actually mean "arbitrarily" in this context, and the method of doing so is not explicated in the report.

The rationale behind this selection was probably that ADWR did not want to have to find and look at many small fields, but rather fewer, larger ones. Such a selection process biases ADWR's results; however, when individual photo years are selected for inspection rather than unioning all photo years by type. It is far more likely that in the large "field" areas created by the unioning process there will be areas that are not being farmed in single years, than in smaller field areas, resulting in ADWR's classification of them as "partial." This is evidenced by the fact that the average acreage of "joined fields" they classify as "Complete" is 21.71 acres, while the average size classified as "Partial" is 72.36 acres.

**ADWR's Approach Misidentifies Irrigated Acreages in the "No" Category such as Orchards and Range Pasture**

ADWR review classified acres in one of four classes: Complete, Partial, Questionable and No. The United States' contractor reviewed a sampling of the fields classified by ADWR as "No" and concluded that ADWR's approach overlooked both orchards and irrigated pasture lands. For example, several of the "No" fields are unequivocally orchards. Most others are characterized by rectilinear outlines, cleared level surfaces some of which are bordered by heavy vegetation. Indeed, a large portion of acreage is a waterspreading area within the Polacca Irrigation Project. This area is irrigated pasture in the BIA classification. A simple visual inspection of the topographic maps in the ADWR Appendix B allows an estimate of about 3,250 acres of areas classed as irrigated pasture (Type 3) reviewed as "No" by ADWR. The irrigated pasture in the United States' inventory appears to have been overlooked by the ADWR review, its recognition dependent more on a definition of what uses of surface water distributed by means of waterspreading structures comprise irrigation than on its photographic signature.

The poor quality of imagery used in the ADWR effort is probably the cause for lack of field recognition in the case of photos taken in 1934. The inability to recognize orchards could be due to inexperience or the small scale of 1954 photos. Even with these problems, fields in this "No" class that were reexamined on digital and hard copy imagery are fully recognizable.

It was not possible to review a large enough sample of the ADWR "Questionable" field. However, field areas identified as "Questionable" by ADWR that were seen during the above described inspection of "No" fields also appear to be good candidates for classification as cultivated fields.

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*Attorneys for LCR Claimants*

RECEIVED
JUL 1 2009
LEGAL
ARIZONA DEPARTMENT OF WATER RESOURCES

**IN THE SUPERIOR COURT OF THE STATE OF ARIZONA**

**IN AND FOR THE COUNTY OF APACHE**

| | |
|---|---|
| IN RE:<br><br>THE GENERAL ADJUDICATION OF ALL RIGHTS TO USE WATER IN THE LITTLE COLORADO RIVER SYSTEM AND SOURCE | Case No. 6417<br><br>LCR CLAIMANTS' COMMENTS TO ADWR'S PRELIMINARY HYDROGRAPHIC SURVEY REPORT FOR THE HOPI INDIAN RESERVATION<br><br>(Submitted to Arizona Department of Water Resources) |

| | |
|---|---|
| **CONTESTED CASE NAME/NO.** | *In re Hopi Tribe Priority* |
| **DESCRIPTIVE SUMMARY** | The LCR Claimants submit their Comments to the Arizona Department of Water Resource's Preliminary Hydrographic Survey Report for the Hopi Indian Reservation |
| **STATEMENT OF CLAIMANT NOS.** | Attached as Exhibit A |
| **NUMBER OF PAGES** | 6 including Exhibit A |
| **DATE OF FILING:** | June 30, 2009 |

## Introduction

ADWR completed its Preliminary Hydrographic Survey Report ("HSR") in this contested matter in December 2008. The Court granted an extension of time in which the

parties can file comments to the Preliminary HSR. The LCR Claimants hereby submit their comments to the Preliminary HSR.

The Preliminary HSR includes an analysis of some of the Hopi's claims. However, many Hopi claims are not included in the analysis. The HSR also excludes analyses of certain attributes of the Hopi claims "until the legal issues before the Court and the Special Mater are resolved". [Section 9.3.3] Accordingly, these comments are cursory in nature and lacking in detail. Nevertheless, the following should be considered in a completed HSR. This list is not exhaustive.

## I. ADWR Should Apply the Court's March 2, 2009 Decision to the HSR.

In an order dated March 2, 2009, the Court granted the Navajo Nation's motion for partial summary judgment and ruled, "that the Hopi Tribe is precluded from asserting water right claims in this adjudication to the extent such claims seek the right to water sources located within the Little Colorado River Basin that neither abut nor traverse Hopi lands." [March 2, 2009 Minute Entry at 2] This ruling limits the sources from which the Hopi can satisfy its water claims under the federal reserved water rights doctrine and it affects the viability of the remainder of their claims.

To take the Court's latest ruling into account, the HSR should be changed in at least the following respects: (1) The "History of Proceedings" Section [§1.2] should include the March 2009 ruling; (2) ADWR's Recommended Water Right Attributes [§9.3.2] should be amended in the paragraph about Water Source to reflect that the Court has ruled that the Hopi have no right to fulfill their water claims from the Little Colorado River; (3) The "Legal Issues Pending Before the Court and Special Master section [§9.3.3] should be changed to reflect the Court's March 2009 ruling, and (4) Many other references throughout the HSR need to be modified to reflect the ruling.

## II. ADWR's HSR Should Analyze all of the Hopi Claims.

The Preliminary HSR does not address the following Hopi Claims:

1. The Hopi Industrial Park claims [§ 1.3]
2. Hopi's state law claims on five ranches [§ 2.3.12]
3. Hopi's claims related to off-reservation tourism [§ 2.9.6]
4. An analysis of Hopi claims under the Treaty of Guadalupe Hidalgo [§9.3.2]

The stated reason for these omissions is the Court's November 4, 2004 minute entry in which the Court told ADWR to limit its Preliminary HSR to the "main reservation lands." In any event, all of the Hopi claims should be added to the HSR before it is completed.

In order to satisfy the "comprehensive requirement" of the McCarran Amendment, an adjudication must include the "whole community of claims." *United States v. District Court of Eagle County*, 401 U.S. 520, 525 (1971). Not only does the federal comprehensiveness requirement necessitate an analysis of all claims, a concern for efficient use of resources also weighs in favor of including all Hopi claims in the HSR. All of the above claims will have to be decided in this adjudication and requiring ADWR to prepare an additional HSR later that addresses these claims would cause a wasteful duplication of effort. In addition, when these claims are raised in this adjudication, if the Court and the parties need hydrographic data, the adjudication will be further stalled while ADWR prepares this data. It would be more efficient to ask ADWR to analyze all of the Hopi claims now, before any evidentiary determinations are made.

## III. The HSR Needs Additional Information

In several places, the HSR lacks information. This information should be completed before the HSR becomes final. Some of the additional information that is needed includes:

1. Additional information promised by the Hopi and the United States regarding the claimed quantities and impoundment facilities for stock watering. [§ 2.3.9]
2. Information from the Hopi and the United States to clarify how much water from impoundments is needed for stock watering and how much is needed for other uses of the impoundments. [§ 2.8.4 ("Neither the Hopi nor the United States claim a separate quantity of water for livestock, but instead include livestock among the purposes for which impoundments, springs and wells are used.")]
3. Additional information promised by the Hopi regarding future stockwatering claims. [§ 2.9.4]
4. The amount of acreage of usable rangeland in the Moenkopi Area [§ 6.1.2]
5. The carrying capacity of rangeland in the Moenkopi Area [§ 6.1.2]
6. Revised storage estimates for impoundments with degraded or eroded berms or siltation. [§ 7.2.2]
7. Flow data for the springs claimed in the Hopi SOC [§ 8.4.3]
8. Any information in any Amended Claims should be considered prior to the issuance of a final HSR.

## IV. The HSR Should Reflect Current Information.

The HSR includes several comments regarding the Mojave Generating Station (MGS) as being one of the bases of the Hopi claim. The new HSR should reflect the fact that MGS was recently decommissioned and will be torn down. *Arizona Republic. June 11, 2009.* Furthermore, the HSR should reflect lack of viability of the claim for Heavy Industrial water use in light of the statement in §8.3.3 that "both projects were abandoned, lacking a sustainable water supply."

## V. HSR Should Not Include ADWR's Analysis of Legal Issues.

In the HSR, ADWR makes several analyses of legal issues. For example, see §9.3.1. Such analysis is not within the purview of the Department's responsibilities and should be deleted.

## Conclusion

The LCR claimants respectfully request that the above-listed issues be considered and included in the HSR before it is finalized and presented to the Court.

RESPECTFULLY SUBMITTED this 30th day of June, 2009.

BROWN & BROWN LAW OFFICES, P.C.

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ORIGINAL of the foregoing mailed/faxed this 30th day of June, 2009, to:

Arizona Department of Water Resources
Adjudications Section
3550 N. Central
Phoenix, AZ 85012

COPIES of the foregoing mailed this 30th day of June, 2009, to those parties who appear on the Court-Approved Mailing List for Case No. 6417.

By _____

## LCR CLAIMANTS REPRESENTED BY BROWN & BROWN LAW OFFICES, P.C.

| | | |
|---|---|---|
| 1. | Town of Eagar | 39-84465, 39-84466, 39-84467, 39-84468, 39-84469, 39-84470, 39-84471 |
| 2. | City of Holbrook | 39-82029, 39-82078, 39-82079, 39-82080, 39-82081, 39-85030 |
| 3. | City of Show Low | 39-84279, 39-84280, 39-84281, 39-84282, 39-84283, 39-84284, 39-84285 |
| 4. | Town of Springerville | 39-84149 |
| 5. | Town of Snowflake | 39-83792, 39-84000 |
| 6. | Town of Taylor | 39-80823 |
| 7. | City of Winslow | 39-84979, 39-84980 |
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Exhibit "A"

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BRADLEY J. PALMER

# FAX TRANSMITTAL

TO: ADWR Legal Services – 602-771-8683

FROM: David A. Brown

RE: LCR Claimants' Comments to ADWR's Preliminary HSR for the Hopi Indian Reservation

DATE: June 30, 2009

NO. OF PAGES: 7 (INCLUDING COVER)

MESSAGE:

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JUN 30 2009
LEGAL
DEPT OF WATER RESOURCES

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St. Johns, Arizona 85936
(928) 337-4225

*Attorneys for LCR Claimants*

**IN THE SUPERIOR COURT OF THE STATE OF ARIZONA**

**IN AND FOR THE COUNTY OF APACHE**

| | |
|---|---|
| IN RE:<br><br>THE GENERAL ADJUDICATION OF ALL RIGHTS TO USE WATER IN THE LITTLE COLORADO RIVER SYSTEM AND SOURCE | Case No. 6417<br><br>LCR CLAIMANTS' COMMENTS TO ADWR'S PRELIMINARY HYDROGRAPHIC SURVEY REPORT FOR THE HOPI INDIAN RESERVATION<br><br>(Submitted to Arizona Department of Water Resources) |

| | |
|---|---|
| **CONTESTED CASE NAME/NO.** | *In re Hopi Tribe Priority* |
| **DESCRIPTIVE SUMMARY** | The LCR Claimants submit their Comments to the Arizona Department of Water Resource's Preliminary Hydrographic Survey Report for the Hopi Indian Reservation |
| **STATEMENT OF CLAIMANT NOS.** | Attached as Exhibit A |
| **NUMBER OF PAGES** | 6 including Exhibit A |
| **DATE OF FILING:** | June 30, 2009 |

## Introduction

ADWR completed its Preliminary Hydrographic Survey Report ("HSR") in this contested matter in December 2008. The Court granted an extension of time in which the

parties can file comments to the Preliminary HSR. The LCR Claimants hereby submit their comments to the Preliminary HSR.

The Preliminary HSR includes an analysis of some of the Hopi's claims. However, many Hopi claims are not included in the analysis. The HSR also excludes analyses of certain attributes of the Hopi claims "until the legal issues before the Court and the Special Mater are resolved". [Section 9.3.3] Accordingly, these comments are cursory in nature and lacking in detail. Nevertheless, the following should be considered in a completed HSR. This list is not exhaustive.

**I. ADWR Should Apply the Court's March 2, 2009 Decision to the HSR.**

In an order dated March 2, 2009, the Court granted the Navajo Nation's motion for partial summary judgment and ruled, "that the Hopi Tribe is precluded from asserting water right claims in this adjudication to the extent such claims seek the right to water sources located within the Little Colorado River Basin that neither abut nor traverse Hopi lands." [March 2, 2009 Minute Entry at 2] This ruling limits the sources from which the Hopi can satisfy its water claims under the federal reserved water rights doctrine and it affects the viability of the remainder of their claims.

To take the Court's latest ruling into account, the HSR should be changed in at least the following respects: (1) The "History of Proceedings" Section [§1.2] should include the March 2009 ruling; (2) ADWR's Recommended Water Right Attributes [§9.3.2] should be amended in the paragraph about Water Source to reflect that the Court has ruled that the Hopi have no right to fulfill their water claims from the Little Colorado River; (3) The "Legal Issues Pending Before the Court and Special Master section [§9.3.3] should be changed to reflect the Court's March 2009 ruling, and (4) Many other references throughout the HSR need to be modified to reflect the ruling.

## II. ADWR's HSR Should Analyze all of the Hopi Claims.

The Preliminary HSR does not address the following Hopi Claims:

1. The Hopi Industrial Park claims [§ 1.3]
2. Hopi's state law claims on five ranches [§ 2.3.12]
3. Hopi's claims related to off-reservation tourism [§ 2.9.6]
4. An analysis of Hopi claims under the Treaty of Guadalupe Hidalgo [§9.3.2]

The stated reason for these omissions is the Court's November 4, 2004 minute entry in which the Court told ADWR to limit its Preliminary HSR to the "main reservation lands." In any event, all of the Hopi claims should be added to the HSR before it is completed.

In order to satisfy the "comprehensive requirement" of the McCarran Amendment, an adjudication must include the "whole community of claims." *United States v. District Court of Eagle County*, 401 U.S. 520, 525 (1971). Not only does the federal comprehensiveness requirement necessitate an analysis of all claims, a concern for efficient use of resources also weighs in favor of including all Hopi claims in the HSR. All of the above claims will have to be decided in this adjudication and requiring ADWR to prepare an additional HSR later that addresses these claims would cause a wasteful duplication of effort. In addition, when these claims are raised in this adjudication, if the Court and the parties need hydrographic data, the adjudication will be further stalled while ADWR prepares this data. It would be more efficient to ask ADWR to analyze all of the Hopi claims now, before any evidentiary determinations are made.

## III. The HSR Needs Additional Information

In several places, the HSR lacks information. This information should be completed before the HSR becomes final. Some of the additional information that is needed includes:

1. Additional information promised by the Hopi and the United States regarding the claimed quantities and impoundment facilities for stock watering. [§ 2.3.9]
2. Information from the Hopi and the United States to clarify how much water from impoundments is needed for stock watering and how much is needed for other uses of the impoundments. [§ 2.8.4 ("Neither the Hopi nor the United States claim a separate quantity of water for livestock, but instead include livestock among the purposes for which impoundments, springs and wells are used.")]
3. Additional information promised by the Hopi regarding future stockwatering claims. [§ 2.9.4]
4. The amount of acreage of usable rangeland in the Moenkopi Area [§ 6.1.2]
5. The carrying capacity of rangeland in the Moenkopi Area [§ 6.1.2]
6. Revised storage estimates for impoundments with degraded or eroded berms or siltation. [§ 7.2.2]
7. Flow data for the springs claimed in the Hopi SOC [§ 8.4.3]
8. Any information in any Amended Claims should be considered prior to the issuance of a final HSR.

## IV. The HSR Should Reflect Current Information.

The HSR includes several comments regarding the Mojave Generating Station (MGS) as being one of the bases of the Hopi claim. The new HSR should reflect the fact that MGS was recently decommissioned and will be torn down. *Arizona Republic. June 11, 2009.* Furthermore, the HSR should reflect lack of viability of the claim for Heavy Industrial water use in light of the statement in §8.3.3 that "both projects were abandoned, lacking a sustainable water supply."

## V. HSR Should Not Include ADWR's Analysis of Legal Issues.

In the HSR, ADWR makes several analyses of legal issues. For example, see §9.3.1. Such analysis is not within the purview of the Department's responsibilities and should be deleted.

## Conclusion

The LCR claimants respectfully request that the above-listed issues be considered and included in the HSR before it is finalized and presented to the Court.

RESPECTFULLY SUBMITTED this 30th day of June, 2009.

BROWN & BROWN LAW OFFICES, P.C.

David A. Brown
Douglas E. Brown
Bradley J. Palmer
Post Office Box 1890
St. Johns, Arizona 85936

ORIGINAL of the foregoing mailed/faxed this 30th day of June, 2009, to:

Arizona Department of Water Resources
Adjudications Section
3550 N. Central
Phoenix, AZ 85012

COPIES of the foregoing mailed this 30th day of June, 2009, to those parties who appear on the Court-Approved Mailing List for Case No. 6417.

By _____

## LCR CLAIMANTS REPRESENTED BY BROWN & BROWN LAW OFFICES, P.C.

| | | |
|---|---|---|
| 1. | Town of Eagar | 39-84465, 39-84466, 39-84467, 39-84468, 39-84469, 39-84470, 39-84471 |
| 2. | City of Holbrook | 39-82029, 39-82078, 39-82079, 39-82080, 39-82081, 39-85030 |
| 3. | City of Show Low | 39-84279, 39-84280, 39-84281, 39-84282, 39-84283, 39-84284, 39-84285 |
| 4. | Town of Springerville | 39-84149 |
| 5. | Town of Snowflake | 39-83792, 39-84000 |
| 6. | Town of Taylor | 39-80823 |
| 7. | City of Winslow | 39-84979, 39-84980 |
| 8. | Navapache Hospital District | 39-80557 |
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