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	**Case No. CV 6417-203** **DRAFT REPORT OF THE SPECIAL MASTER ON PAST AND PRESENT WATER USES ON THE HOPI RESERVATION**

CONTESTED CASE NAME: *In re Hopi Reservation HSR*

HSR INVOLVED: Hopi Reservation Hydrographic Survey Report

DESCRIPTIVE SUMMARY: Draft Report filed pursuant to Ariz. R. Civ. P. 53(g) for phase one of the contested case that includes the past and present uses of water on the Hopi Reservation. Objections to the Draft Report shall be filed with the Clerk of the Superior Court of Apache County on or before **September 30, 2019**.

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The Hopi Tribe is entitled to the benefit of federal reserved rights for the amount of water necessary to ensure the Hopi Reservation remains a permanent homeland for the Hopi. *In re General Adjudication of All Rights to Use Water in the Gila Sys. & Source,* 201 Ariz. 307, 35 P.3d 68, 77 (2001) ("*Gila V*"). The purpose of this contested case is to quantify and define those rights so that water can be appropriately managed and rights to use it can be enforced and protected. This draft report makes findings and conclusions based on the evidence admitted in the first phase of this case. The second phase of this case will be tried beginning June 1, 2020.

1. Legal Standard to Define Federal Reserved Water Rights

The *Gila V* decision governs the quantification of water rights for the Hopi Reservation under the federal reserved rights doctrine. In *Gila V,* the court declined to approve the quantification standard used in *Arizona v. California,* 373 U.S. 546 (1963) and *Arizona v. California*, 460 U.S. 605 (1983), which quantified water rights by calculating the amount necessary to practically and economically irrigate reservation acreage (the "PIA standard"), as the "exclusive quantification measure for determining water rights on Indian lands." *Gila V* at 318, ¶37, 35 P. 3d at 79. The court reasoned that the PIA standard for federal reserved water rights was inconsistent with the directive that the quantity of reserved water must provide for a permanent homeland subject to the limitation that the quantity of water cannot exceed the minimal amount necessary for a permanent homeland. It found that the quantity of federal reserved water rights must be tailored to meet a reservation's minimal need for water in the present and the future determined by an intensive examination of the relevant facts and circumstances applicable to the reservation.

The *Gila V* Court described the mandatory factual inquiry by identifying a set of factors to consider such as the geography, topography, and natural resources including groundwater availability, past water use, religious rituals and cultural practices that require the use of water, economic development, and population. In this first phase of the case, the parties presented evidence at trial about the physical landscape of the Hopi Reservation, the Hopi Tribe's past and present use of water, and religious and cultural practices that require the use of water. Little, if any, controversy exists about the physical landscape or Hopi religious and cultural practices. Similarly, no dispute exists that the Hopi Tribe has used water for such purposes as drinking, mining operations, irrigating crops, and watering livestock. The parties' dispute focuses on the amounts of water used in the past and present and the methodologies that were used to determine the quantities claimed.

Past and present uses alone do not define a federal reserved water right under the *Gila V* standard; they are factors to be considered. Proper consideration of these factors requires comprehensive information about past and present uses to the extent that information is available, the acceptance of hydrological reality, and a uniform unit system to measure water use. A data set rather than a single data point, such as the maximum amount used for a particular purpose, must be examined to define past and present use for two reasons. First, a determination of the maximum amount of water used for a particular purpose is not consistent with the *Gila V* Court direction to implement a "minimalist approach" which "provides a realistic basis for measuring tribal entitlements." *Gila V* at 320, ¶48, 35 P. 3d at 81. Second, the amount of water used for a particular purpose varies from year to year. Expert witnesses in the case have cautioned against defining a particular use by a maximum amount because that amount may be a statistical outlier or

simply not credible. When multiple years of data are available, the experts have recommended using an average, median or the amount at the 90th percentile.

In the past, the courts have been criticized for decisions defining water rights that relied on hydrological concepts not generally accepted by the current scientific community. In these proceedings, every effort will be made to meet the standard imposed by the Arizona Supreme Court that requires a decision to comport "with hydrological reality as it is currently understood." *In re the General Adjudication of All Rights to Use Water in the Gila River System and Source*, 198 Ariz. 330, 334, 9 P.3d 1069, 1073 (2000), *cert. denied sub nom. Phelps Dodge Corp. v. U.S.*, 533 U.S. 941 (2001). The determination of past and present use must incorporate the hydrological reality that precipitation and streamflow do not naturally provide a steady, constant supply of surface water to this semi-arid land. The natural supply of water to the Hopi Reservation requires that the definition of past and present reflect the variation in surface flow.

Another aspect of hydrology that must be incorporated in this case stems from the fact that hydrology is a quantitative geophysical science that operates with unit systems to measure quantities that have dimensional qualities.[1] The appropriate unit system to measure the actual quantities of water used in the past and present is a measurement that has the dimensional qualities of volume and time. Quantities of surface flow or pumped groundwater must be defined in units of volume per unit of time. An acceptable unit of measurement is acre-foot per year or acre-foot annually. This is the unit of measurement consistently applied by Arizona Department of Water Resources ("ADWR") in the final Hydrological Survey Report for the Hopi Indian Reservation (December 2015).

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[1] S. Lawrence Dingman *Physical Hydrology* 2d Ed., 7 (2002).

Conclusion of Law No. 1. A maximum water use does not sufficiently quantify a past or present use.

Conclusion of Law No. 2. A quantity of water used in the past or present must be quantified by a unit of measurement that is a unit of volume per unit of time.

Conclusion of Law No. 3. When quantities of water from different sources are used to establish an actual use of the water for a particular purpose, all quantities of water must have been used for that purpose during the unit of time in the selected unit system of measurement of the quantity.

2. Physical Landscape of the Hopi Reservation

Finding of Fact No. 1. The Hopi Reservation covers approximately 3,000 square miles in northern Arizona. [Hopi Exh. 3884 at 17] It is located within two non-contiguous geographic areas referred to as the 1882 Executive Order Reservation, which covers approximately 1.6 million acres, and Moenkopi Island, which encompasses 61,604 acres. [Hopi Exh. 3911 at 123; Hopi Exh. 1019 at 1]

Finding of Fact No. 2. Geographically, the Hopi Reservation is located within the south-central part of the Colorado Plateau physiographic region. [Hopi Exh. 3875 at 6] The northern portion of the Hopi Reservation is located on the Black Mesa at elevations as high as 7,000 feet above mean sea level. The land on the southern scarp or slope of Black Mesa consists of projections known as Antelope Mesa, First Mesa, Second Mesa, Third Mesa, Howell Mesa and Coal Mine Mesa. The Hopi Reservation also includes semi-arid land located at lower elevations to the southwest of Black Mesa. [Hopi Exh. 3875 at 8]

Finding of Fact No. 3. Semi-desert grassland covers approximately 17 percent of the Hopi Reservation at the lowest elevations and it receives between five and eight inches of precipitation per year. [Hopi Exh. 3878 at 14-15]

Finding of Fact No. 4. Mixed grasslands located between 5500 to 6200 feet in elevation cover the majority of the Hopi Reservation (993,907 acres) and receive between eight and twelve inches of precipitation per year. [Hopi Exh. 3878 at 15]

Finding of Fact No. 5. At higher elevations, 6200-7000 feet above mean sea level, sagebrush and grasses cover 18 percent of the land and receive approximately 12 to 15 inches of precipitation per year. [*Id.*]

Finding of Fact No. 6. Less than one percent of the Hopi Reservation has pinyon-juniper stands which are primarily located in the northern portion of the Reservation and receive between 15 and 17 inches of precipitation per year with smaller stands in the east-central and southeastern portions of the reservation. [Hopi Exh. 3878 at 15; Hopi Exh. 1019 at 3] Isolated riparian forest stands can also be found along portions of the washes on the Reservation. [Hopi Exh. 1019 at 3]

Finding of Fact No. 7. Higher temperatures are found at lower elevations on the Hopi Reservation near the bottom of the Little Colorado River valley, and lower temperatures are found in the mountainous area of the Hopi reservation northeast of Fort Defiance. [U.S. Exh. 564 at 2-4]

Finding of Fact No. 8. Drought conditions have affected the Hopi Mesas and surrounding land during multiple periods lasting years to decades dating back to at least the 1200s. [110918:48-53 AM (Gilpin); 100118:35 PM (Adams)]

Finding of Fact No. 9. Most of the southwestern United States, including the Hopi Reservation, is currently in a long-term drought. [092618:70 PM (Ley)]

a. Surface Water

Surface water on the Hopi Reservation is present in seeps, springs, wetlands, and ephemeral, intermittent, and perennial flow through the washes.

Finding of Fact No. 10. Seeps and springs occur where the surface area has eroded to such an extent that it intersects the water table. [091318:55 (Blandford)] The flow from seeps and springs varies annually as well as seasonally. [U.S. Exh. 564 at 2-1]

Finding of Fact No. 11. Wetlands cover approximately 8,000 acres of land on the Hopi Reservation and are characterized "by the presence of water, for some or all of the year, hydric soils, and wetland vegetation." [Hopi Exh. 3878 at 15]

Finding of Fact No. 12. Pasture Canyon is a long, narrow incised canyon with steep rock cliffs on each side that has a wetland area located along its north wall. [092618:8-9, 11 PM (Ley)] Pasture Canyon is located in the Moenkopi Island. [092618:8 PM (Ley)]

Finding of Fact No. 13. The five major washes on the Hopi Reservation, collectively known as the "Northern Washes" are: Moenkopi, (Begashibito and Hamblin forming Moenkopi Wash); Dinnebito Wash; Oraibi Wash (Oraibi and Corn Creek forming Oraibi Wash); Polacca Wash (Wepo and Polacca Wash forming Polacca Wash, which then join Oraibi Wash upstream of Corn Creek Wash); and Jadito Wash (Coyote Wash and Jadito Wash forming Jadito Wash, which then join Oraibi upstream of Corn Creek Wash). [U.S. Exh. 564 at 2-1]

Finding of Fact No. 14. The Northern Washes originate on the northeast corner of Black Mesa, shown on *figure 1*, where at least a portion of the headwaters for the Northern Washes originate on the Navajo Reservation. [091318:46 AM (Blandford); Hopi Exh. 3865, figure 1] Water flows through the Northern Washes across the Hopi Reservation then through the Navajo Reservation to the Little Colorado River. [092618:81 (Ley); U.S. Exh. 527 at 2-1]

Finding of Fact No. 15. The Northern Washes are characterized by ephemeral or intermittent flow with extensive dry periods occurring between high intensity, short duration flow events primarily in response to rainfall and to a much lesser extent, snowmelt. [Hopi Exh. 3875 at 11; U.S. Exh. 564 at 2-1] Limited reaches within the washes experience perennial flow where groundwater discharges on to the surface. [100218:67 PM (Puhuyesva); U.S. Exh. 564 at 2-1]

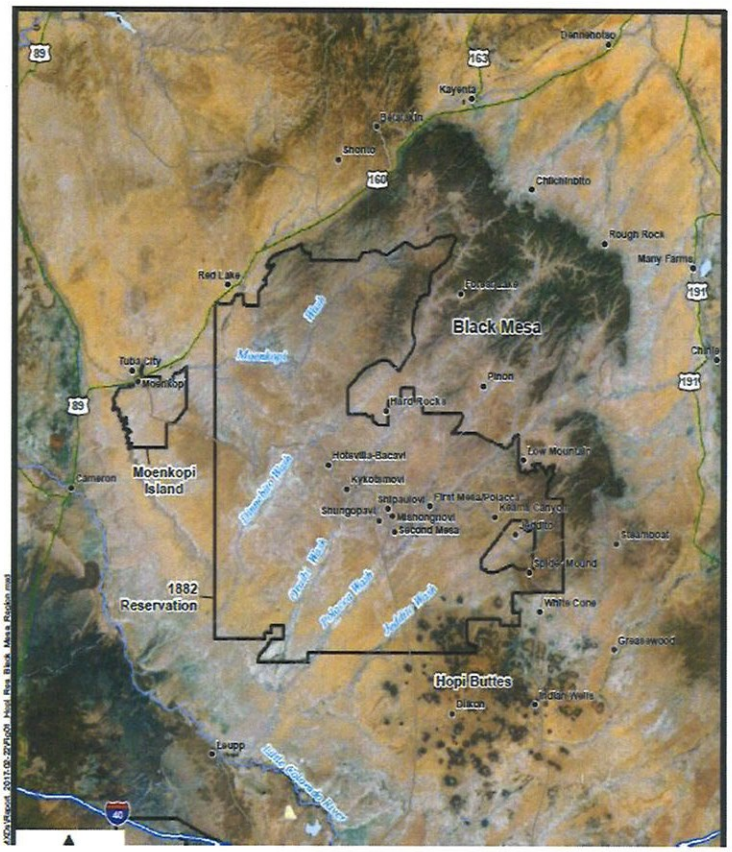

FIGURE 1. Map shows the boundaries of the Hopi Reservation relative to Black Mesa and the Little Colorado River. **SOURCE:** Hopi Exh. 3865 at 2.

Finding of Fact No. 16. The main flow of Moenkopi Wash passes through Moenkopi Island. [091318:44 AM (Blandford)]

Finding of Fact No. 17. The Oraibi Wash is dry most of the time but when it flows, it flows from the northeast and spreads out at the Oraibi delta where sediments have been washed down Oraibi Wash to form a broad alluvial fan. [*Id.* at 45]

Finding of Fact No. 18. Polacca Wash flows between First and Second Mesa. [*Id.*]

Finding of Fact No. 19. The Jadito wash is dry most of the time. [091318:62 PM (Blandford)]

Finding of Fact No. 20. Seasonal temperatures vary in the Northern Washes with July being the warmest month and January being the coldest. [U.S. Exh. 564 at 2-4]

b. Groundwater

Finding of Fact No. 21. Groundwater flows generally from the northeast to the southwest through the layers of aquifers beneath the Hopi Reservation which are illustrated in *figure 2*. [091318:40 PM (Blandford); Hopi Exh. 3875 at 12]

Finding of Fact No. 22. The boundaries of the alluvial aquifer extend underneath the Northern Washes. Flood water as well as springs from the T, D, and N aquifers recharge the alluvial aquifer. [091318:63 AM (Blandford)]

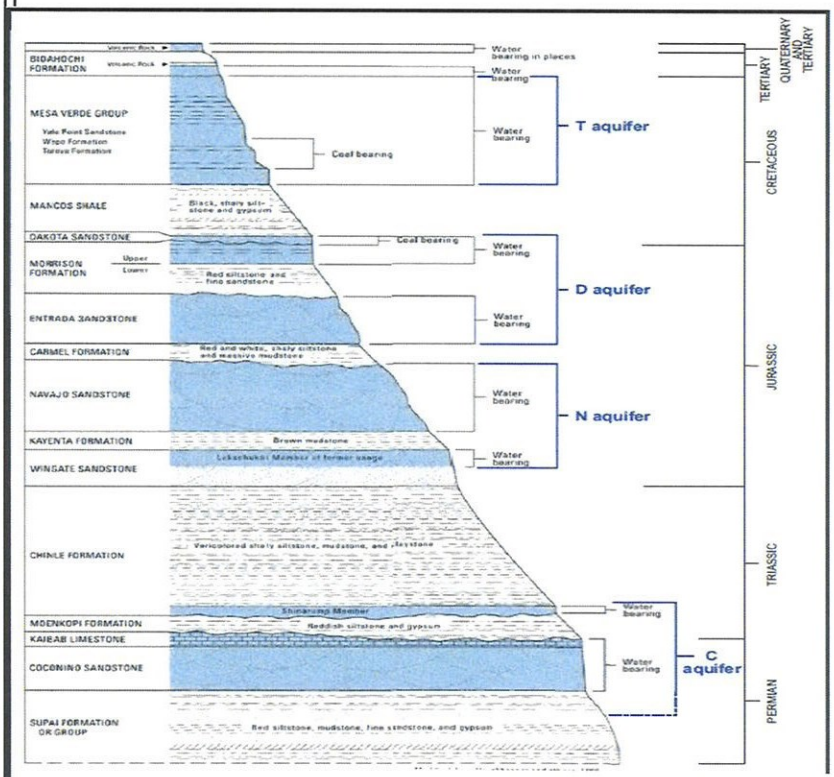

FIGURE 2. Illustration of layered aquifers on the Hopi Reservation.
SOURCE: Hopi Exh. 2174 at 12.

Finding of Fact No. 23. The four primary aquifers, the T, D, N and C aquifers, begin about 100 feet below the land surface in a series of sandstone layers that store water. [Hopi Exh. 3875 at 15]

Finding of Fact No. 24. The uppermost aquifer is the T Aquifer, an unconfined aquifer,

named for the Toreva Sandstone. It is recharged by precipitation that infiltrates the sandstone. Groundwater flows through the Black Mesa and provides a source of water for springs near the Hopi villages. [091318: 52, 64 PM (Blandford)]

Finding of Fact No. 25. The D Aquifer, named for the Dakota Sandstone, underlies the northern portion of the reservation. [Hopi Exh. 3875 at 18] The D aquifer is a confined aquifer for most of its location beneath the Hopi reservation. [091318:37-38 PM (Blandford)]

Finding of Fact No. 26. The N Aquifer, named for the Navajo Sandstone, and known to the Hopi as Pukya, underlies the D Aquifer, and is the first significant aquifer underlying the Reservation [091318:57 AM (Blandford); 101018:21 AM (Pavinyama)]. The N aquifer extends underneath the entire Hopi Reservation with the confined portion existing under most of the Hopi Reservation with the exception of the southwest corner. [Hopi Exh. 3865, figure 6] The northern portion of the aquifer can exceed 900 feet in thickness and decreases to 100 feet or less on the southeastern portion of the Hopi Reservation. [091318:53 PM (Blandford] The N aquifer is relatively thin in the vicinity of the Hopi villages. [*Id.*] Each year the N aquifer is recharged with about 2,500 to 4,750 acre feet of water. [*Id.* at 49] The last glacial period provided the primary source of water in the N aquifer and as a result approximately 90 percent of the water in the N aquifer is more than 10,000 years old. [*Id.* at 46] The unconfined portions of the N Aquifer supplies water for 54 springs on the reservation. [*Id.* at 32] It also provides flow for 81 springs in the Moenkopi area and base flow to the Moenkopi Wash. [*Id.* at 32, 64] The water levels in the N aquifer have been declining. [*Id.* at 77]

Finding of Fact No. 27. The C Aquifer, named for the Coconino Sandstone, is the deepest aquifer and extends beneath the entire Hopi Reservation as well as the entire Little Colorado River

Basin and is generally not recharged by precipitation. [091318:65 AM (Blandford); 091318:40 PM (Blandford)]

3. Water for Mining Use

In 2015, the United States and the Hopi Tribe had reported past and present use of water in mining operations as 1,255 acre feet per year based on the average of the annual amount pumped for industrial use from the Black Mesa Area between 2006 and 2011. [091718: 38 PM (Banet)]

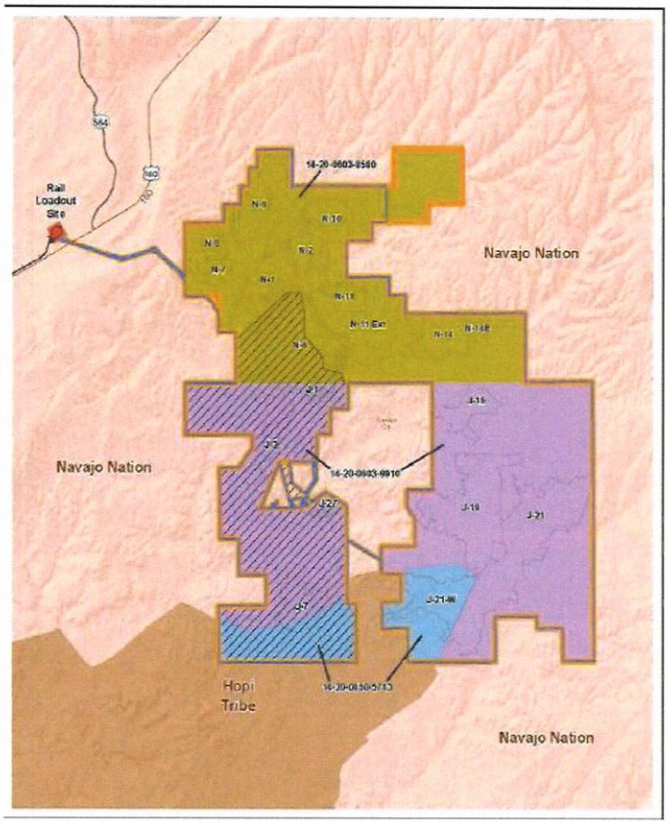

FIGURE 3. The dark area to the north bounds 24,858 acres on the Navajo Nation. The two purple areas running north-south are the 33,863 acres on the Navajo Nation in which the Hopi Tribe has a 50 percent interest in the underlying coal. The blue area is 6,137 acres on the Hopi Reservation for which the Navajo Nation has a 50 percent interest in the coal. The hashmarked land is the site of the Black Mesa Mine.
SOURCE: U.S. Exh. at 751.

In its Fifth Amended Statement of Claimant, the United States, on behalf of the Hopi Tribe, claims past and present use of 1,462 acre feet of water per year for mining activities. This amount represents a 16.5 percent increase from its claim submitted in 2015 and is calculated using a different methodology. In its Fifth Amended Statement of Claimant, the Hopi Tribe claims 3,067 acre feet of water per year, a 144 percent increase from the claim submitted in 2015. The increased claim is also the result of a change in methodology.

Finding of Fact No. 28. All past and present uses of water for mining occurred as

part of the mining and transportation operations at the Black Mesa Mine and the Kayenta Mine. Peabody Western Coal Company ("Peabody Coal") collectively leases 64,585 acres from the Hopi Tribe and the Navajo Nation to mine the coal reserves located on the Navajo and Hopi Reservations. [091718:37, 40-41 AM (Banet)]

Finding of Fact No. 29. The mining operation requires three leases which cover three areas shown in *figure 3*. [091718:40-41 AM (Banet), U.S. Exh. 751]

Finding of Fact No. 30. One mining lease exists between Peabody Coal and the Navajo Nation for the lease of 24,858 acres for which Navajo Nation has the exclusive interest in any coal mined from that site. [U.S. Exh. 753]

Finding of Fact No. 31. Two separate leases to mine coal exist between: (1) Peabody Coal and the Navajo Nation, lease number ending in 9910, for 33,863 acres of land in the Navajo Reservation; and (2) Peabody Coal and the Hopi Tribe, lease number ending in 5743, for 6,137 acres of land in the Hopi Reservation. [091718:40 AM (Banet)]

The Navajo Nation and the Hopi Tribe each own an undivided one-half interest in the coal mined from lease numbers 9910 and 5743.

Finding of Fact No. 32. In 1964, Peabody Coal's predecessor-in-interest signed a lease with the Navajo Nation to permit the coal mining operations and two years later signed a lease with the Hopi Tribe. The Secretary of the United States Department of the Interior approved both leases as being in the best interests of the Navajo Nation and the Hopi Tribe. [NN Exh. 611; NN Exh. 613]

Finding of Fact No. 33. Peabody Coal agreed to make payments to the Navajo Nation and the Hopi Tribe based on the acreage leased, the amount of water pumped, and the amount of coal and uranium sold. [NN Exhs. 607-610] For a portion of the lease term, Peabody Coal did not pay the

Navajo Nation and the Hopi Tribe the same dollar amount for each acre foot of water pumped from the well field. [091818:24, 27 PM (Banet)] The Navajo Nation negotiated a new rate for groundwater pumped in 2015. [110818:28 (Zaman)]

Finding of Fact No. 34. The amounts and criteria determining payments from Peabody Coal have been amended over the lease term. [*Id.*] The amended leases also contain agreements by Peabody Coal to jointly fund a study to examine the impact of Peabody Coal's water usage on the N aquifer; to pay bonuses, taxes, and other fees; to provide educational scholarships; and to improve housing infrastructure. [U.S. Exh. 824]

Finding of Fact No. 35. The leases authorize Peabody Coal to drill wells on the leased property that pump water from the N and D aquifers for its mining operations. [091718:49-50 (Banet); 110818:39 (Zaman)]

Finding of Fact No. 36. Peabody Coal drilled seven wells on the Navajo Reservation that were first put into use during the period 1968 through 1980. [U.S. Exh. 757] The well located on Hopi Reservation, labelled as PCWW 9, was put into use in 1983. [*Id.*]

Finding of Fact No. 37. The wells have formed cones of depression that intersect with each other and lead to mutual drawdown at each location in accordance with the pumping rate and other hydrogeological factors. [091318:75 PM (Blandford)]

Finding of Fact No. 38. Peabody Coal did not pump the wells uniformly; the choice of which well to pump and the amount of water pumped varied from month to month and has varied over the years. [091718:41,53 AM (Banet); 110818:89 (Zaman)] The wells were used interchangeably to supply water for mining operations on any place within the combined leasehold. [091718: 53 AM (Banet); 110818:42 (Zaman)]

Finding of Fact No. 39. The water withdrawn from these wells has been used for dust suppression, fire suppression, road reclamation, coal preparation, blasting and watering of reclaimed areas. [091718:52 (Banet)]

Finding of Fact No. 40. Approximately 75 percent of the groundwater pumped each year was used to transport the mined coal to the Mohave Generating Station. [110818:46 (Zaman)] The water was mixed with pulverized coal and the resulting coal slurry was pumped through a pipeline that crossed the Hopi Reservation to the Mohave Generating Station. [091718:33, 091818:12 (Banet); 110818:46 (Zaman)]

Finding of Fact No. 41. The slurry pipeline has not been used since 2005. [101018:25 AM (Pavinyama)]

The amount of water used for mining operations, unlike the other uses claimed by the United States and the Hopi Tribe, has been monitored and is a matter of public record.

Finding of Fact No. 42. According to a published report from the United States Geological Survey ("USGS"), which monitored the withdrawals from these wells, an average of 3,634 acre feet of water per year was withdrawn during the 1968 – 2005 time period. [Hopi Exh. 1372 at 5]

Finding of Fact No. 43. The single highest annual withdrawal during this period occurred in 1982 when Peabody Coal pumped 4,740 acre feet of water from the wells. [Hopi Exh. 1372 at 5; 091718:7 (Banet)]

Finding of Fact No. 44. For the period 2006-2011, the wells pumped the following amounts (in acre feet) in each year: 1,200, 1,170, 1,210, 1,390, 1,170, and 1,390. [Hopi Exh. 1372 at 5]

In this category of past use, there is little uncertainty about either the total amount of the groundwater used or the fact that it was used for mining purposes. The USGS monitored and

recorded the amounts of groundwater Peabody Coal pumped each year for its mining operations. The Salt River Project correctly assessed the issue that must be resolved with respect to past use of water for mining purposes as one of allocation and not of quantification of the total amount used.

The United States is the legal owner of the land from which Peabody Coal mined the coal and other minerals and from which Peabody Coal pumped groundwater used in the mining operations. The United States seeks federal reserved water rights based in part on the amount of groundwater pumped from land to which it has legal title. In this case, the United States is acting in its fiduciary capacity on behalf of the Hopi Tribe to allocate the groundwater between the two beneficial owners of the land for purposes of quantifying federal reserved water rights on behalf of the Hopi Tribe. The Navajo Nation and the Hopi Tribe are also separately represented.

The division of water used for mining purposes between the Hopi Tribe and the Navajo Nation is complex because, heretofore, the water has been treated as fungible, i.e., not Hopi water and Navajo water. Water has been pumped from groundwater stored under both reservations and used interchangeably in mining operations on both reservations. Peabody Coal controlled the well field that spanned both reservations and directed the pumped water where it was needed in the mining operations. Accordingly, water from the Hopi Reservation was used in mining operations on lands in both reservations, in the slurry pipeline to transport coal across the Hopi Reservation, in mines in which the Hopi Tribe had an undivided interest in the coal, and in mines where the Hopi had no interest in the coal. Similarly, water pumped from the Navajo Reservation was used on both reservations, in the slurry pipeline, and in the mines in which the Navajo Nation had an undivided interest in the coal and had a 100 percent interest in the coal.

Salt River Project did not propose a methodology to allocate the groundwater pumped by Peabody Coal because, as stated above, it took the position that the allocation is an issue between

the Navajo Nation and the Hopi Tribe. The United States, the Hopi Tribe, the LCR Coalition, and the Navajo Nation presented five methodologies to allocate the water for purposes of quantifying federal reserved water rights under the *Gila V* directive. Four methodologies involve the use of a proxy to allocate the amount of groundwater pumped between the Hopi Tribe and the Navajo Nation. The proxies are: (1) the acreage of the leasehold estates in which each party has a mineral interest; (2) amended lease provisions in effect for a portion of the lease term that based one portion of Peabody Coal's payment to the parties on acre feet of water pumped per year; (3) the location of production wells on the leasehold estates; and (4) coal sales from the two mines. The remaining methodology relies on the amount of water Peabody Coal pumped from the well on the Hopi Reservation.

The United States claims that the maximum annual amount pumped during the mining operations should define the amount to be allocated. The maximum annual amount pumped occurred in 1982 when Peabody Coal pumped 4,740 acre feet of groundwater for its mining operations and the transport of coal through the slurry pipeline. According to the methodology urged by the United States, the parties' relative interests in the leased acreage should govern the allocation of the 4,740 acre feet. Peabody Coal leased a total of 64,858 acres in which the Hopi Tribe had an undivided one-half mineral interest in 40,000 acres. The United States calculated that the Hopi Tribe's past and present use equaled 30.84 percent ((0.5 x 40,000)/64,858) x 100) of the 4,740 acre feet of groundwater withdrawn in 1982. It claims that the Hopi Tribe should be allocated a past use of 1,461.82 acre feet of water per year for mining.

As discussed above, the maximum annual amount of water put to a particular use does not quantify a federal reserved water right. Aside from the legal issue, the United States' method of calculating a percentage based on leased acreage (30.84 percent) and replacing that percentage

with a fixed amount of water (1,461.82 acre feet) based on the year in which the greatest annual amount of pumping occurred allocates more than 30.84 percent of Peabody Coal's annual withdrawals to the Hopi Tribe. As shown in *figure 4,* an allocation of 1,464.82 acre feet per year to the Hopi Tribe would allocate 31.5 percent to 198 percent of the water pumped in each year, other than 1982, to the Hopi Tribe.

The methodology proposed by the Hopi Tribe, like the approach recently adopted by the United States, computes a fixed base amount of pumped groundwater and applies a percentage to allocate that base amount between the Hopi Tribe and the Navajo Nation. The Hopi Tribe's base amount equals the sum of the maximum amounts pumped from each of the eight wells over a span of 26 years. The sum of the amounts pumped in the seven years, 1978, 1982, 1985, 1991, 1992, 1995, and 2004, in which each well pumped its maximum amount is 6,134 acre feet. The Hopi Tribe argues that the 6,134 acre feet should be allocated in accordance with the term setting the relative payment rates based on water usage in amended leases signed by the Navajo Nation and the Hopi Tribe with Peabody Coal. Although Peabody Coal paid the Hopi Tribe and the Navajo Nation the same dollar amount for each acre foot of water pumped from the well field for a portion of the lease term, the rate paid for pumped water has not always been the same. [091818:24, 27 PM (Banet)] The Hopi Tribe reasons that because it received 50 percent of the amount paid by Peabody Coal for groundwater for a period of time, it should be allocated 50 percent of the water pumped. Thus, instead of using mineral interests in the leased land as the proxy to allocate the water use, the Hopi Tribe argues that lease terms negotiated with Peabody Coal should serve as the proxy for an allocation of 3,067 acre feet.

The derivation of a base amount of 3,067 acre feet presents a threefold-problem. First, a single maximum data point does not define a use. Second, the base quantity, which is the sum of

measurements in acre feet per year, is only given as a unit of volume and does not include the unit of time applied to the amounts measured. When quantities of water from different sources are used to establish an actual use of the water for a particular purpose, all quantities of water must have been used for that purpose during the unit of time in the selected unit system of measurement of the individual quantities. A legal fiction will not be devised to find an amount different than the amount actually pumped in a defined time period. Third, an annual allocation of 3,067 acre feet results in an allocation greater than 50 percent of the actual amount pumped to the Hopi Tribe. As shown in *figure 4,* an allocation of 3,067 acre feet annually to the Hopi Tribe would allocate to the Tribe e more than 200 percent of the water actually pumped each year during the period 2005-2011.

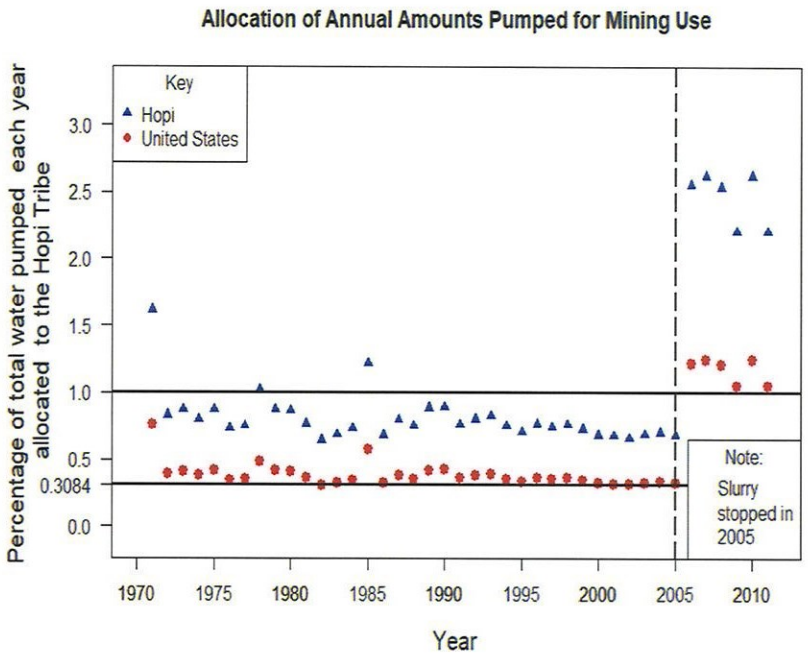

FIGURE 4. Annual percentage of the amount pumped by Peabody Coal for mining for each year that would be allocated to the Hopi Tribe based on an allocaton of either 1,462 acre feet per year or 3,067 acre feet per year.

The use of mining leases that have been repeatedly amended over the lease term that define the complex terms and conditions for mining of coal and assign the risks of that operation between the parties to the contract should not be used for an unintended purpose of allocating water usage in a proceeding that will ultimately determine federal reserved rights between two parties who were not signatories to the same agreement. The tribes have separately negotiated leases with

Peabody Coal. Moreover, there is no basis to choose particular terms during particular time frames to be used to allocate past water usage that was wholly in the control of Peabody Coal. The rates that Peabody paid the Navajo Nation and the Hopi Tribe for an acre of pumped groundwater have differed in the past, and new negotiations have either recently concluded or are in process with respect to new amendments to leases related to the mining of coal. Those negotiations should be allowed to proceed forward on the basis that a new amendment to the lease will govern only the mining operations and will only affect the parties that sign the lease.

The LCR Coalition proposes that the past and present amount of the Hopi Tribe's water use should be determined by the maximum amount pumped from well PWCC 9 that Peabody Coal drilled on the Hopi Reservation. Using the data relied upon by the Hopi Tribe to identify the maximum amount pumped by each well over the terms of the leases, the LCR Coalition proposed that the amount of water that should be allocated to the Hopi Tribe for mining use equals 749 acre feet per year. The designation of 749 acre feet annually would result in an allocation of the water over the 1970-2011 time period of 15.8 percent to 101.2 percent of the water pumped, with an average of 25.6 percent. This approach cannot be accepted because it relies solely upon a maximum water to quantify a past or present use. In addition, the focus on the maximum amount pumped from a single well assumes that only that well pumped water from the Hopi Reservation. As Dr. Blandford testified, the wells in the well field developed cones of depression causing mutual drawdown. Thus, due to the cones of depression that expand the area from which a well draws water, other wells in the well field may be pumping water stored in the portion of aquifer underlying the Hopi Reservation. Finally, given that Peabody Coal determined the amounts pumped from each well for mining purposes, the use of 749 acre feet annually would effectively

mean that Peabody Coal determined the allocation of past use of groundwater between the Hopi Tribe and the Navajo Nation.

The Navajo Nation proposes two approaches to allocate the annual water use between the two parties: (1) allocate the groundwater pumped based on the number and location of production wells drilled by Peabody Coal between the two reservations; or (2) allocate based on the percentage interest in the annual coal sales. Using the first approach, 7/8th of the pumped water would be considered to have been used by the Navajo Reservation and 1/8th of the water would be deemed used by the Hopi Tribe. [110818:32 (Zaman)] As shown by the record of pumping from individual wells for the period 2006 - 2011, the amount of water pumped by the wells is not uniform. Thus the well on the Hopi Reservation could have pumped more or less than 1/8th of the water used in a particular year. Even when all wells were in operation, Peabody rotated among the wells it pumped. [110818:89 (Zaman)] For example, evidence exists that during some time periods only two or three wells were in operation and at some point PCWW 7 was taken out of operation. [110818:90 (Zaman)] Using the Navajo Nation approach, if the well on the Hopi Reservation were only one of two or three wells in operation, then the Hopi should be entitled to an allocation of one half or one third of the water pumped in that year. Insufficient information exists in the record regarding Peabody Coal's rotation and pumping of individual wells to make a reasoned determination of an allocation between the Navajo Nation and the Hopi Tribe using this method. This proposal is also based on the same assumption underlying the LCR Coalition's proposal which is that water from underneath the Hopi reservation is only pumped by a well actually located on the reservation. Based on the testimony of Dr. Blandford, the installation of a well field pumping over a period of time creates interlocking cones of depression that extend the impact of each well.

The second proposal from the Navajo Nation ties water use to the sale of mined coal in which the Hopi have an interest. The Navajo contend that the percentage of water should be allocated based on coal production because coal production serves as a reasonable proxy for water use by each tribe. [110818:44 (Zaman)] In 1982, the year selected by the United States, Akhtar Zaman testified that a total of 12,567,890 tons of coal were produced of which the Hopi Tribe had a 50 percent interest in only 3,073,842 tons of coal. [110818:35 (Zaman)] Allocating groundwater based on tons of coal produced in 1982 results in 12.22 percent of the production attributable to the Hopi Tribe.

The Hopi Tribe subsequently prepared a schedule that identified the amount of coal sold from each mine and calculated the percentage attributable to the Hopi Tribe's interest in the coal mined. [Hopi Exh. 907] The use of coal sales as the proxy to allocate the amounts of pumped groundwater between the Navajo Nation and the Hopi Tribe appears to be the most sound approach based on the record made at trial. As the amount pumped for each year is known, the percentage of coal sales attributable to the Hopi Tribe can be applied to determine an allocation of the amount pumped. *See* Appendix A. The use of the complete data set allows the determination of an average amount, the median, and the maximum amount, which is 1,813.9 acre feet. The use of a percentage based on coal sales for each year also eliminates a set allocation that exceeds the amount of water actually pumped.

Finding of Fact No. 45. The Hopi Tribe benefitted from Peabody Coal's use of an average of 961.4 acre feet annually and a median amount of 1,056.1 acre feet annually.

Finding of Fact No. 46. The use of water for mining is not an aboriginal use of water.

4. Water for Domestic, Commercial, Municipal, and Industrial (DCMI) Uses

The DCMI water use on the Hopi Reservation has significantly changed in the past seventy years. For the time prior to World War II, the domestic water use on the Hopi Reservation has been described as follows:

> Although data on the quantities of water used by the Hopi households in the past are not available, water use was undoubtedly very low. Today households in developing countries that walk such distances to collect water for domestic use typically collect on the order of 2-3 gallons per person per day, and in the past Hopi household water use was probably comparable. Such extremely low levels of water use in the recent past are probably one of the reason that water conservation ethic is so strong on the Hope reservation today.
>
> After World War II this domestic water situation began to change as the US Indian Health Service financed small piped water distribution systems in Hopi villages.

Hopi Exh. 3898 at 54.

Several Hopi tribal members testified about the changes in domestic water use they experienced on the Hopi Reservation during their lifetimes. Tim Nuvangyaoma, Chairman of the Hopi Tribe, testified that until the late 1970s, his mother's house did not have water piped into the house, so they had to drive to a well from which they hauled water back to the house in a 50-gallon barrel. [100818:23-25 AM (Nuvangyaoma)]. Michael Elmer testified that when he was a young child, he lived in a house that did not have plumbing, so he and his brother hauled water from a spring for the family. [010518:25 (Elmer)] Mr. Elmer remembered that the Indian Health Services arranged for indoor plumbing for his family's house in about 1958. [*Id.* at 22, 24-25] Similarly Wallace Youvella recalled that when he was young, one of his jobs was to haul water for the family in buckets from a water source below the mesa because the family home did not have indoor plumbing. [100818:48 (Youvella)] Water is now pumped to that house. [*Id.*]

Finding of Fact No. 47. Most of the villages on the Hopi Reservation currently provide a community water system to at least some of the homes. [Hopi Exh. 3884 at 35; Hopi Exh. 3900 at 5]

Herman Honanie testified that more traditional villages such as Oraibi, which is considered the oldest community in North America, do not allow modern structures including running water in the homes. [100918: 53 AM (Honanie); Hopi Exh. 3884 at 35]

Finding of Fact No. 48. The traditional villages do not have plumbing infrastructure or have limited the installation of infrastructure to the outside boundaries of traditional housing. [*Id.;* 100918:53 AM (Honanie)] The villages of Oraibi and Walpi have no household connections. [100918:52 AM (Honanie); 102218:113 (Hanemann)]

Finding of Fact No. 49. Approximately eight percent of the homes in the village of Lower Moenkopi have private water connections. [Hopi Exh. 3899 at 5]

Finding of Fact No. 50. The village of Hotevilla does not have plumbing for all homes. [*Id* at 52.] A low percentage of the houses in Mishongnovi and Shumgopavi have household water connections. [102218:81 (Hanemann)]

Neither the United States nor the Hopi Tribe quantified DCMI usage prior to the time that the Hopi Reservation had infrastructure that delivered water to public taps, showers, commercial and municipal buildings, and to many of the homes in the Hopi Villages.

Finding of Fact No. 51. DCMI does not include any water uses attributable to light industry because activity that would fit within that category does not exist on the Hopi Reservation. [092018:57 (Hamai)]

Finding of Fact No. 52. DCMI use includes water used in the home for drinking, cooking, cleaning, toilets, and bathing. [092018:52 (Hamai)]

Finding of Fact No. 53. Water made available at public taps and public facilities to those people who live in homes without a connection to a public water service is also included in DCMI use.

Finding of Fact No. 54. In the villages, the public water system provides water to maintain landscaping plants, flowers, and gardens in the area immediately surrounding the home. [092018:52, 54, (Hamai); 102218:37, 73-74 (Whittington)]

Finding of Fact No. 55. Commercial uses include activities undertaken by businesses operated for profit which includes the Hopi Cultural Center hotel and restaurant, Moenkopi Legacy Inn and Suites, Denny's, and the Travel Center. [092018:54, 55(Hamai)]. Municipal uses include schools, tribal buildings, health care facilities, and the Hopi Veterans Memorial Center. [*Id.* at 56-57; US. Exh. 825 at 4]

The Hopi Tribe relies on springs and wells pumping the C, N, and D aquifers to provide water for DCMI uses. Lionel Puhuyesva, the former director of water resources for the Hopi Tribe, testified that the N aquifer provides the primary source of drinking water for the reservation. [102218:68-69 PM (Puhuyesva)] The USGS monitors the wells that pump water from the N aquifer. [092618:48 PM (Ley)] A secondary water source of water is obtained from monitored sources of groundwater outside of the N aquifer. Spring flow and shallow wells provide the third source of water. Counsel for the United States and the Hopi Tribe use the data from the monitored sources, survey information, and estimated population to quantify past DCMI at 582.7 acre feet based on a methodology that combines multiple years of use. The United States uses an alternative methodology to quantify current DCMI use at 531.5 acre feet per year.

Multiple-Year Methodology

The United States retained Paul Hamai to estimate the present DCMI water use on the Hopi Reservation. [092018:18 (Hamai)] Mr. Hamai holds a M.S. in Civil Engineering and serves as the Vice President of Water Resources for Natural Resources Consulting Engineers, Inc. where he has been employed for 26 years. [U.S. Exh. 546] Mr. Hamai quantified the amount of water used on the Hopi Reservation for DCMI by considering three general sources of water. [092018:22 (Hamai); U.S. Exh. 826] Public water systems pumping groundwater constitute two of the sources. He divided those sources into wells monitored by the USGS that pump the N aquifer and wells that are part of a public system but pump water outside the N aquifer. Unmonitored springs and wells used by households without connections to a public water system provide the third general source of water. [092018:18 (Hamai); U.S. Exh. 826 at 4]

Mr. Hamai reported that as part of the USGS program to monitor the impact of wells pumping the N aquifer, the USGS monitors the annual pumping of the wells that serve the Hopi Villages located above the N aquifer. [U.S. Exh. 825 at 6] Table 1, reproduced from Mr. Hamai's report, lists the areas in which the wells are monitored by USGS are located and provides withdrawal data for three years. Mr. Hamai testified that he

Area[1]	Withdrawal[2] (ac-ft)		
	2013	2014	2015
Bacavi	25.4	27.2	31.5
Hopi Civic Center	1.6	1.1	1.4
Hopi Cultural Center	6.6	5.5	5.4
Hopi High School	20.1	15.0	16.7
Hotevilla	43.5	21.8	21.8
Keams Canyon	48.6	57.0	48.8
Kykostmovi	62.6	61.8	71.8
Mishonghovi	4.7	4.2	4.4
Polacca	157.9	148.2	166.6
Second Mesa	4.2	5.0	6.0
Shipaulvi	21.8	19.7	20.8
Shungopovi	33.6	34.6	36.6
Moenkopi	66.6	69.7	82.7
Total	**497.3**	**470.8**	**514.5**

Notes: [1]Area spellings as shown in USGS spreadsheet; [2]Data are provisional.

TABLE 1.
SOURCE: U.S. Exh. 825 at 6.

examined the data provided in his report as well as additional historical data attached to a report prepared by an expert retained by the Navajo Nation for the period 1984 to 2015 and testified that the maximum amount of water withdrawn from the N Aquifer occurred in 2007 in the amount of 562.1 acre feet. 092018:23 (Hamai).

The second category of water examined by Mr. Hamai included water pumped from aquifers other than the N aquifer that serve the village of Moenkopi and Spider Mound. [092018:22 (Hamai)] A well pumping supplemental water for the village of Moenkopi began operation in 2012 and pumps from the C Aquifer. [092018:43-44 (Hamai)] The amounts obtained from the C aquifer are shown in Table 2. [U.S. Exh. 826 at 6]

Year	Amount (acre feet)
2012	0.7
2013	0.7
2014	0.4
2015	1.8
2017 (Jan.-Aug.)	8.0

TABLE 2.
SOURCE: U.S. Exh. 826 at 6.

Also included in this category of monitored pumping of groundwater is the groundwater provided by the Navajo Tribal Utility Authority to Spider Mound. Again, relying on data provided in the report prepared by a consultant retained by the Navajo Nation, Mr. Hamai testified that Spider Mound's largest annual use of water from this source for period 2012 through 2016 occurred in 2014 when the villagers used 3.1 acre feet. [092018:31-32 (Hamai)] Based on this data, Mr. Hamai opined that the total amount for this second category of use is 11.1 acre feet. The unit of measurement unit is not acre feet per year because the amounts are the sum of uses in two different years.

Springs and shallow wells provide a third source of water to those tribal members who do not have connections to a monitored public system pumping groundwater. Quantification for water use from wells and springs is not based on metered use as they are not monitored like the public systems. [U.S. Exh. 826 at 4]. Instead, the data is based upon information obtained from a household survey. *Id.* at 4-5.

The Hopi Tribe retained Dale Whittington and W. Michael Hanemann to conduct a household survey in 2005 and 2006 to determine detailed household water use behavior. [102218:44 (Whittington)]. Dr. Whittington holds a master degree in public affairs and investment economics, a doctorate in business engineering and public affairs, and teaches classes at the University of North Carolina, University of Manchester, and the National University of Singapore in water policy in developing countries and water economics. [102218:39-40 (Whittington); Hopi Exh. 850]. Dr. Hanemann holds a masters degree in development economics and public finance and decision theory and a doctorate in economics. Currently he is a professor at Arizona State University and the University of California at Berkeley. [Hopi Exh. 840]. Drs. Whittington and Hanemann, with the assistance of Joe Cook, authored a report entitled "Household Survey of the Hopi Reservation 2005-2006" ("Household Survey") based on a study of the Hopi Tribe and information received from surveys on 737 households in the 12 main Hopi villages. [102218:18-19 PM (Whittington)]. Mr. Hamai relied upon this study to conclude that the population dependent on wells and springs for water used 8.8 gallons of water per person per day. [092018: 33 (Hamai); U.S. Exh. 826 at 4].

Population estimates for the Hopi Tribe vary and federal census data for the Hopi Tribe can be problematic. [102218:19-21 (Whittington); Hopi Exh. 3884 at 20] Mr. Hamai essentially relied on 2010 census data to determine that 6,607 people lived in the villages and 769 lived in the

rural areas on the Hopi Reservation. According to the Household Survey, 18 percent of the people who lived in homes in villages were not connected to a public water supply. [Hopi Exh. 3898 at 78; U.S. Exh. 826 at 4]. Of those people without a connection to a public water supply, 84 percent accessed water through public taps or neighbors with connections to the public system with the remaining 16 percent obtaining water from windmills and springs. [*Id.*] Based on this analysis, 2.88 percent (0.18 x 0.16) of the estimated population living in the Hopi villages relied on wells and springs for water for domestic use and, because the Household Survey was limited to the population living in the Hopi villages, 100 percent of the people living outside the villages were presumed to obtain all of their water supplies from wells and springs. [*Id.* at 5; 102218:28 (Whittington)] Mr. Hamai calculated the amount of water obtained by people from wells and spring to be approximately 9.5 acre feet per year. [U.S. Exh. 826 at 5]

Thus, by adding the maximum amounts from four general sources over different years in a 10-year period, the United States and the Hopi Tribe quantified the DCMI use on the Hopi Reservation as 582.7 acre feet as shown in Table 3.

Source	**Year**	**Amount (acre feet)**
Monitored Wells pumping the N aquifer	2007	562.1
Unmonitored Wells and Springs	2010	9.5
Monitored Wells pumping the C aquifer	2017	8.0
Water provided by Navajo Tribal Utility Authority	2014	3.1
Total		**582.7**

TABLE 3.

Finding of Fact No. 56. The proposed methodology results in a quantification that exceeds the amount used by the Hopi Tribe in a given year. It does not accurately determine the amount of water used by the Hopi Tribe in the time period that includes the years in which data was collected.

To determine actual use, a set time period must be selected, and the amount of water used in that time period must be quantified. Accordingly, no finding of fact can be made based on the multiple-year methodology.

Single Year Methodology

Mr. Hamai testified about a second quantification which the United States characterized as current use based primarily on data for 2015. He used the same three general categories of DCMI use but the amounts attributed to each source occurred during the same year with one exception.

Finding of Fact No. 57. In 2015, the Black Mesa Wells pumped 514.5 acre feet for the Hopi Villages from the N Aquifer. [U.S. Exh. 826 at 4]

Finding of Fact No. 58. In 2015, the Navajo Tribal Utility Authority provided 2.6 acre feet to Spider Mound. *Id.* at 5.

Although data existed for the amount pumped from the C aquifer, Mr. Hamai averaged the 1.8 acre feet pumped in 2015 with the 8 acre feet pumped in 2017, which is a 400 percent increase from the amount pumped two years earlier. Given that the DCMI is calculated in acre feet per year, the total DCMI usage should be the amount supplied by each source for the same time period.

Finding of Fact No. 59. In 2015, 1.8 acre feet of water was used from the C aquifer.

Finding of Fact No. 60. The DCMI use for the Hopi Tribe is 518.9 acre feet per year.

Finding of Fact No. 61. The use of water for domestic purposes is an aboriginal use.

5. Water for Irrigation Use

Irrigation constitutes the Hopi Tribe's largest use of water on the Hopi Reservation. Final Hopi Indian Reservation Hydrographic Survey Report dated December 2015 ("HSR"), 4-5 The Northern Washes, shown in *figure 1,* provide the primary source of water for irrigation. Historically, and currently, the Hopi grow varieties of corn that are well adapted to the climate. Corn forms the basis of the Hopi diet. [091118:89 AM (Norton); 091218:43, 46 PM (Norton); 100118:32 AM (Adams); 100918:26 PM (Talayumptewa); 101018:13 PM (Selestewa); Hopi Exh 580 at 19]. The Hopi have long traditions associated with planting and growing corn and children are taught at a young age the traditional methods to plant and care for corn plants. [100218:32 AM (Puhuyesva); 100418:56 AM (Loma'omvaya); 100518:29 AM (Elmer); 100818:26-27 AM (Nuvangyaomo); 100808:60 PM; 100918:16 AM (Honanie)] The Hopi people consider corn to be an integral part of their culture. [*Id.*; Hopi Exh. 3898 at 37] Corn is widely used in many Hopi ceremonies and traditional practices. [100418:68-69 AM (Loma'omvaya); 100818:38 AM (Nuvangyaomo); 100818:60 PM (Youvella)] They also grow and have grown beans, maintain orchards with fruit trees, and plant gardens to grow onions, tomatoes, squash, cabbage, carrots, melons, and chilies. [091118:25 AM (Norton); 100118:16 AM (Adams); 100218:26 AM (Puhuyesva); 100418:56 AM (Loma'omvaya); 100918:12 PM (Talayumptewa); Hopi Exh. 3895 at 19, 28]

Finding of Fact No. 62. The Hopi have historically relied on farming for food and trade. They plant, grow, and harvest corn and beans, as well as smaller crops of other vegetables.

Finding of Fact No. 63. Corn and the planting, growing, and harvesting of the corn plant have traditional and cultural significance to the Hopi.

Finding of Fact No. 64. Water used for planting, growing, and harvesting corn, beans, and other vegetables is an aboriginal use of water.

The United States, on behalf of the Hopi Tribe, claim a past and present use of 18,897 acre feet each year to be diverted from the watersheds of the Northern Washes for irrigation that depletes 13,760 acre feet of water annually. United States Fifth Amended Statement of Claimant at 21. The Hopi Tribe quantifies its past and present use of water for irrigation using alternative approaches. Under "Method One," it claims a past use of 31,442 acre feet of water over an unspecified time period. Under "Method Two," it claims a past and present use of 21,543 acre feet of water annually for irrigation. Hopi Tribe's Fifth Amended Statement of Claimant at 31, 34.

Water used for irrigation is not directly measured or gaged for the fields or pastures on the Hopi Reservation, so contemporaneous records do not exist of the amounts of water used annually for irrigation in the past or present. [Hopi Exh. 36 at 8-2; 110118:12 PM (Leeper)] In the absence of records, ADWR adopted an integrated two-step methodology to estimate the amount of water that the Hopi Tribe has used for irrigation. First, it investigated the amount of land that the Hopi Tribe irrigated in the past and present. Second, it calculated the amount of water used on the Hopi fields taking into consideration the different types of agricultural uses and practices.

Arizona Department of Water Resources concluded that the Hopi Tribe irrigated a maximum of 9,553 acres in any single year in the past, which was observed in the 1954-1955 time period. HSR at 5-5. It categorized the acreage according to whether more water-intensive farming methods, which it labelled as modern farming practices, were employed or whether traditional practices were followed and calculated water duties of 4.33 acre feet annually and 0.93 acre feet annually, respectively. Applying these water duties to the 424 acres farmed using modern methods and to the 9,129 traditionally farmed acres, resulted in a total water use of 10,325 acre feet

annually. *Id.* Table 4 summarizes ADWR's conclusions regarding past irrigation on the Hopi Reservation.

General Location	Acres	Water Use (Acre feet Annually)
District 6	6,293	6,129
Hopi Partitioned Land	2,625	2,442
Moenkopi	635	1,754
Total	**9,553**	**10,325**

TABLE 4.

Although the United States and the Hopi Tribe objected to ADWR's final recommendations, they used the same general two-step methodology to establish the amount of water used for irrigation. They both offered methodologies to compute the number of irrigated acres on the Hopi Reservation using historical photographs with the Hopi Tribe offering an alternative approach of population serving as a proxy for irrigated acreage. They both used the claimed acreage as input into a computer model to determine the amount of water used to irrigate. The Hopi Tribe also proposed an alternative approach in which it multiplied the number of acres it claimed had been irrigated in the past by ADWR's water duty figures.

a. *Calculation of Acreage*: United States' Analysis of Acreage by Aerial Photography

James Ian Ebert, an archeologist, anthropologist and forensic scientist, testified that the United States retained his firm to conduct a photo analysis of historical aerial photographs to locate irrigated and non-irrigated fields on the Hopi Reservation. [092418:15 AM (Ebert)] In this case, not only did the historical aerial photographs confirm past use but they identified the extent of past use which was a challenge because cultivated fields exist in isolated plots, distributed over a great deal of territory. [Hopi Exh. 3883 at 150; Hopi Exh. 3882, Appendix B]

The aerial photographs consisted of a series of photographs taken in 1934, photographs taken by the USGS in 1952 of the Moenkopi extension, photographs taken by the United States Army in 1954 of the southern two-thirds of the Hopi Reservation and 1955 of the northern one-third of the reservation, and photographs taken in 1980. [092418:126, 130 PM (Camilli); 092518:53, 68 (Camilli)]. The 1950s photographs were chosen because the photo sets provided full coverage of the reservation that showed separate as opposed to overlapping fields. [092618:14 AM Camilli)] Eileen Camilli, an archeologist and anthropologist, used a process known as photogrammetry to analyze the aerial photographs. Dr. Ebert defined photogrammetry as the combined art, science, and technology of recording, measuring, and interpreting photographic images and patterns of electromagnetic radiant energy and other phenomena to obtain reliable information about physical objects and the environment. [092418:9 AM (Ebert)]

Dr. Camilli explained that she examined the photographs of the reservation to locate the areas of land that had been cultivated, meaning that the land had been planted or harvested. [092418:41 AM (Camilli)] Fields were identified in the aerial photographs by the presence of crops and contextual criteria and the recognition of shape, tonal, and textural characteristics of irrigation projects. [092418:30 AM (Ebert); 092518:90 PM (Camilli); 092618:12 AM (Camilli)] Dr. Camilli also examined the photographs of the fields to determine whether the topography of the land blocked surface flow from adjoining land thereby limiting the possible sources of water to the rain that fell within the boundaries of the field or whether the land received supplemental water from outside the boundaries of the field such as surface flow. [092518:29, 79 PM (Camilli)] The former type of field was characterized as precipitation farming and the latter as irrigated land. [092418:25 (Ebert); [092418:42 AM (Camilli)] Farming that occurs in sand dunes on the tops of mesas is generally regarded as dependent solely on precipitation. [Hopi Exh. 3895 at 32] The

United States excluded most orchards and gardens planted on mesa tops because precipitation alone, not supplemental irrigation, provided the water for the trees and plants. [092418:25 AM (Ebert); 092418:69 AM (Camilli)] It did not include 732.94 precipitation-dependent acres. [U.S. Exh.582 at 19] Dr. Camilli concluded that 13,031.6 acres of land had historically been irrigated on the Hopi Reservation. [092518:38, 40 PM (Camilli)] Arizona Department of Water Resources found that 13,022 acres or 99.9 percent of the land identified by the United States showed evidence of previous agricultural activity. HSR at 4-12.

Dr. Camilli classified the land into six irrigation classifications originally developed by the Bureau of Indian Affairs. [092418:18-19 AM (Ebert); 092418:39, 69, 127 (Camilli); U.S. Exh. 582 at 1, 9] The largest classes, by acreage claimed, are native irrigation, seasonal irrigation, and range and pasture irrigation. The combined acreage in these three classes account for 12,568 acres or 96.4 percent of the land identified by Dr. Camilli. The remaining 3.6 percent of the claimed acreage falls within the perennial irrigation, spring irrigation, and well irrigation categories.

Native irrigation occurs when a farmer strategically locates a field so that it captures overland flow[2] or runoff from surrounding land or adjacent washes such as the Dinnebito Wash. [092418:23 (Ebert); 092418:63 (Camilli); 092618:28 AM (Camilli); U.S. Exh. 582 at 10] Water spreads across a field due to planting design, ditches, small berms, or furrows created in the field or by the manual efforts of the farmer. [092418:63 AM (Camilli); 092618:29 AM (Camilli); 110218:10 PM (Leeper)] Water can also spread out due to the land formation where the field is located at that point where a water channel, such as an arroyo, ceases due to past deposits of silt

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[2] Overland flows occurs when the rainfall rate exceeds the infiltration capacity of the soil and sufficient water ponds on the surface to overcome surface tension effects and the capacity of small depressions in the surface. Larry W. Mays, *Ground and Surface Water Hydrology,* 546 (2012).

that create a smooth fan across the area. [092518:22 PM (Camilli)] A field in this location is referred to as an *akchin* field. [*Id.*] The multiple small fields that are cultivated, fallowed or abandoned over periods of time form a "shifting field system" that has been described as follows:

> Shifting field systems by definition go to where the water is, or where it is expected to be, at a particular moment in time and then shift or expand as conditions change. The borders of fields can change position depending upon water availability and other physical, technological or economic factors that can impact farming from year to year. . . . . changes in the positions, shapes and sizes of individual fields can occur multiple times over a given period of time and they also shift in and out of active and fallow states, which affects their visibility from the air. ...

[Hopi Exh. 3882 at 21]

Changes in location and size of these fields "are constantly occurring in shifting field systems." [*Id.; see also* Hopi Exh. 3895 at 28] An example of a shifting field system consisting of 13.3 acres evidencing cultivated acreage in close proximity at six points in time over 62 years is shown in *figure 5*.

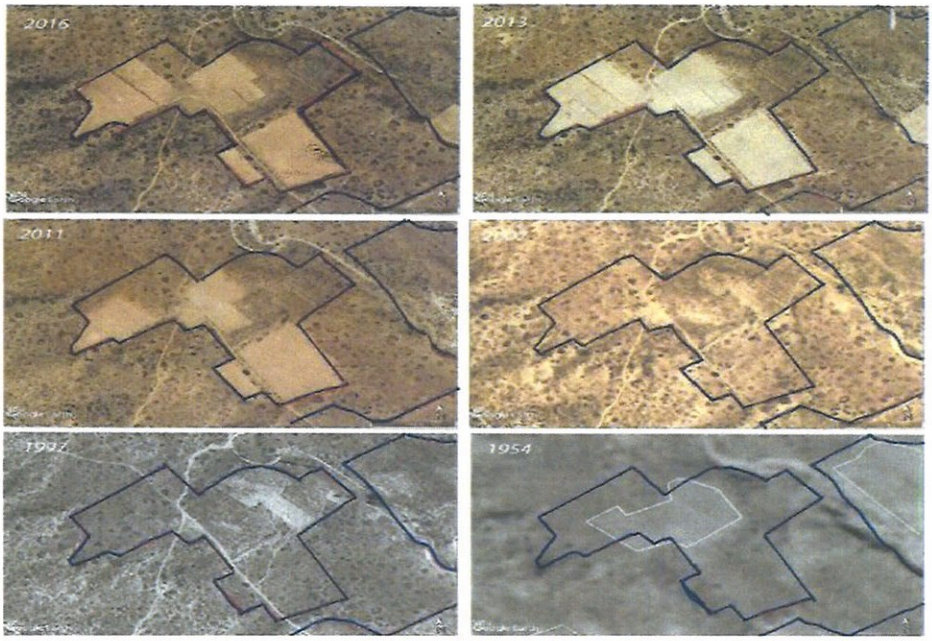

FIGURE 5. Discrete fields planted over a number of years within a 13.3 acre area.
SOURCE: Hopi Exh. 3882 at 17.

Dr. Camilli relied exclusively on the photographs taken by the United States Army in 1954 and 1955 of the Hopi Reservation to inventory the land farmed using native irrigation (with the exception of approximately 17 acres identified from photographs taken in 1934

and 1952). [092418:18 AM (Camilli); 092518:25-26 AM (Camilli); 092518:89 PM (Camilli); U.S. Exh. 582 at 15] She compiled her inventory of that acreage based on the single set of photographs because farmers dependent on native irrigation change the location of the land they choose to plant in response to changes in the environment that affect surface flow. [U.S. Exh. 828 at 17] Dr. Camilli concluded that due to the practice of changing field boundaries and locations, the inclusion of all fields reliant on native irrigation located in all of the photo sets would overrepresent the acreage in the native class. [092518:87 PM (Camilli)]

Seasonal irrigation occurs when temporary or permanent structures, which are primarily those irrigation projects built by the federal government, divert and spread flow from intermittent and ephemeral surface water on to farmlands using dams, canals, water spreading berms, and retention levees. [092418:22-23 AM (Ebert); 092418:45, 54 AM (Camilli); 092418:48 PM (Camilli); U.S. Exh. 582 at 4] Fields that receive water from the canal system and the diversion dam built as part of the Jeddito Irrigation Project are examples of the 4,294.27 acres included in this irrigation class. [092418:54 AM (Camilli)] Other federal projects that divert water to the acreage included in this irrigation class are the Upper Kerley Valley, Phillips Farm, and Sand Springs Irrigation Project. She also included acreage on tributary washes that received water due to the constructions of waterspreading projects. [U.S. Exh. 582 at 61] Fields included in the seasonal irrigation class, unlike those included in the native irrigation class, are stationary field systems due to their use of fixed, exterior diversion structures located outside of the exterior field boundaries. [092418:65-66 PM (Camilli); 092618:38 AM (Camilli)] Dr. Camilli primarily identified acreage from the 1954 photographs, but she did locate additional acres in the project that had not been visible in earlier photo years. [092618:16 AM (Camilli); U.S. Exh. 582 at 21, 61]

John Leeper, who holds masters and Ph.D. degrees in civil engineering, and James McCord, who holds a masters degree in hydrology and a Ph.D. in geoscience, were retained by the Navajo Nation to evaluate the claims made by the United States and the Hopi Tribe. [NN Exhs. 163, 162] As part of their work, they examined a series of site on the Hopi Reservation. Dr. Leeper generally criticized the inclusion of acreage classified as native irrigation because, among other reasons, the land lacked external structures or minimal structures to control the flow of water. [103018:110, 122 PM (Leeper); 103118:67, 71 PM (Leeper; 110218:45 PM (Leeper)]; 110118:41 PM (Leeper)] He testified that without any or minimal control, these fields should not be treated as irrigated fields because the crops on the land do not deplete the flow. [103118:55 AM (Leeper); 103018:71 PM (Leeper)] He also objected to the inclusion of the native irrigation acreage because, absent controls, the topography of the field could prevent full coverage of the field causing the actual acreage watered to be less than the area within the external boundaries of the field. [103118:69 PM (Leeper)]

Dr. Leeper expressed the opinion that the native irrigation acreage should be reduced by 57 percent to 2,061 acres. He also reduced 3,974 of the seasonal acreage, other than the acreage associated with Bureau of Indian Affairs projects, by the same 57 percent he applied to native irrigation. [103018:30-31, 34, 36 PM (Leeper)] Dr. McCord testified that the reduction was based on the need to differentiate fields that received water from irrigation and precipitation from the precipitation-dependent fields. [102918:135 (McCord)] Dr. Leeper chose the actual percentage, 57 percent, based on an analysis of field reports prepared by ADWR to produce a 2005 survey report. [102918:56 (McCord)]

In 2005, ADWR inspected 514 agricultural fields, covering 656.73 acres on the Hopi Reservation, as part of an aerial mapping project in which ADWR identified a total of 5,613 acres

of agricultural land under cultivation on the Hopi Reservation. [Hopi Exh. 53; 110118:77 PM (Leeper)] The field survey notes completed for each of the 514 fields included the following categories to be completed by the field teams along with the following choices to be made for each data category:

Data	Choices								
Water Source	Water diversion	Spring	Well	Floodwater from wash	Hauled	Precipitation-Overland flow			
Irrigation Method	Native irrigation	Range Pasture	Perennial	Precipitation	Seasonal	Spring	Seep	Behind Dike	well
Flood Irrigation Type	Basin	Border	Furrow	Wild flood	N/A				

In its 2005 report, ADWR used the data collected by the field teams to categorize the agricultural land as riparian land, active agriculture, or fallow agriculture. [Hopi Exh. 53 at 9]

Dr. Leeper testified that he reviewed the ADWR 2005 field reports prepared for the mapping project and analyzed the fields based on the categories used for "Irrigation Method". He counted 292 fields, or 57 percent of all fields, as having precipitation as the irrigation method.

When ADWR analyzed the same data in its Preliminary HSR for the Hopi Reservation dated December 2008, it focused on the categories included under "Water Source" as shown in *figure 6.* It did not have a separate category for a field that

APPARENT OR OBSERVED WATER SOURCE	NUMBER OF FIELDS MAPPED
Surface Water Diversion/ Floodwater from Wash	130
Spring	74
Precipitation/Overland Flow	305
Well	5
Total	*514*

FIGURE 6.
SOURCE. Hopi Exh. 38

received water solely from precipitation. Instead, it grouped 305 fields into a category that received water from 'precipitation/overland flow'. Dr. McCord testified that this category that included overland flow represented precipitation farming which, in his opinion, is not irrigated farming. [103018:24 (McCord)] Thus, the primary dispute is one of definition of irrigated land.

Although the experts retained by the Navajo Nation questioned whether the topography of certain fields identified by the United States as having been flood irrigated in the 1950s would have permitted the field to be fully irrigated, the experts' principal position was that water that flowed on to land without internal or external permanent structures to control water could not be considered irrigation and, therefore, could not support a water right. The practicalities of the administration of water rights, once determined, do have all of the importance attributed to them by Dr. Leeper. At this point, however, the task is to identify the cultivated fields that did not rely solely on precipitation and benefited from supplemental water, i.e., irrigation.

The third category of irrigated acreage, Range and Pasture land, differs from the other five categories of land included in the United States inventory because this land is used for forage for livestock and not crops. Dr. Camilli relied on the 1954 and 1955 photos to identify 2,912.31 acres of land within this class. With respect to spreaders constructed after 1954, she used the 1980 photos to identify another 570.86 acres. [*Id.* at 9, 15] The land was located within four waterspreading systems on Jadito, lower Oraibi, Oraibi, and Polacca Washes on the main Hopi Reservation. [092418:58 PM (Camilli); U.S. Exh. 582 at 16, 21] Irrigation of the land resulted from diversion of flow by earthen berms or spreaders on to land to encourage the growth of forage. [U.S. Exh. 582 at 5] The inclusion of this land is consistent with the methodology followed by Dr. Camilli of locating land within the 1954-1955 photo set for which supplemental water was applied and only adding to that acreage when an additional water spreader was located.

The Hopi argue that the United States included too little land in this category. They cite to reports prepared in the decades before the photographs were taken that Dr. Camilli examined to prepare her report to show that hundreds, in some cases, and, in other cases, thousands of acres received supplemental water due to the water spreading structures. [092518:9-15 AM (Camilli)] The identification of land in this case is not for the purpose of identifying all land that has been flooded or irrigated on the Hopi Reservation. The identification of land is part of an integrated two-step process to determine the amount of water used by the Hopi Tribe in the past for irrigation that can be quantified in acre feet per year. Accordingly, Dr. Camilli should only identify land that could have received irrigation within the same time period and, in this category, only include land that had demonstrated photographic evidence of a waterspreading area. In order not to overstate the amount of land, Dr. Camilli imposed the constraint that irrigated acreage had to be observed in a defined set of photographs that also provided a check against counting the same acreage twice.

The Navajo Nation argues that the United States included too much land in this category. Drs. Leeper and McCord analyzed the 3,483.17 acres characterized as range and pasture land consistently with their reasoning that irrigated acreage only includes fields subject to active control as opposed to the passive systems used to divert water to improve forage. [102918:118-119 (McCord)] The projects were dismissed as projects that created diversions that were not primarily for irrigation. [102918:119 (McCord)] Based on personal observation, Dr. McCord also indicated that some the BIA projected appeared to have been abandoned. [103018:37 PM McCord]. Based on the testimony, there does not appear to be a dispute about the fact that the water spreaders did divert water on to rangeland. Dr. Camilli testified that she could see photographic evidence of the effect of the water spreaders in the historic photographs. [092518:63 AM Camilli]

The remaining three classes of irrigation rely on more constant sources of water. The category of perennial irrigation includes the 263.78 acres irrigated from perennially available spring water that is conveyed from and stored in a permanent structure. [092418:45, 46 (Camilli)] Farming using this type of irrigation relies on the result of small reservoirs or impoundments constructed by the Hopi that store spring water that is conveyed to terraced gardens and fields and the Pasture Canyon/Reservoir Canyon Irrigation Project. [U.S. Exh. 582, 2] The Navajo Nation concurs that the 264 acres of land located in Moenkopi were properly identified by Dr. Camilli as irrigated land. [NN Exh. 739] The two remaining classes of irrigation, spring and well irrigation, account for 182.49 acres and 17.34 acres, respectively. They provide water from the stated sources without an intermediary storage facility present for the acreage classified as perennial. [092418:66, 68 (Camilli)] Again, the Navajo Nation concurs that the acreage allocated to spring irrigation is correct although their expert did reclassify a portion of the land from spring irrigation to seasonal irrigation. [NN Exh 739]

Finding of Fact No. 65. Irrigation occurs when supplement water, i.e., not precipitation that falls directly on to the land, flows on to a field that has been strategically located to receive the water or when supplemental water is diverted on to a field to provide water for crops or a pasture to improve forage for livestock.

Finding of Fact No. 66. The United States' methodology of identifying land was consistent and reasonably designed to limit the acreage claimed to acreage that could have been irrigated in the same time period.

Finding of Fact No. 67. The total irrigated acreage for crops located by the United States is 9,547.25 (263.78 + 4294.27 + 4790.59 + 17.34 +182.49) which is approximately 4.4 percent more than the 9,129 acres that ADWR treated as traditionally farmed acres based on its conclusion that a

total of 9,553 acre were irrigated in the 1954-1955 period and historical research that the maximum acreage irrigated in any one year was approximately 9,300 acres.

Finding of Fact No. 68. The United States properly included within its inventory of historically irrigated acreage the additional 3,483 acres of pasture and range land for which water had been diverted to improve forage for cattle.

b. Calculation of Acreage: Hopi Tribe's Analysis of Acreage Using Satellite Imagery

The Hopi Tribe presented an alternative methodology to identify acreage for the purpose of calculating the amount of water used for irrigation in the past. It retained B. Sunday Eiselt, who holds a masters degree and a Ph.D. in anthropology and is currently both an associate professor at Southern Methodist University and the Director of the Southern Methodist University Archeological Research Program Collections. [Hopi Exh. 92] Dr. Eiselt undertook to create "a comprehensive and non-overlapping inventory of all past and present irrigated lands from the 1930s to the present." [Hopi Exh. 3882 at 1, 3, 12; 101118:28, 48 PM (Eiselt)]

To conduct the study that formed the basis of her opinion, Dr. Eiselt used high-resolution satellite imagery available in Google Earth dated 1997, 2007-2010, 2011-2012, 2013-2014, and 2015-2016. She described Google Earth as a "virtual globe and geographic information program. Google Earth maps the Earth by the superimposition of images obtained from satellite imagery, aerial photography, and GIS 3D Globe using digital elevation model (DEM) data." [Hopi Exh. 3882 at 8.] The specific methodology employed by Dr. Eiselt to inspect the Hopi Reservation employed real-time satellite motion to facilitate "the rapid identification and interpretation of fields relative to topographic and other contextual data, including objects identified by ADWR and U.S. experts [citations omitted]. Replicate survey sessions ensured that the entire study area was

scanned a minimum of four times and that all available historical images within this survey universe were examined at least twice." [Hopi Exh. 3882 at 16]

Dr. Eiselt identified fields by the presence of crop growth (crop rows or clumps of plants); field furrows; evidence of plowing or land leveling activities; field shapes, colors, and textural characteristics; the presence of wells, springs, and water impoundment structures; and the proximity to fields identified by the United States. [Hopi Exh.3882 at 13] She did not exclude land she identified using Google Earth as cultivated acreage due to the absence of an identifiable source of water that supplemented direct precipitation for the land. [101118:9-10 PM (Eiselt)] She testified that she conducted her survey based on the assumption that a supplemental water source must exist for each cultivated field located on Google Earth reasoning that a field would not exist absent an irrigation source. [101118:15-16, 50 (Eiselt)]. Consequently, Dr. Eiselt did not distinguish between land solely dependent on precipitation and land that received irrigation. [101118:15 PM (Eiselt)] Dr. Eiselt's resulting inventory of all fields showing evidence of cultivation over a 20 year period totaled 1,452 fields encompassing 13,856 acres. [*Id.* at 20]

Dr. Eiselt compared the 13,856 acres to the acreage previously identified by the United States, the fields claimed by the Hopi Tribe and verified in part or in whole by ADWR as evidencing prior agricultural use, and the additional acreage listed in the Hopi Tribe's amended or supplemental claims submitted in 2015. [Hopi Exh. 3882 at 18] She found that her inventory of land "overlapped in some instances with previously identified fields". [*Id.* at 20-21] Dr. Eiselt concluded that 6,847.87[3] acres of land from her study had been previously identified by the United

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[3] Dr. Eiselt reduced the amount of land for which ADWR had complete evidence of prior use from 1,853.3 acres to 1,732.02 acres and the category for which ADWR had partial evidence from 11,658.5 to 11,657.27 acres. [Hopi Exh. 3882 at 23]

States or the Hopi Tribe and the remaining 7,008.13 acres, or 50.5 percent of the inventory was "newly identified" lands. [101118:42 AM (Eiselt); Hopi Exh. 3882 at 21]

Dr. Eiselt classified the land that she located into five of the six categories used by Dr. Camilli. [1011818:38 AM (Eiselt); Hopi Exh. 3882 at 1] She represented that "[n]o attempt was made to map or quantify the Range/Pasture Irrigation class" of land. [Hopi Exh. 3882 at 26] She nevertheless offered the opinion that "[c]comparison of these areas identifiable in [Google Earth] with areas already mapped as Range/Pasture by Ebert and Associates and the Hopi generally agree. Consequently, these ADWR verified delineations appear to be sufficient for this irrigation category without further direct examination or field verification." [Hopi Exh. 3882 at 14]

The inventory assembled by Dr. Eiselt reveals significantly reduced amounts of land dependent on perennial or seasonal irrigation compared to the amounts identified by the United States and skews heavily toward acreage classified as Native Irrigation as shown in Table 5. The Native Irrigation category constitute 76.9 percent of all land inventoried by Dr. Eiselt compared to 36.8 percent of the acreage identified using the United States methodology (or 50.6 percent of the land excluding the Range/Pasture acreage).

Classification of Use by Name and U.S. Number	**Eiselt Newly-Identified Acreage**	**Eiselt Total Acreage**	**Camilli Acreage**
Perennial (1)	6.62	12.20	264
Seasonal (2)	613.67	2,423.18	4,294
Range/Pasture (3)	5.42	28.00	3,483
Native Irrigation (4)	6,123.84	10,653.60	4,791
Wells (5)	70.87	85.84	17
Spring (6)	188.42	653.90	183
Total Acreage	7,008.85	13,856.72	13,032

TABLE 5.
SOURCE: Hopi Exh. 3882, Table 5, Appendix A; U.S. Exh. ,Table 5

The predominant character of Dr. Eiselt's newly identified 7,008.85 acres confirms the study's emphasis on locating all lands farmed over an extended period of time, which is the time period appropriate for evaluating farming using a shifting field system. Dr. Eiselt specifically used Google Earth to conduct her research because "the historical imagery available in GE enables the composite footprint of shifting field systems in the Native Irrigation class to be mapped with a high degree of confidence." [Hopi Exh. 3882 at 21] Arable acreage is not at issue; water rights in this case will not be set by a PIA standard.

The quantification of federal reserved water rights requires consideration of the actual past use of water for irrigation measured in units of volume per unit of time. The determination of irrigated land is important in this case because, when appropriately identified, it can be used to reasonably estimate the amount of water actually used in a year by the Hopi Tribe in the past to irrigate land. The newly identified land cannot be used for this purpose. Dr. Eiselt could not avow whether all or any of 7,008.85 acres were irrigated because of her assumption that all cultivated fields must have been irrigated precluded any differentiation of the acreage between irrigated and precipitation dependent land. Further, all of the acres were not cultivated in the same year because she makes clear that land classified as native irrigation is part of a shifting field system, which as explained above, means that not all of the acreage in the field is cultivated in the same year which fact is substantiated by Dr. Eiselt's report. [101118:44 (Eiselt); Hopi Exh. 3882, Appendix A]

Todd Umstot, a hydrogeologist, retained by the Hopi Tribe, calculated the irrigation use, or depletion amount, based on the sum of the acreage identified by Dr. Camilli and the 7,008.85 acres identified by Dr. Eiselt. [Hopi Exhs. 137 and 142] Just as the newly identified land cannot advance the requisite quantification of irrigation use neither can estimated depletion amounts

reported in acre feet per year for total acreage all of which was not irrigated in the same time period.

Finding of Fact No. 69. Dr. Eiselt did not exclude cultivated acreage dependent solely on precipitation.

Finding of Fact No. 70. The 13,031.60 acres identified by Dr. Eiselt were not farmed in the same year. The newly identified acreage cannot properly be added to the acreage identified by Dr. Camilli.

c. *Calculation of Acreage*: Hopi Tribe's Determination of Acreage Using Population

The Hopi Tribe contends that the historical population of the tribe can be used to determine the amount of irrigated acreage farmed in the past. Extrapolating from historical population estimates, the Hopi Tribe claims that "the total annual irrigated acreage conservatively ranged from 21,900 to 35,040 acres." Hopi Fifth Amended Statement of Claimant at 29. This range of values is the product of three variables: the historical population of the Hopi Tribe, the estimated acreage cultivated for each person, and the percentage of the fields farmed using *akchin* methods, which excludes those fields reliant solely on direct precipitation. The Hopi Tribe assert that the Hopi historically cultivated between 2.5 and 4 acres per person annually for subsistence. [*Id.* at 28] It offered that a conservative acreage estimate is 2.5 acres per Hopi. [*Id*] The further assumption was made that 73 percent of the total cultivated acreage were *akchin* farms. [*Id.*] Using these values, the Hopi Tribe calculated acreage as follows:

$$Total\ irrigated\ acreage = (population \times 2.5) \times 0.73$$

The claimed acreage of 21,900 to 35,040 acres using the equation above would require a historical Hopi population of 12,000 to 19,200 members living on and farming the land.

E. Charles Adams, who holds a Ph.D. in anthropology and serves as the curator of archeology at the Arizona State Museum at the University of Arizona, prepared a report and testified on behalf of the Hopi Tribe about the population of the Hopi Tribe prior to 1700. The Hopi people are traced back to the 13th century by the archeological record. [Hopi Exh. 3872 at 4] Dr. Adams described the period beginning in 1275 as a time when people immigrated into the plateau area of the Little Colorado River basin concentrating in areas and around the four Hopi Mesas, Homol'ovi, and Moenkopi Wash. [Hopi Exh. 3872 at 80] Dr. Adams testified that archeologists estimate population by examining the physical remains of pueblos to determine the number of rooms in use when the site was occupied. [100118:14 AM (Adams); 110918:22 AM (Gilpin)] Dr. Adams did caution that reliance on room counts can be problematic. [100118:14 AM (Adams)] They can be problematic because, among other reasons, room counts produce estimates rather than precise quantities. Archeological sites are not usually excavated, requiring estimates to be made from rubble mounds instead of walls that define rooms. [110918:23, 30 AM (Gilpin)]

He opined that in the Hopi Mesa area during this period of 1275-1300 there were "approximately 50 pueblos ranging in size from fewer than 50 rooms to perhaps 150 – 200 rooms." [Hopi Exh. 3872 at 80] Using a ratio of people to rooms of 1:1, the Hopi population was greater than 2,500 and less than 10,000 people, with an average population of 6,250 people. By 1350, the number of pueblos decreased but the size of the pueblos increased with estimates made by Dr. Adams of 15 pueblos ranging from 150 to 500 rooms which, using a 1:1 ratio, that equates to a population of greater than 2,250 and less than 7500 people with an average of 4,875 people. [*Id.*

at 82] The pattern of fewer villages with larger populations continued into the 1400s with Dr. Adams reporting 13 villages on the Hopi Mesas with an average of 500 people. [*Id.*] Based on these numbers, the average Hopi population in the Hopi Mesa totaled 6,500 in the 1400s. Two graphs reproduced in Dr. Adams' report reflect a declining population over this period, but Dr. Adams referenced them to support his conclusion that "[p]opulation figures are almost impossible to predict for such a broad area as the basin." [Hopi Exh. 3872 at 5] He also indicated that there is no simple method to determine fluctuations in population that could have occurred due to stress such as droughts. [*Id.*] The Navajo Nation retained Dennis Gilpin, who holds a masters in anthropology, to offer his opinions about the historical Hopi population. Mr. Gilpin testified that the population between 1400 and 1450 was probably as high as 8,000. [110918:30 AM (Gilpin)]

Dr. Adams and Mr. Gilpin dispute the population estimates for the Hopi in the 1500s. Dr. Adams testified that in 1540 a Spanish explorer reported a population of 3,000 to 4,000 Zuni and Hopi men, with Hopi men being in the majority. [100118:15 AM (Adams)] Applying Hopi demographic data collected in 1890 – 1930 to analyze Hopi and Zuni households in the 1540s, Dr. Adams concluded that a population in the range of 10,000 to 12,000 Hopi and Zuni existed. Given that two groups are combined in this observation, and assuming that the Zuni were 10 percent to 40 percent of the combined population (thereby making the Hopi the majority group in all cases) the Hopi members numbered in a range of 6,000 to 10,800. In his report, Dr. Adams stated that "[t]here are no reliable figures for Hopi population at contact [with Spanish explorers], but Luxán, reporting in 1583 for the Espejo expedition, estimated the population of Hopi at about 12,000." [Hopi Exh. 3872 at 82-83] The same expedition also resulted in an estimate of the Hopi population at 50,000, but Dr. Adams deemed that estimate as not credible. [110918:20 AM (Gilpin); 100118:38 AM (Adams)] Dr. Adams testified that he believed that the Spanish

explorers' estimates were consistent and that 12,000 was a reasonable population estimate for the 1500s. [100118:15, 39 AM (Adams)] Mr. Gilpin, relied on archeological evidence to estimate the Hopi population in the 1500s. He opined that there were never more than 8,000 rooms simultaneously occupied in the Hopi villages. He explained that rooms may not be continuously occupied because they are abandoned in the event of destruction or an insect infestation causing new rooms to be built in the village. Following the end of the 16th century, the Hopi population existed in a range of 8,000 to 10,000 people during the period 1630 to 1700, according to Dr. Adams. [100118:57 AM (Adams)]

Another researcher, Fred Anderson retained by the Arizona Department of Water Resources, prepared a paper titled *Historical Research for a Hydrographic Survey Report of the Hopi Reservation* (April 2008) in which he stated:

> Given the long intervals between reports, the overall paucity of information, and the wide variation in the estimates of these Spanish visitors, it is impossible to say with any exactitude how many people lived on the Hopi mesas or in the region that would one day become the Hopi Reservation. Most of the believable estimates fall somewhere between 2,000 and 10,000 residents.

[Hopi Exh. 87 at 117-118]

The Hopi Tribe also retained T. J. Fergson, who holds masters and Ph.D. degrees in anthropology and is a professor of anthropology at the University of Arizona. [101218:41 AM (Ferguson)] Dr. Ferguson prepared a report entitled *Hopi Agricultural and Water Use* on behalf of the Hopi Tribe, in which he reported data collected on the historical Hopi population in the 1800s and 1900s. [Hopi Exhs. 192, 3883] He considered the first reasonable population estimate to have occurred in 1846 when the Hopi population totaled 2,450. [101218:52 (Ferguson)] As shown in *figure 7,* the population of the Hopi remained under 3,000 until the late 1930s, although

in 1852, 1853, and 1869, the population was recorded as 8,000, 6,720, and 4,000, respectively. Dr. Ferguson testified that the 4,000 count in 1869 was high. [101218:48 (Ferguson)] The apparent difficulty of estimating the Hopi population can be demonstrated by the 1869 estimate when an Army captain reported the Hopi population at 1,500 and in that same year the Commissioner of Indian Affairs set the population at 4,000. [Hopi Exh. 3883 at 149] Another leading expert in the field relied upon by Dr. Ferguson concluded that nearly all of the early population estimates were much too high and set the date of the first reliable population count as the census of 1890-1 [Hopi Exh. 3889 at 26]

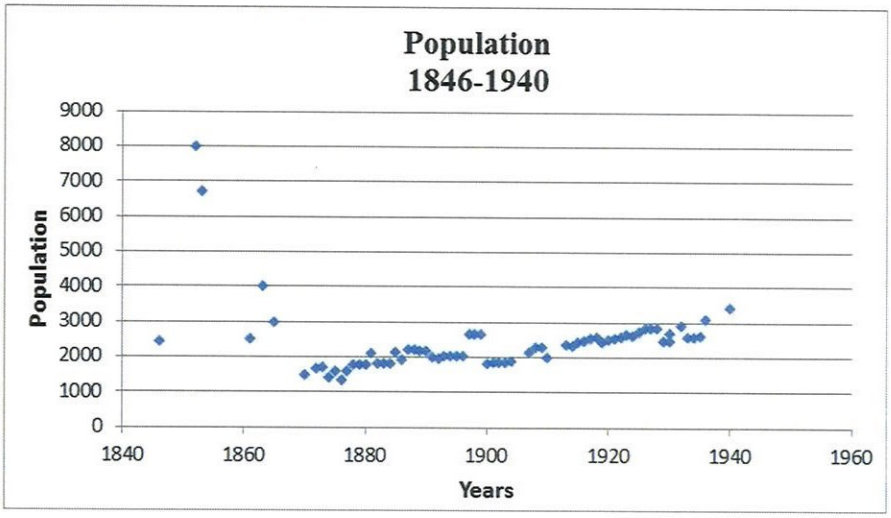

FIGURE 7. Reported population of the Hopi from 1840 to 1940.

The next variable in the Hopi equation is the acreage farmed per capita. In 1971, Maitland Bradfield, an anthropologist, published a paper entitled *The Changing Pattern of Hopi Agriculture,* based on his research in the Oraibi valley that calculated the number of acres the Hopi farmed per member. [Hopi Exh. 3889] This paper is regarded as reputable by experts and relied upon in subsequent studies. [100118:51 AM (Adams)] Mr. Bradfield estimated that 24 bushels of corn per person were necessary for all purposes, meaning consumption, storage, and trade. [Hopi Exh. 3889 at 11] He further approximated the need for land for vegetables and orchards as "about ½ acre person." [*Id.*] Evaluating the total agricultural needs, Mr. Bradfield made the following summary statement: "We may conclude, then, that in the traditional Hopi economy an average of

2½ acres of cultivated land was required per person, that a household of 5 to 6 persons needed about 12 acres to support itself, ..." [*Id.*] Using the household number of five to six people and a total of 12 acres results in acreage per person of of 2 to 2.4 acres. Mr. Bradfield subsequently states that the number of persons per household for the Hopi as a whole in 1960 was 5.8. [*Id* at 28.] Using an average household of 5.8 persons and 12 acres of crops to support that household, the Hopi Tribe farmed on average 2.07 acres per person. Data provided by the parties for the period 1884 through 1946, shown in Table 6, for which there is both population and crop information shows that the Hopi farmed, on average, 2.22 acres per person.

Year	**Population**	**Acres Cultivated**	**No. of Acres per Person**	**Source of Data**
1884	1813	6000-7000	3.31 – 3.86	Hopi Exhibit 87 at 166, 171
1886	1919	1000	0.52	NN Exh. at 615; 101218:49 PM (Ferguson)
1887	2206	6000	2.71	101218:49, 55 PM (Ferguson)
1890	2200	4800	2.18	NN Exh. at 615 101218:112 (Ferguson)
1890-1891	1996	6600	3.30	Hopi Exh. 87 at 171, 166
1893	2029 (1894 pop.)	5600	2.75	101218:112 PM (Ferguson)
1915	2455	4000	1.63	Hopi Exh. 87 at 168, 171
1936	3111	6076	1.95	101218:113(Ferguson) Hopi Exh. 87 at 169, 172
1936	2900	5916	2.04	NN Exh. 142 at 4;
1936	2779	5916	2.18	NN Exh. 142 at 16
1940	3444	6092	1.77	Hopi Exh. 87 at 168, 172
1946	3452	7130	2.06	NN Exh. 615; 101218 50 PM (Ferguson)

Table 6

The final variable in the Hopi equation is the percentage of the cultivated fields farmed using *akchin* methods. Dr. Adams testified that the Hopi engaged in less *akchin* farming during the pre-1700 period than they did in the succeeding centuries and estimated that during the 16th and 17th centuries the Hopi fields were equally divided between *akchin* and rainfall farming. [100118:49-50 AM (Adams)] By the 1900s, the accepted estimate was that rainfall farming accounted for about 27 percent of the Hopi fields. [101218:43 (Ferguson); Hopi Exh. 3895 at 33-34]

Applying the Hopi equation to the range of data discussed above results in a range of irrigated acreage farmed by the Hopi Tribe that were not solely reliant on rainfall from 2,190 to 11,200 acres as shown in Table 7.

Period	Population	Per Capita Acreage	Percentage Farmed Not Reliant Solely on Rainfall	Estimated Irrigated Acreage
1200 - 1700	2,500 - 10,000	2.24	50 percent	2,800 - 11,200
1700 - 1945	1,339 - 3,500	2.22	73 percent	2,170 - 5,672

Table 7.

Substantial uncertainty surrounds the population methodology proposed by the Hopi. An accurate count of the Hopi population, even in current times, has been difficult to achieve. [Hopi Exh. 3884 at 20] Population estimates for the pre-1700 period rely on estimates from archeological sites not cleared of rubble and widely varying accounts from Spanish explorers. Lack of reliability continues to exist into the 1800s even when estimates of population from rubble mounds and by explorers whose accounts varied by tens of thousands and combined groups into a single people are replaced with estimates based on more reliable census methods. Dr. Ferguson

did not believe a reliable count occurred until 1846, while Maitland Bradfield cited the 1891 census as the first reliable count.

Mr. Bradfield's work also demonstrates that population is not necessarily a valid proxy for irrigated acreage. In his discussion of the Oraibi valley, Dr. Maitland reported that in 1908, 1600 acres of farm land supported a population of 580 but by 1931, 1450 acres supported a population of 740. [Hopi Exh. 3889 at 15] The population increased by about one quarter but the cultivated acreage decreased by "about a third in the acreage cultivated per person." [*Id.*] Thus, by 1931, Bradfield concluded that the total acreage farmed per person was 1.75 acres including vegetables and he further found that "at this point there set in an absolute decline in the total area cultivated." [*Id.* at 193]

In more recent years, a trend exists of an increasing population and decreasing cultivated acreage. In 1974, there were 6,335 acres of farmland on the Hopi Reservation and a reported population of 7,500 people. [Hopi Exh. 3883] By 2000, the population of registered members of the Hopi Tribe living on the Reservation was an estimated 9,000 who cultivated approximately 9,000 acres. [Hopi Exh. 3878 at 16]

Finding of Fact No. 71. The use of population to determine historical irrigated acreage is not a superior methodology to the use of historical aerial photographs.

d. Calculation of Amount of Water Used to Irrigate Land

The second step in the quantification of water for irrigation use requires a determination of the amount of water used on the irrigated land. Arizona Department of Water Resources recommended that a water duty should be determined to quantify the past

use of irrigation water. A water duty equals the net irrigation requirement (NIR), which is based on the composite irrigation requirement as explained below, divided by the overall irrigation efficiency:

$$Water\ Duty = NIR \div Irrigation\ Efficiency$$

The amount of water required by the different types of crops, weighted by their percentage in the crop mix is known as the composite irrigation requirement. Arizona Department of Water Resources determined the composite irrigation requirement by evaluating the mix of crops grown on the Hopi Reservation, variations in climate, and the Hopi Tribe's farming practices, which it divided into traditional and modern. HSR at 4-14. The NIR equals the composite irrigation requirement reduced by the annual effective precipitation.

The second variable in the equation, irrigation efficiency, accounts for the loss of water that occurs during the conveyance, distribution, and application of irrigation water to and on the field. [U.S. Exh. 527 at 3-3] This variable is based on the overall irrigation efficiency. Arizona Department of Water Resources applied a 0.55 irrigation efficiency to the irrigation of acreage that the United States had classified as perennial and spring irrigation. It applied a much greater irrigation efficiency factor to traditionally farmed acreage because there is virtually no conveyance loss due to the proximity of the fields to the sources of water. It also elevated the on-farm efficiency factor due to the type of crops the Hopi plant that can access water that in other settings would percolate too deeply into the soil. ADWR calculated an irrigation efficiency of 0.72 for traditional farming. It concluded that appropriate water duties for modern farming and traditional farming are 4.2 acre feet per acre and 0.93 acre feet per acre, respectively.

With respect to the 464 acres of cultivated fields that the United States claimed had a perennial source of water, the United States used a computer model to analyze many of the same factors considered by ADWR in the computation of ADWR's water duty. The United States relied on climate data, assumed periodic water shortages, and applied a higher irrigation efficiency than used by ADWR. The United States analyzed the diversion and depletion amounts separately for each wash. The total amount claimed is 775 acre feet diverted and 698 acre feet depleted which is substantially less than ADWR's calculation that applied a 4.33 acre foot per acre water duty to 424 acres using modern farming. [U.S. Exh. 527 at 3-64 – 3-67] The Hopi Tribe calculated a water duty of 3.6 AF/ac based on the assumption that perennially irrigated acres had a supply of water equivalent to the supply available to the small gardens cultivated on the Hopi Reservation and an irrigation efficiency less than used by the United States and greater than used by ADWR. The Navajo Nation adjusted ADWR's water duty with elements cited by the United States and the Hopi to propose a water duty of 3.8 AF/ac.

Finding of Fact No. 72: The method used by the United States that relied on specific data applicable to the unique conditions of irrigated acreage in each wash provides the most reliable method of determining the quantity of water used for irrigated acreage in the perennial, spring and well classifications.

In contrast to the situation where there is a perennial or substantially perennial water source, irrigation use becomes more of a function of the amount of water available during the growing season than the amount of the water required by the crop where the available water source provides an intermittent supply. [092718:23 AM (Ley)] [092718:107 AM (Ley)] In this situation, a water duty is not the preferred method to calculate irrigation usage. [092718:107 AM (Ley)] The intermittent flow in the Northern Washes resulting from precipitation, i.e., rain and snowmelt,

and runoff provide the sources of water for the native irrigation, seasonal, and range and pasture classes of irrigation use. [092618:19, 20 (Ley)] These sources do not consistently supply surface water flows sufficient for irrigation diversions that meet crop demand. [Exh. 527 at 3-4] Reliance on these intermittent and ephemeral sources of water leads to deficit irrigation that has been defined as "[i]rrigation that does not supply the potential water use for crop ET [evapotranspiration] and leaching requirements. Deficit irrigation results from under-irrigation and non-uniformity of irrigation application. Seasonal flows result in under-irrigation because the flows are irregular and do not meet full irrigation requirements." [U.S. Exh. 527 at 3-2] Due to the deficit irrigation conditions for lands included in the three classes of irrigation use, the United States elected to forego a water duty approach in favor of computer modelling. It generally relied on one computer model to calculate the amount of water available in the Northern Washes and imported the data generated by the first computer model into a second computer model to quantify the amount of diversions and depletions from the deficit irrigation of the native, seasonal, and range and pasture acreage classes in a unit measurement of acre feet per year. [092718:26 AM (Ley); U.S. Exh. 564 at 4-7]

Brent Cody, Ph.D., a civil engineer retained by the United States, programmed the first model, the Precipitation Runoff Modeling System (PRMS), to estimate natural daily flow through the Northern Washes for each day of each year from 1949-2014. [091818:46, 83 PM (Cody); U.S. Exh. 564 at ES-1; 102918:16 AM (McCord)]. More specifically, he produced a continuous record of estimated water movement at 30 to 50 sites within each wash for a total 174 sites throughout the Northern Washes. [U.S. Exh. 564 at 2-2, 2-3, 3-1; 091818:83, 85-86 (Cody)]. He also used the program to compute the water depletion from the basin during periods when little or no

precipitation occurred as well as accounted for evapotranspiration, percolation and total surface flow. [U.S. Exh. 564 at 3-1, 3-2; 091818:87 PM (Cody)]

The PRSM required precipitation and climate data to determine surface flow, infiltration, evaporation, and transpiration. [091818:107 PM (Cody); 102918:17 AM (McCord)] Dr. Cody used precipitation and air temperature datasets compiled by researchers at Oregon State University. [U.S. Exh. 564 at 2-4] Climate data was also obtained from the National Climatic Data Center's gauge records for nine climate gauges in and near the Northern Washes and from 69 other stations to complete those portions of the data sets for which data for the nine selected gages was not available. [U.S. Exh. 564 at 2-4, 2-5, 2-8, 5-1; [091818:89, 95 PM (Cody)]. Dr. Cody used data supplied by the National Climatic Data Center to determine daily solar radiation,[4] necessary for the calculation of evaporation. In addition to the acquisition of hydrological and climatological data, Dr. Cody used other government databases to obtain information about environmental characteristics, referred to in the model as parameters, such as elevations, area, soil types and characteristics, and vegetation. [U.S. Exh. at 3-9, 3-14] Based on the output from the PRSM, Dr. Cody testified that he found that precipitation patterns and average temperatures were similar across the Northern Washes, but the total amount of flow differed due to the different sizes of the catchment areas. [091818:107-108 PM (Cody)]

To test the validity of the valuations chosen for the parameters and the validity of the model overall, Dr. Cody used Coal Mine Wash as the test case. [U.S. Exh. at 4-1] Coal Mine Wash had the benefit of USGS and Peabody Western Coal Company stream gages that permitted the use of one gauge for purposes of calibration and the other gauge for verification of natural flow

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[4] Solar radiation was calculated for each day and is a function of the latitude of the site, day of the year, dew point termperature and total sky cover. [U.S. Exh. at A-1]

because it was not subject to significant human depletions. [U.S. Exh. at 4-1] Dr. Cody calibrated the model for potential evapotranspiration (PET) and for streamflow using the Coal Mine data. Although the parameters estimated in the streamflow calibration process were applied in each wash, the PET calibration process was performed for each wash. [U.S. Exh. at 5-1]

After the model calculated runoff and other lateral flow into the stream channels, losses from seepage, and evaporation of flows, the model routed all of the water downstream to the outlet of the basin. Results were tabulated for the average monthly and annual flow for the 1949-2014 time period for each wash. [U.S. Exh. 527 at 3-10, 4-7.] The average estimated annual flow for the Northern Washes amounted to 29,941 acre feet with a range of 7,161 acre feet to 91,320 acre feet per year. [U.S. Exh. 5-1, 5-2] Flow did not occur evenly among the five washes. Instead, the average annual flow ranged from a low of 2,356 acre feet in Dinnebito Wash to a high of 16,176 acre feet in Moenkopi. [U.S. Exh. at 5-1]

Dr. McCord reviewed the PRMS model and concurred that a computer model was necessary to estimate the water supply and agreed that the PRMS was an appropriate model for that purpose. [102918:22, 40, 45 (McCord)] He offered two general criticisms of decisions that were made with respect to the programming of the PRMS. Dr. McCord testified that because the model, designed for a 5,000 square mile watershed, was calibrated using a 137 square kilometer subwatershed, the model did not fully reflect the conditions of the dryer southern portions of the watershed. [102918:32-33 AM (McCord)] Dr. McCord did not quantify the extent of any deficiency caused by using the Coal Mine Wash to calibrate the model. [102918:44 PM (McCord)] He also testified that because the model used natural flows, it did not take into account depletions of flow that occurred upstream of the Hopi Reservation. [102918:32-33 AM (McCord)] Dr. McCord stated that the failure to reduce the natural flows by the amount diverted on the

Navajo Reservation could result in an over-estimation of the amount of water available during the Hopi Tribe's past and present use of water. [102918:38-40 AM (McCord)] No evidence was offered to quantify the possible reduction in the initial upstream flow.

An upstream diversion for irrigation does not necessarily translate into an equivalent reduction in downstream flow. As water flows through a natural channel, water evaporates from the surface and seeps into the sides and bottom on the channels. When irrigation diverts water, the remaining streamflow has less surface area so there is less evaporation and less seepage into the channel. [092618:90 PM (Ley)] A comparison of natural flow with and without irrigation for the Northern Washes demonstrated that a natural flow of 46,016 acre feet per year had channel losses of 16,075 acre feet per year for an outflow of 29,941 acre feet per year, but if irrigation depleted the natural flow by 8,407 acre feet, there would be 1,111 acre feet less in channel losses and the outflow would be 22,661 acre feet, which is 7,280 acre feet less, not 8,407 acre feet less, than the original outflow. [U.S. Exh. 527 at 3-27]

Finding of Fact No. 73. The PRSM is an acceptable model to calculate input into the DISM and the choice of parameters and calibration were reasonable.

Data from the PRSM supplied the information used in the second computer model, the Deficit Irrigation Supply Model ("DISM"), that the United States used to quantify the amount of water used for deficit irrigation. Thomas W. Ley, who holds a masters degree in agricultural engineering and a Ph.D. in irrigation engineering, was engaged by the United States to estimate the amount of water used on the 13,027 acres of irrigated lands located in District 6 (8,768 acres), the Hopi Partitioned Lands (3,535 acres), and in Moenkopi (724 acres). [092718:38 AM (Ley); U.S. Exh. 528] Dr. Ley created the DISM model that estimated depletion from irrigation use based on the fields identified by Dr. Camilli, crop information, a set of assumptions about farming

practices as well as the available supply of water estimated by the PRMS model. [092618:133 PM (Ley); 102918:41 (McCord); U.S. Exh. 527 at 3-1, 3-5, 3-13, 3-14]

The DISM operates by dividing the Northern Washes into sub-basins to allow modelling of stream reaches and streamflow in multiple locations within the wash drainage areas and to incorporate the climatic data unique to those locations, such as temperature and precipitation, representative of the total received during the year, types of crops grown and planting dates. [U.S. Exh. 527 at 3-6, 3-11] Conceptually, the model links the sub-basins with the outflow from one basin entering the next basin augmented by flow originating in that basin. The model accounts for the impact of evaporation, precipitation, and seepage on the amount of streamflow, as well as taking into account reductions attributable to diversions and depletions from irrigation and the crops. [*Id.*] Appendix B shows a schematic diagram of the operation of DISM. [U.S. Exh. 527 at 3-21]

Dr. Ley testified that the key factors affecting the amount of depletion from irrigation use are the volume of the flow, the duration of the flow, and the timing of the flow. [092618:101 PM (Ley)] The importance of these elements given the need to match usable flow with crop demands during the different crop growth stages that occur during March through October can be shown by a comparison of different flow patterns estimated by DISM for calendar years 1972 and 1988. The model calculated (in acre feet) the monthly flow, the annual outflow, and the depletion of the outflow from irrigation use:

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Outflow	Annual Depletion
1972	13	3	0	149	156	3108	2888	4638	4929	68592	3016	3825	91317	9096
1988	200	692	54	11221	10	5068	324	8566	2370	310	2194	109	31118	10646
Average	1219	1612	1682	1428	1124	668	3960	5441	4993	4555	2008	1252	29941	8392

[U.S. Exh. 527 at G-2 – G-5]

Dr. McCord, the expert called by the Navajo Nation to critique DISM, agreed that in the absence of data about actual water use, a computer model is an appropriate method to estimate water use. [102918:22 AM (McCord); 102918:13, 41 PM (McCord)] He also confirmed that the DISM is a defensible model. [*Id.* at 14.] The points of disagreement with the construct of the DISM focus on decisions made about crop characteristics and farming practices. The crop characteristics at issue concern crop coefficients, which determine the amount of water used by the plants, and the rooting depth of the plants, which affect the ability of the soil to retain water in storage for use by the plant. The farming practice arises from an assumption made by Dr. Ley about a farmer's ability to optimally manage water on the fields.

The amount of water used by a crop includes the amount of crop evapotranspiration (ET), which is the amount of water that evaporates from the soil and transpires from the leaves of the plant. The crop ET used in the DISM is based on the rate of evapotranspiration from a field of actively growing, adequately watered alfalfa, the "reference crop." [U.S. Exh. 527 at 3-65] A crop coefficient is a percentage applied to a reference crop ET to adjust it for the desired crop ET. [U.S. Exh.527 at 3-9]. Dr. Ley applied crop coefficients for corn and grazed pasture in the DISM. [U.S. 527 at 3-16] He adjusted the crop coefficients downward by multiplying the crop coefficient by a factor of 0.7 due to lower plant density, decreased plant vigor due to harsh conditions, and lower soil moisture. [*Id.* at 3-17] Dr. McCord testified that the crop coefficient should have been reduced by a factor of 0.2 to 0.3 to account for the spacing of the corn plants. [102918:58-59 AM (McCord)] He estimated that the change in the factor applied to the crop coefficient would decrease depletion by about 27.7 percent. [102918:47 PM (McCord)] He also stated that the DISM model did not account for the root depth of the plants. A greater root depth would increase depletion of the irrigation water. He estimated that his proposed change would

increase depletion by about 15.3 percent. [*Id.*] Dr. McCord did agree with counsel for the United States that his suggested improvements to the two parameters would not make much of a difference to the final depletion number. [102918:48 PM (McCord)]

Dr. McCord concluded that his concerns about the DISM primarily center on the acreage rather than the design of the model. [102918:8 PM (McCord)]. He ran the DISM model, without making any changes to the parameters of the program other than a 65 percent reduction in the amount of the claimed irrigated acres to support the irrigation claims made by the Navajo Nation

Finding of Fact No. 74. The DISM is a reasonable model to calculate depletion.

Finding of Fact No. 75. The average amount of water diverted for irrigation in the past on the Hopi Reservation was 12,452 acre feet per year and the maximum amount diverted was 18,897 acre feet resulting in an average depletion of 9,105 acre feet per year and a maximum of 18,897 acre feet.

6. Water for Stock and Wildlife Watering and Stockpond Use

The Hopi Tribe began raising livestock approximately 400 years ago. Archeologists confirm the presence of livestock after the missionaries arrived with herds in 1629. [Hopi Exh. 74 at 121] Livestock included horses, cattle, sheep, and goats. By the 1700s, livestock could be found ranging in the area 50 miles around the reservation. [*Id.* at 122] The Hopi did not fence their fields, so livestock were separated from agricultural areas and springs used for domestic sources. Goats and sheep generally grazed between one and 12 miles outside the villages. [*Id.* at 123-124, 126, 129] Cattle ranged in the area of 12 and 50 miles outside of the villages. [*Id.* at 123]

Finding of Fact: 76. Following contact with European missionaries, members of the Hopi Tribe raised cattle and sheep.

Finding of Fact: 77. Water for cattle and livestock is not an aboriginal use of water.

The United States and the Hopi Tribe claim a maximum past use of water for livestock on the Hopi Reservation of 347 acre feet per year and 347.3 acre feet, respectively. United States Fifth Statement of Claimant at 18; Hopi Fifth Statement of Claimant at 38. They further claim that three sources of water have been used to maintain livestock on the Hopi Reservation: springs, wells, and impoundments. There is not a reliable, metered source of water on the Hopi Reservation that can be used to quantify the amount of water actually used by the livestock in the past or in the present. As a result, the parties have calculated the amount of water used for livestock based on the number of livestock raised in the past and the amount of water required to meet the demand of the livestock.

As part of the permitting and management process, the livestock present on the Hopi Reservation are inventoried annually. [100518:54 AM (Pavatea); 100918:33 AM (Honanie); 101018:67 AM (Pavinyama)] The Bureau of Indian Affairs performed the range inventories until 2002 when the Hopi Tribe's Office of Range Management assumed the responsibility. [100518:57 AM (Pavatea); 101018:67 AM (Pavinyama)] The Hopi Tribe produced a summary of the recorded inventories maintained at its Office of Range Management of the number of cattle and sheep on the reservation for select years between 1978 and 2017. [Hopi Exh. 892] Christopher Banet, a Trust and Resources and Protection Manager for the Bureau of Indian Affairs who holds a masters in plant and soil science, testified that he reviewed approximately 20 years of livestock count data, but only focused on the data that he received from the Hopi Tribe for 1997. [091718:24-25 AM (Banet)]

The data collected from the Office of Range Management details the inventory in "animal units" owned by the Hopi Tribe for many of the years in the data set and by the number of sheep owned by the Navajo Nation that graze in the range units designated by the Hopi Tribe. [Hopi Exh. 892] For three of the years, the number of sheep attributed to the Hopi Tribe is reported separately from animal units. [*Id.*] In order to analyze the livestock count data it is necessary to convert the inventory into animal units. [091718:32 AM (Banet)] An animal unit is a measurement used to relate the individual water needs of different types of livestock. A cow is defined as one animal unit. Mr. Banet used a conversion factor of 0.20 for a sheep which means that five sheep require the same amount of water as one cow. He acknowledged that a 0.25 conversion factor for a sheep is also used by experts. [091718:32 AM (Banet)] Priscella Pavatea, Director of the Office of Range Management, testified that 0.25 is an appropriate conversion factor for a sheep. [100518:52 AM (Pavatea)]

Finding of Fact No. 76. The conversion factors applicable to specific types of animal are shown in Table 8:

Livestock Class	Conversion Factor from Animal to Animal Unit
Bull	1.25
Cow	1.00
Goat	0.20
Sheep	0.25
Yearling Heifer	0.70
Yearling Steer	0.70

TABLE 8.

[091718: 27 AM (Banet); 100518:52 AM (Pavatea); U.S. Exhibit 763;

Mr. Banet calculated the amount of water used by the Hopi Tribe for the past and present based on a livestock count of 15,879 because the number of animal units for 1997 exceeded the livestock count for the other years for which Mr. Banet had data. [091718:23 (Banet)] For the

period 1997 through 2017, the livestock count did not exceed 5,007.25 in any year. As discussed above, a maximum amount is only a single data point and it may be a statistical outlier or not credible. The factual issue presented by this approach is whether the data for 1997 is credible.

The number of livestock varies from year to year. [Hopi Exh. 892; 100518:68-69 AM (Pavatea)]. Factors influencing the number of livestock that a Hopi member may choose to raise or sell include: the availability of water, the condition of the range, permits, market price for cattle, and expectations about the animals' ability to survive a cold winter or hot summer. [100518:68 AM (Pavatea); 100918:35, 38, 50 AM (Homanie); 101018:66, 70 AM (Pavinyama)] In the case of the 1997 reported data, 15,879.75 animal units represents a 77 percent increase in herd size between 1996 and 1997, followed by a 85 percent reduction between 1997 and 1998. Ms. Pavatea testified that in her experience as a range manager she has not seen such a large change in animal units as shown by the 1997 data. [100518:26 (Pavatea)] Mr. Banet stated that the Hopi collected the data, but Ms. Pavatea stated that the Office of Range Management did not undertake that responsibility until 2002. [091718:26 (Banet); 100518:15 (Pavatea)] The validity of the 1997 inventory was also called into question by the apparently erroneous inclusion of a name associated with three head of cattle that was unknown to a Hopi tribal member with the same surname. Finally, the Hopi Tribe produced an historic inventory of livestock compiled by ADWR for years between 1878 and 1981 (although not all years) that report a similar number of livestock in 1937, 40 years earlier. The 1937 count in excess of 15,000 animal units was notated as "seems high" [Hopi Exh. 38 at 32]

Finding of Fact No. 77. The amount of livestock reported on the Hopi Reservation in 1997 does not provide a credible basis for a determination for the amount of water used in the past for livestock.

Finding of Fact No. 78. The average count based on the data available for the period 1978 through 2017 was 3,478 and the median was 2,310.25 animal units. The maximum number after excluding 1997 was 8,917.75 in 1996 and the minimum count was 1,383 in 2002.

The second step in the analysis of demand requires a determination of the amount of water required by each animal unit. Mr. Banet began by stating that each animal unit required 12 gallons of water per day. [091418:85 (Banet)] Mr. Banet arrived at the 12-gallon figure by assuming that the source of the water would come from a well and calculated the amount of water that must be produced by a typical well that will be stored in a tank or stockpond. After factoring in losses due to transmission losses, leaks, spills, seepage, and evaporation, he concluded that 20 gallons must be produced from a well that is pumped into a storage facility for each animal unit. All of the parties stipulated to a factual determination that the appropriate measure of water for each animal unit is 20 gallons per day. [Stipulation of the parties 091718:110-111]

Finding of Fact No. 79. Using 20 gallons per day per animal unit, the past and present usage of water by livestock on the Hopi Reservation was between 31 and 201 acre feet annually.

Mr. Banet testified that groundwater is the primary source of water for livestock on the Reservation because it is the most reliable source of water [091418:74 (Banet)] He testified that he surveyed 198 wells that were identified by the United States as a source of water for livestock on the Hopi Reservation, and of the wells that could be located, determined that a typical well is powered by a windmill. [091718:11, 14 (Banet] The amount of water pumped is affected by the diameter of the windmill rotor, which, based on aerial photography, ranged in size from 12 to 16 feet, although most were 14 feet in diameter. [*Id* at 12] The size of the hole drilled for the well and related equipment and the depth to the water table also affected the amount of water pumped

from the well. [*Id.* at 13] Based on his statistical analysis, Mr. Banet determined that the median production of these wells was 1.43 acre feet per year. [091718:20 (Banet); U.S. Exhibit 761] Assuming losses as a percent of production ranging from 24 percent to 57 percent, [U.S. Exhibit 761] then these wells could produce collectively in the range of 121 to 215.18 acre feet per year if they were all operational. Dr. Ley testified that during his visits he found wells that were dry and he did not measure flow in the wells. [092618:35-36 PM (Ley)]

Although springs are listed as a source of water for livestock, according to Mr. Banet, springs on the Hopi Reservation do not provide sufficient surface water for the livestock because they are small and not uniformly distributed among the range units. [091418:78 (Banet)] The United States and the Hopi Tribe did not quantify past use of springs or wells, so no finding of fact is made with respect to either as to past use.

The final source of water listed for livestock are impoundments or stockponds. The claims made by the United States and Hopi Tribe are not based on past use but are based on the storage capacity of stockponds. Arizona Department of Water Resources investigated the claims and found a significant difference between the volume of storage claimed by the Hopi Tribe and that claimed by the United States. It did verify the existence of 993 impoundments and calculated the combined volume of the impoundments as 3,167 acre feet. HSR at 5-7.

It is undoubtedly true that multiple sources of water are required to maintain livestock because the amount available from each source will vary seasonally and annually, and the availability will sources will vary across the reservation where livestock are permitted to graze. At this point in this contested case, however, essentially the only evidence offered is that these sources exist. Water from wells and springs has not been quantified. Stockponds have been quantified in terms of their capacity to hold water, but not as to the amount of water they typically hold in a

year. No findings of fact can be made about the amount of water that has been used from springs, wells, and stockponds for livestock. Given the large difference between the potential amount of water involved with these three sources and the amount of water actually used by livestock in the past, the better approach is to address the these sources in the next phase of this case that will concern the present and future needs on the Reservation, including the livestock anticipated to be raised in the future.

7. Water for Riparian and Wetland Habitat (Pasture Canyon) Use

The United States, on behalf of the Hopi Tribe, claimed 315.5 acre feet of water per year for riparian and wetland habitat in Pasture Canyon. In the HSR, ADWR estimated water use for Pasture Canyon riparian area in the range of 165.7 to 317 acre feet per year and recommended a finding of 294 acre feet per year. HSR at 4-40; 5-8; Table 5-1.

Finding of Fact No. 80. The riparian vegetation and wetlands in Pasture Canyon cover approximately 69.4 acres and rely on the upper Pasture Canyon springs as the source of water. [U.S. Exh. 539 at 20; U.S. Exh. 729 at 3-1]

Finding of Fact No. 81. Pasture Canyon is a slot canyon with seeps along the sides and wetlands areas along the bottom of the canyon. [100218:47 AM (Puhuyesva)]

Darren Talayumptewa, Director of Wildlife and Ecosystems Management Program, testified that the wetlands sustain plants that the Hopi people use for medicinal, traditional, and consumptive purposes; provide habitat for aquatic life important to the Hopi Tribe; and support birds used in Hopi ceremonies. [100918:28, 42 PM (Talayumptewa).] Mr. Puhuyesva explained that the Pasture Canyon wetland is a habitat for wildlife, for birds that provide feathers for religious and ceremonial purposes, and for plants such as whipple cattails that are used in

ceremonial dances. [100218:47, 52-53 AM (Puhuyesva)] Selestewas Pavinyama, the former president of the Moenkopi Natural Resources Conservation District and former chair of the village water and sanitation committee, explained that Pasture Canyon has religious significance to the Hopi in addition to providing a source of reeds and other plants. [101018:19-20 AM (Pavinyama); 101018:6 PM (Pavinyama)]

Finding of Fact No. 82. The wetlands of Pasture Canyon have cultural and religious significance to the Hopi Tribe.

The United States retained Dr. Ley to quantify the past and present use of water in Pasture Canyon. Dr. Ley conducted his analysis by categorizing Pasture Canyon into four discrete areas: grass with overlying shrub canopy; grass with overlying tree canopy; wetlands; and small, shallow open water/wet soil. [U.S. Exh. 539 at 4-2] For each category, he estimated the evapotranspiration losses normally associated with the category and consumptive requirements and used the PRMS model discussed above to model water use for the 66-year period from 1949 to 2014. The water analysis included wet and dry cycles. [092618:16 PM (Ley)] Water use by riparian vegetation and wetlands occur as a result of physical location and generally not as a result of water diversion and conveyance to those areas. Thus, total consumptive water requirements of riparian areas and wetlands were assumed to be equal to the net consumptive water requirements. [U.S. Exh. 539 at 3-2] Dr. Ley concluded that the average annual total water requirement was 286.8 acre feet per year, which is within the range estimated by ADWR. [U.S. Exh. 539 at 3-3] He also calculated a maximum water usage with the explanation that it is "estimated to be 10 percent greater than the average

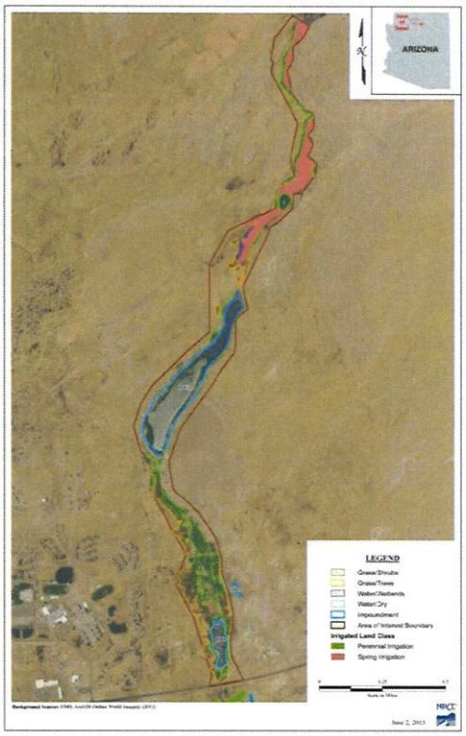

FIGURE 8. Map of wetlands and perennially irrigated areas in Pasture Canyon area.

annual demand depletion." [*Id.* at 3-3] No other evidence is included in the record to substantiate the greater use.[5]

Initially the primary issue with respect to the wetland claims was whether the same acreage was used to support a claim for past and present use of water for perennial irrigation and for wetlands. As shown on *figure 8,* the areas are discrete. Dr. Ley testified that he reviewed historical and current photographs and that none of the photographs showed an overlap between the wetlands and the irrigated areas and he further testified that the water uses for the wetlands and for the 22.2 acres of irrigated land were mutually exclusive. [092618:11-12, 14, 16 (Ley)] At trial, however, the issue seemed to be that there was no observable surface flow to or in the riparian area. [103118:46, 48 PM (Leeper)] Dr. Ley's data clearly establishes the presence of past flow.

Finding of Fact No. 83. Duplicate claims were not made for the same acreage for perennial irrigation and wetland habitat.

Finding of Fact No. 84. Pasture Canyon has a past and present use of 294 acre feet of water per year.

8. Water for Additional Cultural, Religious, and Ceremonial Uses

The *Gila V* decision states that the court should consider tribal culture when quantifying federally reserved rights. "Water uses that have particular cultural significance should be respected, where possible. The length of time a practice has been engaged in, its nature (e.g., religious or otherwise) and its importance in the tribe's daily affairs may all be relevant." 201 Ariz. at 318, ¶43, 35 P.3d at 79. The United States does not make any claim for water rights in this category in addition to the claims made with respect to Pasture Canyon.

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[5] Dr. Ley's report, U.S. Exh. 539, does contain tables in Appendix B listing his data for each year for each category. No attempt was made to separately analyze those tables for additional statistical information.

The Hopi Tribe makes a general claim to the right to use the flow in each spring on the Hopi Reservation for ceremonial, religious and cultural uses. Hopi 5th Amended Statement of Claimant at 49-50. The claim is not quantified and evidence as to specific quantities used in the past to meet these needs was not provided separately from the broad categories of water use discussed above. Accordingly, no finding of fact can be made as to a particular quantity of past and present use in this category except as specifically set forth in earlier portions of this report and no additional finding regarding quantification should be implied. Based on the testimony and evidence offered by the Hopi Tribe during the course of the trial, water has religious significance to the Hopi Tribe. Hopi tribal members provided general explanations of Hopi religious beliefs and practices concerning water. They described their prayers for rain and snow and the fact that religious ceremonies are held at springs. [100918:41 AM (Honanie); 100418:75 AM (Loma'omvaya); 100918:9 PM (Talayumptewa)] Mr. Leonard Selestewa eloquently testified: "Water to the Hopi people is very sacred. Water is alive. It is a spirit with life." [101018:16 AM (Selestewa)]

Finding of Fact No. 85. Continued flow in the springs on the Hopi Reservation has religious significance to the Hopi Tribe.

9. Filing Dates for Objections and Responses

Written objections to this Draft Report shall be filed on or before **September 30, 2019** with the Clerk of the Superior Court in Apache County. No page limit applies to the objections. Objections should be specific and should contain citations to the record to support the party's position. Similarly, requests for additional findings of fact should contain citations to the trial record that support the finding. No exhibits may be attached to the objections. A copy of

objections shall be served on all persons listed on the Court-approved mailing list for this contested case. Responses to the objections may be filed by a party but are not required. If a party chooses to file a response, the response shall be filed not later than **November 11, 2019**. Responses shall not exceed 15 pages.

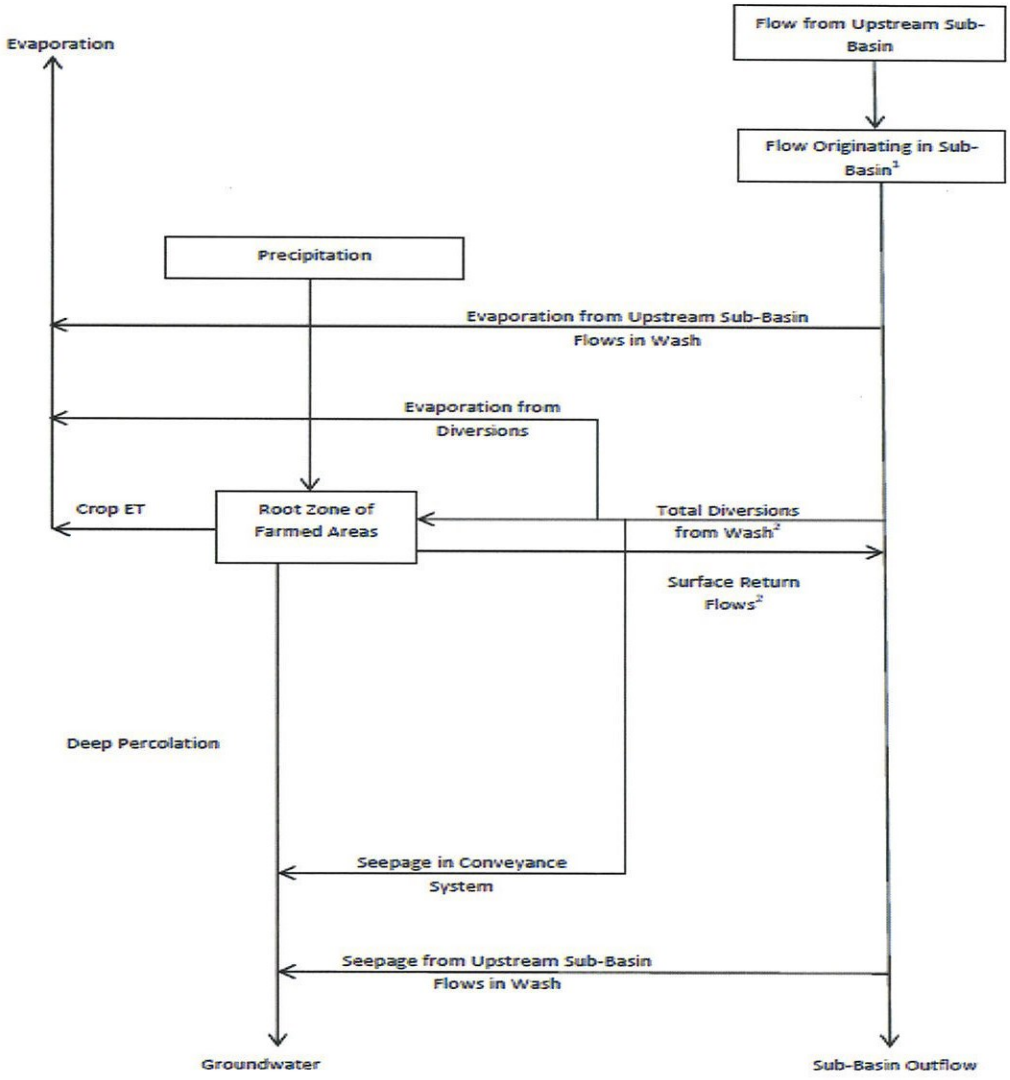
Susan Ward Harris
Special Master

The original of the foregoing was mailed to the Clerk of the Apache County Superior Court for filing and distributing a copy to all persons listed on the Court approved mailing list this contested case.

Appendix A - Percentage Of Coal Sales Attributable To Hopi Mineral Interests

Year	Amount Pumped	Percentage of Coal Sales	Amount Allocated to Hopi Tribe (AFA)
1972	3,680	49.29%	1,813.9
1973	3,520	39.79%	1,400.6
1974	3,830	29.54%	1,131.4
1975	3,500	29.23%	1,023.1
1976	4,180	26.92%	1,125.3
1977	4,090	19.51%	798.0
1978	3,000	13.21%	396.3
1979	3,500	13.05%	456.8
1980	3,540	12.01%	425.2
1981	4,010	11.55%	463.2
1982	4,740	12.27%	581.6
1983	4,460	14.22%	634.2
1984	4,170	15.77%	657.6
1985	2,520	27.32%	688.5
1986	4,480	26.03%	1,166.1
1987	3,830	30.08%	1,152.1
1988	4,090	26.63%	1,089.2
1989	3,450	28.55%	985.0
1990	3,430	26.96%	924.7
1991	4,020	27.36%	1,099.9
1992	3,820	25.97%	992.1
1993	3,700	26.21%	969.8
1994	4,080	34.29%	1,399.0
1995	4,340	33.58%	1,457.4
1996	4,010	31.77%	1,274.0
1997	4,130	29.76%	1,229.1
1998	4,030	28.44%	1,146.1
1999	4,210	29.64%	1,247.8
2000	4,490	29.16%	1,309.3
2001	4,530	28.75%	1,302.4
2002	4,640	28.02%	1,300.1
2003	4,450	27.50%	1,223.8
2004	4,370	30.41%	1,328.9
2005	4,480	33.81%	1,514.7
2006	1,200	43.12%	517.4
2007	1,170	34.51%	403.8
2008	1,210	28.89%	349.6
2009	1,390	37.98%	527.9
2010	1,170	37.39%	437.5
2011	1,390	36.84%	512.1

Appendix B - Schematic Of DISM



1) Flows Originating in Wash are from PRMS Output
2) Net Diversion is Total Diversion Minus Surface Return Flows