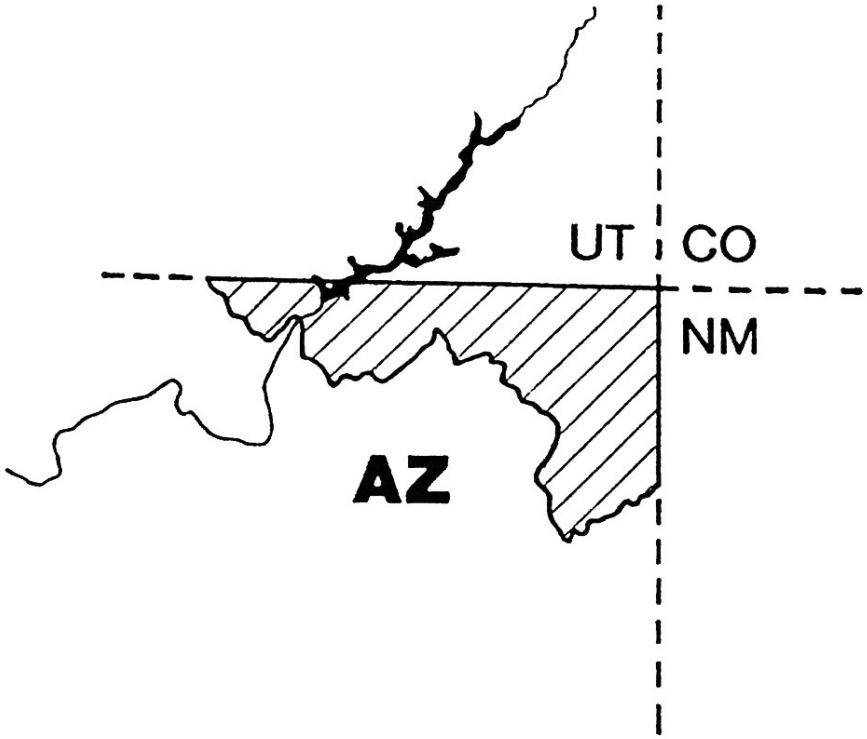
RECLAMATION

Managing Water in the West

Consumptive Uses and Losses

Arizona Portion of the Upper Colorado River Basin Calendar Year 1996



U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

July 2007

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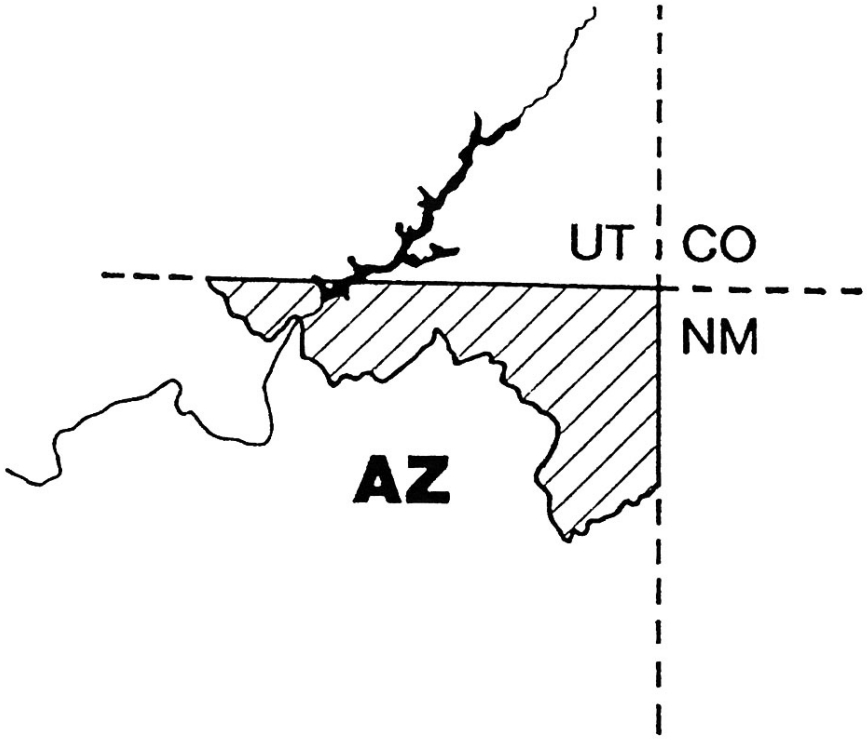

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Denver, Colorado

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CONSUMPTIVE USES AND LOSSES

ARIZONA PORTION OF THE UPPER COLORADO RIVER BASIN

CALENDAR YEAR 1996

AUTHORITY

This report was prepared in compliance with Public Law 90-537, Section 601 (b)(1), dated September 30, 1968, which directs the Secretary of the Interior to "make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis." Additionally, this report is in compliance with Section 49 of the Navajo Project Participation Agreement dated September 30, 1969, which states in part: "The Secretary of the Interior further agrees to make the reports required by Section 601 (b)(1) of Public Law 90-537 as they pertain to Arizona's Upper Basin uses annually rather than every five years. Within fifteen days following the completion of said reports, the Secretary of the Interior shall furnish copies of such reports to the Co-Tenants, the Navajo Tribe, each of the Upper Basin States, and the Upper Colorado River Commission."

SUMMARY

The total consumptive use and loss value for the Arizona portion of the Upper Colorado River Basin for calendar year 1996 was 34,273 ($\pm$1,615) acre-feet.

STUDY AREA DESCRIPTION

The Arizona portion of the Upper Colorado River Basin covers approximately 6,900 square miles in the north-east corner of Arizona, as shown on the location map (Drawing 1246-406-1). The climate of the 5,900 square mile area to the west of the Chuska and Carrizo Mountains is largely arid to semiarid, with mean annual precipitation ranging from 6 to 12 inches and with summertime temperatures often reaching 100 degrees Fahrenheit (^{o}F). The potential evaporation rate is high and exceeds mean annual precipitation, with gross lake evaporation values of up to 55 inches per year or more. Elevations in the western portion range from 3200 feet on the Colorado River at Lees Ferry to over 8000 feet on the northern edge of the Black Mesa and across the Zilnez and Skeleton Mesas, back down to 5280 feet in the Chinle Valley, and back up to about 6500 feet on the western edge of the Chuska Mountains. Much of the western part

of the study area is starkly beautiful southwestern desert country with mesas and canyons intertwined across a pastoral landscape. By contrast, the eastern 1,000 square miles is largely mountainous, with elevations rising to nearly 10,000 feet and mean annual precipitation reaching 30 inches. The mountainous land responds with grass meadows interspersed with conifer forest of mostly ponderosa pine.

Except for Page, Arizona; a small area around Lees Ferry; and a portion of the Paria Plateau administered by the Bureau of Land Management; the study area lies entirely within the Navajo Nation. According to census data, 43,289 persons were living within the area in 1990, and of these 36,641 resided on the Navajo Nation.

The largest cities are Page and Chinle, with 1990 populations of 6,598 and 5059, respectively. Other major communities and their populations include Dennehotso (616), Kaibeto (641), Kayenta (4,372), Lukachukai (113), Many Farms (1,294), Rough Rock (523), Teec Nos Pos (317), and Tsaile (1,043). Subsistence in the region is derived principally from livestock grazing, farming, tourist-related industries, employment at the Navajo Generating Station (NGS), which consumes 60 to 70 percent of the water used or lost in the study area every year. Agriculture accounted for 4 percent of the total water use; municipal and industrial about 78 percent; recreation, fish and wildlife, about 5 percent; and reservoir evaporation, 13 percent.

AGRICULTURAL CONSUMPTIVE USE

Agricultural consumptive use is divided into three categories: irrigation, stock pond, and livestock. Irrigation use includes all use related to irrigating crops including the incidental losses. Stock pond use is the evaporation that occurs from stock ponds and livestock use is the water consumed by livestock.

IRRIGATION USES

Within the Arizona portion of the Upper Colorado River Basin, historically 23 irrigated areas were scattered across the Navajo Nation plus a small amount of land near Lees Ferry irrigated by the National Park Service. Currently, only 15 irrigated areas are in production. An accurate assessment of consumptive use on the irrigated land is difficult due to poor quality of information, such as the exact number of acres under irrigation, the cropping pattern for each irrigated area, site climatological conditions, and the amount of water actually diverted. In many cases, during the latter part of the irrigation season, farmers have to rely on dry land farming since there is little water available in the streams. This means that the crops do not receive their full water requirement.

For this report, the U.S. Department of Agriculture, Soil Conservation Service's (SCS) Modified Blaney-Criddle ET estimation model was used for computing irrigated crop consumptive use. This model, along with appropriate crop-growth stage coefficients and the method for computing effective precipitation, is described in SCS's *Irrigation Water Requirements Technical Release No. 21* (TR 21). Information required for applying this model includes mean monthly temperature and precipitation values, growing season data for each crop type, and the total number of acres planted by crop at each site. With the

exception of Teec Nos Pos, Canyon de Chelly, Lukachukai, and Lees Ferry, no climatological data exist for the irrigation sites, and site values must be generated from data collected at surrounding established weather stations. Growing season dates depend largely on the judgment of the local inhabitants and are, therefore, not known. Although several reports are available with published values for irrigated acres, it is unclear if these values are meant to represent potential irrigated acres, acres irrigated in the past, acres for which farming permits have been issued, or actual acres currently under irrigation.

The crop acreage used to estimate consumptive use by irrigated crops for the year 1996 is shown in table 1. These values were determined from direct field examination by a party composed of representatives from the State of Arizona and the Navajo Nation.

Table 1.—Total irrigated acreage, 1996

PROJECT	CORN (ACRES)	ALFALFA (ACRES)	GRASS PASTURE (ACRES)	SPRING GRAINS (ACRES)	SMALL VEGETABLES (ACRES)	ORCHARD (ACRES)	TOTAL (ACRES)
CHINLE AGENCY							
Canyon de Chelly	0.36	0.00	0.00	3.03	2.26	0.00	5.65
Lukachukai	39.09	7.69	0.00	7.50	5.98	2.07	62.33
Nazlini	0.00	0.00	0.00	0.00	1.79	0.74	2.53
Rough Rock	30.00	0.00	11.87	0.00	12.43	0.00	54.30
Tsaile	23.72	5.27	15.67	5.73	5.42	0.00	55.81
Wheatfields	0.00	60.80	0.00	0.00	0.00	0.00	60.80
TOTAL	93.17	73.76	27.54	16.26	27.88	2.81	241.42
SHIPROCK AGENCY							
Red Rock Valley	26.22	0.00	10.19	5.12	10.22	0.00	51.75
Teec Nos Pos	20.00	0.00	0.00	0.00	3.67	0.00	23.67
Toh Chin Lini	0.00	0.00	0.00	0.00	3.90	13.67	17.57
Totacon	0.00	0.00	0.00	0.00	1.00	0.00	1.00
TOTAL	46.22	0.00	10.19	5.12	18.79	13.67	94.0
WESTERN NAVAJO AGENCY							
Dennehotso	1.82	0.00	38.70	0.00	0.00	0.00	40.52
Lees Ferry	0.00	0.00	1.00	0.00	0.00	2.00	3.00
Marsh Pass	7.02	3.31	0.00	0.00	1.99	0.00	12.32
Navajo Canyon	0.00	0.00	0.00	0.00	0.00	3.50	3.50
Paiute Canyon	2.64	0.00	0.00	0.00	3.86	0.00	6.50
TOTAL	11.48	3.31	39.70	0.00	5.85	5.50	65.84
GRAND TOTAL	150.87	77.07	77.43	21.38	52.52	21.98	401.25

Consumptive Uses and Losses

Several factors complicated the modeling of irrigation consumptive use. For example, the computer program used to model consumptive use assumes a full water supply; if shortages exist, as they often do in this semiarid study area, adjustments must be made. These adjustments are complicated because some of the projects have no storage water and may only have a reliable irrigation water supply during spring runoff. After spring runoff, farming becomes essentially dry land until rains in July and August provide intermittent flows for irrigation. Finally, no ditch diversion records are available to help estimate irrigation water supplies and shortages.

A full irrigation supply seldom exists at many of the projects. Generally, a full supply is available for Lees Ferry, Navajo Canyon, Tsaile, and Wheatfields projects because of adequate stream flows or because of available storage water. In years with average precipitation, it is estimated that Chinle Wash provides approximately 75 percent of the irrigation requirement. Precipitation in the area averages approximately 9.5 inches per year. Based on this information, it would require approximately 12.67 inches of precipitation to provide 100 percent of the irrigation requirement. The percent of crop water requirement met was computed as a ratio of annual precipitation to 12.67 inches. These values are found in table 2.

The percentage of crop water requirement met was multiplied by the total net crop water requirement to come up with the amount of crop consumptive use. Incidental irrigation losses, evaporation, and phreatophyte consumptive use along supply canals are estimated to be 5 percent of the consumptive use of the irrigated area and are added to the crop consumptive use value to develop a total consumptive use value.

A portion of the water used for irrigation at these sites may not be contributing to the Colorado River System, since evaporation rates in the area are high and the nature of most of the drainage enhances evapotranspiration. A good example of such a drainage is Chinle Wash, which after it leaves Canyon de Chelly, becomes wide and sandy and is lined with willows, cottonwoods, and other phreatophytes.

The uncertainties in the irrigation consumptive use values displayed in table 2 are very large and are estimated as 40 percent of the total consumptive use. This estimate of possible error only reflects the uncertainty of consumptive use and does not account for any possible errors in the acreage estimates. The effective consumptive use for irrigation for 1996 was estimated to equal 405 acre-feet. Including the 5 percent for incidental losses, the irrigation related consumptive use is 426 ($\pm$170) acre-feet.

Table 2.—Net consumptive use values, 1996

PROJECT	CROP WATER REQUIREMENT (INCHES)	TOTAL IRRIGATED (ACRES)	TOTAL WATER REQUIRED (ACRE-FEET)	CROP WATER REQUIREMENT MET (%)	CROP WATER REQUIREMENT MET (ACRE-FEET)	TOTAL CONSUMPTIVE USE (ACRE-FEET)[1]
CHINLE AGENCY						
Canyon de Chelly	8.61	5.65	4	37%	1	2
Lukachukai	20.75	62.33	108	41%	44	46
Nazlini	17.54	2.53	4	41%	2	2
Rough Rock	22.80	54.30	103	52%	54	56
Tsaile	21.89	55.81	102	41%	42	44
Wheatfields	29.72	60.80	151	41%	62	65
TOTAL	—	241.42	471	—	204	214
SHIPROCK AGENCY						
Red Rock Valley	22.65	51.75	98	52%	51	54
Teec Nos Pos	26.24	23.67	52	64%	33	35
Toh Chin Lini	35.20	17.57	52	56%	29	30
Totacon	15.68	1.00	1	56%	1	1
TOTAL	—	93.99	202	—	114	119
WESTERN NAVAJO AGENCY						
Dennehotso	33.96	40.52	115	42%	48	51
Lees Ferry	46.10	3.00	12	100%	12	12
Marsh Pass	24.04	12.32	25	63%	15	16
Navajo Canyon	40.99	3.50	12	54%	6	7
Paiute Canyon	18.60	6.50	10	58%	6	6
TOTAL	—	65.84	173	—	88	92
GRAND TOTAL	—	401.25	846	—	405	426

[1] Total includes 5% addition for incidental losses.

STOCK POND EVAPORATION

Stock pond consumptive use is assumed to be the evaporation from the stock pond. It is also assumed that any consumptive use by natural vegetation prior to the construction of the stock ponds is limited to precipitation, which is subtracted from the evaporation losses.

A compilation of the stock ponds in the study area, including their locations and the water surface areas when ponds are full, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 3. For an average year conditions, the stock pond evaporative surface area was estimated as one-third the water surface area that occurs when the ponds are full. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average water surface area. These values are found in table 3.

Table 3.—Stock pond evaporation, 1996

COUNTY	SURFACE AREA FULL (ACRES)	SURFACE AREA USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Coconino	80	20	100%	57	5.02	51.98	86
Navajo	40	10	100%	55	6.99	48.01	38
Apache	646	142	63%	53	5.95	47.05	557
TOTAL	766	172	—	—	—	—	682

This method of evaporation estimation was used because continuous useful water level records for all stock ponds from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual stock ponds. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation. It was assumed that any consumptive use by natural vegetation prior to construction of the stock ponds is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for stock pond evaporation for calendar year 1996 are shown in table 3. The total evaporative losses in 1996 are 682 ($\pm$204) acre-feet with the stock pond evaporation uncertainty being estimated as 30 percent.

LIVESTOCK WATER

The source of most livestock water in the study area is from wells, with windmill-operated pumps developed and maintained by Navajo Water Operations and Maintenance, and water collected in small surface ponds. The estimated number of

livestock in the area was obtained based on livestock tallies. It was estimated that horses and cattle consume 12 gallons per day; sheep and goats consume 2 gallons per day.

The number of animals for the Upper Colorado portion of each district is shown in table 4. The computed value for livestock consumptive use is 243 acre-feet. The uncertainty in this number is estimated as 30 percent of the total or ±73 acre-feet.

Table 4.—Number of livestock, 1996

AGENCY	CATTLE	HORSES	SHEEP	GOATS
Western Navajo District No. 1	1,871	425	1,855	1,231
Western Navajo District No. 2	512	129	1,031	716
Western Navajo District No. 8	1,749	324	2,563	2,419
Shiprock District No. 9	1,869	429	1,912	2,053
Chinle District No. 10	2,741	715	3,598	2,178
Chinle District No. 11	1,784	337	1,434	1,660
Shiprock District No. 12	380	88	1,592	660
Fort Defiance District No. 17	69	35	313	144
Fort Defiance District No. 18	255	81	308	166
TOTAL	11,231	2,562	14,607	11,227

TOTAL AGRICULTURAL CONSUMPTIVE USE

The total agricultural consumptive use, displayed in table 5, is the sum of the individual components discussed in the previous sections. Agricultural water consumption represents approximately 4 percent of the total use in the study area. Total degree of uncertainty was computed by taking the square root of the sum of the individual uncertainties squared; known as the quadratic sum. This method and nomenclature is used throughout this report. This method was used because a simple sum does not account for the partial cancellation of errors occurring when calculating the total uncertainty derived from individual values that are random and independent of each other. As previously discussed, the individual uncertainties were set as a percent of the consumptive use value.

Table 5.—Total agricultural consumptive use, 1996

CATEGORY	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Irrigation	426	170
Stock Ponds	682	204
Livestock	243	73
TOTAL	1,351	276

MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

Municipal and industrial consumptive use is divided into three categories: mineral resources, thermal electric power, and other. Mineral resources consumptive use includes water used for mineral production. No mineral resources consumptive use is reported in the study area. Thermal electric power consumptive use includes the water used at the power plants, and that used to transport material to the power plant (such as a coal slurry pipeline). Other consumptive use includes urban, rural, and industrial uses.

THERMAL ELECTRIC POWER

Thermal electric power consumptive use includes the water used in the power plant and the water used to transport material to the plant.

Navajo Generating Station

The water used by the NGS is pumped directly from Lake Powell and comprises over half of the total consumption in the study area. Since all NGS water use is metered, this quantity is among those most precisely known, with the maximum uncertainty in the metered quantities believed to be less than 3 percent. The actual quantity consumed, along with the estimated uncertainty for the calendar year 1996, was 21,427 (±643) acre-feet.

Consumption is expected to grow during the years 1997-1999, due to antipollution "scrubbers" scheduled to be installed on the exhaust stack. Water use is expected to increase by and estimated 3,000 acre-feet.

OTHER

The other consumptive use category includes the remaining use by urban, rural, and industries.

Page, AZ and Vicinity

***City of Page, AZ*. –** The city of Page pumps its domestic water directly from Lake Powell. The water pumped is metered, and the uncertainty of the pumped quantities was assumed to be less than 3 percent. A portion of the water pumped and treated by the City of Page, is supplied to the community of Le Chee on the Navajo Nation and is accounted for separately. The quantity supplied to the City of Page and its associated uncertainty for the calendar year 1996 was 3,060 (±92) acre-feet. Water returning to the waste water treatment plant is metered as well. The waste water for the City of Page is treated and is either evaporated from lined ponds or applied to the golf course, with a portion being returned to the Colorado River. The return flow is estimated to be 907 acre-feet. The net consumptive use is estimated to be 2,152 acre-feet (±96).

Le Chee – The community of Le Chee is supplied and metered by the City of Page. Total water supplied for 1996 was 100 (±3) acre-feet. The uncertainty was estimated to be 3 percent.

Greenhaven Water Company – The Greenhaven Water Company derives its domestic water supply from wells. Well pumping records are available. According to these records, the total water pumped for 1996 was 92 (±6) acre-feet. The uncertainty was estimated to be 7 percent.

Arizona Department of Transportation Housing – The Arizona Department of Transportation operates a housing, maintenance, and administrative facility located on US Hwy 89, north of Page, AZ. This facility is supplied from wells that have no meters installed. It is estimated that the total water pumped for 1996 was 8 acre-feet with an uncertainty of 30 percent of this value or ±3 acre-feet.

Navajo Nation

Community Water Systems – Statistics from the Division of Community Development of the Navajo Nation reveal that various community water systems served 26,086, or about 83 percent of the 31,429 people residing within the study area in 1980. This percentage was used for 1996 resulting in 32,964 out of 39,716 people being served. These systems include those operated by the Navajo Tribal Utility Authority (NTUA), the BIA, and the Water Operations and Maintenance Department of the Navajo Nation, and some privately developed community water systems.

Table 6 shows the source of water and estimated population served by each source of water for people living on the Navajo Nation during 1996. All of the communities obtain their water supply from ground water.

Table 6.—Domestic water sources, 1996

SOURCE	PERCENTAGE OF POPULATION SERVED	NUMBER OF POPULATION SERVED[1]
Community Water Systems	83	32,964
NTUA	[2](60)	19,779
BIA	[2](25)	8,241
Navajo WOM	[2](13)	4,285
Private	[2](2)	659
Individual Wells	17	6,752
TOTAL[2]	100	39,716

[1] Estimated total population within the Upper Colorado River Basin portion of the Navajo Nation provided by Larry Rodgers, Demographer for the Division of Community Development of the Navajo Nation, letter DCDA-L94052, June 20, 1995.

[2] These numbers are a percentage of the Community Water Systems.

NTUA Water Systems – The cities and surrounding communities of Oak Springs, Red Valley, Sweetwater, Chinle , Rough Rock, Round Rock, Rock Point, Wheatfields, Lukachukai, Kayenta, Chilchinbeto, Dennehotso, and Kaibeto derive most of their domestic water supply from wells operated by NTUA. Well pumping records are available. According to these records, the total water pumped for 1996 was 1,594 acre-feet with an uncertainty estimated to be 7 percent of this value or ±112 acre-feet.

The NTUA manages the raw waste water; portions of which flow to individual septic tanks, some to evaporation ponds, and some, such as for the cities of Chinle and Kayenta, flow to waste water treatment plants. Very little water, if any, is returned to the ground water system through leakage from the evaporation ponds, but there are losses from the main collection system. Effluent from the Chinle and Kayenta waste water treatment plants is metered. Under normal conditions, the effluent returns to the Colorado River System and is subtracted from the pumping totals to determine a net consumptive use. For 1996, Chinle treatment plant effluent was 419 (±29) acre-feet, and Kayenta effluent was 267 (±19) acre-feet. An estimated uncertainty of 7 percent was used for the effluent of these two plants. The total effluent of 686 acre-feet is subtracted from the NTUA pumping total of 1,594 acre-feet to arrive at a net consumptive use of 908 (±121) acre-feet.

BIA Water Systems – Wells developed and operated by the BIA serve numerous Navajo communities. These systems also serve BIA schools, hospitals, agency offices, and some housing on the Navajo Nation. Metered records for total amounts of water pumped from BIA wells were available for a portion of the Shiprock Agency, the Western Navajo Agency, and the Chinle Agency. Drawing 1246-406-2 shows the agency boundaries within the Upper Colorado River Basin. The uncertainty was estimated to be about 7 percent for all three agencies.

The BIA systems include sewage disposal units terminating in lined evaporation ponds with very little or no return water returning to the ground water system. Undoubtedly, some losses occur in distribution, but insufficient data currently exist to estimate these losses. The losses are probably less than the uncertainties for each of the reported values.

The BIA well data available for the Shiprock Agency include: Cove, Red Rock, and Teec Nos Pos. Total consumptive use values are 70 (±5) acre-feet.

Pumping records for the Western Navajo Agency include data for the following schools: Chilchinbeto Day School, Dennehotso Boarding School, Kaibeto Boarding School, and Kayenta Boarding School. Total consumptive use for the Western Navajo Agency was 210 (±15) acre-feet.

Well pumping records for the Chinle Agency include data for the following schools: Cottonwood Day School, Lukachukai School, and Rock Point School. Rough Rock School maintains its own records, but the data was included with the Chinle Agency data. Total consumptive use for the Chinle Agency was 360 (±25) acre-feet.

Navajo WOM Water Systems – Water use in 1996 by the Navajo WOM service areas was based on an assumed consumption rate of 110 gallons per capita per day (gpcd). For a 1996 estimated service area population of 4,285, the estimated annual

water use was 528 (±158) acre-feet. The uncertainty is estimated as 30 percent of the total.

Private Water Systems – The estimated 1996 population served by private water systems on the Navajo Nation was 659. Assuming a consumptive use rate of 110 gcpd, the annual water use for 1996 was 81 (±24) acre-feet. The uncertainty is estimated as 30 percent of the total.

Individual Wells – According to census data from the Division of Community Development of the Navajo Nation, approximately 17 percent of the study area's population on the reservation (about 6,752 persons in 1996) receives a domestic water supply from individual wells. A consumptive use of 110 gpcd was derived as being a reasonable water use rate. Based on these figures, the annual consumptive use was 832 (±250) acre-feet for 1996.

TOTAL MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

The total municipal and industrial consumptive use, displayed in table 7, is the sum of the individual components discussed in the previous sections. Municipal and industrial water consumption represents approximately 78 percent of the total use in the study area.

Table 7.—Total municipal and industrial consumptive use, 1996

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
THERMAL ELECTRIC POWER		
Navajo Generating Station	21,427	643
OTHER		
Page, AZ and Vicinity		
City of Page	2,152	96
Le Chee	100	3
Greenhaven Water Company	92	6
Arizona Department of Transportation	8	3
Navajo Indian Reservation		
Community Water Systems		
NTUA Water Systems	908	121
BIA Water Systems	640	30
Navajo WOM	528	158
Private Water Systems	81	24
Individual Wells	832	250
TOTAL	26,769	724

It is questionable whether all the water pumped from wells should be considered a depletion to the Colorado River System; however, it is assumed that 100 percent of the water pumped is considered lost to the system. It is proposed that a future joint study be completed by Reclamation, the State of Arizona, and the Navajo Nation to estimate what percentage of water pumped could actually be attributed to the Colorado River System and would have affected the river flows for a particular year.

RECREATION, FISH AND WILDLIFE

The recreation, fish and wildlife consumptive uses include evaporation from reservoirs used exclusively for fish & wildlife purposes as well as acreages irrigated for wildlife feeding. Consumptive use at National and State parks is also accounted for.

GLEN CANYON NATIONAL RECREATION AREA

Colorado River water is used by the Glen Canyon National Recreation Area (GCNRA) at Wahweap and Lees Ferry. The recreational area at Wahweap gets its water supply from a series of wells on the shore of Lake Powell. Pumping records for both Wahweap and Lees Ferry show 348 ($\pm$10) acre-feet of water withdrawn during 1996. The uncertainty is estimated at 3 percent. This water was used for domestic purposes at the campgrounds, picnic areas, and trailer parks. It was also used to irrigate approximately 60 acres of Bermuda grass and cottonwood trees. The domestic waste water is treated and the effluent is allowed to evaporate from two lines evaporation ponds with a total surface area of 16.7 acres.

Based on estimates of evaporation and consumptive use by the plants, there is some water which is unaccounted for and is assumed to be leakage from the delivery system, the evaporation pond, or deep percolation from irrigation application. However, since these water losses are difficult to quantify and verify, the losses were charged as consumptive uses. Therefore, net consumptive use of water is estimated to be equal to the quantity of water pumped.

RESERVOIR EVAPORATION

A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled “1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River” and are shown in table 8.

Efforts are made to maintain a nearly full condition and to minimize water surface fluctuations in reservoirs managed for a fishery. Under average operating conditions, the water surface area of a reservoir used primarily for fishing is assumed to be equal to a normal water surface area. In 1996, these reservoirs filled in the spring and were maintained at the normal pool level.

Table 8. —Recreation, fish and wildlife reservoir evaporation, 1996

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE AREA USED (ACRES)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Tsaile	260	260	35	5.19	29.81	646
Wheatfields	272	272	32	5.19	26.81	608
TOTAL	532	532	—	—	—	1,254

This method of evaporation estimation was used because continuous useful water level records for all reservoirs from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs.

For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for reservoir evaporation for calendar year 1996 are shown in table 8. The total evaporative losses in 1996 are 1,254 (±376) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent.

TOTAL RECREATION, FISH AND WILDLIFE

The total recreation, fish and wildlife consumptive use, displayed in table 9, is the sum of the individual components discussed in the previous sections. Recreation, fish and wildlife water consumption represents approximately 5 percent of the total use in the study area.

Table 9.—Total recreation, fish and wildlife consumptive use, 1996

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Glen Canyon National Recreation Area	348	10
Reservoir Evaporation	1,254	376
TOTAL	1,602	376

RESERVOIR EVAPORATION

Reservoir evaporation losses make up about 13 percent of the total water uses and losses in the study area. A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 10. These reservoirs are used primarily for irrigation.

Table 10.—Reservoir evaporation, 1996

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE ACRES USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Many Farms	1,800	1,006	—	56	4.63	51.37	4305
Marsh Pass	40	14	69%	40	7.77	32.23	37
Round Rock	83	22	52%	57	4.91	52.09	93
Walker Creek	30	15	100%	59	8.07	50.93	64
Others	38	13	70%	55	7.06	47.94	53
TOTAL	1,991	1,069	—	—	—	—	4,552

Reservoirs used primarily for irrigation experience large fluctuations in water levels and, correspondingly, large variations in surface area. Reservoir level records and elevation – area curves were available at Many Farms, but not for the remaining reservoirs in table 10. For the reservoirs with no records from which surface area could be accurately computed, the average evaporative surface area was estimated as one-half the water surface area of a full reservoir. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average evaporative surface area.

Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses. The computed values for reservoir evaporation for 1996 are shown in table 10. The total evaporative losses in 1996 are 4,552 ($\pm$1366) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent of the total evaporation.

CONCLUSIONS

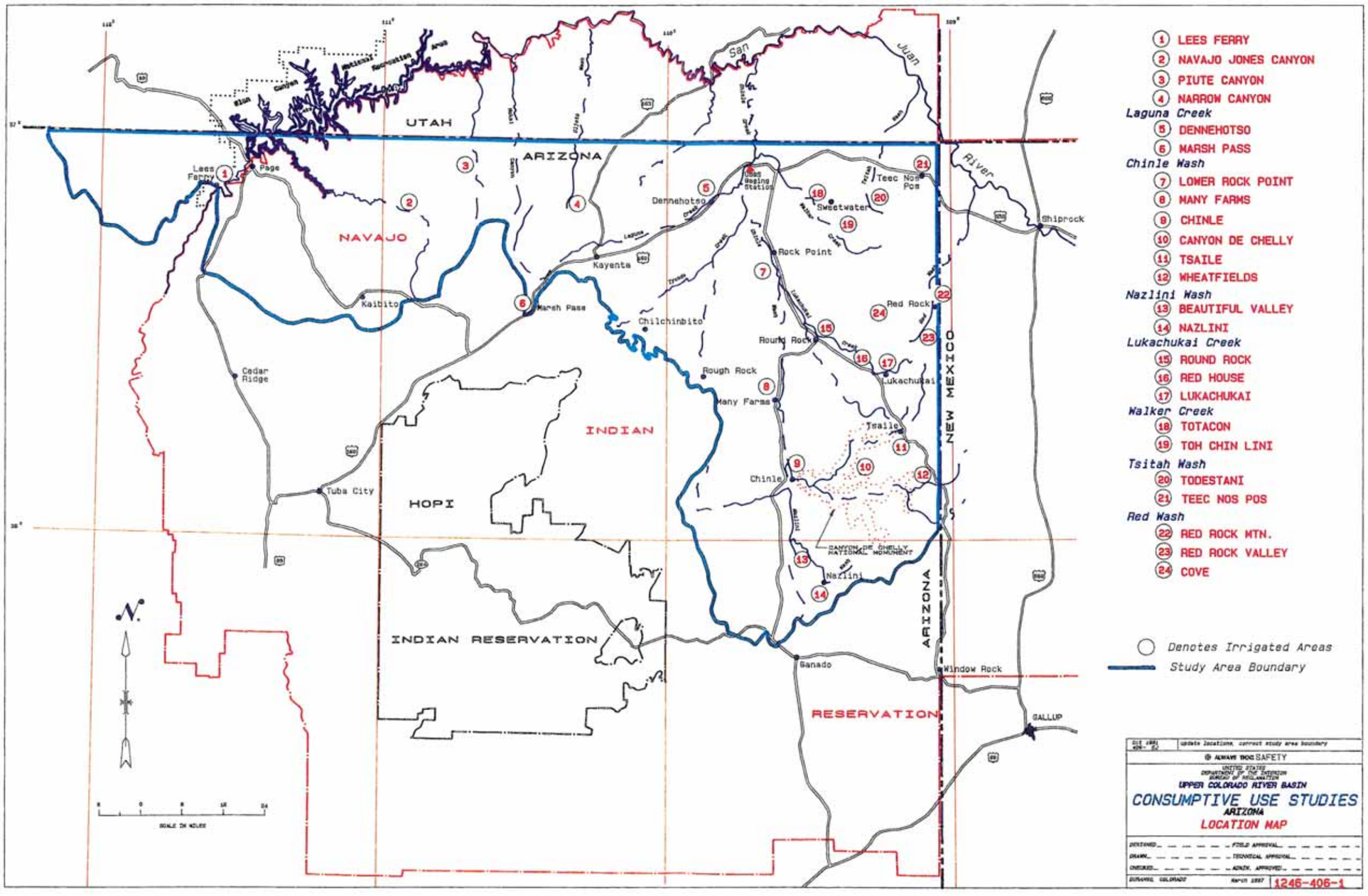
This report assesses the total consumptive use of the Arizona portion of the Upper Colorado River System surface water systems, depletion of ground water, and evaporative losses. Clearly, the amounts of water used by the Navajo Generating Station, City of Page, and Wahweap and Lees Ferry recreation areas are direct depletions of water from the Upper Colorado River System, but the situation is not as clear for other consumptive uses and losses occurring in other sections of the study area. For example, the source of water used by the Navajo Nation for domestic and municipal purposes is from wells, some exceeding 1,000 feet in depth. For our purposes here, it is considered to be consumed and a depletion to the Colorado River System. But this may not actually result in a reduction of Colorado River stream flows in the same year that the withdrawal occurs. Little knowledge and information exists of ground water movement and subsurface flow rates in the study area that are accurate descriptions of the effects on river flows.

Although the water diverted for agricultural purposes is considered as consumptive use in this report, a portion of the remaining surface water on the Navajo Nation, excess to needs, does evaporate before reaching the Colorado River. An attempt has not been made for this report to quantify these losses.

Uncertainties in estimating uses and losses exist, and the degree of variation in the figures is presented. Fortunately, the areas with the highest degree of uncertainty account for only a small percentage of the total consumptive use. The largest component, use by the Navajo Generating Station, is also the most accurately monitored. The total annual value for estimated consumptive use of water within the Arizona portion of the Upper Colorado River Basin for 1996 was 34,273 acre-feet, as shown in table 11.

Table 11.—Consumptive use for Arizona portion of Upper Colorado River Basin for 1996

USE CATEGORY	TOTAL CONSUMPTIVE USE (ACRE-FEET)	UNCERTAINTY	PERCENT OF TOTAL
Agriculture	1,351	276	4
Municipal & Industrial	26,769	724	78
Recreation, Fish & Wildlife	1,602	376	5
Reservoir Evaporation	4,552	1,366	13
TOTAL	34,273	1,615	100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ARIZONA
NEW MEXICO
NAVAJO
INDIAN
HOPI
INDIAN RESERVATION
RESERVATION
San Juan River
Lees Ferry
Page
Kaibito
Cedar Ridge
Tuba City
Marsh Pass
Kayenta
Dennehotso
Chilchinbito
Rough Rock
Many Farms
Chinle
Rock Point
Sweetwater
Teec Nos Pos
Red Rock
Round Rock
Lukachukai
Tsaile
Nazlini
Ganado
Window Rock
GALLUP
Shiprock
CANYON DE CHELLY NATIONAL MONUMENT
1 LEES FERRY
2 NAVAJO JONES CANYON
3 PIUTE CANYON
4 NARROW CANYON
Laguna Creek
5 DENNEHOTSO
6 MARSH PASS
Chinle Wash
7 LOWER ROCK POINT
8 MANY FARMS
9 CHINLE
10 CANYON DE CHELLY
11 TSAILE
12 WHEATFIELDS
Nazlini Wash
13 BEAUTIFUL VALLEY
14 NAZLINI
Lukachukai Creek
15 ROUND ROCK
16 RED HOUSE
17 LUKACHUKAI
Walker Creek
18 TOTACON
19 TOH CHIN LINI
Tsitah Wash
20 TODESTANI
21 TEEC NOS POS
Red Wash
22 RED ROCK MTN.
23 RED ROCK VALLEY
24 COVE
Denotes Irrigated Areas
Study Area Boundary
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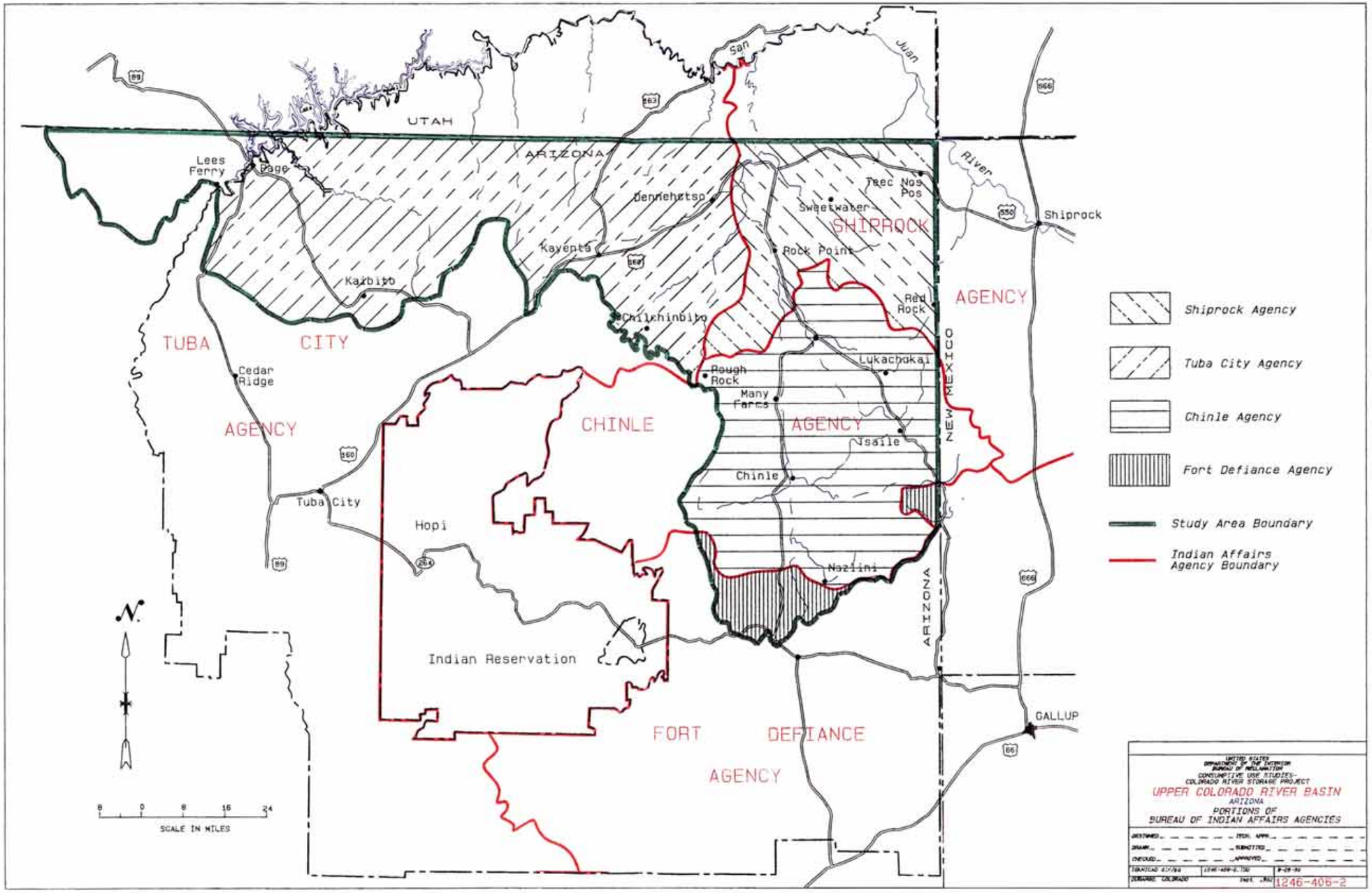
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
UPPER COLORADO RIVER BASIN
CONSUMPTIVE USE STUDIES
ARIZONA
LOCATION MAP
DENVER, COLORADO
March 1987
1246-406-1


UTAH
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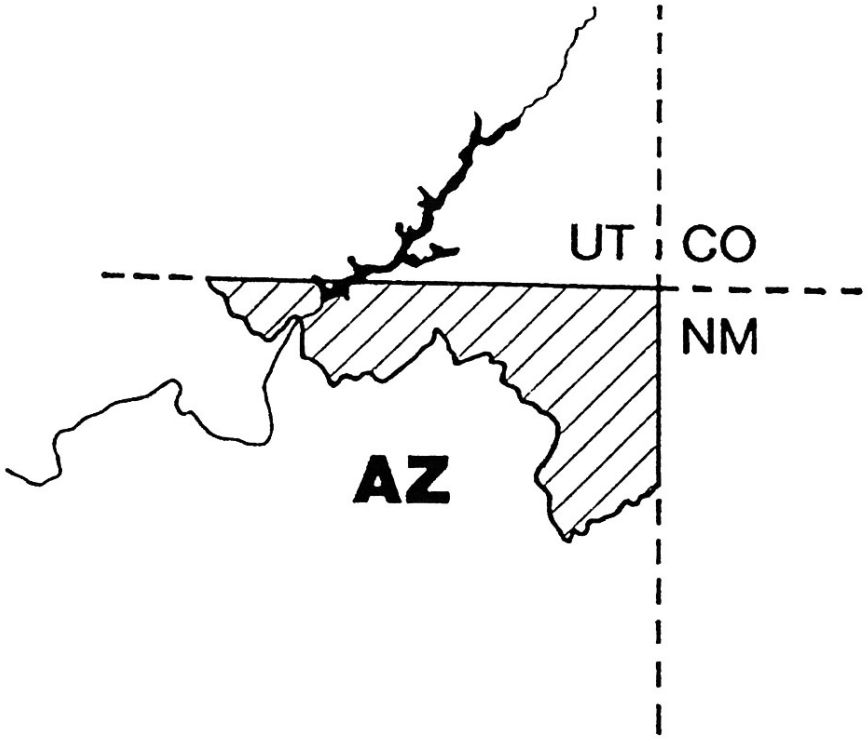
NEW MEXICO
Lees Ferry
Page
Kaibito
Kayenta
Dennehotso
Chilchinbito
Tsec Nos Pos
Sweetwater
Rock Point
Red Rock
Lukachukai
Rough Rock
Many Farms
Chinle
Nazlini
Tuba City
Cedar Ridge
Hopi
Indian Reservation
Shiprock
GALLUP
San Juan River
TUBA CITY AGENCY
CHINLE AGENCY
SHIPROCK AGENCY
FORT DEFIANCE AGENCY
Shiprock Agency
Tuba City Agency
Chinle Agency
Fort Defiance Agency
Study Area Boundary
Indian Affairs Agency Boundary
N.
SCALE IN MILES
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CONSUMPTIVE USE STUDIES-
COLORADO RIVER STORAGE PROJECT
UPPER COLORADO RIVER BASIN
ARIZONA
PORTIONS OF
BUREAU OF INDIAN AFFAIRS AGENCIES
1246-406-2

RECLAMATION

Managing Water in the West

Consumptive Uses and Losses

Arizona Portion of the Upper Colorado River Basin Calendar Year 1997

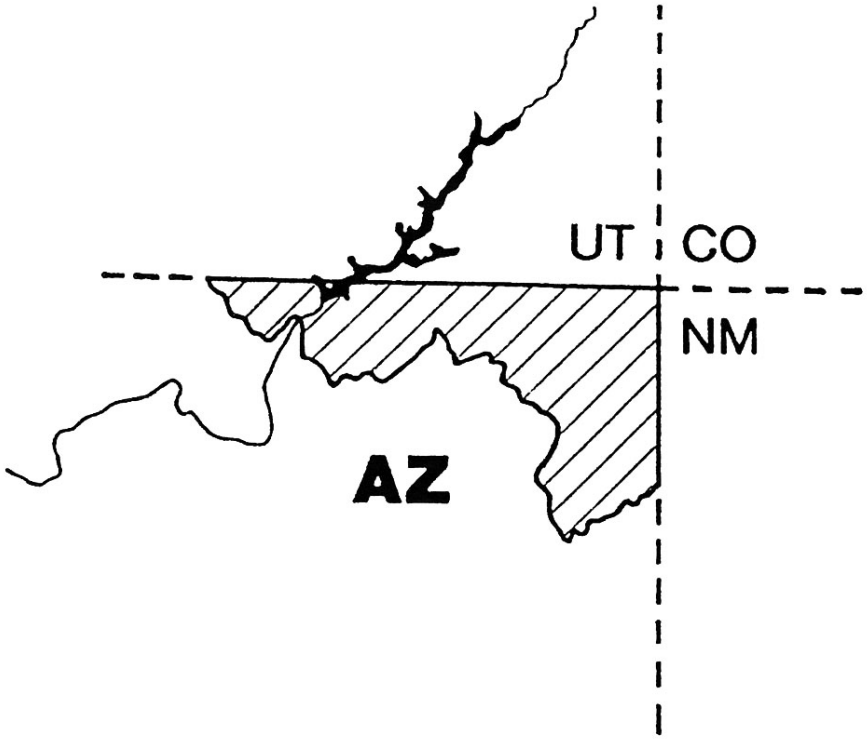


U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

July 2007

Consumptive Uses and Losses

Arizona Portion of the Upper Colorado River Basin
Calendar Year 1997



U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

July 2007

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Tables

CONSUMPTIVE USES AND LOSSES

ARIZONA PORTION OF THE UPPER COLORADO RIVER BASIN

CALENDAR YEAR 1997

AUTHORITY

This report was prepared in compliance with Public Law 90-537, Section 601 (b)(1), dated September 30, 1968, which directs the Secretary of the Interior to "make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis." Additionally, this report is in compliance with Section 49 of the Navajo Project Participation Agreement dated September 30, 1969, which states in part: "The Secretary of the Interior further agrees to make the reports required by Section 601 (b)(1) of Public Law 90-537 as they pertain to Arizona's Upper Basin uses annually rather than every five years. Within fifteen days following the completion of said reports, the Secretary of the Interior shall furnish copies of such reports to the Co-Tenants, the Navajo Tribe, each of the Upper Basin States, and the Upper Colorado River Commission."

SUMMARY

The total consumptive use and loss value for the Arizona portion of the Upper Colorado River Basin for calendar year 1997 was 34,312 ($\pm$1,588) acre-feet.

STUDY AREA DESCRIPTION

The Arizona portion of the Upper Colorado River Basin covers approximately 6,900 square miles in the north-east corner of Arizona, as shown on the location map (Drawing 1246-406-1). The climate of the 5,900 square mile area to the west of the Chuska and Carrizo Mountains is largely arid to semiarid, with mean annual precipitation ranging from 6 to 12 inches and with summertime temperatures often reaching 100 degrees Fahrenheit (^{o}F). The potential evaporation rate is high and exceeds mean annual precipitation, with gross lake evaporation values of up to 55 inches per year or more. Elevations in the western portion range from 3200 feet on the Colorado River at Lees Ferry to over 8000 feet on the northern edge of the Black Mesa and across the Zilnez and Skeleton Mesas, back down to 5280 feet in the Chinle Valley, and back up to about 6500 feet on the western edge of the Chuska Mountains. Much of the western part

of the study area is starkly beautiful southwestern desert country with mesas and canyons intertwined across a pastoral landscape. By contrast, the eastern 1,000 square miles is largely mountainous, with elevations rising to nearly 10,000 feet and mean annual precipitation reaching 30 inches. The mountainous land responds with grass meadows interspersed with conifer forest of mostly ponderosa pine.

Except for Page, Arizona; a small area around Lees Ferry; and a portion of the Paria Plateau administered by the Bureau of Land Management; the study area lies entirely within the Navajo Nation. According to census data, 43,289 persons were living within the area in 1990, and of these 36,641 resided on the Navajo Nation.

The largest cities are Page and Chinle, with 1990 populations of 6,598 and 5059, respectively. Other major communities and their populations include Dennehotso (616), Kaibeto (641), Kayenta (4,372), Lukachukai (113), Many Farms (1,294), Rough Rock (523), Teec Nos Pos (317), and Tsaile (1,043). Subsistence in the region is derived principally from livestock grazing, farming, tourist-related industries, employment at the Navajo Generating Station (NGS), which consumes 60 to 70 percent of the water used or lost in the study area every year. Agriculture accounted for 4 percent of the total water use; municipal and industrial about 78 percent; recreation, fish and wildlife, about 5 percent; and reservoir evaporation, 13 percent.

AGRICULTURAL CONSUMPTIVE USE

Agricultural consumptive use is divided into three categories: irrigation, stock pond, and livestock. Irrigation use includes all use related to irrigating crops including the incidental losses. Stock pond use is the evaporation that occurs from stock ponds and livestock use is the water consumed by livestock.

IRRIGATION USES

Within the Arizona portion of the Upper Colorado River Basin, historically 23 irrigated areas were scattered across the Navajo Nation plus a small amount of land near Lees Ferry irrigated by the National Park Service. Currently, only 15 irrigated areas are in production. An accurate assessment of consumptive use on the irrigated land is difficult due to poor quality of information, such as the exact number of acres under irrigation, the cropping pattern for each irrigated area, site climatological conditions, and the amount of water actually diverted. In many cases, during the latter part of the irrigation season, farmers have to rely on dry land farming since there is little water available in the streams. This means that the crops do not receive their full water requirement.

For this report, the U.S. Department of Agriculture, Soil Conservation Service's (SCS) Modified Blaney-Criddle ET estimation model was used for computing irrigated crop consumptive use. This model, along with appropriate crop-growth stage coefficients and the method for computing effective precipitation, is described in SCS's *Irrigation Water Requirements Technical Release No. 21* (TR 21). Information required for applying this model includes mean monthly temperature and precipitation values, growing season data for each crop type, and the total number of acres planted by crop at each site. With the

exception of Teec Nos Pos, Canyon de Chelly, Lukachukai, and Lees Ferry, no climatological data exist for the irrigation sites, and site values must be generated from data collected at surrounding established weather stations. Growing season dates depend largely on the judgment of the local inhabitants and are, therefore, not known. Although several reports are available with published values for irrigated acres, it is unclear if these values are meant to represent potential irrigated acres, acres irrigated in the past, acres for which farming permits have been issued, or actual acres currently under irrigation.

The crop acreage used to estimate consumptive use by irrigated crops for the year 1997 is shown in table 1. These values were determined from direct field examination by a party composed of representatives from the State of Arizona and the Navajo Nation.

Table 1.—Total irrigated acreage, 1997

PROJECT	CORN (ACRES)	ALFALFA (ACRES)	GRASS PASTURE (ACRES)	SPRING GRAINS (ACRES)	SMALL VEGETABLES (ACRES)	ORCHARD (ACRES)	TOTAL (ACRES)
CHINLE AGENCY							
Canyon de Chelly	0.36	0.00	0.00	3.03	2.26	0.00	5.65
Lukachukai	39.09	7.69	0.00	7.50	5.98	2.07	62.33
Nazlini	0.00	0.00	0.00	0.00	1.79	0.74	2.53
Rough Rock	30.00	0.00	11.87	0.00	12.43	0.00	54.30
Tsaile	23.72	5.27	15.67	5.73	5.42	0.00	55.81
Wheatfields	0.00	60.80	0.00	0.00	0.00	0.00	60.80
TOTAL	93.17	73.76	27.54	16.26	27.88	2.81	241.42
SHIPROCK AGENCY							
Red Rock Valley	26.22	0.00	10.19	5.12	10.22	0.00	51.75
Teec Nos Pos	20.00	0.00	0.00	0.00	3.67	0.00	23.67
Toh Chin Lini	0.00	0.00	0.00	0.00	3.90	13.67	17.57
Totacon	0.00	0.00	0.00	0.00	1.00	0.00	1.00
TOTAL	46.22	0.00	10.19	5.12	18.79	13.67	94.0
WESTERN NAVAJO AGENCY							
Dennehotso	1.82	0.00	38.70	0.00	0.00	0.00	40.52
Lees Ferry	0.00	0.00	1.00	0.00	0.00	2.00	3.00
Marsh Pass	7.02	3.31	0.00	0.00	1.99	0.00	12.32
Navajo Canyon	0.00	0.00	0.00	0.00	0.00	3.50	3.50
Paiute Canyon	2.64	0.00	0.00	0.00	3.86	0.00	6.50
TOTAL	11.48	3.31	39.70	0.00	5.85	5.50	65.84
GRAND TOTAL	150.87	77.07	77.43	21.38	52.52	21.98	401.25

Consumptive Uses and Losses

Several factors complicated the modeling of irrigation consumptive use. For example, the computer program used to model consumptive use assumes a full water supply; if shortages exist, as they often do in this semiarid study area, adjustments must be made. These adjustments are complicated because some of the projects have no storage water and may only have a reliable irrigation water supply during spring runoff. After spring runoff, farming becomes essentially dry land until rains in July and August provide intermittent flows for irrigation. Finally, no ditch diversion records are available to help estimate irrigation water supplies and shortages.

A full irrigation supply seldom exists at many of the projects. Generally, a full supply is available for Lees Ferry, Navajo Canyon, Tsaile, and Wheatfields projects because of adequate stream flows or because of available storage water. In years with average precipitation, it is estimated that Chinle Wash provides approximately 75 percent of the irrigation requirement. Precipitation in the area averages approximately 9.5 inches per year. Based on this information, it would require approximately 12.67 inches of precipitation to provide 100 percent of the irrigation requirement. The percent of crop water requirement met was computed as a ratio of annual precipitation to 12.67 inches. These values are found in table 2.

The percentage of crop water requirement met was multiplied by the total net crop water requirement to come up with the amount of crop consumptive use. Incidental irrigation losses, evaporation, and phreatophyte consumptive use along supply canals are estimated to be 5 percent of the consumptive use of the irrigated area and are added to the crop consumptive use value to develop a total consumptive use value.

A portion of the water used for irrigation at these sites may not be contributing to the Colorado River System, since evaporation rates in the area are high and the nature of most of the drainage enhances evapotranspiration. A good example of such a drainage is Chinle Wash, which after it leaves Canyon de Chelly, becomes wide and sandy and is lined with willows, cottonwoods, and other phreatophytes.

The uncertainties in the irrigation consumptive use values displayed in table 2 are very large and are estimated as 40 percent of the total consumptive use. This estimate of possible error only reflects the uncertainty of consumptive use and does not account for any possible errors in the acreage estimates. The effective consumptive use for irrigation for 1997 was estimated to equal 380 acre-feet. Including the 5 percent for incidental losses, the irrigation related consumptive use is 399 ($\pm$160) acre-feet.

Table 2.—Net consumptive use values, 1997

PROJECT	CROP WATER REQUIREMENT (INCHES)	TOTAL IRRIGATED (ACRES)	TOTAL WATER REQUIRED (ACRE-FEET)	CROP WATER REQUIREMENT MET (%)	CROP WATER REQUIREMENT MET (ACRE-FEET)	TOTAL CONSUMPTIVE USE (ACRE-FEET)[1]
CHINLE AGENCY						
Canyon de Chelly	6.61	5.65	3	37%	1	1
Lukachukai	18.57	62.33	96	35%	34	35
Nazlini	15.86	2.53	3	35%	1	1
Rough Rock	16.70	54.30	76	83%	63	66
Tsaile	19.91	55.81	93	35%	32	34
Wheatfields	27.89	60.80	141	35%	49	52
TOTAL	—	241.42	412	—	180	189
SHIPROCK AGENCY						
Red Rock Valley	19.69	51.75	85	60%	51	54
Teec Nos Pos	20.66	23.67	41	86%	35	37
Toh Chin Lini	31.83	17.57	47	66%	31	32
Totacon	13.70	1.00	1	66%	1	1
TOTAL	—	93.99	173	—	117	123
WESTERN NAVAJO AGENCY						
Dennehotso	26.76	40.52	90	41%	37	39
Lees Ferry	38.79	3.00	10	100%	10	10
Marsh Pass	18.38	12.32	19	100%	19	20
Navajo Canyon	33.52	3.50	10	94%	9	10
Paiute Canyon	15.54	6.50	8	88%	7	8
TOTAL	—	65.84	137	—	82	86
GRAND TOTAL	—	401.25	723	—	380	399

[1] Total includes 5% addition for incidental losses.

STOCK POND EVAPORATION

Stock pond consumptive use is assumed to be the evaporation from the stock pond. It is also assumed that any consumptive use by natural vegetation prior to the construction of the stock ponds is limited to precipitation, which is subtracted from the evaporation losses.

A compilation of the stock ponds in the study area, including their locations and the water surface areas when ponds are full, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 3. For an average year conditions, the stock pond evaporative surface area was estimated as one-third the water surface area that occurs when the ponds are full. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average water surface area. These values are found in table 3.

Table 3.—Stock pond evaporation, 1997

COUNTY	SURFACE AREA FULL (ACRES)	SURFACE AREA USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Coconino	80	27	100%	57	9.90	47.10	105
Navajo	40	13	100%	55	11.47	43.54	48
Apache	646	135	63%	53	5.65	47.35	533
TOTAL	766	175	—	—	—	—	686

This method of evaporation estimation was used because continuous useful water level records for all stock ponds from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual stock ponds. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation. It was assumed that any consumptive use by natural vegetation prior to construction of the stock ponds is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for stock pond evaporation for calendar year 1997 are shown in table 3. The total evaporative losses in 1997 are 686 ($\pm$206) acre-feet with the stock pond evaporation uncertainty being estimated as 30 percent.

LIVESTOCK WATER

The source of most livestock water in the study area is from wells, with windmill-operated pumps developed and maintained by Navajo Water Operations and Maintenance, and water collected in small surface ponds. The estimated number of

livestock in the area was obtained based on livestock tallies. It was estimated that horses and cattle consume 12 gallons per day; sheep and goats consume 2 gallons per day.

The number of animals for the Upper Colorado portion of each district is shown in table 4. The computed value for livestock consumptive use is 243 acre-feet. The uncertainty in this number is estimated as 30 percent of the total or ±73 acre-feet.

Table 4.—Number of livestock, 1997

AGENCY	CATTLE	HORSES	SHEEP	GOATS
Western Navajo District No. 1	1,871	425	1,855	1,231
Western Navajo District No. 2	512	129	1,031	716
Western Navajo District No. 8	1,749	324	2,563	2,419
Shiprock District No. 9	1,869	429	1,912	2,053
Chinle District No. 10	2,741	715	3,598	2,178
Chinle District No. 11	1,784	337	1,434	1,660
Shiprock District No. 12	380	88	1,592	660
Fort Defiance District No. 17	69	35	313	144
Fort Defiance District No. 18	255	81	308	166
TOTAL	11,231	2,562	14,607	11,227

TOTAL AGRICULTURAL CONSUMPTIVE USE

The total agricultural consumptive use, displayed in table 5, is the sum of the individual components discussed in the previous sections. Agricultural water consumption represents approximately 4 percent of the total use in the study area. Total degree of uncertainty was computed by taking the square root of the sum of the individual uncertainties squared; known as the quadratic sum. This method and nomenclature is used throughout this report. This method was used because a simple sum does not account for the partial cancellation of errors occurring when calculating the total uncertainty derived from individual values that are random and independent of each other. As previously discussed, the individual uncertainties were set as a percent of the consumptive use value.

Table 5.—Total agricultural consumptive use, 1997

CATEGORY	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Irrigation	399	160
Stock Ponds	686	206
Livestock	243	73
TOTAL	1,328	270

MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

Municipal and industrial consumptive use is divided into three categories: mineral resources, thermal electric power, and other. Mineral resources consumptive use includes water used for mineral production. No mineral resources consumptive use is reported in the study area. Thermal electric power consumptive use includes the water used at the power plants, and that used to transport material to the power plant (such as a coal slurry pipeline). Other consumptive use includes urban, rural, and industrial uses.

THERMAL ELECTRIC POWER

Thermal electric power consumptive use includes the water used in the power plant and the water used to transport material to the plant.

Navajo Generating Station

The water used by the NGS is pumped directly from Lake Powell and comprises over half of the total consumption in the study area. Since all NGS water use is metered, this quantity is among those most precisely known, with the maximum uncertainty in the metered quantities believed to be less than 3 percent. The actual quantity consumed, along with the estimated uncertainty for the calendar year 1997, was 22,364 (±671) acre-feet.

Consumption is expected to grow during the years 1997-1999, due to antipollution "scrubbers" scheduled to be installed on the exhaust stack. Water use is expected to increase by and estimated 3,000 acre-feet.

OTHER

The other consumptive use category includes the remaining use by urban, rural, and industries.

Page, AZ and Vicinity

***City of Page, AZ*. –** The city of Page pumps its domestic water directly from Lake Powell. The water pumped is metered, and the uncertainty of the pumped quantities was assumed to be less than 3 percent. A portion of the water pumped and treated by the City of Page, is supplied to the community of Le Chee on the Navajo Nation and is accounted for separately. The quantity supplied to the City of Page and its associated uncertainty for the calendar year 1997 was 2,613 (±78) acre-feet. Water returning to the waste water treatment plant is metered as well. The waste water for the City of Page is treated and is either evaporated from lined ponds or applied to the golf course, with a portion being returned to the Colorado River. The return flow is estimated to be 890 acre-feet. The net consumptive use is estimated to be 1,723 acre-feet (±83).

Le Chee – The community of Le Chee is supplied and metered by the City of Page. Total water supplied for 1997 was 95 (±3) acre-feet. The uncertainty was estimated to be 3 percent.

Greenhaven Water Company – The Greenhaven Water Company derives its domestic water supply from wells. Well pumping records are available. According to these records, the total water pumped for 1997 was 75 (±5) acre-feet. The uncertainty was estimated to be 7 percent.

Arizona Department of Transportation Housing – The Arizona Department of Transportation operates a housing, maintenance, and administrative facility located on US Hwy 89, north of Page, AZ. This facility is supplied from wells that have no meters installed. It is estimated that the total water pumped for 1997 was 11 acre-feet with an uncertainty of 30 percent of this value or ±3 acre-feet.

Navajo Nation

Community Water Systems – Statistics from the Division of Community Development of the Navajo Nation reveal that various community water systems served 26,086, or about 83 percent of the 31,429 people residing within the study area in 1980. This percentage was used for 1997 resulting in 33,391 out of 40,230 people being served. These systems include those operated by the Navajo Tribal Utility Authority (NTUA), the BIA, and the Water Operations and Maintenance Department of the Navajo Nation, and some privately developed community water systems.

Table 6 shows the source of water and estimated population served by each source of water for people living on the Navajo Nation during 1997. All of the communities obtain their water supply from ground water.

Table 6.—Domestic water sources, 1997

SOURCE	PERCENTAGE OF POPULATION SERVED	NUMBER OF POPULATION SERVED[1]
Community Water Systems	83	33,391
NTUA	[2](60)	20,034
BIA	[2](25)	8,348
Navajo WOM	[2](13)	4,341
Private	[2](2)	668
Individual Wells	17	6,839
TOTAL[2]	100	40,230

[1] Estimated total population within the Upper Colorado River Basin portion of the Navajo Nation provided by Larry Rodgers, Demographer for the Division of Community Development of the Navajo Nation, letter DCDA-L94052, June 20, 1995.

[2] These numbers are a percentage of the Community Water Systems.

NTUA Water Systems – The cities and surrounding communities of Oak Springs, Red Valley, Sweetwater, Chinle , Rough Rock, Round Rock, Rock Point, Wheatfields, Lukachukai, Kayenta, Chilchinbeto, Dennehotso, and Kaibeto derive most of their domestic water supply from wells operated by NTUA. Well pumping records are available. According to these records, the total water pumped for 1997 was 1,339 acre-feet with an uncertainty estimated to be 7 percent of this value or ±94 acre-feet.

The NTUA manages the raw waste water; portions of which flow to individual septic tanks, some to evaporation ponds, and some, such as for the cities of Chinle and Kayenta, flow to waste water treatment plants. Very little water, if any, is returned to the ground water system through leakage from the evaporation ponds, but there are losses from the main collection system. Effluent from the Chinle and Kayenta waste water treatment plants is metered. Under normal conditions, the effluent returns to the Colorado River System and is subtracted from the pumping totals to determine a net consumptive use. For 1997, Chinle's treatment plant effluent was 424 (±30) acre-feet, and Kayenta's effluent was 264 (±18) acre-feet. An estimated uncertainty of 7 percent was used for the effluent of these two plants. The total effluent of 688 acre-feet is subtracted from the NTUA pumping total of 1,339 acre-feet to arrive at a net consumptive use of 651 (±105) acre-feet.

BIA Water Systems – Wells developed and operated by the BIA serve numerous Navajo communities. These systems also serve BIA schools, hospitals, agency offices, and some housing on the Navajo Nation. Metered records for total amounts of water pumped from BIA wells were available for a portion of the Shiprock Agency, the Western Navajo Agency, and the Chinle Agency. Drawing 1246-406-2 shows the agency boundaries within the Upper Colorado River Basin. The uncertainty was estimated to be about 7 percent for all three agencies.

The BIA systems include sewage disposal units terminating in lined evaporation ponds with very little or no return water returning to the ground water system. Undoubtedly, some losses occur in distribution, but insufficient data currently exist to estimate these losses. The losses are probably less than the uncertainties for each of the reported values.

The BIA well data available for the Shiprock Agency include: Cove, Red Rock, and Teec Nos Pos. Total consumptive use values are 46 (±3) acre-feet.

Pumping records for the Western Navajo Agency include data for the following schools: Chilchinbeto Day School, Dennehotso Boarding School, Kaibeto Boarding School, and Kayenta Boarding School. Total consumptive use for the Western Navajo Agency was 136 (±9) acre-feet.

Well pumping records for the Chinle Agency include data for the following schools: Cottonwood Day School, Lukachukai School, and Rock Point School. Rough Rock School maintains its own records, but the data was included with the Chinle Agency data. Total consumptive use for the Chinle Agency was 360 (±25) acre-feet.

Navajo WOM Water Systems – Water use in 1997 by the Navajo WOM service areas was based on an assumed consumption rate of 110 gallons per capita per day (gpcd). For a 1997 estimated service area population of 4,341, the estimated annual

water use was 535 (±160) acre-feet. The uncertainty is estimated as 30 percent of the total.

Private Water Systems – The estimated 1997 population served by private water systems on the Navajo Nation was 668. Assuming a consumptive use rate of 110 gcpd, the annual water use for 1997 was 82 (±25) acre-feet. The uncertainty is estimated as 30 percent of the total.

Individual Wells – According to census data from the Division of Community Development of the Navajo Nation, approximately 17 percent of the study area's population on the reservation (about 6,839 persons in 1997) receives a domestic water supply from individual wells. A consumptive use of 110 gpcd was derived as being a reasonable water use rate. Based on these figures, the annual consumptive use was 843 (±253) acre-feet for 1997.

TOTAL MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

The total municipal and industrial consumptive use, displayed in table 7, is the sum of the individual components discussed in the previous sections. Municipal and industrial water consumption represents approximately 78 percent of the total use in the study area.

Table 7.—Total municipal and industrial consumptive use, 1997

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
THERMAL ELECTRIC POWER		
Navajo Generating Station	22,364	671
OTHER		
Page, AZ and Vicinity		
City of Page	1,723	83
Le Chee	95	3
Greenhaven Water Company	75	5
Arizona Department of Transportation	11	3
Navajo Indian Reservation		
Community Water Systems		
NTUA Water Systems	651	105
BIA Water Systems	541	27
Navajo WOM	535	160
Private Water Systems	82	25
Individual Wells	843	253
TOTAL	26,919	747

It is questionable whether all the water pumped from wells should be considered a depletion to the Colorado River System; however, it is assumed that 100 percent of the water pumped is considered lost to the system. It is proposed that a future joint study be completed by Reclamation, the State of Arizona, and the Navajo Nation to estimate what percentage of water pumped could actually be attributed to the Colorado River System and would have affected the river flows for a particular year.

RECREATION, FISH AND WILDLIFE

The recreation, fish and wildlife consumptive uses include evaporation from reservoirs used exclusively for fish & wildlife purposes as well as acreages irrigated for wildlife feeding. Consumptive use at National and State parks is also accounted for.

GLEN CANYON NATIONAL RECREATION AREA

Colorado River water is used by the Glen Canyon National Recreation Area (GCNRA) at Wahweap and Lees Ferry. The recreational area at Wahweap gets its water supply from a series of wells on the shore of Lake Powell. Pumping records for both Wahweap and Lees Ferry show 378 ($\pm$11) acre-feet of water withdrawn during 1997. The uncertainty is estimated at 3 percent. This water was used for domestic purposes at the campgrounds, picnic areas, and trailer parks. It was also used to irrigate approximately 60 acres of Bermuda grass and cottonwood trees. The domestic waste water is treated and the effluent is allowed to evaporate from two lines evaporation ponds with a total surface area of 16.7 acres.

Based on estimates of evaporation and consumptive use by the plants, there is some water which is unaccounted for and is assumed to be leakage from the delivery system, the evaporation pond, or deep percolation from irrigation application. However, since these water losses are difficult to quantify and verify, the losses were charged as consumptive uses. Therefore, net consumptive use of water is estimated to be equal to the quantity of water pumped.

RESERVOIR EVAPORATION

A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled “1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River” and are shown in table 8.

Efforts are made to maintain a nearly full condition and to minimize water surface fluctuations in reservoirs managed for a fishery. Under average operating conditions, the water surface area of a reservoir used primarily for fishing is assumed to be equal to a normal water surface area. In 1997, these reservoirs filled in the spring and were maintained at the normal pool level.

Table 8. —Recreation, fish and wildlife reservoir evaporation, 1997

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE AREA USED (ACRES)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Tsaile	260	260	35	4.42	30.58	663
Wheatfields	272	272	32	4.42	27.58	625
TOTAL	532	532	—	—	—	1,288

This method of evaporation estimation was used because continuous useful water level records for all reservoirs from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs.

For this report, the NOAA Technical Report NWS 33 “Evaporation Atlas for the Contiguous 48 United States,” June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for reservoir evaporation for calendar year 1997 are shown in table 8. The total evaporative losses in 1997 are 1,288 (±386) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent.

TOTAL RECREATION, FISH AND WILDLIFE

The total recreation, fish and wildlife consumptive use, displayed in table 9, is the sum of the individual components discussed in the previous sections. Recreation, fish and wildlife water consumption represents approximately 5 percent of the total use in the study area.

Table 9.—Total recreation, fish and wildlife consumptive use, 1997

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Glen Canyon National Recreation Area	378	11
Reservoir Evaporation	1,288	386
TOTAL	1,666	386

RESERVOIR EVAPORATION

Reservoir evaporation losses make up about 13 percent of the total water uses and losses in the study area. A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 10. These reservoirs are used primarily for irrigation.

Table 10.—Reservoir evaporation, 1997

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE ACRES USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Many Farms	1,800	967	—	56	4.63	51.37	4,138
Marsh Pass	40	20	100%	40	13.93	26.07	43
Round Rock	83	20	48%	57	4.53	52.48	87
Walker Creek	30	15	100%	59	10.85	48.15	60
Others	38	19	100%	55	10.56	44.44	70
TOTAL	1,991	1,041	—	—	—	—	4,399

Reservoirs used primarily for irrigation experience large fluctuations in water levels and, correspondingly, large variations in surface area. Reservoir level records and elevation – area curves were available at Many Farms, but not for the remaining reservoirs in table 10. For the reservoirs with no records from which surface area could be accurately computed, the average evaporative surface area was estimated as one-half the water surface area of a full reservoir. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average evaporative surface area.

Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses. The computed values for reservoir evaporation for 1997 are shown in table 10. The total evaporative losses in 1997 are 4,399 ($\pm$1,320) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent of the total evaporation.

CONCLUSIONS

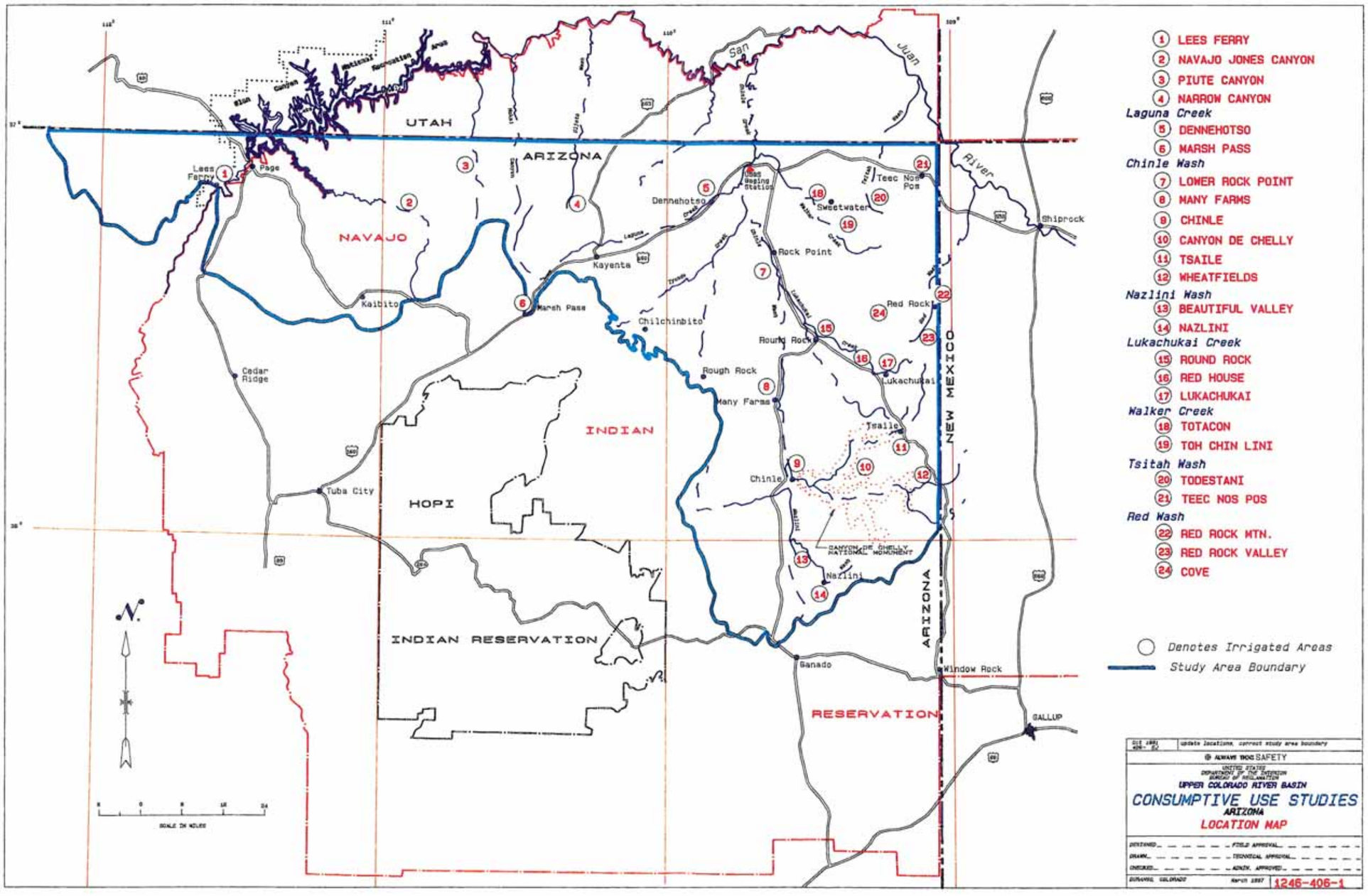
This report assesses the total consumptive use of the Arizona portion of the Upper Colorado River System surface water systems, depletion of ground water, and evaporative losses. Clearly, the amounts of water used by the Navajo Generating Station, City of Page, and Wahweap and Lees Ferry recreation areas are direct depletions of water from the Upper Colorado River System, but the situation is not as clear for other consumptive uses and losses occurring in other sections of the study area. For example, the source of water used by the Navajo Nation for domestic and municipal purposes is from wells, some exceeding 1,000 feet in depth. For our purposes here, it is considered to be consumed and a depletion to the Colorado River System. But this may not actually result in a reduction of Colorado River stream flows in the same year that the withdrawal occurs. Little knowledge and information exists of ground water movement and subsurface flow rates in the study area that are accurate descriptions of the effects on river flows.

Although the water diverted for agricultural purposes is considered as consumptive use in this report, a portion of the remaining surface water on the Navajo Nation, excess to needs, does evaporate before reaching the Colorado River. An attempt has not been made for this report to quantify these losses.

Uncertainties in estimating uses and losses exist, and the degree of variation in the figures is presented. Fortunately, the areas with the highest degree of uncertainty account for only a small percentage of the total consumptive use. The largest component, use by the Navajo Generating Station, is also the most accurately monitored. The total annual value for estimated consumptive use of water within the Arizona portion of the Upper Colorado River Basin for 1997 was 34,312 acre-feet, as shown in table 11.

Table 11.—Consumptive use for Arizona portion of Upper Colorado River Basin for 1997

USE CATEGORY	TOTAL CONSUMPTIVE USE (ACRE-FEET)	UNCERTAINTY	PERCENT OF TOTAL
Agriculture	1,328	270	4
Municipal & Industrial	26,919	747	78
Recreation, Fish & Wildlife	1,666	386	5
Reservoir Evaporation	4,399	1,320	13
TOTAL	34,312	1,588	100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ARIZONA
NEW MEXICO
NAVAJO
INDIAN
HOPI
INDIAN RESERVATION
RESERVATION
San Juan River
Lees Ferry
Page
Kaibito
Cedar Ridge
Tuba City
Marsh Pass
Kayenta
Dennehotso
Chilchinbito
Rough Rock
Many Farms
Chinle
Rock Point
Sweetwater
Teec Nos Pos
Red Rock
Round Rock
Lukachukai
Tsaile
Nazlini
Ganado
Window Rock
GALLUP
Shiprock
CANYON DE CHELLY NATIONAL MONUMENT
1 LEES FERRY
2 NAVAJO JONES CANYON
3 PIUTE CANYON
4 NARROW CANYON
Laguna Creek
5 DENNEHOTSO
6 MARSH PASS
Chinle Wash
7 LOWER ROCK POINT
8 MANY FARMS
9 CHINLE
10 CANYON DE CHELLY
11 TSAILE
12 WHEATFIELDS
Nazlini Wash
13 BEAUTIFUL VALLEY
14 NAZLINI
Lukachukai Creek
15 ROUND ROCK
16 RED HOUSE
17 LUKACHUKAI
Walker Creek
18 TOTACON
19 TOH CHIN LINI
Tsitah Wash
20 TODESTANI
21 TEEC NOS POS
Red Wash
22 RED ROCK MTN.
23 RED ROCK VALLEY
24 COVE
Denotes Irrigated Areas
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DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
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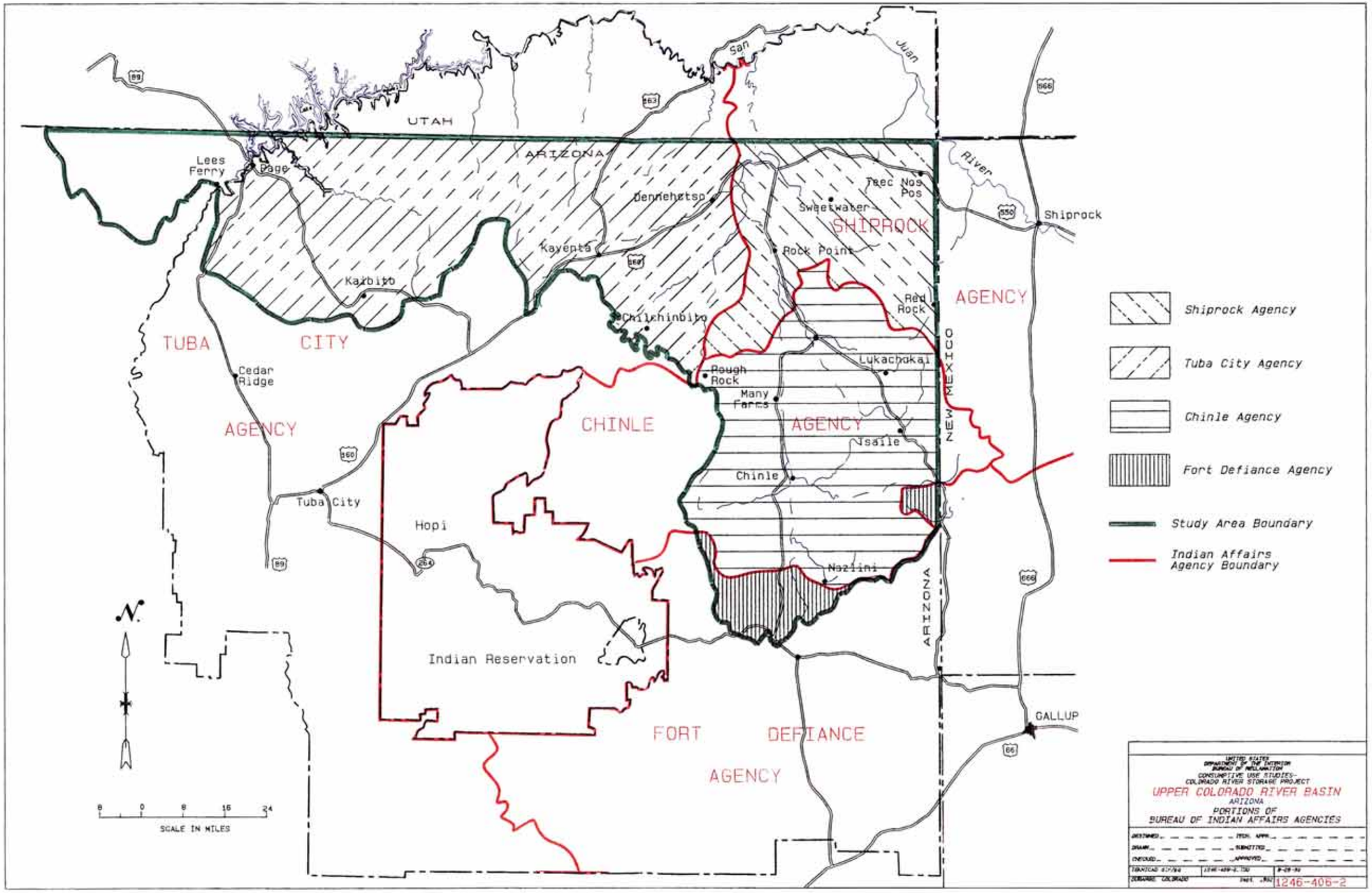
CONSUMPTIVE USE STUDIES
ARIZONA
LOCATION MAP
DENVER, COLORADO
March 1987
1246-406-1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Lees Ferry
Page
Kaibito
Kayenta
Dennehotso
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Tsec Nos Pos
Sweetwater
Rock Point
Red Rock
Lukachukai
Rough Rock
Many Farms
Chinle
Nazlini
Tuba City
Cedar Ridge
Hopi
Indian Reservation
Shiprock
GALLUP
San Juan River
TUBA CITY AGENCY
CHINLE AGENCY
SHIPROCK AGENCY
FORT DEFIANCE AGENCY
Shiprock Agency
Tuba City Agency
Chinle Agency
Fort Defiance Agency
Study Area Boundary
Indian Affairs Agency Boundary
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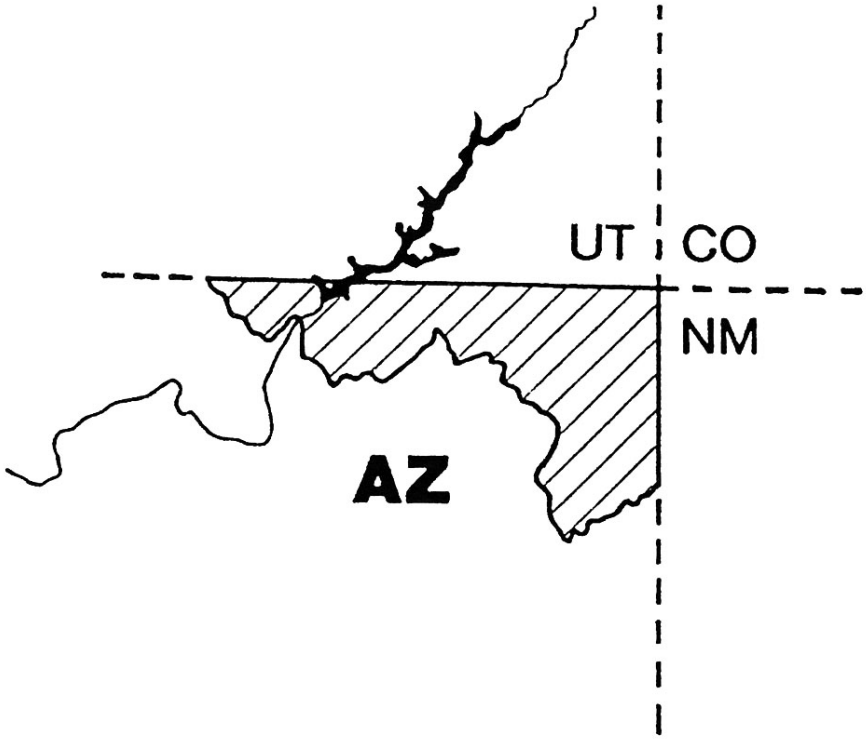
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CONSUMPTIVE USE STUDIES-
COLORADO RIVER STORAGE PROJECT
UPPER COLORADO RIVER BASIN
ARIZONA
PORTIONS OF
BUREAU OF INDIAN AFFAIRS AGENCIES
1246-406-2

RECLAMATION

Managing Water in the West

Consumptive Uses and Losses

Arizona Portion of the Upper Colorado River Basin Calendar Year 1998

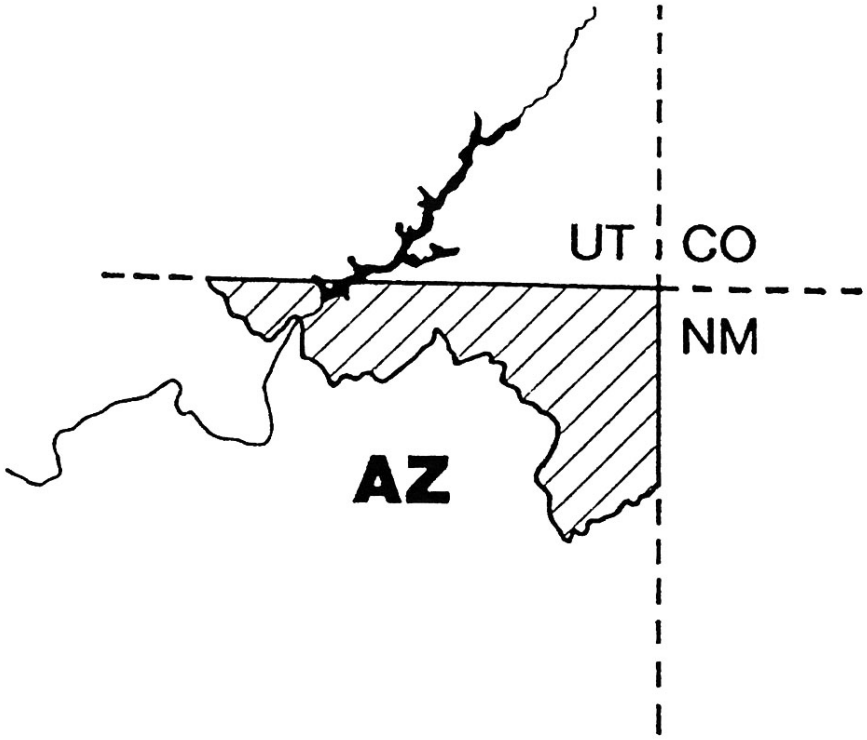


U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

July 2007

Consumptive Uses and Losses

Arizona Portion of the Upper Colorado River Basin
Calendar Year 1998



U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

July 2007

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CONSUMPTIVE USES AND LOSSES

ARIZONA PORTION OF THE UPPER COLORADO RIVER BASIN

CALENDAR YEAR 1998

AUTHORITY

This report was prepared in compliance with Public Law 90-537, Section 601 (b)(1), dated September 30, 1968, which directs the Secretary of the Interior to "make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis." Additionally, this report is in compliance with Section 49 of the Navajo Project Participation Agreement dated September 30, 1969, which states in part: "The Secretary of the Interior further agrees to make the reports required by Section 601 (b)(1) of Public Law 90-537 as they pertain to Arizona's Upper Basin uses annually rather than every five years. Within fifteen days following the completion of said reports, the Secretary of the Interior shall furnish copies of such reports to the Co-Tenants, the Navajo Tribe, each of the Upper Basin States, and the Upper Colorado River Commission."

SUMMARY

The total consumptive use and loss value for the Arizona portion of the Upper Colorado River Basin for calendar year 1998 was 37,123 (±1,543) acre-feet.

STUDY AREA DESCRIPTION

The Arizona portion of the Upper Colorado River Basin covers approximately 6,900 square miles in the north-east corner of Arizona, as shown on the location map (Drawing 1246-406-1). The climate of the 5,900 square mile area to the west of the Chuska and Carrizo Mountains is largely arid to semiarid, with mean annual precipitation ranging from 6 to 12 inches and with summertime temperatures often reaching 100 degrees Fahrenheit (^{o}F). The potential evaporation rate is high and exceeds mean annual precipitation, with gross lake evaporation values of up to 55 inches per year or more. Elevations in the western portion range from 3200 feet on the Colorado River at Lees Ferry to over 8000 feet on the northern edge of the Black Mesa and across the Zilnez and Skeleton Mesas, back down to 5280 feet in the Chinle Valley, and back up to about 6500 feet on the western edge of the Chuska Mountains. Much of the western part

of the study area is starkly beautiful southwestern desert country with mesas and canyons intertwined across a pastoral landscape. By contrast, the eastern 1,000 square miles is largely mountainous, with elevations rising to nearly 10,000 feet and mean annual precipitation reaching 30 inches. The mountainous land responds with grass meadows interspersed with conifer forest of mostly ponderosa pine.

Except for Page, Arizona; a small area around Lees Ferry; and a portion of the Paria Plateau administered by the Bureau of Land Management; the study area lies entirely within the Navajo Nation. According to census data, 43,289 persons were living within the area in 1990, and of these 36,641 resided on the Navajo Nation.

The largest cities are Page and Chinle, with 1990 populations of 6,598 and 5059, respectively. Other major communities and their populations include Dennehotso (616), Kaibeto (641), Kayenta (4,372), Lukachukai (113), Many Farms (1,294), Rough Rock (523), Teec Nos Pos (317), and Tsaile (1,043). Subsistence in the region is derived principally from livestock grazing, farming, tourist-related industries, employment at the Navajo Generating Station (NGS), which consumes 60 to 70 percent of the water used or lost in the study area every year. Agriculture accounted for 4 percent of the total water use; municipal and industrial about 81 percent; recreation, fish and wildlife, about 4 percent; and reservoir evaporation, 11 percent.

AGRICULTURAL CONSUMPTIVE USE

Agricultural consumptive use is divided into three categories: irrigation, stock pond, and livestock. Irrigation use includes all use related to irrigating crops including the incidental losses. Stock pond use is the evaporation that occurs from stock ponds and livestock use is the water consumed by livestock.

IRRIGATION USES

Within the Arizona portion of the Upper Colorado River Basin, historically 23 irrigated areas were scattered across the Navajo Nation plus a small amount of land near Lees Ferry irrigated by the National Park Service. Currently, only 15 irrigated areas are in production. An accurate assessment of consumptive use on the irrigated land is difficult due to poor quality of information, such as the exact number of acres under irrigation, the cropping pattern for each irrigated area, site climatological conditions, and the amount of water actually diverted. In many cases, during the latter part of the irrigation season, farmers have to rely on dry land farming since there is little water available in the streams. This means that the crops do not receive their full water requirement.

For this report, the U.S. Department of Agriculture, Soil Conservation Service's (SCS) Modified Blaney-Criddle ET estimation model was used for computing irrigated crop consumptive use. This model, along with appropriate crop-growth stage coefficients and the method for computing effective precipitation, is described in SCS's *Irrigation Water Requirements Technical Release No. 21* (TR 21). Information required for applying this model includes mean monthly temperature and precipitation values, growing season data for each crop type, and the total number of acres planted by crop at each site. With the

exception of Teec Nos Pos, Canyon de Chelly, Lukachukai, and Lees Ferry, no climatological data exist for the irrigation sites, and site values must be generated from data collected at surrounding established weather stations. Growing season dates depend largely on the judgment of the local inhabitants and are, therefore, not known. Although several reports are available with published values for irrigated acres, it is unclear if these values are meant to represent potential irrigated acres, acres irrigated in the past, acres for which farming permits have been issued, or actual acres currently under irrigation.

The crop acreage used to estimate consumptive use by irrigated crops for the year 1998 is shown in table 1. These values were determined from direct field examination by a party composed of representatives from the State of Arizona and the Navajo Nation.

Table 1.—Total irrigated acreage, 1998

PROJECT	CORN (ACRES)	ALFALFA (ACRES)	GRASS PASTURE (ACRES)	SPRING GRAINS (ACRES)	SMALL VEGETABLES (ACRES)	ORCHARD (ACRES)	TOTAL (ACRES)
CHINLE AGENCY							
Canyon de Chelly	0.36	0.00	0.00	3.03	2.26	0.00	5.65
Lukachukai	39.09	7.69	0.00	7.50	5.98	2.07	62.33
Nazlini	0.00	0.00	0.00	0.00	1.79	0.74	2.53
Rough Rock	30.00	0.00	11.87	0.00	12.43	0.00	54.30
Tsaile	23.72	5.27	15.67	5.73	5.42	0.00	55.81
Wheatfields	0.00	60.80	0.00	0.00	0.00	0.00	60.80
TOTAL	93.17	73.76	27.54	16.26	27.88	2.81	241.42
SHIPROCK AGENCY							
Red Rock Valley	26.22	0.00	10.19	5.12	10.22	0.00	51.75
Teec Nos Pos	20.00	0.00	0.00	0.00	3.67	0.00	23.67
Toh Chin Lini	0.00	0.00	0.00	0.00	3.90	13.67	17.57
Totacon	0.00	0.00	0.00	0.00	1.00	0.00	1.00
TOTAL	46.22	0.00	10.19	5.12	18.79	13.67	94.0
WESTERN NAVAJO AGENCY							
Dennehotso	1.82	0.00	38.70	0.00	0.00	0.00	40.52
Lees Ferry	0.00	0.00	1.00	0.00	0.00	2.00	3.00
Marsh Pass	7.02	3.31	0.00	0.00	1.99	0.00	12.32
Navajo Canyon	0.00	0.00	0.00	0.00	0.00	3.50	3.50
Paiute Canyon	2.64	0.00	0.00	0.00	3.86	0.00	6.50
TOTAL	11.48	3.31	39.70	0.00	5.85	5.50	65.84
GRAND TOTAL	150.87	77.07	77.43	21.38	52.52	21.98	401.25

Consumptive Uses and Losses

Several factors complicated the modeling of irrigation consumptive use. For example, the computer program used to model consumptive use assumes a full water supply; if shortages exist, as they often do in this semiarid study area, adjustments must be made. These adjustments are complicated because some of the projects have no storage water and may only have a reliable irrigation water supply during spring runoff. After spring runoff, farming becomes essentially dry land until rains in July and August provide intermittent flows for irrigation. Finally, no ditch diversion records are available to help estimate irrigation water supplies and shortages.

A full irrigation supply seldom exists at many of the projects. Generally, a full supply is available for Lees Ferry, Navajo Canyon, Tsaile, and Wheatfields projects because of adequate stream flows or because of available storage water. In years with average precipitation, it is estimated that Chinle Wash provides approximately 75 percent of the irrigation requirement. Precipitation in the area averages approximately 9.5 inches per year. Based on this information, it would require approximately 12.67 inches of precipitation to provide 100 percent of the irrigation requirement. The percent of crop water requirement met was computed as a ratio of annual precipitation to 12.67 inches. These values are found in table 2.

The percentage of crop water requirement met was multiplied by the total net crop water requirement to come up with the amount of crop consumptive use. Incidental irrigation losses, evaporation, and phreatophyte consumptive use along supply canals are estimated to be 5 percent of the consumptive use of the irrigated area and are added to the crop consumptive use value to develop a total consumptive use value.

A portion of the water used for irrigation at these sites may not be contributing to the Colorado River System, since evaporation rates in the area are high and the nature of most of the drainage enhances evapotranspiration. A good example of such a drainage is Chinle Wash, which after it leaves Canyon de Chelly, becomes wide and sandy and is lined with willows, cottonwoods, and other phreatophytes.

The uncertainties in the irrigation consumptive use values displayed in table 2 are very large and are estimated as 40 percent of the total consumptive use. This estimate of possible error only reflects the uncertainty of consumptive use and does not account for any possible errors in the acreage estimates. The effective consumptive use for irrigation for 1998 was estimated to equal 441 acre-feet. Including the 5 percent for incidental losses, the irrigation related consumptive use is 463 ($\pm$185) acre-feet.

Table 2.—Net consumptive use values, 1998

PROJECT	CROP WATER REQUIREMENT (INCHES)	TOTAL IRRIGATED (ACRES)	TOTAL WATER REQUIRED (ACRE-FEET)	CROP WATER REQUIREMENT MET (%)	CROP WATER REQUIREMENT MET (ACRE-FEET)	TOTAL CONSUMPTIVE USE (ACRE-FEET)[1]
CHINLE AGENCY						
Canyon de Chelly	7.74	5.65	4	73%	3	3
Lukachukai	20.64	62.33	107	35%	37	39
Nazlini	17.05	2.53	4	35%	1	1
Rough Rock	20.95	54.30	95	95%	90	95
Tsaile	21.49	55.81	100	35%	35	37
Wheatfields	30.09	60.80	152	35%	53	56
TOTAL	—	241.42	462	—	220	231
SHIPROCK AGENCY						
Red Rock Valley	20.97	51.75	90	55%	49	52
Teec Nos Pos	23.23	23.67	46	74%	34	36
Toh Chin Lini	31.35	17.57	46	60%	28	29
Totacon	14.65	1.00	1	60%	1	1
TOTAL	—	93.99	183	—	112	117
WESTERN NAVAJO AGENCY						
Dennehotso	30.31	40.52	102	60%	61	64
Lees Ferry	37.87	3.00	9	100%	9	10
Marsh Pass	21.57	12.32	22	100%	22	23
Navajo Canyon	33.93	3.50	10	91%	9	9
Paiute Canyon	17.87	6.50	10	82%	8	8
TOTAL	—	65.84	154	—	110	115
GRAND TOTAL	—	401.25	799	—	441	463

[1] Total includes 5% addition for incidental losses.

STOCK POND EVAPORATION

Stock pond consumptive use is assumed to be the evaporation from the stock pond. It is also assumed that any consumptive use by natural vegetation prior to the construction of the stock ponds is limited to precipitation, which is subtracted from the evaporation losses.

A compilation of the stock ponds in the study area, including their locations and the water surface areas when ponds are full, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 3. For an average year conditions, the stock pond evaporative surface area was estimated as one-third the water surface area that occurs when the ponds are full. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average water surface area. These values are found in table 3.

Table 3.—Stock pond evaporation, 1998

COUNTY	SURFACE AREA FULL (ACRES)	SURFACE AREA USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Coconino	80	27	100%	57	9.27	47.73	106
Navajo	40	13	100%	55	9.95	45.06	50
Apache	646	199	92%	53	8.33	44.67	741
TOTAL	766	239	—	—	—	—	897

This method of evaporation estimation was used because continuous useful water level records for all stock ponds from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual stock ponds. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation. It was assumed that any consumptive use by natural vegetation prior to construction of the stock ponds is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for stock pond evaporation for calendar year 1998 are shown in table 3. The total evaporative losses in 1998 are 897 ($\pm$269) acre-feet with the stock pond evaporation uncertainty being estimated as 30 percent.

LIVESTOCK WATER

The source of most livestock water in the study area is from wells, with windmill-operated pumps developed and maintained by Navajo Water Operations and Maintenance, and water collected in small surface ponds. The estimated number of

livestock in the area was obtained based on livestock tallies. It was estimated that horses and cattle consume 12 gallons per day; sheep and goats consume 2 gallons per day.

The number of animals for the Upper Colorado portion of each district is shown in table 4. The computed value for livestock consumptive use is 243 acre-feet. The uncertainty in this number is estimated as 30 percent of the total or ±73 acre-feet.

Table 4.—Number of livestock, 1998

AGENCY	CATTLE	HORSES	SHEEP	GOATS
Western Navajo District No. 1	1,871	425	1,855	1,231
Western Navajo District No. 2	512	129	1,031	716
Western Navajo District No. 8	1,749	324	2,563	2,419
Shiprock District No. 9	1,869	429	1,912	2,053
Chinle District No. 10	2,741	715	3,598	2,178
Chinle District No. 11	1,784	337	1,434	1,660
Shiprock District No. 12	380	88	1,592	660
Fort Defiance District No. 17	69	35	313	144
Fort Defiance District No. 18	255	81	308	166
TOTAL	11,231	2,562	14,607	11,227

TOTAL AGRICULTURAL CONSUMPTIVE USE

The total agricultural consumptive use, displayed in table 5, is the sum of the individual components discussed in the previous sections. Agricultural water consumption represents approximately 4 percent of the total use in the study area. Total degree of uncertainty was computed by taking the square root of the sum of the individual uncertainties squared; known as the quadratic sum. This method and nomenclature is used throughout this report. This method was used because a simple sum does not account for the partial cancellation of errors occurring when calculating the total uncertainty derived from individual values that are random and independent of each other. As previously discussed, the individual uncertainties were set as a percent of the consumptive use value.

Table 5.—Total agricultural consumptive use, 1998

CATEGORY	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Irrigation	463	185
Stock Ponds	897	269
Livestock	243	73
TOTAL	1,603	335

MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

Municipal and industrial consumptive use is divided into three categories: mineral resources, thermal electric power, and other. Mineral resources consumptive use includes water used for mineral production. No mineral resources consumptive use is reported in the study area. Thermal electric power consumptive use includes the water used at the power plants, and that used to transport material to the power plant (such as a coal slurry pipeline). Other consumptive use includes urban, rural, and industrial uses.

THERMAL ELECTRIC POWER

Thermal electric power consumptive use includes the water used in the power plant and the water used to transport material to the plant.

Navajo Generating Station

The water used by the NGS is pumped directly from Lake Powell and comprises over half of the total consumption in the study area. Since all NGS water use is metered, this quantity is among those most precisely known, with the maximum uncertainty in the metered quantities believed to be less than 3 percent. The actual quantity consumed, along with the estimated uncertainty for the calendar year 1998, was 25,017 ($\pm$751) acre-feet.

Consumption is expected to grow during the years 1997-1999, due to antipollution "scrubbers" scheduled to be installed on the exhaust stack. Water use is expected to increase by and estimated 3,000 acre-feet.

OTHER

The other consumptive use category includes the remaining use by urban, rural, and industries.

Page, AZ and Vicinity

***City of Page, AZ*. –** The city of Page pumps its domestic water directly from Lake Powell. The water pumped is metered, and the uncertainty of the pumped quantities was assumed to be less than 3 percent. A portion of the water pumped and treated by the City of Page, is supplied to the community of Le Chee on the Navajo Nation and is accounted for separately. The quantity supplied to the City of Page and its associated uncertainty for the calendar year 1998 was 2,589 ($\pm$78) acre-feet. Water returning to the waste water treatment plant is metered as well. The waste water for the City of Page is treated and is either evaporated from lined ponds or applied to the golf course, with a portion being returned to the Colorado River. The return flow is estimated to be 810 acre-feet. The net consumptive use is estimated to be 1,779 acre-feet ($\pm$81).

Le Chee – The community of Le Chee is supplied and metered by the City of Page. Total water supplied for 1998 was 95 (±3) acre-feet. The uncertainty was estimated to be 3 percent.

Greenhaven Water Company – The Greenhaven Water Company derives its domestic water supply from wells. Well pumping records are available. According to these records, the total water pumped for 1998 was 74 (±5) acre-feet. The uncertainty was estimated to be 7 percent.

Arizona Department of Transportation Housing – The Arizona Department of Transportation operates a housing, maintenance, and administrative facility located on US Hwy 89, north of Page, AZ. This facility is supplied from wells that have no meters installed. It is estimated that the total water pumped for 1998 was 11 acre-feet with an uncertainty of 30 percent of this value or ±3 acre-feet.

Navajo Nation

Community Water Systems – Statistics from the Division of Community Development of the Navajo Nation reveal that various community water systems served 26,086, or about 83 percent of the 31,429 people residing within the study area in 1980. This percentage was used for 1998 resulting in 33,823 out of 40,751 people being served. These systems include those operated by the Navajo Tribal Utility Authority (NTUA), the BIA, and the Water Operations and Maintenance Department of the Navajo Nation, and some privately developed community water systems.

Table 6 shows the source of water and estimated population served by each source of water for people living on the Navajo Nation during 1998. All of the communities obtain their water supply from ground water.

Table 6.—Domestic water sources, 1998

SOURCE	PERCENTAGE OF POPULATION SERVED	NUMBER OF POPULATION SERVED[1]
Community Water Systems	83	33,823
NTUA	[2](60)	20,294
BIA	[2](25)	8,456
Navajo WOM	[2](13)	4,397
Private	[2](2)	676
Individual Wells	17	6,928
TOTAL[2]	100	40,751

[1] Estimated total population within the Upper Colorado River Basin portion of the Navajo Nation provided by Larry Rodgers, Demographer for the Division of Community Development of the Navajo Nation, letter DCDA-L94052, June 20, 1995.

[2] These numbers are a percentage of the Community Water Systems.

NTUA Water Systems – The cities and surrounding communities of Oak Springs, Red Valley, Sweetwater, Chinle , Rough Rock, Round Rock, Rock Point, Wheatfields, Lukachukai, Kayenta, Chilchinbeto, Dennehotso, and Kaibeto derive most of their domestic water supply from wells operated by NTUA. Well pumping records are available. According to these records, the total water pumped for 1998 was 1,569 acre-feet with an uncertainty estimated to be 7 percent of this value or ±110 acre-feet.

The NTUA manages the raw waste water; portions of which flow to individual septic tanks, some to evaporation ponds, and some, such as for the cities of Chinle and Kayenta, flow to waste water treatment plants. Very little water, if any, is returned to the ground water system through leakage from the evaporation ponds, but there are losses from the main collection system. Effluent from the Chinle and Kayenta waste water treatment plants is metered. Under normal conditions, the effluent returns to the Colorado River System and is subtracted from the pumping totals to determine a net consumptive use. For 1998, Chinle's treatment plant effluent was 425 (±30) acre-feet, and Kayenta's effluent was 258 (±18) acre-feet. An estimated uncertainty of 7 percent was used for the effluent of these two plants. The total effluent of 682 acre-feet is subtracted from the NTUA pumping total of 1,339 acre-feet to arrive at a net consumptive use of 887 (±120) acre-feet.

BIA Water Systems – Wells developed and operated by the BIA serve numerous Navajo communities. These systems also serve BIA schools, hospitals, agency offices, and some housing on the Navajo Nation. Metered records for total amounts of water pumped from BIA wells were available for a portion of the Shiprock Agency, the Western Navajo Agency, and the Chinle Agency. Drawing 1246-406-2 shows the agency boundaries within the Upper Colorado River Basin. The uncertainty was estimated to be about 7 percent for all three agencies.

The BIA systems include sewage disposal units terminating in lined evaporation ponds with very little or no return water returning to the ground water system. Undoubtedly, some losses occur in distribution, but insufficient data currently exist to estimate these losses. The losses are probably less than the uncertainties for each of the reported values.

The BIA well data available for the Shiprock Agency include: Cove, Red Rock, and Teec Nos Pos. Total consumptive use values are 29 (±2) acre-feet.

Pumping records for the Western Navajo Agency include data for the following schools: Chilchinbeto Day School, Dennehotso Boarding School, Kaibeto Boarding School, and Kayenta Boarding School. Total consumptive use for the Western Navajo Agency was 209 (±15) acre-feet.

Well pumping records for the Chinle Agency include data for the following schools: Cottonwood Day School, Lukachukai School, and Rock Point School. Rough Rock School maintains its own records, but the data was included with the Chinle Agency data. Total consumptive use for the Chinle Agency was 370 (±26) acre-feet.

Navajo WOM Water Systems – Water use in 1998 by the Navajo WOM service areas was based on an assumed consumption rate of 110 gallons per capita per day (gpcd). For a 1998 estimated service area population of 4,397, the estimated annual

water use was 542 (±163) acre-feet. The uncertainty is estimated as 30 percent of the total.

Private Water Systems – The estimated 1998 population served by private water systems on the Navajo Nation was 676. Assuming a consumptive use rate of 110 gcpd, the annual water use for 1998 was 83 (±25) acre-feet. The uncertainty is estimated as 30 percent of the total.

Individual Wells – According to census data from the Division of Community Development of the Navajo Nation, approximately 17 percent of the study area's population on the reservation (about 6,928 persons in 1998) receives a domestic water supply from individual wells. A consumptive use of 110 gpcd was derived as being a reasonable water use rate. Based on these figures, the annual consumptive use was 854 (±256) acre-feet for 1998.

TOTAL MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

The total municipal and industrial consumptive use, displayed in table 7, is the sum of the individual components discussed in the previous sections. Municipal and industrial water consumption represents approximately 84 percent of the total use in the study area.

Table 7.—Total municipal and industrial consumptive use, 1998

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
THERMAL ELECTRIC POWER		
Navajo Generating Station	25,017	751
OTHER		
Page, AZ and Vicinity		
City of Page	1,779	81
Le Chee	95	3
Greenhaven Water Company	74	5
Arizona Department of Transportation	11	3
Navajo Indian Reservation		
Community Water Systems		
NTUA Water Systems	887	120
BIA Water Systems	607	30
Navajo WOM	542	163
Private Water Systems	83	25
Individual Wells	854	256
TOTAL	29,950	823

It is questionable whether all the water pumped from wells should be considered a depletion to the Colorado River System; however, it is assumed that 100 percent of the water pumped is considered lost to the system. It is proposed that a future joint study be completed by Reclamation, the State of Arizona, and the Navajo Nation to estimate what percentage of water pumped could actually be attributed to the Colorado River System and would have affected the river flows for a particular year.

RECREATION, FISH AND WILDLIFE

The recreation, fish and wildlife consumptive uses include evaporation from reservoirs used exclusively for fish & wildlife purposes as well as acreages irrigated for wildlife feeding. Consumptive use at National and State parks is also accounted for.

GLEN CANYON NATIONAL RECREATION AREA

Colorado River water is used by the Glen Canyon National Recreation Area (GCNRA) at Wahweap and Lees Ferry. The recreational area at Wahweap gets its water supply from a series of wells on the shore of Lake Powell. Pumping records for both Wahweap and Lees Ferry show 336 ($\pm$10) acre-feet of water withdrawn during 1998. The uncertainty is estimated at 3 percent. This water was used for domestic purposes at the campgrounds, picnic areas, and trailer parks. It was also used to irrigate approximately 60 acres of Bermuda grass and cottonwood trees. The domestic waste water is treated and the effluent is allowed to evaporate from two lines evaporation ponds with a total surface area of 16.7 acres.

Based on estimates of evaporation and consumptive use by the plants, there is some water which is unaccounted for and is assumed to be leakage from the delivery system, the evaporation pond, or deep percolation from irrigation application. However, since these water losses are difficult to quantify and verify, the losses were charged as consumptive uses. Therefore, net consumptive use of water is estimated to be equal to the quantity of water pumped.

RESERVOIR EVAPORATION

A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled “1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River” and are shown in table 8.

Efforts are made to maintain a nearly full condition and to minimize water surface fluctuations in reservoirs managed for a fishery. Under average operating conditions, the water surface area of a reservoir used primarily for fishing is assumed to be equal to a normal water surface area. In 1998, these reservoirs filled in the spring and were maintained at the normal pool level.

Table 8. —Recreation, fish and wildlife reservoir evaporation, 1998

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE AREA USED (ACRES)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Tsaile	260	260	35	6.28	28.72	622
Wheatfields	272	272	32	6.28	25.72	583
TOTAL	532	532	—	—	—	1,205

This method of evaporation estimation was used because continuous useful water level records for all reservoirs from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs.

For this report, the NOAA Technical Report NWS 33 “Evaporation Atlas for the Contiguous 48 United States,” June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for reservoir evaporation for calendar year 1998 are shown in table 8. The total evaporative losses in 1998 are 1,205 ($\pm$362) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent.

TOTAL RECREATION, FISH AND WILDLIFE

The total recreation, fish and wildlife consumptive use, displayed in table 9, is the sum of the individual components discussed in the previous sections. Recreation, fish and wildlife water consumption represents approximately 4 percent of the total use in the study area.

Table 9.—Total recreation, fish and wildlife consumptive use, 1998

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Glen Canyon National Recreation Area	336	10
Reservoir Evaporation	1,205	362
TOTAL	1,541	362

RESERVOIR EVAPORATION

Reservoir evaporation losses make up about 8 percent of the total water uses and losses in the study area. A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 10. These reservoirs are used primarily for irrigation.

Table 10.—Reservoir evaporation, 1998

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE ACRES USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Many Farms	1,800	953	—	56	9.26	46.74	3,712
Marsh Pass	40	20	100%	40	12.42	27.58	46
Round Rock	83	34	82%	57	7.77	49.23	140
Walker Creek	30	15	100%	59	9.42	49.58	62
Others	38	19	100%	55	11.17	43.83	69
TOTAL	1,991	1,041	—	—	—	—	4,029

Reservoirs used primarily for irrigation experience large fluctuations in water levels and, correspondingly, large variations in surface area. Reservoir level records and elevation – area curves were available at Many Farms, but not for the remaining reservoirs in table 10. For the reservoirs with no records from which surface area could be accurately computed, the average evaporative surface area was estimated as one-half the water surface area of a full reservoir. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average evaporative surface area.

Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses. The computed values for reservoir evaporation for 1998 are shown in table 10. The total evaporative losses in 1998 are 4,028 ($\pm$1,209) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent of the total evaporation.

CONCLUSIONS

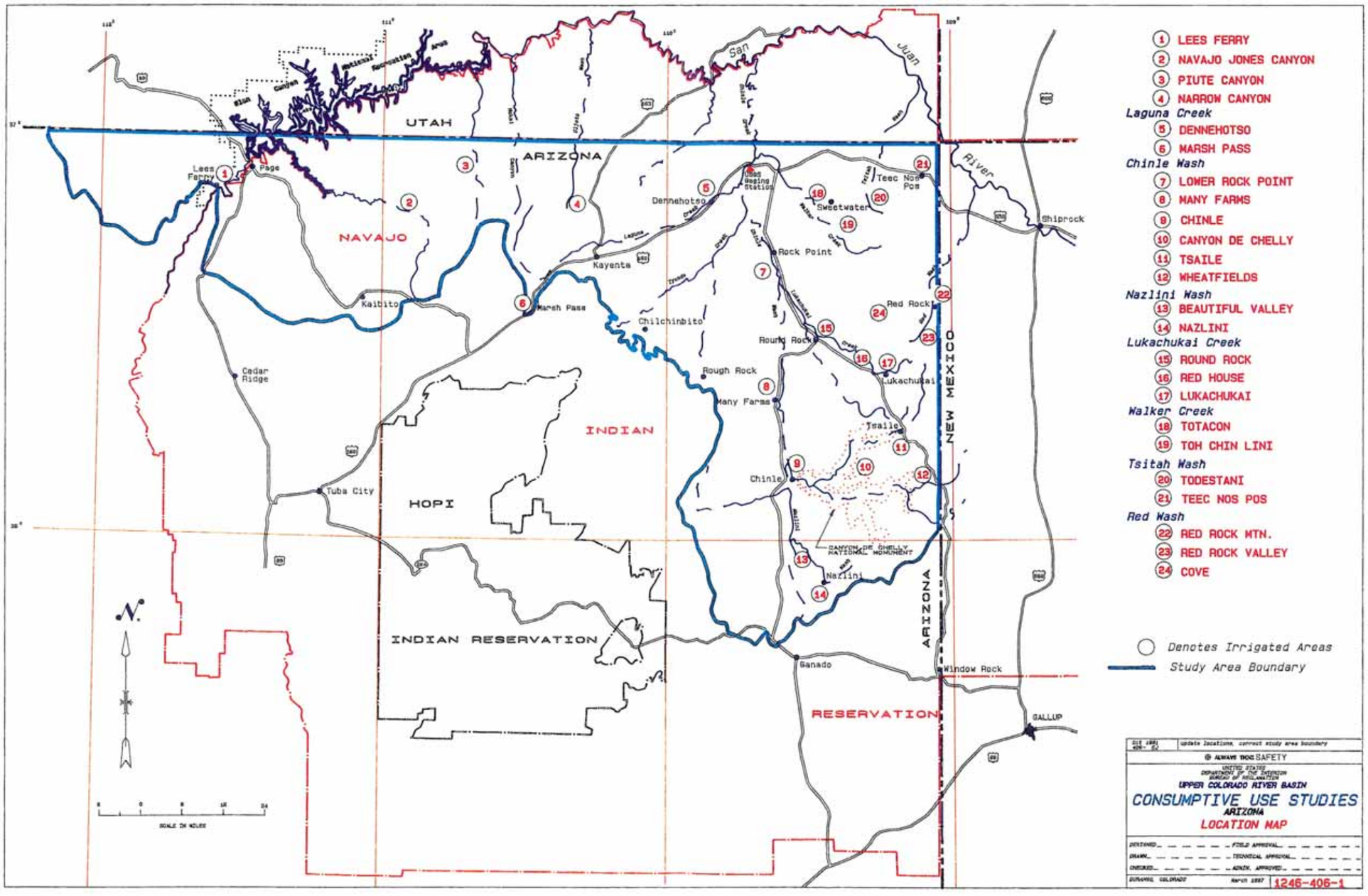
This report assesses the total consumptive use of the Arizona portion of the Upper Colorado River System surface water systems, depletion of ground water, and evaporative losses. Clearly, the amounts of water used by the Navajo Generating Station, City of Page, and Wahweap and Lees Ferry recreation areas are direct depletions of water from the Upper Colorado River System, but the situation is not as clear for other consumptive uses and losses occurring in other sections of the study area. For example, the source of water used by the Navajo Nation for domestic and municipal purposes is from wells, some exceeding 1,000 feet in depth. For our purposes here, it is considered to be consumed and a depletion to the Colorado River System. But this may not actually result in a reduction of Colorado River stream flows in the same year that the withdrawal occurs. Little knowledge and information exists of ground water movement and subsurface flow rates in the study area that are accurate descriptions of the effects on river flows.

Although the water diverted for agricultural purposes is considered as consumptive use in this report, a portion of the remaining surface water on the Navajo Nation, excess to needs, does evaporate before reaching the Colorado River. An attempt has not been made for this report to quantify these losses.

Uncertainties in estimating uses and losses exist, and the degree of variation in the figures is presented. Fortunately, the areas with the highest degree of uncertainty account for only a small percentage of the total consumptive use. The largest component, use by the Navajo Generating Station, is also the most accurately monitored. The total annual value for estimated consumptive use of water within the Arizona portion of the Upper Colorado River Basin for 1998 was 37,123 acre-feet, as shown in table 11.

Table 11.—Consumptive use for Arizona portion of Upper Colorado River Basin for 1998

USE CATEGORY	TOTAL CONSUMPTIVE USE (ACRE-FEET)	UNCERTAINTY	PERCENT OF TOTAL
Agriculture	1,603	335	4
Municipal & Industrial	29,950	823	81
Recreation, Fish & Wildlife	1,541	362	4
Reservoir Evaporation	4,029	1,209	11
TOTAL	37,123	1,543	100


UTAH
ARIZONA
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NAVAJO
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INDIAN RESERVATION
RESERVATION
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Lees Ferry
Page
Kaibito
Cedar Ridge
Tuba City
Marsh Pass
Kayenta
Dennehotso
Chilchinbito
Rough Rock
Many Farms
Chinle
Rock Point
Sweetwater
Teec Nos Pos
Red Rock
Round Rock
Lukachukai
Tsaile
Nazlini
Ganado
Window Rock
GALLUP
Shiprock
CANYON DE CHELLY NATIONAL MONUMENT
1 LEES FERRY
2 NAVAJO JONES CANYON
3 PIUTE CANYON
4 NARROW CANYON
Laguna Creek
5 DENNEHOTSO
6 MARSH PASS
Chinle Wash
7 LOWER ROCK POINT
8 MANY FARMS
9 CHINLE
10 CANYON DE CHELLY
11 TSAILE
12 WHEATFIELDS
Nazlini Wash
13 BEAUTIFUL VALLEY
14 NAZLINI
Lukachukai Creek
15 ROUND ROCK
16 RED HOUSE
17 LUKACHUKAI
Walker Creek
18 TOTACON
19 TOH CHIN LINI
Tsitah Wash
20 TODESTANI
21 TEEC NOS POS
Red Wash
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23 RED ROCK VALLEY
24 COVE
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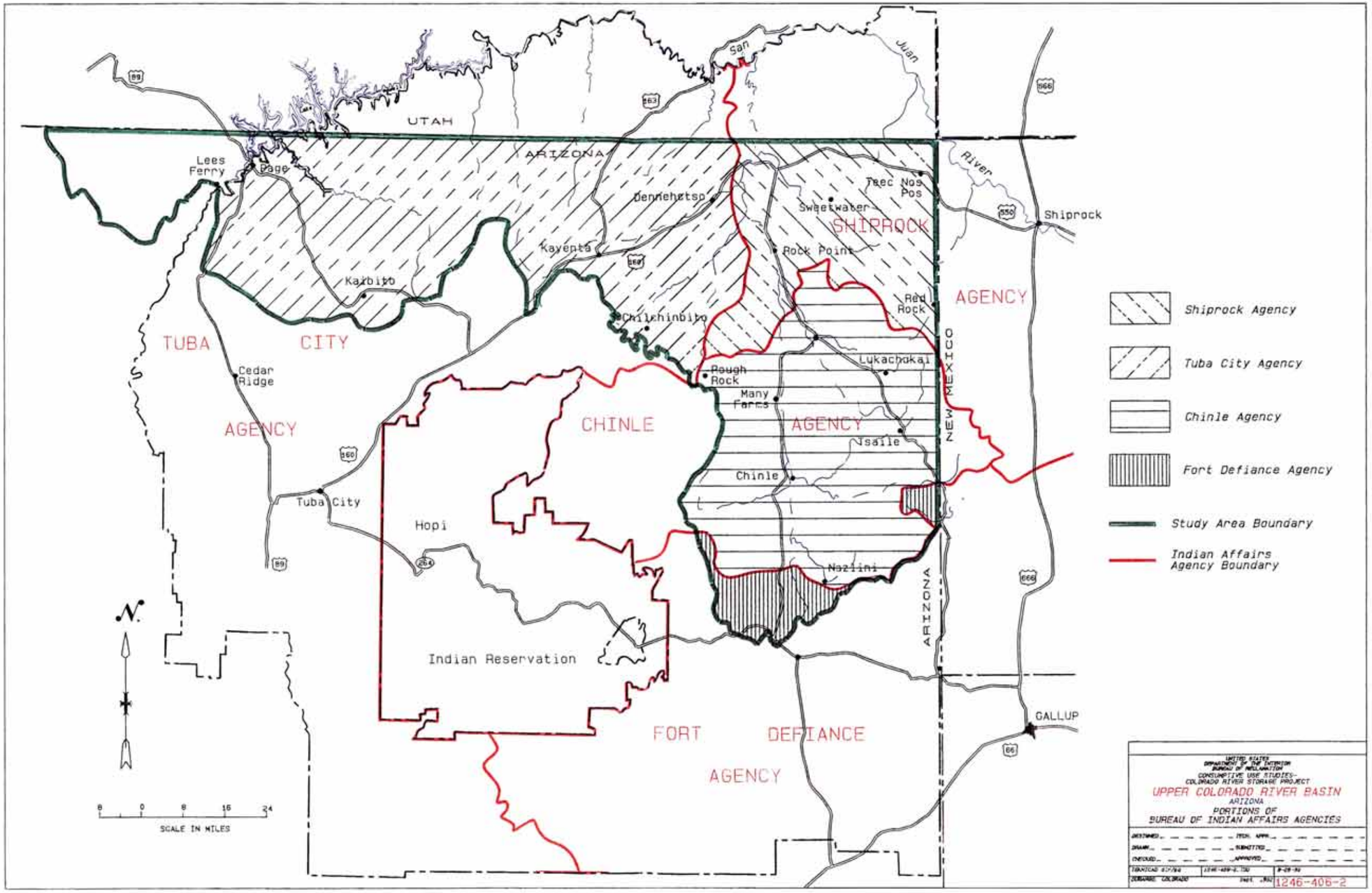
UPPER COLORADO RIVER BASIN
CONSUMPTIVE USE STUDIES
ARIZONA
LOCATION MAP
DENVER, COLORADO
March 1987
1246-406-1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Lukachukai
Rough Rock
Many Farms
Chinle
Nazlini
Tuba City
Cedar Ridge
Hopi
Indian Reservation
Shiprock
GALLUP
San Juan River
TUBA CITY AGENCY
CHINLE AGENCY
SHIPROCK AGENCY
FORT DEFIANCE AGENCY
Shiprock Agency
Tuba City Agency
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Fort Defiance Agency
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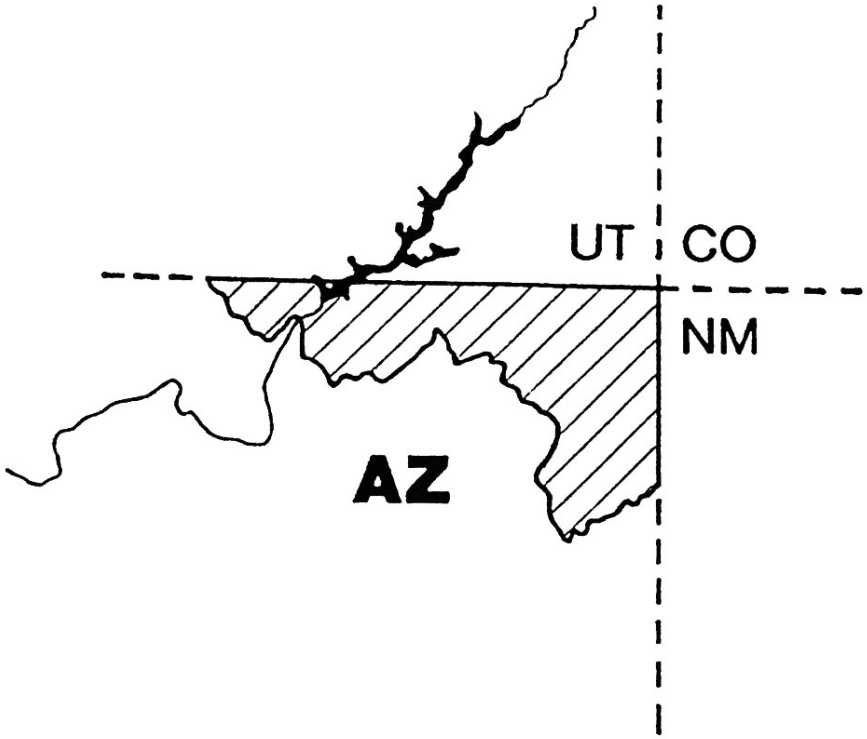
BUREAU OF RECLAMATION
CONSUMPTIVE USE STUDIES-
COLORADO RIVER STORAGE PROJECT
UPPER COLORADO RIVER BASIN
ARIZONA
PORTIONS OF
BUREAU OF INDIAN AFFAIRS AGENCIES
1246-406-2

RECLAMATION

Managing Water in the West

Consumptive Uses and Losses

Arizona Portion of the Upper Colorado River Basin Calendar Year 1999

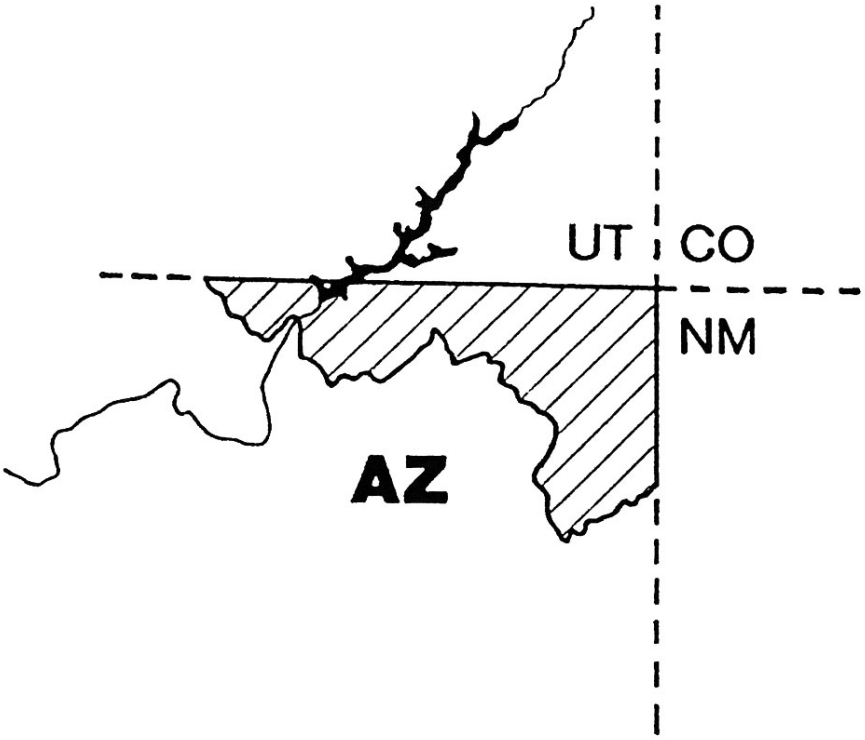


U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

July 2007

Consumptive Uses and Losses

Arizona Portion of the Upper Colorado River Basin
Calendar Year 1999



U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

July 2007

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CONSUMPTIVE USES AND LOSSES

ARIZONA PORTION OF THE UPPER COLORADO RIVER BASIN

CALENDAR YEAR 1999

AUTHORITY

This report was prepared in compliance with Public Law 90-537, Section 601 (b)(1), dated September 30, 1968, which directs the Secretary of the Interior to "make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis." Additionally, this report is in compliance with Section 49 of the Navajo Project Participation Agreement dated September 30, 1969, which states in part: "The Secretary of the Interior further agrees to make the reports required by Section 601 (b)(1) of Public Law 90-537 as they pertain to Arizona's Upper Basin uses annually rather than every five years. Within fifteen days following the completion of said reports, the Secretary of the Interior shall furnish copies of such reports to the Co-Tenants, the Navajo Tribe, each of the Upper Basin States, and the Upper Colorado River Commission."

SUMMARY

The total consumptive use and loss value for the Arizona portion of the Upper Colorado River Basin for calendar year 1999 was 38,530 ($\pm$1,519) acre-feet.

STUDY AREA DESCRIPTION

The Arizona portion of the Upper Colorado River Basin covers approximately 6,900 square miles in the north-east corner of Arizona, as shown on the location map (Drawing 1246-406-1). The climate of the 5,900 square mile area to the west of the Chuska and Carrizo Mountains is largely arid to semiarid, with mean annual precipitation ranging from 6 to 12 inches and with summertime temperatures often reaching 100 degrees Fahrenheit (^{o}F). The potential evaporation rate is high and exceeds mean annual precipitation, with gross lake evaporation values of up to 55 inches per year or more. Elevations in the western portion range from 3200 feet on the Colorado River at Lees Ferry to over 8000 feet on the northern edge of the Black Mesa and across the Zilnez and Skeleton Mesas, back down to 5280 feet in the Chinle Valley, and back up to about 6500 feet on the western edge of the Chuska Mountains. Much of the western part

of the study area is starkly beautiful southwestern desert country with mesas and canyons intertwined across a pastoral landscape. By contrast, the eastern 1,000 square miles is largely mountainous, with elevations rising to nearly 10,000 feet and mean annual precipitation reaching 30 inches. The mountainous land responds with grass meadows interspersed with conifer forest of mostly ponderosa pine.

Except for Page, Arizona; a small area around Lees Ferry; and a portion of the Paria Plateau administered by the Bureau of Land Management; the study area lies entirely within the Navajo Nation. According to census data, 43,289 persons were living within the area in 1990, and of these 36,641 resided on the Navajo Nation.

The largest cities are Page and Chinle, with 1990 populations of 6,598 and 5059, respectively. Other major communities and their populations include Dennehotso (616), Kaibeto (641), Kayenta (4,372), Lukachukai (113), Many Farms (1,294), Rough Rock (523), Teec Nos Pos (317), and Tsaile (1,043). Subsistence in the region is derived principally from livestock grazing, farming, tourist-related industries, employment at the Navajo Generating Station (NGS), which consumes 60 to 70 percent of the water used or lost in the study area every year. Agriculture accounted for 4 percent of the total water use; municipal and industrial about 82 percent; recreation, fish and wildlife, about 4 percent; and reservoir evaporation, 10 percent.

AGRICULTURAL CONSUMPTIVE USE

Agricultural consumptive use is divided into three categories: irrigation, stock pond, and livestock. Irrigation use includes all use related to irrigating crops including the incidental losses. Stock pond use is the evaporation that occurs from stock ponds and livestock use is the water consumed by livestock.

IRRIGATION USES

Within the Arizona portion of the Upper Colorado River Basin, historically 23 irrigated areas were scattered across the Navajo Nation plus a small amount of land near Lees Ferry irrigated by the National Park Service. Currently, only 15 irrigated areas are in production. An accurate assessment of consumptive use on the irrigated land is difficult due to poor quality of information, such as the exact number of acres under irrigation, the cropping pattern for each irrigated area, site climatological conditions, and the amount of water actually diverted. In many cases, during the latter part of the irrigation season, farmers have to rely on dry land farming since there is little water available in the streams. This means that the crops do not receive their full water requirement.

For this report, the U.S. Department of Agriculture, Soil Conservation Service's (SCS) Modified Blaney-Criddle ET estimation model was used for computing irrigated crop consumptive use. This model, along with appropriate crop-growth stage coefficients and the method for computing effective precipitation, is described in SCS's *Irrigation Water Requirements Technical Release No. 21* (TR 21). Information required for applying this model includes mean monthly temperature and precipitation values, growing season data for each crop type, and the total number of acres planted by crop at each site. With the

exception of Teec Nos Pos, Canyon de Chelly, Lukachukai, and Lees Ferry, no climatological data exist for the irrigation sites, and site values must be generated from data collected at surrounding established weather stations. Growing season dates depend largely on the judgment of the local inhabitants and are, therefore, not known. Although several reports are available with published values for irrigated acres, it is unclear if these values are meant to represent potential irrigated acres, acres irrigated in the past, acres for which farming permits have been issued, or actual acres currently under irrigation.

The crop acreage used to estimate consumptive use by irrigated crops for the year 1999 is shown in table 1. These values were determined from direct field examination by a party composed of representatives from the State of Arizona and the Navajo Nation.

Table 1.—Total irrigated acreage, 1999

PROJECT	CORN (ACRES)	ALFALFA (ACRES)	GRASS PASTURE (ACRES)	SPRING GRAINS (ACRES)	SMALL VEGETABLES (ACRES)	ORCHARD (ACRES)	TOTAL (ACRES)
CHINLE AGENCY							
Canyon de Chelly	0.36	0.00	0.00	3.03	2.26	0.00	5.65
Lukachukai	39.09	7.69	0.00	7.50	5.98	2.07	62.33
Nazlini	0.00	0.00	0.00	0.00	1.79	0.74	2.53
Rough Rock	30.00	0.00	11.87	0.00	12.43	0.00	54.30
Tsaile	23.72	5.27	15.67	5.73	5.42	0.00	55.81
Wheatfields	0.00	60.80	0.00	0.00	0.00	0.00	60.80
TOTAL	93.17	73.76	27.54	16.26	27.88	2.81	241.42
SHIPROCK AGENCY							
Red Rock Valley	26.22	0.00	10.19	5.12	10.22	0.00	51.75
Teec Nos Pos	20.00	0.00	0.00	0.00	3.67	0.00	23.67
Toh Chin Lini	0.00	0.00	0.00	0.00	3.90	13.67	17.57
Totacon	0.00	0.00	0.00	0.00	1.00	0.00	1.00
TOTAL	46.22	0.00	10.19	5.12	18.79	13.67	94.0
WESTERN NAVAJO AGENCY							
Dennehotso	1.82	0.00	38.70	0.00	0.00	0.00	40.52
Lees Ferry	0.00	0.00	1.00	0.00	0.00	2.00	3.00
Marsh Pass	7.02	3.31	0.00	0.00	1.99	0.00	12.32
Navajo Canyon	0.00	0.00	0.00	0.00	0.00	3.50	3.50
Paiute Canyon	2.64	0.00	0.00	0.00	3.86	0.00	6.50
TOTAL	11.48	3.31	39.70	0.00	5.85	5.50	65.84
GRAND TOTAL	150.87	77.07	77.43	21.38	52.52	21.98	401.25

Consumptive Uses and Losses

Several factors complicated the modeling of irrigation consumptive use. For example, the computer program used to model consumptive use assumes a full water supply; if shortages exist, as they often do in this semiarid study area, adjustments must be made. These adjustments are complicated because some of the projects have no storage water and may only have a reliable irrigation water supply during spring runoff. After spring runoff, farming becomes essentially dry land until rains in July and August provide intermittent flows for irrigation. Finally, no ditch diversion records are available to help estimate irrigation water supplies and shortages.

A full irrigation supply seldom exists at many of the projects. Generally, a full supply is available for Lees Ferry, Navajo Canyon, Tsaile, and Wheatfields projects because of adequate stream flows or because of available storage water. In years with average precipitation, it is estimated that Chinle Wash provides approximately 75 percent of the irrigation requirement. Precipitation in the area averages approximately 9.5 inches per year. Based on this information, it would require approximately 12.67 inches of precipitation to provide 100 percent of the irrigation requirement. The percent of crop water requirement met was computed as a ratio of annual precipitation to 12.67 inches. These values are found in table 2.

The percentage of crop water requirement met was multiplied by the total net crop water requirement to come up with the amount of crop consumptive use. Incidental irrigation losses, evaporation, and phreatophyte consumptive use along supply canals are estimated to be 5 percent of the consumptive use of the irrigated area and are added to the crop consumptive use value to develop a total consumptive use value.

A portion of the water used for irrigation at these sites may not be contributing to the Colorado River System, since evaporation rates in the area are high and the nature of most of the drainage enhances evapotranspiration. A good example of such a drainage is Chinle Wash, which after it leaves Canyon de Chelly, becomes wide and sandy and is lined with willows, cottonwoods, and other phreatophytes.

The uncertainties in the irrigation consumptive use values displayed in table 2 are very large and are estimated as 40 percent of the total consumptive use. This estimate of possible error only reflects the uncertainty of consumptive use and does not account for any possible errors in the acreage estimates. The effective consumptive use for irrigation for 1999 was estimated to equal 463 acre-feet. Including the 5 percent for incidental losses, the irrigation related consumptive use is 486 ($\pm$194) acre-feet.

Table 2.—Net consumptive use values, 1999

PROJECT	CROP WATER REQUIREMENT (INCHES)	TOTAL IRRIGATED (ACRES)	TOTAL WATER REQUIRED (ACRE-FEET)	CROP WATER REQUIREMENT MET (%)	CROP WATER REQUIREMENT MET (ACRE-FEET)	TOTAL CONSUMPTIVE USE (ACRE-FEET)[1]
CHINLE AGENCY						
Canyon de Chelly	6.23	5.65	3	72%	2	2
Lukachukai	16.58	62.33	86	72%	62	65
Nazlini	15.33	2.53	3	72%	2	2
Rough Rock	16.32	54.30	74	75%	56	59
Tsaile	18.49	55.81	86	72%	62	65
Wheatfields	25.65	60.80	130	72%	93	98
TOTAL	—	241.42	382	—	277	291
SHIPROCK AGENCY						
Red Rock Valley	18.35	51.75	79	64%	51	53
Teec Nos Pos	19.68	23.67	39	56%	22	23
Toh Chin Lini	30.87	17.57	45	51%	23	24
Totacon	12.45	1.00	1	51%	1	1
TOTAL	—	93.99	164	—	96	101
WESTERN NAVAJO AGENCY						
Dennehotso	28.48	40.52	96	59%	56	59
Lees Ferry	40.56	3.00	10	100%	10	11
Marsh Pass	17.57	12.32	18	71%	13	13
Navajo Canyon	33.69	3.50	10	54%	5	6
Paiute Canyon	13.91	6.50	8	62%	5	5
TOTAL	—	65.84	142	—	89	94
GRAND TOTAL	—	401.25	688	—	463	486

[1] Total includes 5% addition for incidental losses.

STOCK POND EVAPORATION

Stock pond consumptive use is assumed to be the evaporation from the stock pond. It is also assumed that any consumptive use by natural vegetation prior to the construction of the stock ponds is limited to precipitation, which is subtracted from the evaporation losses.

A compilation of the stock ponds in the study area, including their locations and the water surface areas when ponds are full, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 3. For an average year conditions, the stock pond evaporative surface area was estimated as one-third the water surface area that occurs when the ponds are full. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average water surface area. These values are found in table 3.

Table 3.—Stock pond evaporation, 1999

COUNTY	SURFACE AREA FULL (ACRES)	SURFACE AREA USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Coconino	80	19	71%	57	4.78	52.22	82
Navajo	40	10	77%	55	7.52	47.48	41
Apache	646	199	92%	53	8.12	44.88	743
TOTAL	766	228	—	—	—	—	866

This method of evaporation estimation was used because continuous useful water level records for all stock ponds from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual stock ponds. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation. It was assumed that any consumptive use by natural vegetation prior to construction of the stock ponds is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for stock pond evaporation for calendar year 1999 are shown in table 3. The total evaporative losses in 1999 are 866 ($\pm$260) acre-feet with the stock pond evaporation uncertainty being estimated as 30 percent.

LIVESTOCK WATER

The source of most livestock water in the study area is from wells, with windmill-operated pumps developed and maintained by Navajo Water Operations and Maintenance, and water collected in small surface ponds. The estimated number of

livestock in the area was obtained based on livestock tallies. It was estimated that horses and cattle consume 12 gallons per day; sheep and goats consume 2 gallons per day.

The number of animals for the Upper Colorado portion of each district is shown in table 4. The computed value for livestock consumptive use is 248 acre-feet. The uncertainty in this number is estimated as 30 percent of the total or ±74 acre-feet.

Table 4.—Number of livestock, 1999

AGENCY	CATTLE	HORSES	SHEEP	GOATS
Western Navajo District No. 1	1,941	350	2,045	1,941
Western Navajo District No. 2	600	94	1,081	600
Western Navajo District No. 8	1,968	277	3,109	1,968
Shiprock District No. 9	1,906	340	1,844	1,906
Chinle District No. 10	2,827	532	3,958	2,827
Chinle District No. 11	1,656	262	1,265	1,656
Shiprock District No. 12	531	73	1,278	531
Fort Defiance District No. 17	112	43	491	112
Fort Defiance District No. 18	297	63	374	297
TOTAL	11,838	2,033	15,445	11,838

TOTAL AGRICULTURAL CONSUMPTIVE USE

The total agricultural consumptive use, displayed in table 5, is the sum of the individual components discussed in the previous sections. Agricultural water consumption represents approximately 4 percent of the total use in the study area. Total degree of uncertainty was computed by taking the square root of the sum of the individual uncertainties squared; known as the quadratic sum. This method and nomenclature is used throughout this report. This method was used because a simple sum does not account for the partial cancellation of errors occurring when calculating the total uncertainty derived from individual values that are random and independent of each other. As previously discussed, the individual uncertainties were set as a percent of the consumptive use value.

Table 5.—Total agricultural consumptive use, 1999

CATEGORY	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Irrigation	486	194
Stock Ponds	866	260
Livestock	248	74
TOTAL	1,599	333

MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

Municipal and industrial consumptive use is divided into three categories: mineral resources, thermal electric power, and other. Mineral resources consumptive use includes water used for mineral production. No mineral resources consumptive use is reported in the study area. Thermal electric power consumptive use includes the water used at the power plants, and that used to transport material to the power plant (such as a coal slurry pipeline). Other consumptive use includes urban, rural, and industrial uses.

THERMAL ELECTRIC POWER

Thermal electric power consumptive use includes the water used in the power plant and the water used to transport material to the plant.

Navajo Generating Station

The water used by the NGS is pumped directly from Lake Powell and comprises over half of the total consumption in the study area. Since all NGS water use is metered, this quantity is among those most precisely known, with the maximum uncertainty in the metered quantities believed to be less than 3 percent. Installation of antipollution "scrubbers" was completed in 1999. Consumptive use has increased since installation began in 1997. The actual quantity consumed, along with the estimated uncertainty for the calendar year 1999, was 26,697 (±801) acre-feet.

OTHER

The other consumptive use category includes the remaining use by urban, rural, and industries.

Page, AZ and Vicinity

City of Page, AZ. – The city of Page pumps its domestic water directly from Lake Powell. The water pumped is metered, and the uncertainty of the pumped quantities was assumed to be less than 3 percent. A portion of the water pumped and treated by the City of Page, is supplied to the community of Le Chee on the Navajo Nation and is accounted for separately. The quantity supplied to the City of Page and its associated uncertainty for the calendar year 1999 was 2,567 (±77) acre-feet. Water returning to the waste water treatment plant is metered as well. The waste water for the City of Page is treated and is either evaporated from lined ponds or applied to the golf course, with a portion being returned to the Colorado River. The return flow is estimated to be 766 acre-feet. The net consumptive use is estimated to be 1,800 acre-feet (±80).

Le Chee – The community of Le Chee is supplied and metered by the City of Page. Total water supplied for 1999 was 89 (±3) acre-feet. The uncertainty was estimated to be 3 percent.

Greenhaven Water Company – The Greenhaven Water Company derives its domestic water supply from wells. Well pumping records are available. According to these records, the total water pumped for 1999 was 77 (±5) acre-feet. The uncertainty was estimated to be 7 percent.

Arizona Department of Transportation Housing – The Arizona Department of Transportation operates a housing, maintenance, and administrative facility located on US Hwy 89, north of Page, AZ. This facility is supplied from wells that have no meters installed. It is estimated that the total water pumped for 1999 was 11 acre-feet with an uncertainty of 30 percent of this value or ±3 acre-feet.

Navajo Nation

Community Water Systems – Statistics from the Division of Community Development of the Navajo Nation reveal that various community water systems served 26,086, or about 83 percent of the 31,429 people residing within the study area in 1980. This percentage was used for 1999 resulting in 34,254 out of 41,270 people being served. These systems include those operated by the Navajo Tribal Utility Authority (NTUA), the BIA, and the Water Operations and Maintenance Department of the Navajo Nation, and some privately developed community water systems.

Table 6 shows the source of water and estimated population served by each source of water for people living on the Navajo Nation during 1999. All of the communities obtain their water supply from ground water.

Table 6.—Domestic water sources, 1999

SOURCE	PERCENTAGE OF POPULATION SERVED	NUMBER OF POPULATION SERVED[1]
Community Water Systems	83	34,254
NTUA	[2](60)	20,552
BIA	[2](25)	8,564
Navajo WOM	[2](13)	4,453
Private	[2](2)	685
Individual Wells	17	7,016
TOTAL[2]	100	41,270

[1] Estimated total population within the Upper Colorado River Basin portion of the Navajo Nation provided by Larry Rodgers, Demographer for the Division of Community Development of the Navajo Nation, letter DCDA-L94052, June 20, 1995.

[2] These numbers are a percentage of the Community Water Systems.

NTUA Water Systems – The cities and surrounding communities of Oak Springs, Red Valley, Sweetwater, Chinle , Rough Rock, Round Rock, Rock Point, Wheatfields, Lukachukai, Kayenta, Chilchinbeto, Dennehotso, and Kaibeto derive most of their domestic water supply from wells operated by NTUA. Well pumping records are available. According to these records, the total water pumped for 1999 was 1,608 acre-feet with an uncertainty estimated to be 7 percent of this value or ±113 acre-feet.

The NTUA manages the raw waste water; portions of which flow to individual septic tanks, some to evaporation ponds, and some, such as for the cities of Chinle and Kayenta, flow to waste water treatment plants. Very little water, if any, is returned to the ground water system through leakage from the evaporation ponds, but there are losses from the main collection system. Effluent from the Chinle and Kayenta waste water treatment plants is metered. Under normal conditions, the effluent returns to the Colorado River System and is subtracted from the pumping totals to determine a net consumptive use. For 1999, Chinle's treatment plant effluent was 549 (±38) acre-feet, and Kayenta's effluent was 303 (±21) acre-feet. An estimated uncertainty of 7 percent was used for the effluent of these two plants. The total effluent of 852 acre-feet is subtracted from the NTUA pumping total of 1,608 acre-feet to arrive at a net consumptive use of 756 (±127) acre-feet.

BIA Water Systems – Wells developed and operated by the BIA serve numerous Navajo communities. These systems also serve BIA schools, hospitals, agency offices, and some housing on the Navajo Nation. Metered records for total amounts of water pumped from BIA wells were available for a portion of the Shiprock Agency, the Western Navajo Agency, and the Chinle Agency. Drawing 1246-406-2 shows the agency boundaries within the Upper Colorado River Basin. The uncertainty was estimated to be about 7 percent for all three agencies.

The BIA systems include sewage disposal units terminating in lined evaporation ponds with very little or no return water returning to the ground water system. Undoubtedly, some losses occur in distribution, but insufficient data currently exist to estimate these losses. The losses are probably less than the uncertainties for each of the reported values.

The BIA well data available for the Shiprock Agency include: Cove, Red Rock, and Teec Nos Pos. Total consumptive use values are 11 (±1) acre-feet .

Pumping records for the Western Navajo Agency include data for the following schools: Chilchinbeto Day School, Dennehotso Boarding School, Kaibeto Boarding School, and Kayenta Boarding School. Total consumptive use for the Western Navajo Agency was 249 (±17) acre-feet.

Well pumping records for the Chinle Agency include data for the following schools: Cottonwood Day School, Lukachukai School, and Rock Point School. Rough Rock School maintains its own records, but the data was included with the Chinle Agency data. Total consumptive use for the Chinle Agency was 370 (±26) acre-feet.

Navajo WOM Water Systems – Water use in 1999 by the Navajo WOM service areas was based on an assumed consumption rate of 110 gallons per capita per day (gpcd). For a 1999 estimated service area population of 4,453, the estimated annual

water use was 549 (±165) acre-feet. The uncertainty is estimated as 30 percent of the total.

Private Water Systems – The estimated 1999 population served by private water systems on the Navajo Nation was 685. Assuming a consumptive use rate of 110 gcpd, the annual water use for 1999 was 84 (±25) acre-feet. The uncertainty is estimated as 30 percent of the total.

Individual Wells – According to census data from the Division of Community Development of the Navajo Nation, approximately 17 percent of the study area's population on the reservation (about 7,016 persons in 1999) receives a domestic water supply from individual wells. A consumptive use of 110 gpcd was derived as being a reasonable water use rate. Based on these figures, the annual consumptive use was 864 (±259) acre-feet for 1999.

TOTAL MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

The total municipal and industrial consumptive use, displayed in table 7, is the sum of the individual components discussed in the previous sections. Municipal and industrial water consumption represents approximately 82 percent of the total use in the study area.

Table 7.—Total municipal and industrial consumptive use, 1999

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
THERMAL ELECTRIC POWER		
Navajo Generating Station	26,697	801
OTHER		
Page, AZ and Vicinity		
City of Page	1,800	80
Le Chee	89	3
Greenhaven Water Company	77	5
Arizona Department of Transportation	11	3
Navajo Indian Reservation		
Community Water Systems		
NTUA Water Systems	756	127
BIA Water Systems	630	31
Navajo WOM	549	165
Private Water Systems	84	25
Individual Wells	864	259
TOTAL	31,558	871

It is questionable whether all the water pumped from wells should be considered a depletion to the Colorado River System; however, it is assumed that 100 percent of the water pumped is considered lost to the system. It is proposed that a future joint study be completed by Reclamation, the State of Arizona, and the Navajo Nation to estimate what percentage of water pumped could actually be attributed to the Colorado River System and would have affected the river flows for a particular year.

RECREATION, FISH AND WILDLIFE

The recreation, fish and wildlife consumptive uses include evaporation from reservoirs used exclusively for fish & wildlife purposes as well as acreages irrigated for wildlife feeding. Consumptive use at National and State parks is also accounted for.

GLEN CANYON NATIONAL RECREATION AREA

Colorado River water is used by the Glen Canyon National Recreation Area (GCNRA) at Wahweap and Lees Ferry. The recreational area at Wahweap gets its water supply from a series of wells on the shore of Lake Powell. Pumping records for both Wahweap and Lees Ferry show 445 ($\pm$13) acre-feet of water withdrawn during 1999. The uncertainty is estimated at 3 percent. This water was used for domestic purposes at the campgrounds, picnic areas, and trailer parks. It was also used to irrigate approximately 60 acres of Bermuda grass and cottonwood trees. The domestic waste water is treated and the effluent is allowed to evaporate from two lines evaporation ponds with a total surface area of 16.7 acres.

Based on estimates of evaporation and consumptive use by the plants, there is some water which is unaccounted for and is assumed to be leakage from the delivery system, the evaporation pond, or deep percolation from irrigation application. However, since these water losses are difficult to quantify and verify, the losses were charged as consumptive uses. Therefore, net consumptive use of water is estimated to be equal to the quantity of water pumped.

RESERVOIR EVAPORATION

A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled “1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River” and are shown in table 8.

Efforts are made to maintain a nearly full condition and to minimize water surface fluctuations in reservoirs managed for a fishery. Under average operating conditions, the water surface area of a reservoir used primarily for fishing is assumed to be equal to a normal water surface area. In 1999, these reservoirs filled in the spring and were maintained at the normal pool level.

Table 8. —Recreation, fish and wildlife reservoir evaporation, 1999

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE AREA USED (ACRES)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Tsaile	260	260	35	9.11	25.89	561
Wheatfields	272	272	32	9.11	22.89	519
TOTAL	532	532	—	—	—	1080

This method of evaporation estimation was used because continuous useful water level records for all reservoirs from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs.

For this report, the NOAA Technical Report NWS 33 “Evaporation Atlas for the Contiguous 48 United States,” June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for reservoir evaporation for calendar year 1999 are shown in table 8. The total evaporative losses in 1999 are 1,080 ($\pm$324) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent.

TOTAL RECREATION, FISH AND WILDLIFE

The total recreation, fish and wildlife consumptive use, displayed in table 9, is the sum of the individual components discussed in the previous sections. Recreation, fish and wildlife water consumption represents approximately 4 percent of the total use in the study area.

Table 9.—Total recreation, fish and wildlife consumptive use, 1999

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Glen Canyon National Recreation Area	445	13
Reservoir Evaporation	1,080	324
TOTAL	1,545	324

RESERVOIR EVAPORATION

Reservoir evaporation losses make up about 10 percent of the total water uses and losses in the study area. A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 10. These reservoirs are used primarily for irrigation.

Table 10.—Reservoir evaporation, 1999

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE ACRES USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Many Farms	1,800	903	—	56	9.11	46.89	3,529
Marsh Pass	40	16	78%	40	8.77	31.24	40
Round Rock	83	39	94%	57	8.62	48.39	157
Walker Creek	30	13	88%	59	7.13	51.87	57
Others	38	16	86%	55	8.75	46.25	63
TOTAL	1,991	987	—	—	—	—	3,847

Reservoirs used primarily for irrigation experience large fluctuations in water levels and, correspondingly, large variations in surface area. Reservoir level records and elevation – area curves were available at Many Farms, but not for the remaining reservoirs in table 10. For the reservoirs with no records from which surface area could be accurately computed, the average evaporative surface area was estimated as one-half the water surface area of a full reservoir. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average evaporative surface area.

Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses. The computed values for reservoir evaporation for 1999 are shown in table 10. The total evaporative losses in 1999 are 3,847 ($\pm$1,154) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent of the total evaporation.

CONCLUSIONS

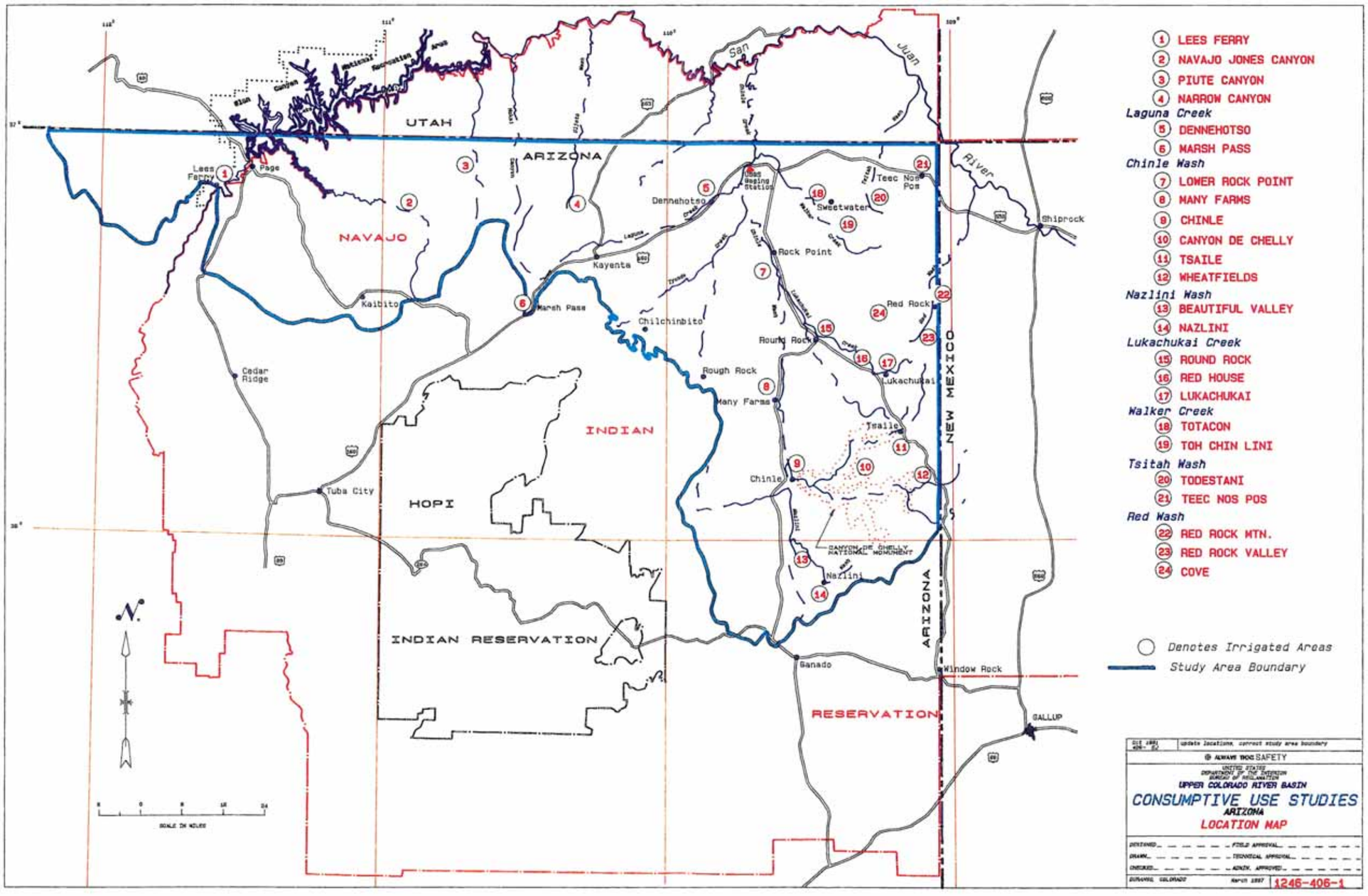
This report assesses the total consumptive use of the Arizona portion of the Upper Colorado River System surface water systems, depletion of ground water, and evaporative losses. Clearly, the amounts of water used by the Navajo Generating Station, City of Page, and Wahweap and Lees Ferry recreation areas are direct depletions of water from the Upper Colorado River System, but the situation is not as clear for other consumptive uses and losses occurring in other sections of the study area. For example, the source of water used by the Navajo Nation for domestic and municipal purposes is from wells, some exceeding 1,000 feet in depth. For our purposes here, it is considered to be consumed and a depletion to the Colorado River System. But this may not actually result in a reduction of Colorado River stream flows in the same year that the withdrawal occurs. Little knowledge and information exists of ground water movement and subsurface flow rates in the study area that are accurate descriptions of the effects on river flows.

Although the water diverted for agricultural purposes is considered as consumptive use in this report, a portion of the remaining surface water on the Navajo Nation, excess to needs, does evaporate before reaching the Colorado River. An attempt has not been made for this report to quantify these losses.

Uncertainties in estimating uses and losses exist, and the degree of variation in the figures is presented. Fortunately, the areas with the highest degree of uncertainty account for only a small percentage of the total consumptive use. The largest component, use by the Navajo Generating Station, is also the most accurately monitored. The total annual value for estimated consumptive use of water within the Arizona portion of the Upper Colorado River Basin for 1999 was 37,462 acre-feet, as shown in table 11.

Table 11.—Consumptive use for Arizona portion of Upper Colorado River Basin for 1999

USE CATEGORY	TOTAL CONSUMPTIVE USE (ACRE-FEET)	UNCERTAINTY	PERCENT OF TOTAL
Agriculture	1,599	33	4
Municipal & Industrial	31,558	871	82
Recreation, Fish & Wildlife	1,525	324	4
Reservoir Evaporation	3,847	1,154	10
TOTAL	38,530	1,519	100


UTAH
ARIZONA
NEW MEXICO
NAVAJO
INDIAN
HOPI
INDIAN RESERVATION
RESERVATION
San Juan River
Lees Ferry
Page
Kaibito
Cedar Ridge
Tuba City
Marsh Pass
Kayenta
Dennehotso
Chilchinbito
Rough Rock
Many Farms
Chinle
Rock Point
Sweetwater
Teec Nos Pos
Red Rock
Round Rock
Lukachukai
Tsaile
Nazlini
Ganado
Window Rock
GALLUP
Shiprock
CANYON DE CHELLY NATIONAL MONUMENT
1 LEES FERRY
2 NAVAJO JONES CANYON
3 PIUTE CANYON
4 NARROW CANYON
Laguna Creek
5 DENNEHOTSO
6 MARSH PASS
Chinle Wash
7 LOWER ROCK POINT
8 MANY FARMS
9 CHINLE
10 CANYON DE CHELLY
11 TSAILE
12 WHEATFIELDS
Nazlini Wash
13 BEAUTIFUL VALLEY
14 NAZLINI
Lukachukai Creek
15 ROUND ROCK
16 RED HOUSE
17 LUKACHUKAI
Walker Creek
18 TOTACON
19 TOH CHIN LINI
Tsitah Wash
20 TODESTANI
21 TEEC NOS POS
Red Wash
22 RED ROCK MTN.
23 RED ROCK VALLEY
24 COVE
Denotes Irrigated Areas
Study Area Boundary
N.
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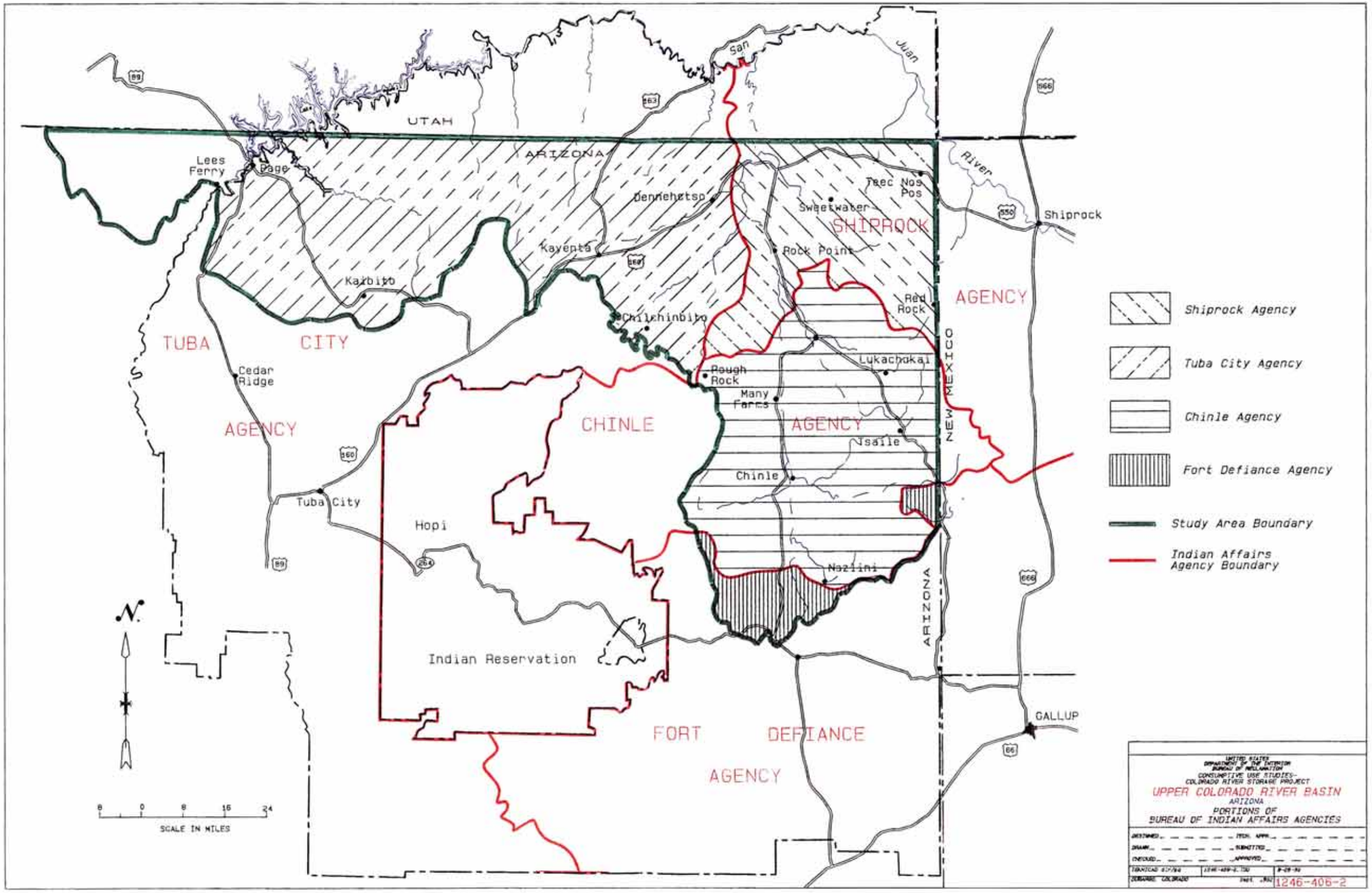
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
UPPER COLORADO RIVER BASIN
CONSUMPTIVE USE STUDIES
ARIZONA
LOCATION MAP
DENVER, COLORADO
March 1987
1246-406-1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ARIZONA
NEW MEXICO
Lees Ferry
Page
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Kayenta
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Tsec Nos Pos
Sweetwater
Rock Point
Red Rock
Lukachukai
Rough Rock
Many Farms
Chinle
Nazlini
Tuba City
Cedar Ridge
Hopi
Indian Reservation
Shiprock
GALLUP
San Juan River
TUBA CITY AGENCY
CHINLE AGENCY
SHIPROCK AGENCY
FORT DEFIANCE AGENCY
Shiprock Agency
Tuba City Agency
Chinle Agency
Fort Defiance Agency
Study Area Boundary
Indian Affairs Agency Boundary
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SCALE IN MILES
UNITED STATES
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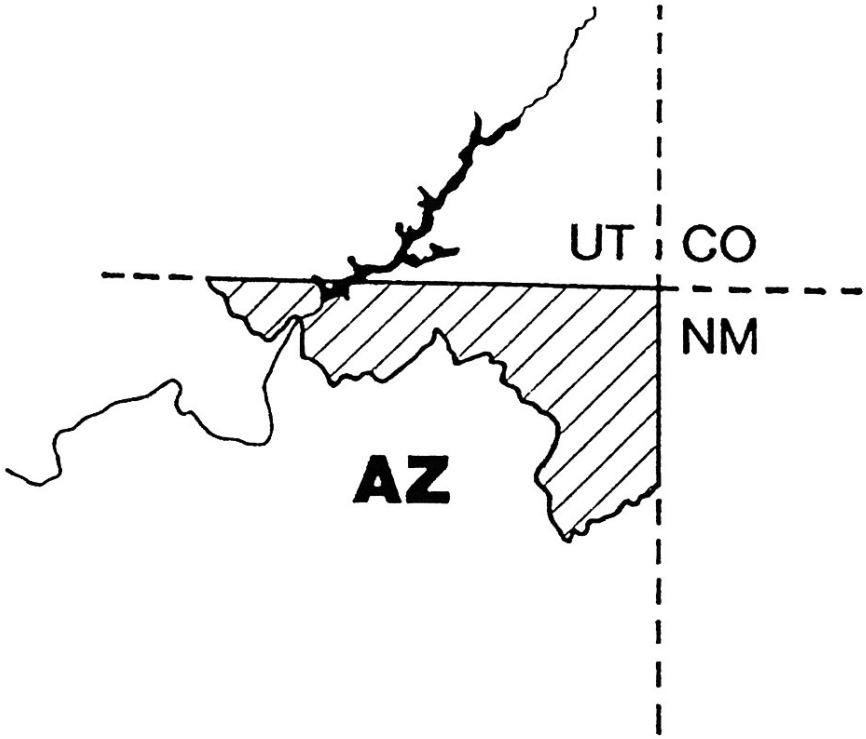
BUREAU OF RECLAMATION
CONSUMPTIVE USE STUDIES-
COLORADO RIVER STORAGE PROJECT
UPPER COLORADO RIVER BASIN
ARIZONA
PORTIONS OF
BUREAU OF INDIAN AFFAIRS AGENCIES
1246-406-2

RECLAMATION

Managing Water in the West

Consumptive Uses and Losses

Arizona Portion of the Upper Colorado River Basin Calendar Year 2000

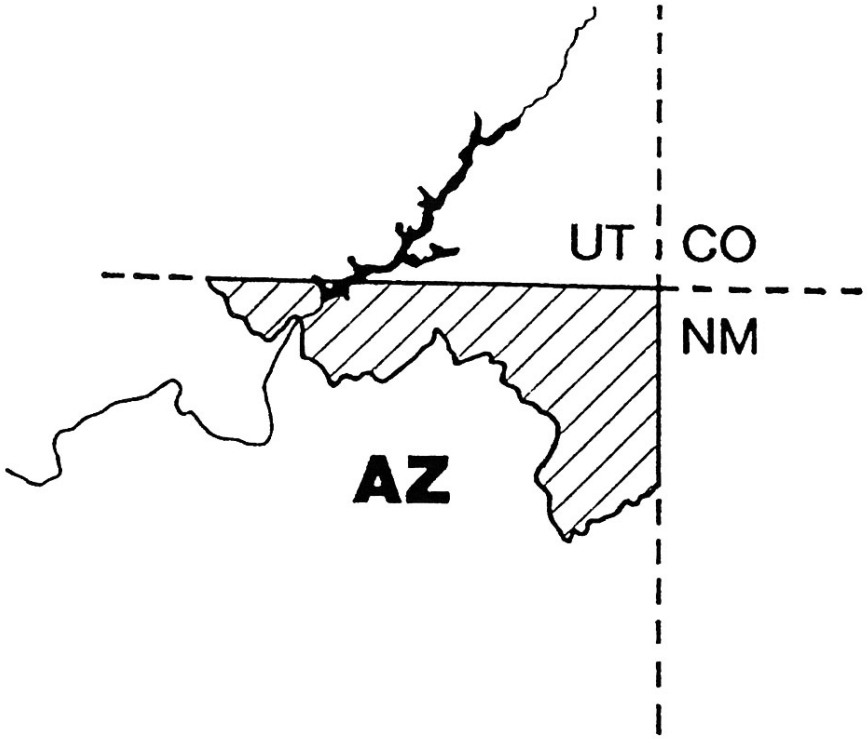


U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

July 2007

Consumptive Uses and Losses

Arizona Portion of the Upper Colorado River Basin
Calendar Year 2000



U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

July 2007

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CONSUMPTIVE USES AND LOSSES

ARIZONA PORTION OF THE UPPER COLORADO RIVER BASIN

CALENDAR YEAR 2000

AUTHORITY

This report was prepared in compliance with Public Law 90-537, Section 601 (b)(1), dated September 30, 1968, which directs the Secretary of the Interior to "make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis." Additionally, this report is in compliance with Section 49 of the Navajo Project Participation Agreement dated September 30, 1969, which states in part: "The Secretary of the Interior further agrees to make the reports required by Section 601 (b)(1) of Public Law 90-537 as they pertain to Arizona's Upper Basin uses annually rather than every five years. Within fifteen days following the completion of said reports, the Secretary of the Interior shall furnish copies of such reports to the Co-Tenants, the Navajo Tribe, each of the Upper Basin States, and the Upper Colorado River Commission."

SUMMARY

The total consumptive use and loss value for the Arizona portion of the Upper Colorado River Basin for calendar year 2000 was 40,192 ($\pm$1,468) acre-feet.

STUDY AREA DESCRIPTION

The Arizona portion of the Upper Colorado River Basin covers approximately 6,900 square miles in the north-east corner of Arizona, as shown on the location map (Drawing 1246-406-1). The climate of the 5,900 square mile area to the west of the Chuska and Carrizo Mountains is largely arid to semiarid, with mean annual precipitation ranging from 6 to 12 inches and with summertime temperatures often reaching 100 degrees Fahrenheit (^{o}F). The potential evaporation rate is high and exceeds mean annual precipitation, with gross lake evaporation values of up to 55 inches per year or more. Elevations in the western portion range from 3200 feet on the Colorado River at Lees Ferry to over 8000 feet on the northern edge of the Black Mesa and across the Zilnez and Skeleton Mesas, back down to 5280 feet in the Chinle Valley, and back up to about 6500 feet on the western edge of the Chuska Mountains. Much of the western part

of the study area is starkly beautiful southwestern desert country with mesas and canyons intertwined across a pastoral landscape. By contrast, the eastern 1,000 square miles is largely mountainous, with elevations rising to nearly 10,000 feet and mean annual precipitation reaching 30 inches. The mountainous land responds with grass meadows interspersed with conifer forest of mostly ponderosa pine.

Except for Page, Arizona; a small area around Lees Ferry; and a portion of the Paria Plateau administered by the Bureau of Land Management; the study area lies entirely within the Navajo Nation. According to census data, 48,613 persons were living within the area in 2000, and of these 41,804 resided on the Navajo Nation.

The largest cities are Page and Chinle, with 2000 populations of 6,809 and 5,366, respectively. Other major communities and their populations include Dennehotso (734), Kaibeto (1,607), Kayenta (4,922), LeChee (1,606), Lukachukai (1,565), Many Farms (1,548), Rock Point (724), Teec Nos Pos (799), and Tsaile (1,078). Subsistence in the region is derived principally from livestock grazing, farming, tourist-related industries, employment at the Navajo Generating Station (NGS), which consumes 60 to 70 percent of the water used or lost in the study area every year. Agriculture accounted for 5 percent of the total water use; municipal and industrial about 84 percent; recreation, fish and wildlife, about 3 percent; and reservoir evaporation, 8 percent.

AGRICULTURAL CONSUMPTIVE USE

Agricultural consumptive use is divided into three categories: irrigation, stock pond, and livestock. Irrigation use includes all use related to irrigating crops including the incidental losses. Stock pond use is the evaporation that occurs from stock ponds and livestock use is the water consumed by livestock.

IRRIGATION USES

Within the Arizona portion of the Upper Colorado River Basin, historically 23 irrigated areas were scattered across the Navajo Nation plus a small amount of land near Lees Ferry irrigated by the National Park Service. Currently, only 15 irrigated areas are in production. An accurate assessment of consumptive use on the irrigated land is difficult due to poor quality of information, such as the exact number of acres under irrigation, the cropping pattern for each irrigated area, site climatological conditions, and the amount of water actually diverted. In many cases, during the latter part of the irrigation season, farmers have to rely on dry land farming since there is little water available in the streams. This means that the crops do not receive their full water requirement.

For this report, the U.S. Department of Agriculture, Soil Conservation Service's (SCS) Modified Blaney-Criddle ET estimation model was used for computing irrigated crop consumptive use. This model, along with appropriate crop-growth stage coefficients and the method for computing effective precipitation, is described in SCS's *Irrigation Water Requirements Technical Release No. 21* (TR 21). Information required for applying this model includes mean monthly temperature and precipitation values, growing season data for each crop type, and the total number of acres planted by crop at each site. With the

exception of Teec Nos Pos, Canyon de Chelly, Lukachukai, and Lees Ferry, no climatological data exist for the irrigation sites, and site values must be generated from data collected at surrounding established weather stations. Growing season dates depend largely on the judgment of the local inhabitants and are, therefore, not known. Although several reports are available with published values for irrigated acres, it is unclear if these values are meant to represent potential irrigated acres, acres irrigated in the past, acres for which farming permits have been issued, or actual acres currently under irrigation.

The crop acreage used to estimate consumptive use by irrigated crops for the year 2000 is shown in table 1. These values were determined from direct field examination by a party composed of representatives from the State of Arizona and the Navajo Nation.

Table 1.—Total irrigated acreage, 2000

PROJECT	CORN (ACRES)	ALFALFA (ACRES)	GRASS PASTURE (ACRES)	SPRING GRAINS (ACRES)	SMALL VEGETABLES (ACRES)	ORCHARD (ACRES)	TOTAL (ACRES)
CHINLE AGENCY							
Canyon de Chelly	0.36	0.00	0.00	3.03	2.26	0.00	5.65
Lukachukai	39.09	7.69	0.00	7.50	5.98	2.07	62.33
Nazlini	0.00	0.00	0.00	0.00	1.79	0.74	2.53
Rough Rock	30.00	0.00	11.87	0.00	12.43	0.00	54.30
Tsaile	23.72	5.27	15.67	5.73	5.42	0.00	55.81
Wheatfields	0.00	60.80	0.00	0.00	0.00	0.00	60.80
TOTAL	93.17	73.76	27.54	16.26	27.88	2.81	241.42
SHIPROCK AGENCY							
Red Rock Valley	26.22	0.00	10.19	5.12	10.22	0.00	51.75
Teec Nos Pos	20.00	0.00	0.00	0.00	3.67	0.00	23.67
Toh Chin Lini	0.00	0.00	0.00	0.00	3.90	13.67	17.57
Totacon	0.00	0.00	0.00	0.00	1.00	0.00	1.00
TOTAL	46.22	0.00	10.19	5.12	18.79	13.67	94.0
WESTERN NAVAJO AGENCY							
Dennehotso	1.82	0.00	38.70	0.00	0.00	0.00	40.52
Lees Ferry	0.00	0.00	1.00	0.00	0.00	2.00	3.00
Marsh Pass	7.02	3.31	0.00	0.00	1.99	0.00	12.32
Navajo Canyon	0.00	0.00	0.00	0.00	0.00	3.50	3.50
Paiute Canyon	2.64	0.00	0.00	0.00	3.86	0.00	6.50
TOTAL	11.48	3.31	39.70	0.00	5.85	5.50	65.84
GRAND TOTAL	150.87	77.07	77.43	21.38	52.52	21.98	401.25

Consumptive Uses and Losses

Several factors complicated the modeling of irrigation consumptive use. For example, the computer program used to model consumptive use assumes a full water supply; if shortages exist, as they often do in this semiarid study area, adjustments must be made. These adjustments are complicated because some of the projects have no storage water and may only have a reliable irrigation water supply during spring runoff. After spring runoff, farming becomes essentially dry land until rains in July and August provide intermittent flows for irrigation. Finally, no ditch diversion records are available to help estimate irrigation water supplies and shortages.

A full irrigation supply seldom exists at many of the projects. Generally, a full supply is available for Lees Ferry, Navajo Canyon, Tsaile, and Wheatfields projects because of adequate stream flows or because of available storage water. In years with average precipitation, it is estimated that Chinle Wash provides approximately 75 percent of the irrigation requirement. Precipitation in the area averages approximately 9.5 inches per year. Based on this information, it would require approximately 12.67 inches of precipitation to provide 100 percent of the irrigation requirement. The percent of crop water requirement met was computed as a ratio of annual precipitation to 12.67 inches. These values are found in table 2.

The percentage of crop water requirement met was multiplied by the total net crop water requirement to come up with the amount of crop consumptive use. Incidental irrigation losses, evaporation, and phreatophyte consumptive use along supply canals are estimated to be 5 percent of the consumptive use of the irrigated area and are added to the crop consumptive use value to develop a total consumptive use value.

A portion of the water used for irrigation at these sites may not be contributing to the Colorado River System, since evaporation rates in the area are high and the nature of most of the drainage enhances evapotranspiration. A good example of such a drainage is Chinle Wash, which after it leaves Canyon de Chelly, becomes wide and sandy and is lined with willows, cottonwoods, and other phreatophytes.

The uncertainties in the irrigation consumptive use values displayed in table 2 are very large and are estimated as 40 percent of the total consumptive use. This estimate of possible error only reflects the uncertainty of consumptive use and does not account for any possible errors in the acreage estimates. The effective consumptive use for irrigation for 2000 was estimated to equal 618 acre-feet. Including the 5 percent for incidental losses, the irrigation related consumptive use is 649 ($\pm$260) acre-feet.

Table 2.—Net consumptive use values, 2000

PROJECT	CROP WATER REQUIREMENT (INCHES)	TOTAL IRRIGATED (ACRES)	TOTAL WATER REQUIRED (ACRE-FEET)	CROP WATER REQUIREMENT MET (%)	CROP WATER REQUIREMENT MET (ACRE-FEET)	TOTAL CONSUMPTIVE USE (ACRE-FEET)[1]
CHINLE AGENCY						
Canyon de Chelly	8.56	5.65	4	74%	3	3
Lukachukai	23.24	62.33	121	74%	89	94
Nazlini	21.28	2.53	4	74%	3	3
Rough Rock	22.86	54.30	103	73%	75	79
Tsaile	24.88	55.81	116	74%	86	90
Wheatfields	35.87	60.80	182	74%	134	141
TOTAL	—	241.42	530	—	391	410
SHIPROCK AGENCY						
Red Rock Valley	24.62	51.75	106	68%	72	76
Teec Nos Pos	26.11	23.67	52	62%	32	34
Toh Chin Lini	37.74	17.57	55	45%	25	26
Totacon	15.99	1.00	1	45%	1	1
TOTAL	—	93.99	214	—	129	136
WESTERN NAVAJO AGENCY						
Dennehotso	33.79	40.52	114	51%	58	61
Lees Ferry	45.88	3.00	11	100%	11	12
Marsh Pass	25.21	12.32	26	61%	16	17
Navajo Canyon	40.47	3.50	12	68%	8	8
Paiute Canyon	19.66	6.50	11	50%	5	6
TOTAL	—	65.84	174	—	98	103
GRAND TOTAL	—	401.25	918	—	618	649

[1] Total includes 5% addition for incidental losses.

STOCK POND EVAPORATION

Stock pond consumptive use is assumed to be the evaporation from the stock pond. It is also assumed that any consumptive use by natural vegetation prior to the construction of the stock ponds is limited to precipitation, which is subtracted from the evaporation losses.

A compilation of the stock ponds in the study area, including their locations and the water surface areas when ponds are full, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 3. For an average year conditions, the stock pond evaporative surface area was estimated as one-third the water surface area that occurs when the ponds are full. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average water surface area. These values are found in table 3.

Table 3.—Stock pond evaporation, 2000

COUNTY	SURFACE AREA FULL (ACRES)	SURFACE AREA USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Coconino	80	23	86%	57	5.78	51.22	98
Navajo	40	11	83%	55	8.11	46.90	43
Apache	646	211	98%	53	8.61	44.39	779
TOTAL	766	245	—	—	—	—	920

This method of evaporation estimation was used because continuous useful water level records for all stock ponds from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual stock ponds. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation. It was assumed that any consumptive use by natural vegetation prior to construction of the stock ponds is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for stock pond evaporation for calendar year 2000 are shown in table 3. The total evaporative losses in 2000 are 920 ($\pm$276) acre-feet with the stock pond evaporation uncertainty being estimated as 30 percent.

LIVESTOCK WATER

The source of most livestock water in the study area is from wells, with windmill-operated pumps developed and maintained by Navajo Water Operations and Maintenance, and water collected in small surface ponds. The estimated number of

livestock in the area was obtained based on livestock tallies. It was estimated that horses and cattle consume 12 gallons per day; sheep and goats consume 2 gallons per day.

The number of animals for the Upper Colorado portion of each district is shown in table 4. The computed value for livestock consumptive use is 250 acre-feet. The uncertainty in this number is estimated as 30 percent of the total or ±75 acre-feet.

Table 4.—Number of livestock, 2000

AGENCY	CATTLE	HORSES	SHEEP	GOATS
Western Navajo District No. 1	2,011	273	2,235	1,288
Western Navajo District No. 2	688	58	1,130	738
Western Navajo District No. 8	2,185	229	3,652	2,916
Shiprock District No. 9	1,944	249	1,775	2,278
Chinle District No. 10	2,913	348	4,315	2,213
Chinle District No. 11	1,527	187	1,094	1,264
Shiprock District No. 12	679	56	963	601
Fort Defiance District No. 17	156	50	670	193
Fort Defiance District No. 18	338	45	440	211
TOTAL	12,441	1,496	16,274	11,701

TOTAL AGRICULTURAL CONSUMPTIVE USE

The total agricultural consumptive use, displayed in table 5, is the sum of the individual components discussed in the previous sections. Agricultural water consumption represents approximately 5 percent of the total use in the study area. Total degree of uncertainty was computed by taking the square root of the sum of the individual uncertainties squared; known as the quadratic sum. This method and nomenclature is used throughout this report. This method was used because a simple sum does not account for the partial cancellation of errors occurring when calculating the total uncertainty derived from individual values that are random and independent of each other. As previously discussed, the individual uncertainties were set as a percent of the consumptive use value.

Table 5.—Total agricultural consumptive use, 2000

CATEGORY	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Irrigation	649	260
Stock Ponds	920	276
Livestock	250	75
TOTAL	1,819	386

MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

Municipal and industrial consumptive use is divided into three categories: mineral resources, thermal electric power, and other. Mineral resources consumptive use includes water used for mineral production. No mineral resources consumptive use is reported in the study area. Thermal electric power consumptive use includes the water used at the power plants, and that used to transport material to the power plant (such as a coal slurry pipeline). Other consumptive use includes urban, rural, and industrial uses.

THERMAL ELECTRIC POWER

Thermal electric power consumptive use includes the water used in the power plant and the water used to transport material to the plant.

Navajo Generating Station

The water used by the NGS is pumped directly from Lake Powell and comprises over half of the total consumption in the study area. Since all NGS water use is metered, this quantity is among those most precisely known, with the maximum uncertainty in the metered quantities believed to be less than 3 percent. The actual quantity consumed, along with the estimated uncertainty for the calendar year 2000, was 28,709 (±861) acre-feet.

OTHER

The other consumptive use category includes the remaining use by urban, rural, and industries.

Page, AZ and Vicinity

***City of Page, AZ*. –** The city of Page pumps its domestic water directly from Lake Powell. The water pumped is metered, and the uncertainty of the pumped quantities was assumed to be less than 3 percent. A portion of the water pumped and treated by the City of Page, is supplied to the community of Le Chee on the Navajo Nation and is accounted for separately. The quantity supplied to the City of Page and its associated uncertainty for the calendar year 2000 was 2,768 (±83) acre-feet. Water returning to the waste water treatment plant is metered as well. The waste water for the City of Page is treated and is either evaporated from lined ponds or applied to the golf course, with a portion being returned to the Colorado River. The return flow is estimated to be 865 acre-feet. The net consumptive use is estimated to be 1,903 acre-feet (±87).

***Le Chee* –** The community of Le Chee is supplied and metered by the City of Page. Total water supplied for 2000 was 99 (±3) acre-feet. The uncertainty was estimated to be 3 percent.

Greenhaven Water Company – The Greenhaven Water Company derives its domestic water supply from wells. Well pumping records are available. According to these records, the total water pumped for 2000 was 75 (±5) acre-feet. The uncertainty was estimated to be 7 percent.

Arizona Department of Transportation Housing – The Arizona Department of Transportation operates a housing, maintenance, and administrative facility located on US Hwy 89, north of Page, AZ. This facility is supplied from wells that have no meters installed. It is estimated that the total water pumped for 2000 was 11 acre-feet with an uncertainty of 30 percent of this value or ±3 acre-feet.

Navajo Nation

Community Water Systems – Statistics from the Division of Community Development of the Navajo Nation reveal that various community water systems served 26,086, or about 83 percent of the 31,429 people residing within the study area in 1980. This percentage was used for 2000 resulting in 34,697 out of 41,804 people being served. These systems include those operated by the Navajo Tribal Utility Authority (NTUA), the BIA, and the Water Operations and Maintenance Department of the Navajo Nation, and some privately developed community water systems.

Table 6 shows the source of water and estimated population served by each source of water for people living on the Navajo Nation during 2000. All of the communities obtain their water supply from ground water.

Table 6.—Domestic water sources, 2000

SOURCE	PERCENTAGE OF POPULATION SERVED	NUMBER OF POPULATION SERVED[1]
Community Water Systems	83	34,696
NTUA	[2](60)	20,818
BIA	[2](25)	8,674
Navajo WOM	[2](13)	4,511
Private	[2](2)	694
Individual Wells	17	7,107
TOTAL[2]	100	41,804

[1] Estimated total population within the Upper Colorado River Basin portion of the Navajo Nation provided by Larry Rodgers, Demographer for the Division of Community Development of the Navajo Nation, letter DCDA-L94052, June 20, 1995.
[2] These numbers are a percentage of the Community Water Systems.

NTUA Water Systems – The cities and surrounding communities of Oak Springs, Red Valley, Sweetwater, Chinle , Rough Rock, Round Rock, Rock Point, Wheatfields, Lukachukai, Kayenta, Chilchinbeto, Dennehotso, and Kaibeto derive most of their domestic water supply from wells operated by NTUA. Well pumping records are

available. According to these records, the total water pumped for 2000 was 1,640 acre-feet with an uncertainty estimated to be 7 percent of this value or ±115 acre-feet.

The NTUA manages the raw waste water; portions of which flow to individual septic tanks, some to evaporation ponds, and some, such as for the cities of Chinle and Kayenta, flow to waste water treatment plants. Very little water, if any, is returned to the ground water system through leakage from the evaporation ponds, but there are losses from the main collection system. Effluent from the Chinle and Kayenta waste water treatment plants is metered. Under normal conditions, the effluent returns to the Colorado River System and is subtracted from the pumping totals to determine a net consumptive use. For 2000, Chinle's treatment plant effluent was 561 (±39) acre-feet, and Kayenta's effluent was 284 (±20) acre-feet. An estimated uncertainty of 7 percent was used for the effluent of these two plants. The total effluent of 846 acre-feet is subtracted from the NTUA pumping total of 1,640 acre-feet to arrive at a net consumptive use of 794 (±129) acre-feet.

BIA Water Systems – Wells developed and operated by the BIA serve numerous Navajo communities. These systems also serve BIA schools, hospitals, agency offices, and some housing on the Navajo Nation. Metered records for total amounts of water pumped from BIA wells were available for a portion of the Shiprock Agency, the Western Navajo Agency, and the Chinle Agency. Drawing 1246-406-2 shows the agency boundaries within the Upper Colorado River Basin. The uncertainty was estimated to be about 7 percent for all three agencies.

The BIA systems include sewage disposal units terminating in lined evaporation ponds with very little or no return water returning to the ground water system. Undoubtedly, some losses occur in distribution, but insufficient data currently exist to estimate these losses. The losses are probably less than the uncertainties for each of the reported values.

The BIA well data available for the Shiprock Agency include: Cove, Red Rock, and Teec Nos Pos. Total consumptive use values are 12 (±1) acre-feet.

Pumping records for the Western Navajo Agency include data for the following schools: Chilchinbeto Day School, Dennehotso Boarding School, Kaibeto Boarding School, and Kayenta Boarding School. Total consumptive use for the Western Navajo Agency was 185 (±13) acre-feet.

Well pumping records for the Chinle Agency include data for the following schools: Cottonwood Day School, Lukachukai School, and Rock Point School. Rough Rock School maintains its own records, but the data was included with the Chinle Agency data. Total consumptive use for the Chinle Agency was 334 (±23) acre-feet.

Navajo WOM Water Systems – Water use in 2000 by the Navajo WOM service areas was based on an assumed consumption rate of 110 gallons per capita per day (gpcd). For a 2000 estimated service area population of 4,511, the estimated annual water use was 556 (±167) acre-feet. The uncertainty is estimated as 30 percent of the total.

Private Water Systems – The estimated 2000 population served by private water systems on the Navajo Nation was 694. Assuming a consumptive use rate of 110

gcpd, the annual water use for 2000 was 86 (±26) acre-feet. The uncertainty is estimated as 30 percent of the total.

Individual Wells – According to census data from the Division of Community Development of the Navajo Nation, approximately 17 percent of the study area's population on the reservation (about 7,107 persons in 2000) receives a domestic water supply from individual wells. A consumptive use of 110 gpcd was derived as being a reasonable water use rate. Based on these figures, the annual consumptive use was 876 (±263) acre-feet for 2000.

TOTAL MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

The total municipal and industrial consumptive use, displayed in table 7, is the sum of the individual components discussed in the previous sections. Municipal and industrial water consumption represents approximately 84 percent of the total use in the study area.

Table 7.—Total municipal and industrial consumptive use, 2000

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
THERMAL ELECTRIC POWER		
Navajo Generating Station	28,709	861
OTHER		
Page, AZ and Vicinity		
City of Page	1,903	87
Le Chee	99	3
Greenhaven Water Company	75	5
Arizona Department of Transportation	11	3
Navajo Indian Reservation		
Community Water Systems		
NTUA Water Systems	794	129
BIA Water Systems	531	27
Navajo WOM	556	167
Private Water Systems	86	26
Individual Wells	876	263
TOTAL	33,639	929

It is questionable whether all the water pumped from wells should be considered a depletion to the Colorado River System; however, it is assumed that 100 percent of the water pumped is considered lost to the system. It is proposed that a future joint study be completed by Reclamation, the State of Arizona, and the Navajo Nation to estimate what

percentage of water pumped could actually be attributed to the Colorado River System and would have affected the river flows for a particular year.

RECREATION, FISH AND WILDLIFE

The recreation, fish and wildlife consumptive uses include evaporation from reservoirs used exclusively for fish & wildlife purposes as well as acreages irrigated for wildlife feeding. Consumptive use at National and State parks is also accounted for.

GLEN CANYON NATIONAL RECREATION AREA

Colorado River water is used by the Glen Canyon National Recreation Area (GCNRA) at Wahweap and Lees Ferry. The recreational area at Wahweap gets its water supply from a series of wells on the shore of Lake Powell. Pumping records for both Wahweap and Lees Ferry show 265±8) acre-feet of water withdrawn during 2000. The uncertainty is estimated at 3 percent. This water was used for domestic purposes at the campgrounds, picnic areas, and trailer parks. It was also used to irrigate approximately 60 acres of Bermuda grass and cottonwood trees. The domestic waste water is treated and the effluent is allowed to evaporate from two lines evaporation ponds with a total surface area of 16.7 acres.

Based on estimates of evaporation and consumptive use by the plants, there is some water which is unaccounted for and is assumed to be leakage from the delivery system, the evaporation pond, or deep percolation from irrigation application. However, since these water losses are difficult to quantify and verify, the losses were charged as consumptive uses. Therefore, net consumptive use of water is estimated to be equal to the quantity of water pumped.

RESERVOIR EVAPORATION

A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled “1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River” and are shown in table 8.

Table 8. —Recreation, fish and wildlife reservoir evaporation, 2000

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE AREA USED (ACRES)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Tsaile	260	260	35	9.36	25.64	556
Wheatfields	272	272	32	9.36	22.64	513
TOTAL	532	532	—	—	—	1,069

Efforts are made to maintain a nearly full condition and to minimize water surface fluctuations in reservoirs managed for a fishery. Under average operating conditions, the

water surface area of a reservoir used primarily for fishing is assumed to be equal to a normal water surface area. In 2000, these reservoirs filled in the spring and were maintained at the normal pool level.

This method of evaporation estimation was used because continuous useful water level records for all reservoirs from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs.

For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for reservoir evaporation for calendar year 2000 are shown in table 8. The total evaporative losses in 2000 are 1,069 (±321) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent.

TOTAL RECREATION, FISH AND WILDLIFE

The total recreation, fish and wildlife consumptive use, displayed in table 9, is the sum of the individual components discussed in the previous sections. Recreation, fish and wildlife water consumption represents approximately 3 percent of the total use in the study area.

Table 9.—Total recreation, fish and wildlife consumptive use, 2000

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Glen Canyon National Recreation Area	265	8
Reservoir Evaporation	1,069	321
TOTAL	1,333	321

RESERVOIR EVAPORATION

Reservoir evaporation losses make up about 8 percent of the total water uses and losses in the study area. A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 10. These reservoirs are used primarily for irrigation.

Table 10.—Reservoir evaporation, 2000

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE ACRES USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Many Farms	1,800	790	—	56	9.36	46.64	3072
Marsh Pass	40	15	76%	40	8.60	31.40	40
Round Rock	83	41	98%	57	8.61	48.39	164
Walker Creek	30	15	97%	59	7.86	51.14	62
Others	38	16	87%	55	8.78	46.22	63
TOTAL	1,991	877	—	—	—	—	3,401

Reservoirs used primarily for irrigation experience large fluctuations in water levels and, correspondingly, large variations in surface area. Reservoir level records and elevation – area curves were available at Many Farms, but not for the remaining reservoirs in table 10. For the reservoirs with no records from which surface area could be accurately computed, the average evaporative surface area was estimated as one-half the water surface area of a full reservoir. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average evaporative surface area.

Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses. The computed values for reservoir evaporation for 2000 are shown in table 10. The total evaporative losses in 2000 are 3,401 ($\pm$1,020) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent of the total evaporation.

CONCLUSIONS

This report assesses the total consumptive use of the Arizona portion of the Upper Colorado River System surface water systems, depletion of ground water, and evaporative losses. Clearly, the amounts of water used by the Navajo Generating Station, City of Page, and Wahweap and Lees Ferry recreation areas are direct depletions of water from the Upper Colorado River System, but the situation is not as clear for other consumptive uses and losses occurring in other sections of the study area. For example, the source of water used by the Navajo Nation for domestic and municipal purposes is from wells, some exceeding 1,000 feet in depth. For our purposes here, it is considered to be consumed and a depletion to the Colorado River System. But this may not actually result in a reduction of Colorado River stream flows in the same year that the withdrawal occurs. Little knowledge and information exists of ground water movement and

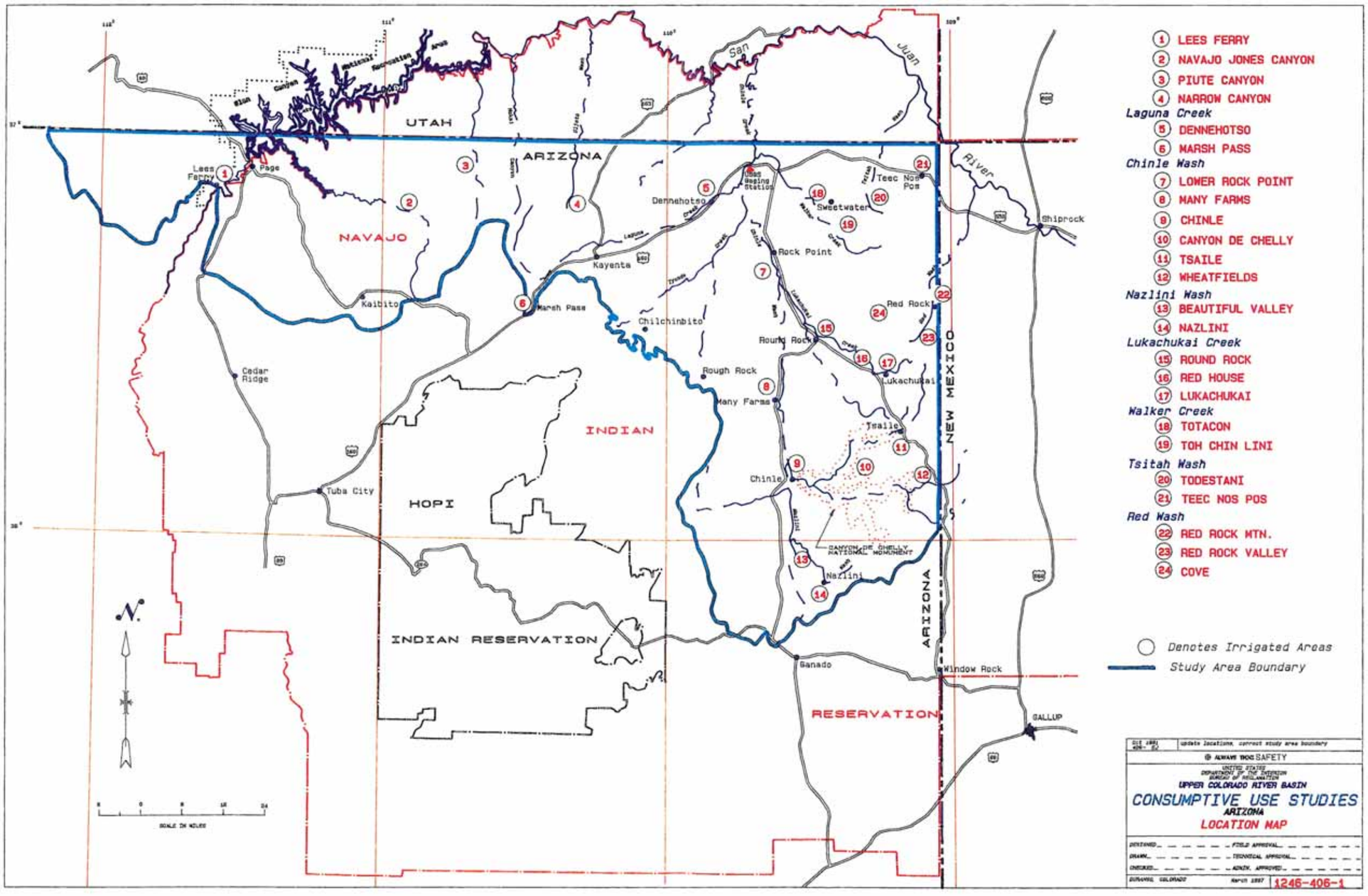
subsurface flow rates in the study area that are accurate descriptions of the effects on river flows.

Although the water diverted for agricultural purposes is considered as consumptive use in this report, a portion of the remaining surface water on the Navajo Nation, excess to needs, does evaporate before reaching the Colorado River. An attempt has not been made for this report to quantify these losses.

Uncertainties in estimating uses and losses exist, and the degree of variation in the figures is presented. Fortunately, the areas with the highest degree of uncertainty account for only a small percentage of the total consumptive use. The largest component, use by the Navajo Generating Station, is also the most accurately monitored. The total annual value for estimated consumptive use of water within the Arizona portion of the Upper Colorado River Basin for 2000 was 40,192 acre-feet, as shown in table 11.

Table 11.—Consumptive use for Arizona portion of Upper Colorado River Basin for 2000

USE CATEGORY	TOTAL CONSUMPTIVE USE (ACRE-FEET)	UNCERTAINTY	PERCENT OF TOTAL
Agriculture	1,819	386	5
Municipal & Industrial	33,639	929	84
Recreation, Fish & Wildlife	1,333	321	3
Reservoir Evaporation	3,401	1,020	8
TOTAL	40,192	1,468	100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NEW MEXICO
NAVAJO
INDIAN
HOPI
INDIAN RESERVATION
RESERVATION
San Juan River
Lees Ferry
Page
Kaibito
Cedar Ridge
Tuba City
Marsh Pass
Kayenta
Dennehotso
Chilchinbito
Rough Rock
Many Farms
Chinle
Rock Point
Sweetwater
Teec Nos Pos
Red Rock
Round Rock
Lukachukai
Tsaile
Nazlini
Ganado
Window Rock
GALLUP
Shiprock
CANYON DE CHELLY NATIONAL MONUMENT
1 LEES FERRY
2 NAVAJO JONES CANYON
3 PIUTE CANYON
4 NARROW CANYON
Laguna Creek
5 DENNEHOTSO
6 MARSH PASS
Chinle Wash
7 LOWER ROCK POINT
8 MANY FARMS
9 CHINLE
10 CANYON DE CHELLY
11 TSAILE
12 WHEATFIELDS
Nazlini Wash
13 BEAUTIFUL VALLEY
14 NAZLINI
Lukachukai Creek
15 ROUND ROCK
16 RED HOUSE
17 LUKACHUKAI
Walker Creek
18 TOTACON
19 TOH CHIN LINI
Tsitah Wash
20 TODESTANI
21 TEEC NOS POS
Red Wash
22 RED ROCK MTN.
23 RED ROCK VALLEY
24 COVE
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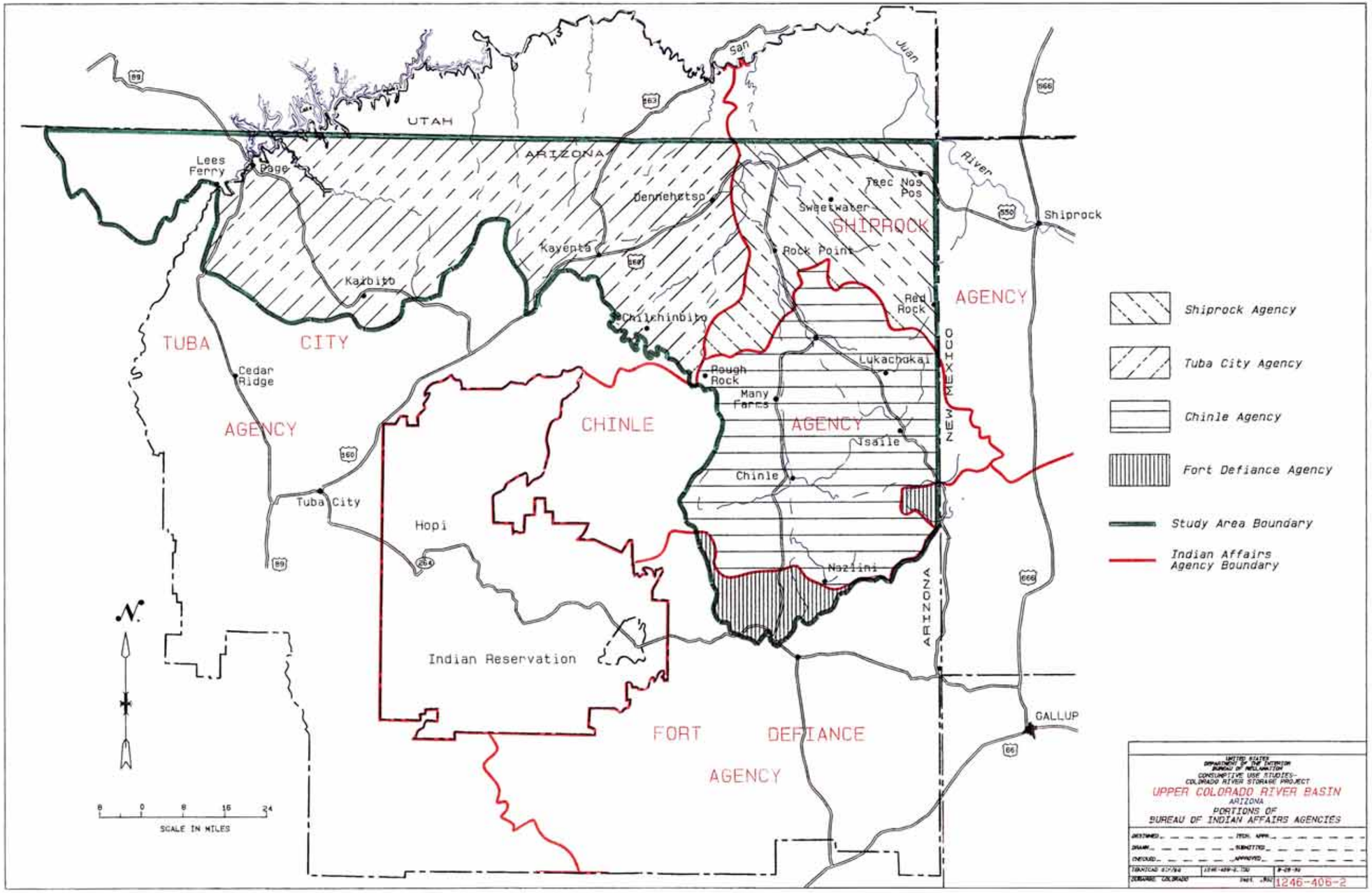
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
UPPER COLORADO RIVER BASIN
CONSUMPTIVE USE STUDIES
ARIZONA
LOCATION MAP
DENVER, COLORADO
March 1987
1246-406-1


UTAH
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Page
Kaibito
Kayenta
Dennehotso
Chilchinbito
Tsec Nos Pos
Sweetwater
Rock Point
Red Rock
Lukachukai
Rough Rock
Many Farms
Chinle
Nazlini
Tuba City
Cedar Ridge
Hopi
Indian Reservation
Shiprock
GALLUP
San Juan River
TUBA CITY AGENCY
CHINLE AGENCY
SHIPROCK AGENCY
FORT DEFIANCE AGENCY
Shiprock Agency
Tuba City Agency
Chinle Agency
Fort Defiance Agency
Study Area Boundary
Indian Affairs Agency Boundary
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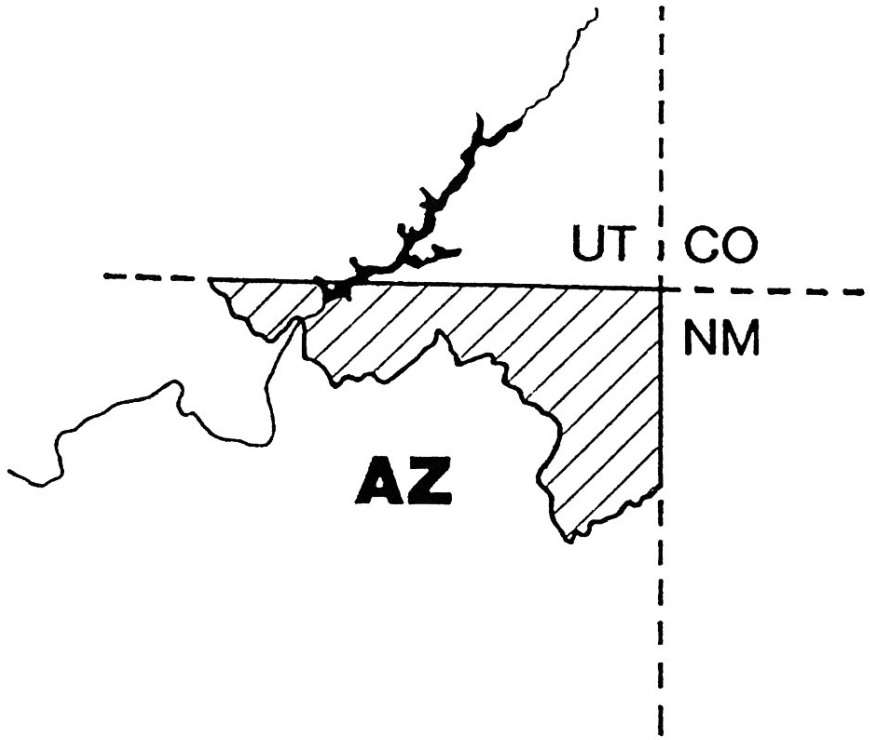
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CONSUMPTIVE USE STUDIES-
COLORADO RIVER STORAGE PROJECT
UPPER COLORADO RIVER BASIN
ARIZONA
PORTIONS OF
BUREAU OF INDIAN AFFAIRS AGENCIES
1246-406-2

RECLAMATION

Managing Water in the West

Consumptive Uses and Losses

Arizona Portion of the Upper Colorado River Basin Calendar Year 2001

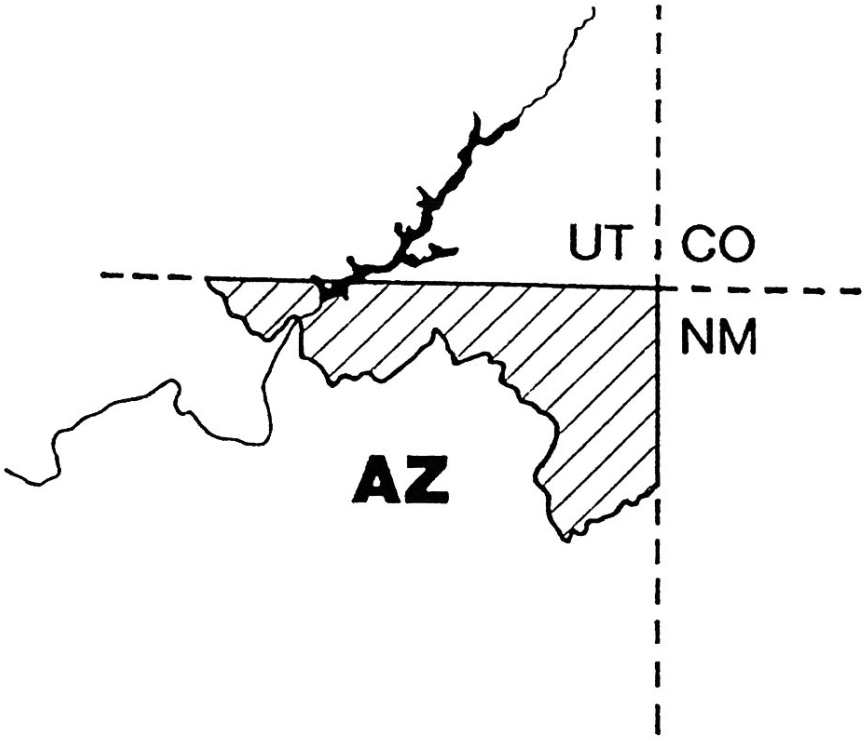


U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

October 2009

Consumptive Uses and Losses

Arizona Portion of the Upper Colorado River Basin
Calendar Year 2001



U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

October 2009

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Tables

CONSUMPTIVE USES AND LOSSES

ARIZONA PORTION OF THE UPPER COLORADO RIVER BASIN

CALENDAR YEAR 2001

AUTHORITY

This report was prepared in compliance with Public Law 90-537, Section 601 (b)(1), dated September 30, 1968, which directs the Secretary of the Interior to "make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis." Additionally, this report is in compliance with Section 49 of the Navajo Project Participation Agreement dated September 30, 1969, which states in part: "The Secretary of the Interior further agrees to make the reports required by Section 601 (b)(1) of Public Law 90-537 as they pertain to Arizona's Upper Basin uses annually rather than every five years. Within fifteen days following the completion of said reports, the Secretary of the Interior shall furnish copies of such reports to the Co-Tenants, the Navajo Tribe, each of the Upper Basin States, and the Upper Colorado River Commission."

SUMMARY

The total consumptive use and loss value for the Arizona portion of the Upper Colorado River Basin for calendar year 2001 was 38,542 ($\pm$1,402) acre-feet.

STUDY AREA DESCRIPTION

The Arizona portion of the Upper Colorado River Basin covers approximately 6,900 square miles in the north-east corner of Arizona, as shown on the location map (Drawing 1246-406-1). The climate of the 5,900 square mile area to the west of the Chuska and Carrizo Mountains is largely arid to semiarid, with mean annual precipitation ranging from 6 to 12 inches and with summertime temperatures often reaching 100 degrees Fahrenheit (^{o}F). The potential evaporation rate is high and exceeds mean annual precipitation, with gross lake evaporation values of up to 55 inches per year or more. Elevations in the western portion range from 3200 feet on the Colorado River at Lees Ferry to over 8000 feet on the northern edge of the Black Mesa and across the Zilnez and Skeleton Mesas, back down to 5280 feet in the Chinle Valley, and back up to about 6500 feet on the western edge of the Chuska Mountains. Much of the western part

of the study area is starkly beautiful southwestern desert country with mesas and canyons intertwined across a pastoral landscape. By contrast, the eastern 1,000 square miles is largely mountainous, with elevations rising to nearly 10,000 feet and mean annual precipitation reaching 30 inches. The mountainous land responds with grass meadows interspersed with conifer forest of mostly ponderosa pine.

Except for Page, Arizona; a small area around Lees Ferry; and a portion of the Paria Plateau administered by the Bureau of Land Management; the study area lies entirely within the Navajo Nation. According to census data, 48,613 persons were living within the area in 2000, and of these 41,804 resided on the Navajo Nation.

The largest cities are Page and Chinle, with 2000 populations of 6,809 and 5,366, respectively. Other major communities and their populations include Dennehotso (734), Kaibeto (1,607), Kayenta (4,922), LeChee (1,606), Lukachukai (1,565), Many Farms (1,548), Rock Point (724), Teec Nos Pos (799), and Tsaile (1,078). Subsistence in the region is derived principally from livestock grazing, farming, tourist-related industries, employment at the Navajo Generating Station (NGS), which consumes 60 to 70 percent of the water used or lost in the study area every year. Agriculture accounted for 4 percent of the total water use; municipal and industrial about 84 percent; recreation, fish and wildlife, about 4 percent; and reservoir evaporation, 8 percent.

AGRICULTURAL CONSUMPTIVE USE

Agricultural consumptive use is divided into three categories: irrigation, stock pond, and livestock. Irrigation use includes all use related to irrigating crops including the incidental losses. Stock pond use is the evaporation that occurs from stock ponds and livestock use is the water consumed by livestock.

IRRIGATION USES

Within the Arizona portion of the Upper Colorado River Basin, historically 23 irrigated areas were scattered across the Navajo Nation plus a small amount of land near Lees Ferry irrigated by the National Park Service. Currently, only 15 irrigated areas are in production. An accurate assessment of consumptive use on the irrigated land is difficult due to poor quality of information, such as the exact number of acres under irrigation, the cropping pattern for each irrigated area, site climatological conditions, and the amount s of water actually diverted. In many cases, during the latter part of the irrigation season, farmers have to rely on dry land farming since there is little water available in the streams. This means that the crops do not receive their full water requirement.

For this report, the U.S. Department of Agriculture, Soil Conservation Service's (SCS) Modified Blaney-Criddle ET estimation model was used for computing irrigated crop consumptive use. This model, along with appropriate crop-growth stage coefficients and the method for computing effective precipitation, is described in SCS's *Irrigation Water Requirements Technical Release No. 21* (TR 21). Information required for applying this model includes mean monthly temperature and precipitation values, growing season data for each crop type, and the total number of acres planted by crop at each site. With the

exception of Teec Nos Pos, Canyon de Chelly, Lukachukai, and Lees Ferry, no climatological data exist for the irrigation sites, and site values must be generated from data collected at surrounding established weather stations. Growing season dates depend largely on the judgment of the local inhabitants and are, therefore, not known. Although several reports are available with published values for irrigated acres, it is unclear if these values are meant to represent potential irrigated acres, acres irrigated in the past, acres for which farming permits have been issued, or actual acres currently under irrigation.

The crop acreage used to estimate consumptive use by irrigated crops for the year 2001 is shown in table 1. These values were determined from direct field examination by a party composed of representatives from the State of Arizona and the Navajo Nation.

Table 1.—Total irrigated acreage, 2001

PROJECT	CORN (ACRES)	ALFALFA (ACRES)	GRASS PASTURE (ACRES)	SPRING GRAINS (ACRES)	SMALL VEGETABLES (ACRES)	ORCHARD (ACRES)	TOTAL (ACRES)
CHINLE AGENCY							
Canyon de Chelly	0.36	0.00	0.00	3.03	2.26	0.00	5.65
Lukachukai	39.09	7.69	0.00	7.50	5.98	2.07	62.33
Nazlini	0.00	0.00	0.00	0.00	1.79	0.74	2.53
Rough Rock	30.00	0.00	11.87	0.00	12.43	0.00	54.30
Tsaile	23.72	5.27	15.67	5.73	5.42	0.00	55.81
Wheatfields	0.00	60.80	0.00	0.00	0.00	0.00	60.80
TOTAL	93.17	73.76	27.54	16.26	27.88	2.81	241.42
SHIPROCK AGENCY							
Red Rock Valley	26.22	0.00	10.19	5.12	10.22	0.00	51.75
Teec Nos Pos	20.00	0.00	0.00	0.00	3.67	0.00	23.67
Toh Chin Lini	0.00	0.00	0.00	0.00	3.90	13.67	17.57
Totacon	0.00	0.00	0.00	0.00	1.00	0.00	1.00
TOTAL	46.22	0.00	10.19	5.12	18.79	13.67	94.0
WESTERN NAVAJO AGENCY							
Dennehotso	1.82	0.00	38.70	0.00	0.00	0.00	40.52
Lees Ferry	0.00	0.00	1.00	0.00	0.00	2.00	3.00
Marsh Pass	7.02	3.31	0.00	0.00	1.99	0.00	12.32
Navajo Canyon	0.00	0.00	0.00	0.00	0.00	3.50	3.50
Paiute Canyon	2.64	0.00	0.00	0.00	3.86	0.00	6.50
TOTAL	11.48	3.31	39.70	0.00	5.85	5.50	65.84
GRAND TOTAL	150.87	77.07	77.43	21.38	52.52	21.98	401.25

Consumptive Uses and Losses

Several factors complicated the modeling of irrigation consumptive use. For example, the computer program used to model consumptive use assumes a full water supply; if shortages exist, as they often do in this semiarid study area, adjustments must be made. These adjustments are complicated because some of the projects have no storage water and may only have a reliable irrigation water supply during spring runoff. After spring runoff, farming becomes essentially dry land until rains in July and August provide intermittent flows for irrigation. Finally, no ditch diversion records are available to help estimate irrigation water supplies and shortages.

A full irrigation supply seldom exists at many of the projects. Generally, a full supply is available for Lees Ferry, Navajo Canyon, Tsaile, and Wheatfields projects because of adequate stream flows or because of available storage water. In years with average precipitation, it is estimated that Chinle Wash provides approximately 75 percent of the irrigation requirement. Precipitation in the area averages approximately 9.5 inches per year. Based on this information, it would require approximately 12.67 inches of precipitation to provide 100 percent of the irrigation requirement. The percent of crop water requirement met was computed as a ratio of annual precipitation to 12.67 inches. These values are found in table 2.

The percentage of crop water requirement met was multiplied by the total net crop water requirement to come up with the amount of crop consumptive use. Incidental irrigation losses, evaporation, and phreatophyte consumptive use along supply canals are estimated to be 5 percent of the consumptive use of the irrigated area and are added to the crop consumptive use value to develop a total consumptive use value.

A portion of the water used for irrigation at these sites may not be contributing to the Colorado River System since evaporation rates in the area are high and the nature of most of the drainage enhances evapotranspiration. A good example of such a drainage is Chinle Wash, which after it leaves Canyon de Chelly, becomes wide and sandy and is lined with willows, cottonwoods, and other phreatophytes.

The uncertainties in the irrigation consumptive use values displayed in table 2 are very large and are estimated as 40 percent of the total consumptive use. This estimate of possible error only reflects the uncertainty of consumptive use and does not account for any possible errors in the acreage estimates. The effective consumptive use for irrigation for 2001 was estimated to equal 490 acre-feet. Including the 5 percent for incidental losses, the irrigation related consumptive use is 515 ($\pm$206) acre-feet.

Table 2.—Net consumptive use values, 2001

PROJECT	CROP WATER REQUIREMENT (INCHES)	TOTAL IRRIGATED (ACRES)	TOTAL WATER REQUIRED (ACRE-FEET)	CROP WATER REQUIREMENT MET (%)	CROP WATER REQUIREMENT MET (ACRE-FEET)	TOTAL CONSUMPTIVE USE (ACRE-FEET)[1]
CHINLE AGENCY						
Canyon de Chelly	16.91	5.65	8	52%	4	4
Lukachukai	23.66	62.33	123	52%	64	67
Nazlini	20.58	2.53	4	52%	2	2
Rough Rock	22.40	54.30	101	50%	51	54
Tsaile	25.25	55.81	117	52%	61	64
Wheatfields	35.59	60.80	180	52%	93	98
TOTAL	—	241.42	534	—	275	289
SHIPROCK AGENCY						
Red Rock Valley	22.30	51.75	96	67%	65	68
Teec Nos Pos	21.26	23.67	42	83%	35	36
Toh Chin Lini	35.18	17.57	52	57%	29	31
Totacon	13.88	1.00	1	57%	1	1
TOTAL	—	93.99	191	—	129	136
WESTERN NAVAJO AGENCY						
Dennehotso	36.89	40.52	125	41%	52	54
Lees Ferry	53.39	3.00	13	100%	13	14
Marsh Pass	23.03	12.32	24	44%	10	11
Navajo Canyon	40.09	3.50	12	56%	7	7
Paiute Canyon	18.50	6.50	10	40%	4	4
TOTAL	—	65.84	183	—	86	90
GRAND TOTAL	—	401.25	908	—	490	515

[1] Total includes 5% addition for incidental losses.

STOCK POND EVAPORATION

Stock pond consumptive use is assumed to be the evaporation from the stock pond. It is also assumed that any consumptive use by natural vegetation prior to the construction of the stock ponds is limited to precipitation which is subtracted from the evaporation losses.

A compilation of the stock ponds in the study area, including their locations and the water surface areas when ponds are full, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 3. For an average year conditions, the stock pond evaporative surface area was estimated as one-third the water surface area that occurs when the ponds are full. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average water surface area. These values are found in table 3.

Table 3.—Stock pond evaporation, 2001

COUNTY	SURFACE AREA FULL (ACRES)	SURFACE AREA USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Coconino	80	22	84%	57	5.67	51.33	96
Navajo	40	8	58%	55	5.65	49.36	32
Apache	646	208	97%	53	8.52	44.49	772
TOTAL	766	238	—	—	—	—	900

This method of evaporation estimation was used because continuous useful water level records for all stock ponds from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual stock ponds. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation. It was assumed that any consumptive use by natural vegetation prior to construction of the stock ponds is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for stock pond evaporation for calendar year 2001 are shown in table 3. The total evaporative losses in 2001 are 900 ($\pm$270) acre-feet with the stock pond evaporation uncertainty being estimated as 30 percent.

LIVESTOCK WATER

The source of most livestock water in the study area is from wells, with windmill-operated pumps developed and maintained by Navajo Water Operations and Maintenance, and water collected in small surface ponds. The estimated number of

livestock in the area was obtained based on livestock tallies. It was estimated that horses and cattle consume 12 gallons per day; sheep and goats consume 2 gallons per day.

The number of animals for the Upper Colorado portion of each district is shown in table 4. The computed value for livestock consumptive use is 218 acre-feet. The uncertainty in this number is estimated as 30 percent of the total or ±65 acre-feet.

Table 4.—Number of livestock, 2001

AGENCY	CATTLE	HORSES	SHEEP	GOATS
Western Navajo District No. 1	2,079	328	2,398	1,263
Western Navajo District No. 2	709	81	1,339	898
Western Navajo District No. 8	1,910	169	2,960	2,069
Shiprock District No. 9	1,134	179	1,226	1,494
Chinle District No. 10	2,694	369	3,605	1,967
Chinle District No. 11	1,041	156	956	1,041
Shiprock District No. 12	897	84	1,075	827
Fort Defiance District No. 17	100	15	370	141
Fort Defiance District No. 18	248	23	329	145
TOTAL	10,812	1,404	14,257	9,844

TOTAL AGRICULTURAL CONSUMPTIVE USE

The total agricultural consumptive use, displayed in table 5, is the sum of the individual components discussed in the previous sections. Agricultural water consumption represents approximately 4 percent of the total use in the study area. Total degree of uncertainty was computed by taking the square root of the sum of the individual uncertainties squared; known as the quadratic sum. This method and nomenclature is used throughout this report. This method was used because a simple sum does not account for the partial cancellation of errors occurring when calculating the total uncertainty derived from individual values that are random and independent of each other. As previously discussed, the individual uncertainties were set as a percent of the consumptive use value.

Table 5.—Total agricultural consumptive use, 2001

CATEGORY	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Irrigation	515	206
Stock Ponds	900	270
Livestock	218	65
TOTAL	1,633	346

MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

Municipal and industrial consumptive use is divided into three categories: mineral resources, thermal electric power, and other. Mineral resources consumptive use includes water used for mineral production. No mineral resources consumptive use is reported in the study area. Thermal electric power consumptive use includes the water used at the power plants, and that used to transport material to the power plant (such as a coal slurry pipeline). Other consumptive use includes urban, rural, and industrial uses.

THERMAL ELECTRIC POWER

Thermal electric power consumptive use includes the water used in the power plant and the water used to transport material to the plant.

Navajo Generating Station

The water used by the NGS is pumped directly from Lake Powell and comprises over half of the total consumption in the study area. Since all NGS water use is metered, this quantity is among those most precisely known, with the maximum uncertainty in the metered quantities believed to be less than 3 percent. The actual quantity consumed, along with the estimated uncertainty for the calendar year 2001, was 27,620 (±829) acre-feet.

OTHER

The other consumptive use category includes the remaining use by urban, rural, and industries.

Page, AZ and Vicinity

***City of Page, AZ*. –** The city of Page pumps its domestic water directly from Lake Powell. The water pumped is metered, and the uncertainty of the pumped quantities was assumed to be less than 3 percent. A portion of the water pumped and treated by the City of Page, is supplied to the community of Le Chee on the Navajo Nation and is accounted for separately. The quantity supplied to the City of Page and its associated uncertainty for the calendar year 2001 was 3,837 (±115) acre-feet. Water returning to the waste water treatment plant is metered as well. The waste water for the City of Page is treated and is either evaporated from lined ponds or applied to the golf course, with a portion being returned to the Colorado River. The return flow is estimated to be 2,004 acre-feet. The net consumptive use is estimated to be 1,833 acre-feet (±130).

***Le Chee* –** The community of Le Chee is supplied and metered by the City of Page. Total water supplied for 2001 was 90 (±3) acre-feet. The uncertainty was estimated to be 3 percent.

Greenhaven Water Company – The Greenhaven Water Company derives its domestic water supply from wells. Well pumping records are available. According to these records, the total water pumped for 2001 was 76 (±5) acre-feet. The uncertainty was estimated to be 7 percent.

Arizona Department of Transportation Housing – The Arizona Department of Transportation operates a housing, maintenance, and administrative facility located on US Hwy 89, north of Page, AZ. This facility is supplied from wells that have no meters installed. It is estimated that the total water pumped for 2001 was 13 acre-feet with an uncertainty of 30 percent of this value or ±4 acre-feet.

Navajo Nation

Community Water Systems – Statistics from the Division of Community Development of the Navajo Nation reveal that various community water systems served 26,086, or about 83 percent of the 31,429 people residing within the study area in 1980. This percentage was used for 2001 resulting in 35,140 out of 42,337 people being served. These systems include those operated by the Navajo Tribal Utility Authority (NTUA), the BIA, and the Water Operations and Maintenance Department of the Navajo Nation, and some privately developed community water systems.

Table 6 shows the source of water and estimated population served by each source of water for people living on the Navajo Nation during 2001. All of the communities obtain their water supply from ground water.

Table 6.—Domestic water sources, 2001

SOURCE	PERCENTAGE OF POPULATION SERVED	NUMBER OF POPULATION SERVED[1]
Community Water Systems	83	35,140
NTUA	[2](60)	21,084
BIA	[2](25)	8,785
Navajo WOM	[2](13)	4,568
Private	[2](2)	703
Individual Wells	17	7,197
TOTAL[2]	100	42,337

[1] Estimated total population within the Upper Colorado River Basin portion of the Navajo Nation provided by Larry Rodgers, Demographer for the Division of Community Development of the Navajo Nation, letter DCDA-L94052, June 20, 1995.
[2] These numbers are a percentage of the Community Water Systems.

NTUA Water Systems – The cities and surrounding communities of Oak Springs, Red Valley, Sweetwater, Chinle , Rough Rock, Round Rock, Rock Point, Wheatfields, Lukachukai, Kayenta, Chilchinbeto, Dennehotso, and Kaibeto derive most of their domestic water supply from wells operated by NTUA. Well pumping records are

available. According to these records, the total water pumped for 2001 was 1,637 acre-feet with an uncertainty estimated to be 7 percent of this value or ±115 acre-feet.

The NTUA manages the raw waste water; portions of which flow to individual septic tanks, some to evaporation ponds, and some, such as for the cities of Chinle and Kayenta, flow to waste water treatment plants. Very little water, if any, is returned to the ground water system through leakage from the evaporation ponds, but there are losses from the main collection system. Effluent from the Chinle and Kayenta waste water treatment plants is metered. Under normal conditions, the effluent returns to the Colorado River System and is subtracted from the pumping totals to determine a net consumptive use. For 2001, Chinle's treatment plant effluent was 638 (±45) acre-feet, and Kayenta's effluent was 259 (±18) acre-feet. An estimated uncertainty of 7 percent was used for the effluent of these two plants. The total effluent of 896 acre-feet is subtracted from the NTUA pumping total of 1,637 acre-feet to arrive at a net consumptive use of 741 (±131) acre-feet.

BIA Water Systems – Wells developed and operated by the BIA serve numerous Navajo communities. These systems also serve BIA schools, hospitals, agency offices, and some housing on the Navajo Nation. Metered records for total amounts of water pumped from BIA wells were available for a portion of the Shiprock Agency, the Western Navajo Agency, and the Chinle Agency. Drawing 1246-406-2 shows the agency boundaries within the Upper Colorado River Basin. The uncertainty was estimated to be about 7 percent for all three agencies.

The BIA systems include sewage disposal units terminating in lined evaporation ponds with very little or no return water returning to the ground water system. Undoubtedly, some losses occur in distribution, but insufficient data currently exist to estimate these losses. The losses are probably less than the uncertainties for each of the reported values.

The BIA well data available for the Shiprock Agency include: Cove, Red Rock, and Teec Nos Pos. Total consumptive use values are 11 (±1) acre-feet.

Pumping records for the Western Navajo Agency include data for the following schools: Chilchinbeto Day School, Dennehotso Boarding School, Kaibeto Boarding School, and Kayenta Boarding School. Total consumptive use for the Western Navajo Agency was 185 (±13) acre-feet.

Well pumping records for the Chinle Agency include data for the following schools: Cottonwood Day School, Lukachukai School, and Rock Point School. Rough Rock School maintains its own records, but the data was included with the Chinle Agency data. Total consumptive use for the Chinle Agency was 64 (±4) acre-feet.

Navajo WOM Water Systems – Water use in 2001 by the Navajo WOM service areas was based on an assumed consumption rate of 110 gallons per capita per day (gpcd). For a 2001 estimated service area population of 4,568, the estimated annual water use was 563 (±169) acre-feet. The uncertainty is estimated as 30 percent of the total.

Private Water Systems – The estimated 2001 population served by private water systems on the Navajo Nation was 703. Assuming a consumptive use rate of 110

gcpd, the annual water use for 2001 was 87 (±26) acre-feet. The uncertainty is estimated as 30 percent of the total.

Individual Wells – According to census data from the Division of Community Development of the Navajo Nation, approximately 17 percent of the study area's population on the reservation (about 7,197 persons in 2001) receives a domestic water supply from individual wells. A consumptive use of 110 gpcd was derived as being a reasonable water use rate. Based on these figures, the annual consumptive use was 887 (±266) acre-feet for 2001.

TOTAL MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

The total municipal and industrial consumptive use, displayed in table 7, is the sum of the individual components discussed in the previous sections. Municipal and industrial water consumption represents approximately 84 percent of the total use in the study area.

Table 7.—Total municipal and industrial consumptive use, 2001

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
THERMAL ELECTRIC POWER		
Navajo Generating Station	27,620	829
OTHER		
Page, AZ and Vicinity		
City of Page	1,833	130
Le Chee	90	3
Greenhaven Water Company	76	5
Arizona Department of Transportation	13	4
Navajo Indian Reservation		
Community Water Systems		
NTUA Water Systems	741	131
BIA Water Systems	260	14
Navajo WOM	563	169
Private Water Systems	87	26
Individual Wells	887	266
TOTAL	32,169	906

It is questionable whether all the water pumped from wells should be considered a depletion to the Colorado River System; however, it is assumed that 100 percent of the water pumped is considered lost to the system. It is proposed that a future joint study be completed by Reclamation, the State of Arizona, and the Navajo Nation to estimate what

percentage of water pumped could actually be attributed to the Colorado River System and would have affected the river flows for a particular year.

RECREATION, FISH AND WILDLIFE

The recreation, fish and wildlife consumptive uses include evaporation from reservoirs used exclusively for fish & wildlife purposes as well as acreages irrigated for wildlife feeding. Consumptive use at National and State parks is also accounted for.

GLEN CANYON NATIONAL RECREATION AREA

Colorado River water is used by the Glen Canyon National Recreation Area (GCNRA) at Wahweap and Lees Ferry. The recreational area at Wahweap gets its water supply from a series of wells on the shore of Lake Powell. Pumping records for both Wahweap and Lees Ferry show 387 (±12) acre-feet of water withdrawn during 2001. The uncertainty is estimated at 3 percent. This water was used for domestic purposes at the campgrounds, picnic areas, and trailer parks. It was also used to irrigate approximately 60 acres of Bermuda grass and cottonwood trees. The domestic waste water is treated and the effluent is allowed to evaporate from two lines evaporation ponds with a total surface area of 16.7 acres.

Based on estimates of evaporation and consumptive use by the plants, there is some water which is unaccounted for and is assumed to be leakage from the delivery system, the evaporation pond, or deep percolation from irrigation application. However, since these water losses are difficult to quantify and verify, the losses were charged as consumptive uses. Therefore, net consumptive use of water is estimated to be equal to the quantity of water pumped.

RESERVOIR EVAPORATION

A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled “1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River” and are shown in table 8.

Table 8. —Recreation, fish and wildlife reservoir evaporation, 2001

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE AREA USED (ACRES)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Tsaile	260	260	35	6.56	28.44	616
Wheatfields	272	272	32	6.56	25.44	577
TOTAL	532	532	—	—	—	1,193

Efforts are made to maintain a nearly full condition and to minimize water surface fluctuations in reservoirs managed for a fishery. Under average operating conditions, the

water surface area of a reservoir used primarily for fishing is assumed to be equal to a normal water surface area. It is assumed that, in 2001, these reservoirs filled in the spring and were maintained at the normal pool level.

This method of evaporation estimation was used because continuous useful water level records for all reservoirs from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs.

For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for reservoir evaporation for calendar year 2001 are shown in table 8. The total evaporative losses in 2001 are 1,193 (±358) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent.

TOTAL RECREATION, FISH AND WILDLIFE

The total recreation, fish and wildlife consumptive use, displayed in table 9, is the sum of the individual components discussed in the previous sections. Recreation, fish and wildlife water consumption represents approximately 4 percent of the total use in the study area.

Table 9.—Total recreation, fish and wildlife consumptive use, 2001

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Glen Canyon National Recreation Area	387	12
Reservoir Evaporation	1,193	358
TOTAL	1,580	358

RESERVOIR EVAPORATION

Reservoir evaporation losses make up about 8 percent of the total water uses and losses in the study area. A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 10. These reservoirs are used primarily for irrigation.

Table 10.—Reservoir evaporation, 2001

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE ACRES USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Many Farms	1,800	693	—	56	6.56	49.44	2857
Marsh Pass	40	10	52%	40	5.91	34.09	30
Round Rock	83	40	97%	57	8.52	48.49	162
Walker Creek	30	15	100%	59	10.47	48.53	61
Others	38	14	76%	55	7.72	47.28	57
TOTAL	1,991	773	—	—	—	—	3,166

Reservoirs used primarily for irrigation experience large fluctuations in water levels and, correspondingly, large variations in surface area. Reservoir level records and elevation – area curves were available at Many Farms, but not for the remaining reservoirs in table 10. For the reservoirs with no records from which surface area could be accurately computed, the average evaporative surface area was estimated as one-half the water surface area of a full reservoir. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average evaporative surface area.

Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses. The computed values for reservoir evaporation for 2001 are shown in table 10. The total evaporative losses in 2001 are 3,166 ($\pm$950) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent of the total evaporation.

CONCLUSIONS

This report assesses the total consumptive use of the Arizona portion of the Upper Colorado River System surface water systems, depletion of ground water, and evaporative losses. Clearly, the amounts of water used by the Navajo Generating Station, City of Page, and Wahweap and Lees Ferry recreation areas are direct depletions of water from the Upper Colorado River System, but the situation is not as clear for other consumptive uses and losses occurring in other sections of the study area. For example, the source of water used by the Navajo Nation for domestic and municipal purposes is from wells, some exceeding 1,000 feet in depth. For our purposes here, it is considered to be consumed and a depletion to the Colorado River System. But this may not actually result in a reduction of Colorado River stream flows in the same year that the withdrawal occurs. Little knowledge and information exists of ground water movement and

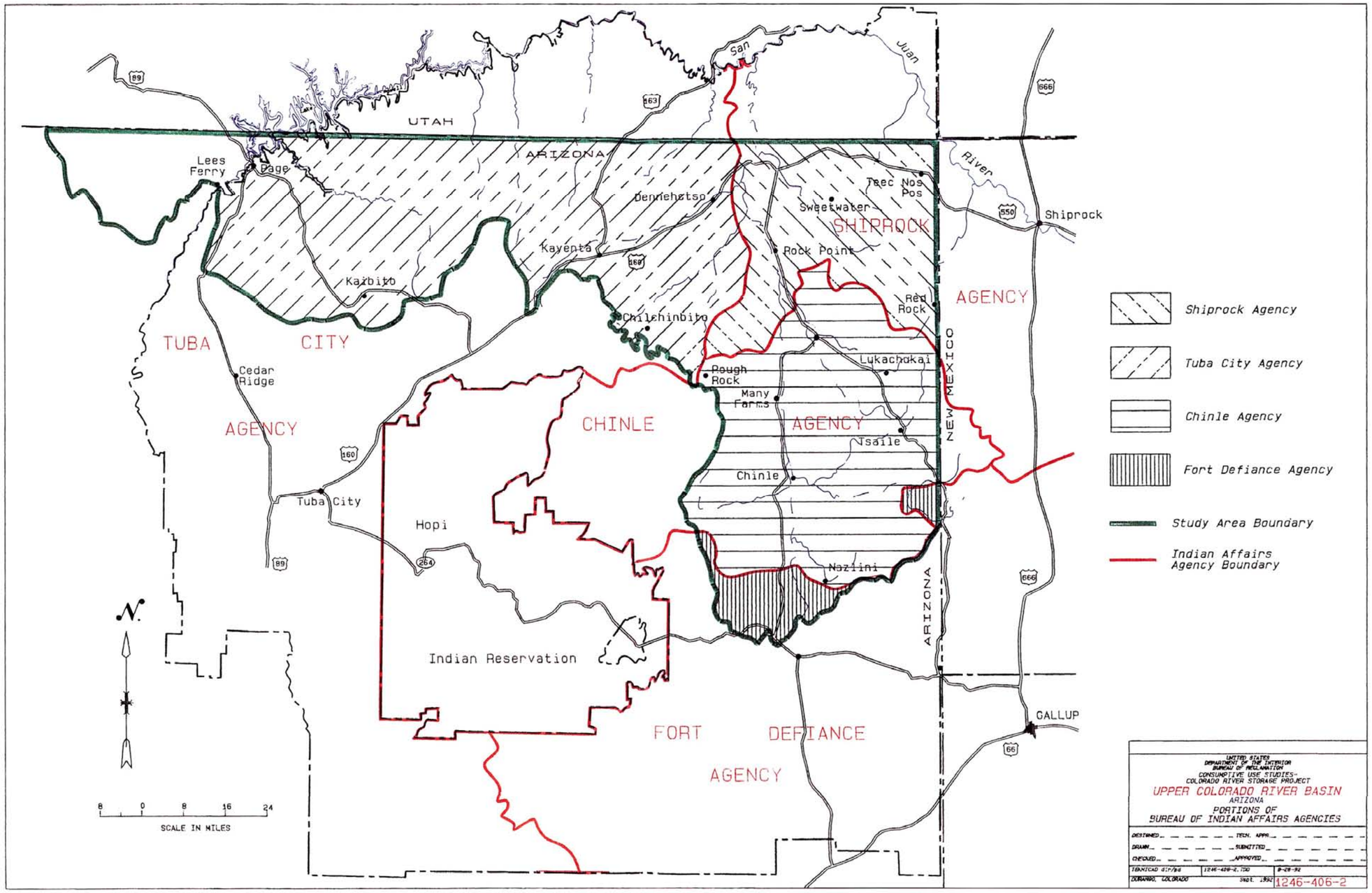
subsurface flow rates in the study area that are accurate descriptions of the effects on river flows.

Although the water diverted for agricultural purposes is considered as consumptive use in this report, a portion of the remaining surface water on the Navajo Nation, excess to needs, does evaporate before reaching the Colorado River. An attempt has not been made for this report to quantify these losses.

Uncertainties in estimating uses and losses exist, and the degree of variation in the figures is presented. Fortunately, the areas with the highest degree of uncertainty account for only a small percentage of the total consumptive use. The largest component, use by the Navajo Generating Station, is also the most accurately monitored. The total annual value for estimated consumptive use of water within the Arizona portion of the Upper Colorado River Basin for 2001 was 38,542 acre-feet, as shown in table 11.

Table 11.—Consumptive use for Arizona portion of Upper Colorado River Basin for 2001

USE CATEGORY	TOTAL CONSUMPTIVE USE (ACRE-FEET)	UNCERTAINTY	PERCENT OF TOTAL
Agriculture	1,633	346	4
Municipal & Industrial	32,163	906	84
Recreation, Fish & Wildlife	1,580	358	4
Reservoir Evaporation	3,166	950	8
TOTAL	38,542	1,404	100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ARIZONA
NEW MEXICO
Lees Ferry
Page
Kaibito
Kayenta
Dennehotso
Chilchinbito
Teec Nos Pos
Sweetwater
Rock Point
Red Rock
Lukachukai
Rough Rock
Many Farms
Tsaile
Chinle
Nazlini
Shiprock
Cedar Ridge
Tuba City
Hopi
Indian Reservation
GALLUP
San Juan River
TUBA CITY AGENCY
CHINLE AGENCY
SHIPROCK AGENCY
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Shiprock Agency
Tuba City Agency
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Study Area Boundary
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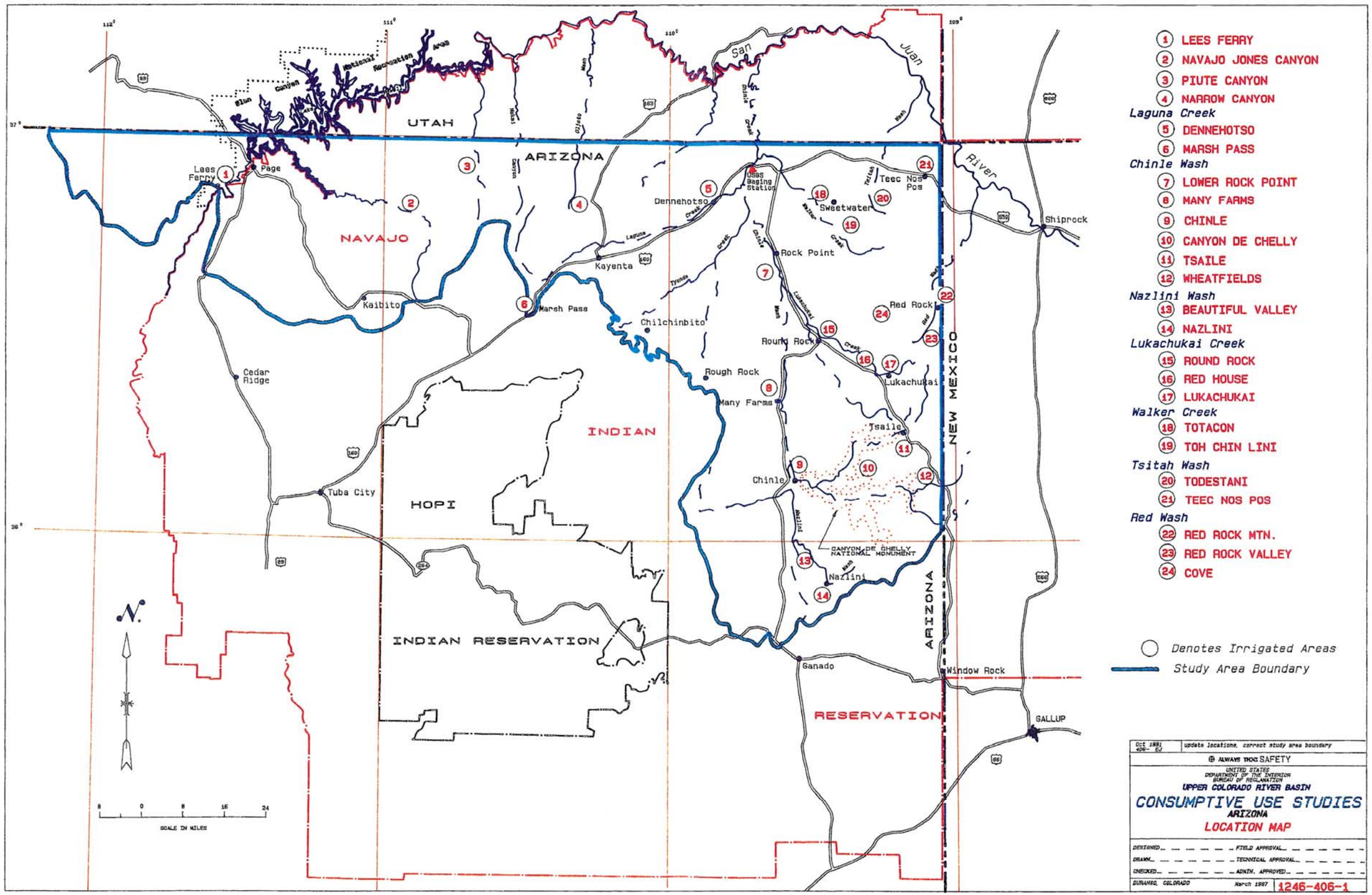
1 LEES FERRY
2 NAVAJO JONES CANYON
3 PIUTE CANYON
4 NARROW CANYON
Laguna Creek
5 DENNEHOTSO
6 MARSH PASS
Chinle Wash
7 LOWER ROCK POINT
8 MANY FARMS
9 CHINLE
10 CANYON DE CHELLY
11 TSAILE
12 WHEATFIELDS
Nazlini Wash
13 BEAUTIFUL VALLEY
14 NAZLINI
Lukachukai Creek
15 ROUND ROCK
16 RED HOUSE
17 LUKACHUKAI
Walker Creek
18 TOTACON
19 TOH CHIN LINI
Tsitah Wash
20 TODESTANI
21 TEEC NOS POS
Red Wash
22 RED ROCK MTN.
23 RED ROCK VALLEY
24 COVE
Denotes Irrigated Areas
Study Area Boundary
UTAH
ARIZONA
NAVAJO
INDIAN
HOPI
INDIAN RESERVATION
RESERVATION
NEW MEXICO
ARIZONA
San Juan River
Lees Ferry
Page
Kaibito
Cedar Ridge
Tuba City
Marsh Pass
Kayenta
Dennehotso
USGS Gaging Station
Sweetwater
Teec Nos Pos
Shiprock
Rock Point
Red Rock
Chilchinbito
Round Rock
Rough Rock
Many Farms
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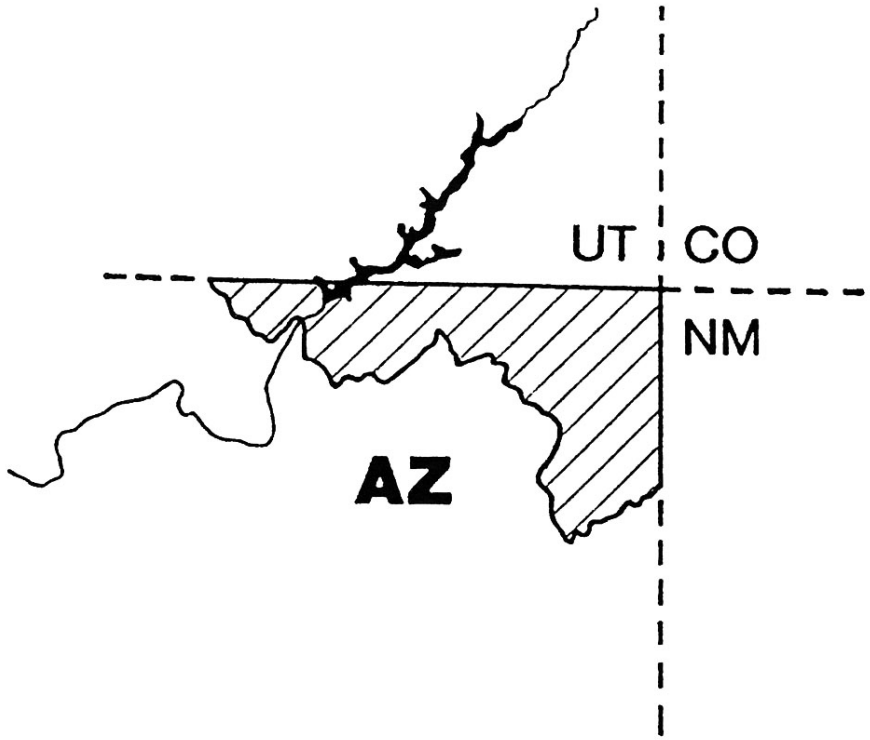
March 1987
1246-406-1

RECLAMATION

Managing Water in the West

Consumptive Uses and Losses

Arizona Portion of the Upper Colorado River Basin
Calendar Year 2002

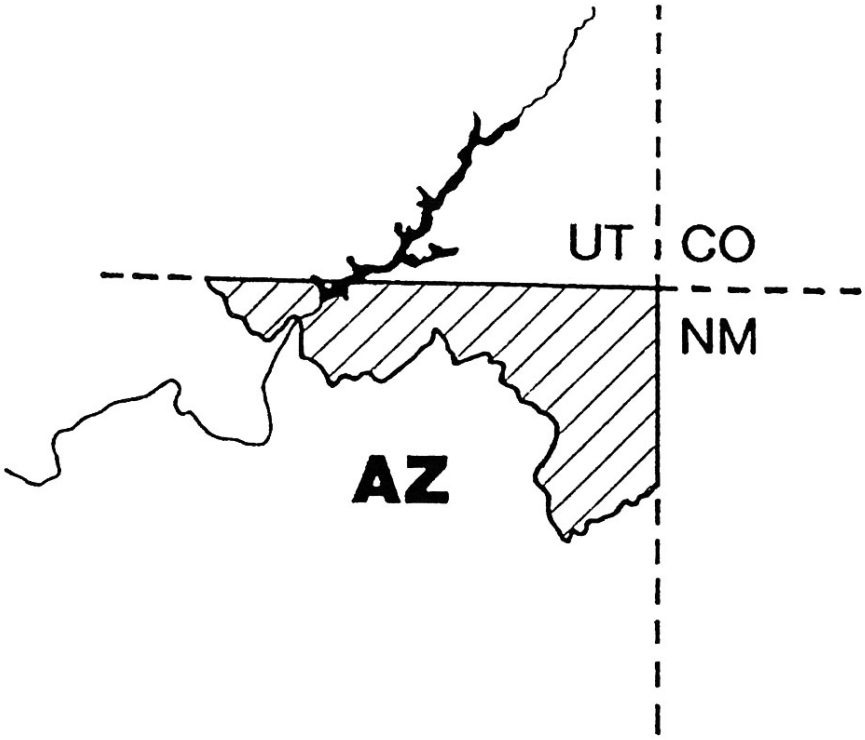


U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

October 2009

Consumptive Uses and Losses

Arizona Portion of the Upper Colorado River Basin
Calendar Year 2002



U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

October 2009

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Tables

CONSUMPTIVE USES AND LOSSES

ARIZONA PORTION OF THE UPPER COLORADO RIVER BASIN

CALENDAR YEAR 2002

AUTHORITY

This report was prepared in compliance with Public Law 90-537, Section 601 (b)(1), dated September 30, 1968, which directs the Secretary of the Interior to "make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis." Additionally, this report is in compliance with Section 49 of the Navajo Project Participation Agreement dated September 30, 1969, which states in part: "The Secretary of the Interior further agrees to make the reports required by Section 601 (b)(1) of Public Law 90-537 as they pertain to Arizona's Upper Basin uses annually rather than every five years. Within fifteen days following the completion of said reports, the Secretary of the Interior shall furnish copies of such reports to the Co-Tenants, the Navajo Tribe, each of the Upper Basin States, and the Upper Colorado River Commission."

SUMMARY

The total consumptive use and loss value for the Arizona portion of the Upper Colorado River Basin for calendar year 2002 was 38,468 ($\pm$1,253) acre-feet.

STUDY AREA DESCRIPTION

The Arizona portion of the Upper Colorado River Basin covers approximately 6,900 square miles in the north-east corner of Arizona, as shown on the location map (Drawing 1246-406-1). The climate of the 5,900 square mile area to the west of the Chuska and Carrizo Mountains is largely arid to semiarid, with mean annual precipitation ranging from 6 to 12 inches and with summertime temperatures often reaching 100 degrees Fahrenheit (^{o}F). The potential evaporation rate is high and exceeds mean annual precipitation, with gross lake evaporation values of up to 55 inches per year or more. Elevations in the western portion range from 3200 feet on the Colorado River at Lees Ferry to over 8000 feet on the northern edge of the Black Mesa and across the Zilnez and Skeleton Mesas, back down to 5280 feet in the Chinle Valley, and back up to about 6500 feet on the western edge of the Chuska Mountains. Much of the western part

of the study area is starkly beautiful southwestern desert country with mesas and canyons intertwined across a pastoral landscape. By contrast, the eastern 1,000 square miles is largely mountainous, with elevations rising to nearly 10,000 feet and mean annual precipitation reaching 30 inches. The mountainous land responds with grass meadows interspersed with conifer forest of mostly ponderosa pine.

Except for Page, Arizona; a small area around Lees Ferry; and a portion of the Paria Plateau administered by the Bureau of Land Management; the study area lies entirely within the Navajo Nation. According to census data, 48,613 persons were living within the area in 2000, and of these 41,804 resided on the Navajo Nation.

The largest cities are Page and Chinle, with 2000 populations of 6,809 and 5,366, respectively. Other major communities and their populations include Dennehotso (734), Kaibeto (1,607), Kayenta (4,922), LeChee (1,606), Lukachukai (1,565), Many Farms (1,548), Rock Point (724), Teec Nos Pos (799), and Tsaile (1,078). Subsistence in the region is derived principally from livestock grazing, farming, tourist-related industries, employment at the Navajo Generating Station (NGS), which consumes 60 to 70 percent of the water used or lost in the study area every year. Agriculture accounted for 4 percent of the total water use; municipal and industrial about 86 percent; recreation, fish and wildlife, about 4 percent; and reservoir evaporation, 6 percent.

AGRICULTURAL CONSUMPTIVE USE

Agricultural consumptive use is divided into three categories: irrigation, stock pond, and livestock. Irrigation use includes all use related to irrigating crops including the incidental losses. Stock pond use is the evaporation that occurs from stock ponds and livestock use is the water consumed by livestock.

IRRIGATION USES

Within the Arizona portion of the Upper Colorado River Basin, historically 23 irrigated areas were scattered across the Navajo Nation plus a small amount of land near Lees Ferry irrigated by the National Park Service. Currently, only 15 irrigated areas are in production. An accurate assessment of consumptive use on the irrigated land is difficult due to poor quality of information, such as the exact number of acres under irrigation, the cropping pattern for each irrigated area, site climatological conditions, and the amount s of water actually diverted. In many cases, during the latter part of the irrigation season, farmers have to rely on dry land farming since there is little water available in the streams. This means that the crops do not receive their full water requirement.

For this report, the U.S. Department of Agriculture, Soil Conservation Service's (SCS) Modified Blaney-Criddle ET estimation model was used for computing irrigated crop consumptive use. This model, along with appropriate crop-growth stage coefficients and the method for computing effective precipitation, is described in SCS's *Irrigation Water Requirements Technical Release No. 21* (TR 21). Information required for applying this model includes mean monthly temperature and precipitation values, growing season data for each crop type, and the total number of acres planted by crop at each site. With the

exception of Teec Nos Pos, Canyon de Chelly, Lukachukai, and Lees Ferry, no climatological data exist for the irrigation sites, and site values must be generated from data collected at surrounding established weather stations. Growing season dates depend largely on the judgment of the local inhabitants and are, therefore, not known. Although several reports are available with published values for irrigated acres, it is unclear if these values are meant to represent potential irrigated acres, acres irrigated in the past, acres for which farming permits have been issued, or actual acres currently under irrigation.

The crop acreage used to estimate consumptive use by irrigated crops for the year 2002 is shown in table 1. These values were determined from direct field examination by a party composed of representatives from the State of Arizona and the Navajo Nation.

Table 1.—Total irrigated acreage, 2002

PROJECT	CORN (ACRES)	ALFALFA (ACRES)	GRASS PASTURE (ACRES)	SPRING GRAINS (ACRES)	SMALL VEGETABLES (ACRES)	ORCHARD (ACRES)	TOTAL (ACRES)
CHINLE AGENCY							
Canyon de Chelly	0.36	0.00	0.00	3.03	2.26	0.00	5.65
Lukachukai	39.09	7.69	0.00	7.50	5.98	2.07	62.33
Nazlini	0.00	0.00	0.00	0.00	1.79	0.74	2.53
Rough Rock	30.00	0.00	11.87	0.00	12.43	0.00	54.30
Tsaile	23.72	5.27	15.67	5.73	5.42	0.00	55.81
Wheatfields	0.00	60.80	0.00	0.00	0.00	0.00	60.80
TOTAL	93.17	73.76	27.54	16.26	27.88	2.81	241.42
SHIPROCK AGENCY							
Red Rock Valley	26.22	0.00	10.19	5.12	10.22	0.00	51.75
Teec Nos Pos	20.00	0.00	0.00	0.00	3.67	0.00	23.67
Toh Chin Lini	0.00	0.00	0.00	0.00	3.90	13.67	17.57
Totacon	0.00	0.00	0.00	0.00	1.00	0.00	1.00
TOTAL	46.22	0.00	10.19	5.12	18.79	13.67	94.0
WESTERN NAVAJO AGENCY							
Dennehotso	1.82	0.00	38.70	0.00	0.00	0.00	40.52
Lees Ferry	0.00	0.00	1.00	0.00	0.00	2.00	3.00
Marsh Pass	7.02	3.31	0.00	0.00	1.99	0.00	12.32
Navajo Canyon	0.00	0.00	0.00	0.00	0.00	3.50	3.50
Paiute Canyon	2.64	0.00	0.00	0.00	3.86	0.00	6.50
TOTAL	11.48	3.31	39.70	0.00	5.85	5.50	65.84
GRAND TOTAL	150.87	77.07	77.43	21.38	52.52	21.98	401.25

Consumptive Uses and Losses

Several factors complicated the modeling of irrigation consumptive use. For example, the computer program used to model consumptive use assumes a full water supply; if shortages exist, as they often do in this semiarid study area, adjustments must be made. These adjustments are complicated because some of the projects have no storage water and may only have a reliable irrigation water supply during spring runoff. After spring runoff, farming becomes essentially dry land until rains in July and August provide intermittent flows for irrigation. Finally, no ditch diversion records are available to help estimate irrigation water supplies and shortages.

A full irrigation supply seldom exists at many of the projects. Generally, a full supply is available for Lees Ferry, Navajo Canyon, Tsaile, and Wheatfields projects because of adequate stream flows or because of available storage water. In years with average precipitation, it is estimated that Chinle Wash provides approximately 75 percent of the irrigation requirement. Precipitation in the area averages approximately 9.5 inches per year. Based on this information, it would require approximately 12.67 inches of precipitation to provide 100 percent of the irrigation requirement. The percent of crop water requirement met was computed as a ratio of annual precipitation to 12.67 inches. These values are found in table 2.

The percentage of crop water requirement met was multiplied by the total net crop water requirement to come up with the amount of crop consumptive use. Incidental irrigation losses, evaporation, and phreatophyte consumptive use along supply canals are estimated to be 5 percent of the consumptive use of the irrigated area and are added to the crop consumptive use value to develop a total consumptive use value.

A portion of the water used for irrigation at these sites may not be contributing to the Colorado River System since evaporation rates in the area are high and the nature of most of the drainage enhances evapotranspiration. A good example of such a drainage is Chinle Wash, which after it leaves Canyon de Chelly, becomes wide and sandy and is lined with willows, cottonwoods, and other phreatophytes.

The uncertainties in the irrigation consumptive use values displayed in table 2 are very large and are estimated as 40 percent of the total consumptive use. This estimate of possible error only reflects the uncertainty of consumptive use and does not account for any possible errors in the acreage estimates. The effective consumptive use for irrigation for 2002 was estimated to equal 415 acre-feet. Including the 5 percent for incidental losses, the irrigation related consumptive use is 436 ($\pm$174) acre-feet.

Table 2.—Net consumptive use values, 2002

PROJECT	CROP WATER REQUIREMENT (INCHES)	TOTAL IRRIGATED (ACRES)	TOTAL WATER REQUIRED (ACRE-FEET)	CROP WATER REQUIREMENT MET (%)	CROP WATER REQUIREMENT MET (ACRE-FEET)	TOTAL CONSUMPTIVE USE (ACRE-FEET)[1]
CHINLE AGENCY						
Canyon de Chelly	17.89	5.65	8	43%	4	4
Lukachukai	24.54	62.33	127	43%	55	58
Nazlini	21.55	2.53	5	43%	2	2
Rough Rock	22.27	54.30	101	36%	36	38
Tsaile	26.20	55.81	122	43%	53	55
Wheatfields	35.83	60.80	182	43%	78	82
TOTAL	—	241.42	545	—	228	239
SHIPROCK AGENCY						
Red Rock Valley	24.69	51.75	106	49%	52	55
Teec Nos Pos	25.70	23.67	51	55%	28	29
Toh Chin Lini	36.60	17.57	54	49%	26	28
Totacon	16.85	1.00	1	49%	1	1
TOTAL	—	93.99	212	—	107	113
WESTERN NAVAJO AGENCY						
Dennehotso	36.05	40.52	122	43%	53	55
Lees Ferry	53.22	3.00	13	100%	13	14
Marsh Pass	21.58	12.32	22	32%	7	7
Navajo Canyon	41.57	3.50	12	26%	3	3
Paiute Canyon	20.10	6.50	11	36%	4	4
TOTAL	—	65.84	180	—	80	84
GRAND TOTAL	—	401.25	937	—	415	436

[1] Total includes 5% addition for incidental losses.

STOCK POND EVAPORATION

Stock pond consumptive use is assumed to be the evaporation from the stock pond. It is also assumed that any consumptive use by natural vegetation prior to the construction of the stock ponds is limited to precipitation which is subtracted from the evaporation losses.

A compilation of the stock ponds in the study area, including their locations and the water surface areas when ponds are full, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 3. For an average year conditions, the stock pond evaporative surface area was estimated as one-third the water surface area that occurs when the ponds are full. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average water surface area. These values are found in table 3.

Table 3.—Stock pond evaporation, 2002

COUNTY	SURFACE AREA FULL (ACRES)	SURFACE AREA USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Coconino	80	16	60%	57	4.03	52.97	70
Navajo	40	7	52%	55	5.08	49.93	29
Apache	646	152	71%	53	6.23	46.77	594
TOTAL	766	175	—	—	—	—	693

This method of evaporation estimation was used because continuous useful water level records for all stock ponds from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual stock ponds. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation. It was assumed that any consumptive use by natural vegetation prior to construction of the stock ponds is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for stock pond evaporation for calendar year 2002 are shown in table 3. The total evaporative losses in 2002 are 693 ($\pm$208) acre-feet with the stock pond evaporation uncertainty being estimated as 30 percent.

LIVESTOCK WATER

The source of most livestock water in the study area is from wells, with windmill-operated pumps developed and maintained by Navajo Water Operations and Maintenance, and water collected in small surface ponds. The estimated number of

livestock in the area was obtained based on livestock tallies. It was estimated that horses and cattle consume 12 gallons per day; sheep and goats consume 2 gallons per day.

The number of animals for the Upper Colorado portion of each district is shown in table 4. The computed value for livestock consumptive use is 218 acre-feet. The uncertainty in this number is estimated as 30 percent of the total or ±65 acre-feet.

Table 4.—Number of livestock, 2002

AGENCY	CATTLE	HORSES	SHEEP	GOATS
Western Navajo District No. 1	2,079	328	2,398	1,263
Western Navajo District No. 2	709	81	1,339	898
Western Navajo District No. 8	1,910	169	2,960	2,069
Shiprock District No. 9	1,134	179	1,226	1,494
Chinle District No. 10	2,694	369	3,605	1,967
Chinle District No. 11	1,041	156	956	1,041
Shiprock District No. 12	897	84	1,075	827
Fort Defiance District No. 17	100	15	370	141
Fort Defiance District No. 18	248	23	329	145
TOTAL	10,812	1,404	14,257	9,844

TOTAL AGRICULTURAL CONSUMPTIVE USE

The total agricultural consumptive use, displayed in table 5, is the sum of the individual components discussed in the previous sections. Agricultural water consumption represents approximately 4 percent of the total use in the study area. Total degree of uncertainty was computed by taking the square root of the sum of the individual uncertainties squared; known as the quadratic sum. This method and nomenclature is used throughout this report. This method was used because a simple sum does not account for the partial cancellation of errors occurring when calculating the total uncertainty derived from individual values that are random and independent of each other. As previously discussed, the individual uncertainties were set as a percent of the consumptive use value.

Table 5.—Total agricultural consumptive use, 2002

CATEGORY	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Irrigation	436	174
Stock Ponds	693	208
Livestock	218	65
TOTAL	1,347	279

MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

Municipal and industrial consumptive use is divided into three categories: mineral resources, thermal electric power, and other. Mineral resources consumptive use includes water used for mineral production. No mineral resources consumptive use is reported in the study area. Thermal electric power consumptive use includes the water used at the power plants, and that used to transport material to the power plant (such as a coal slurry pipeline). Other consumptive use includes urban, rural, and industrial uses.

THERMAL ELECTRIC POWER

Thermal electric power consumptive use includes the water used in the power plant and the water used to transport material to the plant.

Navajo Generating Station

The water used by the NGS is pumped directly from Lake Powell and comprises over half of the total consumption in the study area. Since all NGS water use is metered, this quantity is among those most precisely known, with the maximum uncertainty in the metered quantities believed to be less than 3 percent. The actual quantity consumed, along with the estimated uncertainty for the calendar year 2002, was 28,415 (±852) acre-feet.

OTHER

The other consumptive use category includes the remaining use by urban, rural, and industries.

Page, AZ and Vicinity

***City of Page, AZ*. –** The city of Page pumps its domestic water directly from Lake Powell. The water pumped is metered, and the uncertainty of the pumped quantities was assumed to be less than 3 percent. A portion of the water pumped and treated by the City of Page, is supplied to the community of Le Chee on the Navajo Nation and is accounted for separately. The quantity supplied to the City of Page and its associated uncertainty for the calendar year 2002 was 2,641 (±79) acre-feet. Water returning to the waste water treatment plant is metered as well. The waste water for the City of Page is treated and is either evaporated from lined ponds or applied to the golf course, with a portion being returned to the Colorado River. The return flow is estimated to be 794 acre-feet. The net consumptive use is estimated to be 1,848 acre-feet (±83).

***Le Chee* –** The community of Le Chee is supplied and metered by the City of Page. Total water supplied for 2002 was 86 (±3) acre-feet. The uncertainty was estimated to be 3 percent.

Greenhaven Water Company – The Greenhaven Water Company derives its domestic water supply from wells. Well pumping records are available. According to these records, the total water pumped for 2002 was 101 (±7) acre-feet. The uncertainty was estimated to be 7 percent.

Arizona Department of Transportation Housing – The Arizona Department of Transportation operates a housing, maintenance, and administrative facility located on US Hwy 89, north of Page, AZ. This facility is supplied from wells that have no meters installed. It is estimated that the total water pumped for 2002 was 16 acre-feet with an uncertainty of 30 percent of this value or ±5 acre-feet.

Navajo Nation

Community Water Systems – Statistics from the Division of Community Development of the Navajo Nation reveal that various community water systems served 26,086, or about 83 percent of the 31,429 people residing within the study area in 1980. This percentage was used for 2002 resulting in 35,591 out of 42,881 people being served. These systems include those operated by the Navajo Tribal Utility Authority (NTUA), the BIA, and the Water Operations and Maintenance Department of the Navajo Nation, and some privately developed community water systems.

Table 6 shows the source of water and estimated population served by each source of water for people living on the Navajo Nation during 2002. All of the communities obtain their water supply from ground water.

Table 6.—Domestic water sources, 2002

SOURCE	PERCENTAGE OF POPULATION SERVED	NUMBER OF POPULATION SERVED[1]
Community Water Systems	83	35,591
NTUA	[2](60)	21,354
BIA	[2](25)	8,898
Navajo WOM	[2](13)	4,627
Private	[2](2)	712
Individual Wells	17	7,290
TOTAL[2]	100	42,881

[1] Estimated total population within the Upper Colorado River Basin portion of the Navajo Nation provided by Larry Rodgers, Demographer for the Division of Community Development of the Navajo Nation, letter DCDA-L94052, June 20, 1995.
[2] These numbers are a percentage of the Community Water Systems.

NTUA Water Systems – The cities and surrounding communities of Oak Springs, Red Valley, Sweetwater, Chinle , Rough Rock, Round Rock, Rock Point, Wheatfields, Lukachukai, Kayenta, Chilchinbeto, Dennehotso, and Kaibeto derive most of their domestic water supply from wells operated by NTUA. Well pumping records are

available. According to these records, the total water pumped for 2002 was 1,593 acre-feet with an uncertainty estimated to be 7 percent of this value or ±112 acre-feet.

The NTUA manages the raw waste water; portions of which flow to individual septic tanks, some to evaporation ponds, and some, such as for the cities of Chinle and Kayenta, flow to waste water treatment plants. Very little water, if any, is returned to the ground water system through leakage from the evaporation ponds, but there are losses from the main collection system. Effluent from the Chinle and Kayenta waste water treatment plants is metered. Under normal conditions, the effluent returns to the Colorado River System and is subtracted from the pumping totals to determine a net consumptive use. For 2002, Chinle's treatment plant effluent was 506 (±35) acre-feet, and Kayenta's effluent was 224 (±16) acre-feet. An estimated uncertainty of 7 percent was used for the effluent of these two plants. The total effluent of 730 acre-feet is subtracted from the NTUA pumping total of 1,593 acre-feet to arrive at a net consumptive use of 864 (±123) acre-feet.

BIA Water Systems – Wells developed and operated by the BIA serve numerous Navajo communities. These systems also serve BIA schools, hospitals, agency offices, and some housing on the Navajo Nation. Metered records for total amounts of water pumped from BIA wells were available for a portion of the Shiprock Agency, the Western Navajo Agency, and the Chinle Agency. Drawing 1246-406-2 shows the agency boundaries within the Upper Colorado River Basin. The uncertainty was estimated to be about 7 percent for all three agencies.

The BIA systems include sewage disposal units terminating in lined evaporation ponds with very little or no return water returning to the ground water system. Undoubtedly, some losses occur in distribution, but insufficient data currently exist to estimate these losses. The losses are probably less than the uncertainties for each of the reported values.

The BIA well data available for the Shiprock Agency include: Cove, Red Rock, and Teec Nos Pos. Total consumptive use values are 11 (±1) acre-feet.

Pumping records for the Western Navajo Agency include data for the following schools: Chilchinbeto Day School, Dennehotso Boarding School, Kaibeto Boarding School, and Kayenta Boarding School. Total consumptive use for the Western Navajo Agency was 176 (±12) acre-feet.

Well pumping records for the Chinle Agency include data for the following schools: Cottonwood Day School, Lukachukai School, and Rock Point School. Rough Rock School maintains its own records, but the data was included with the Chinle Agency data. Total consumptive use for the Chinle Agency was 73 (±5) acre-feet.

Navajo WOM Water Systems – Water use in 2002 by the Navajo WOM service areas was based on an assumed consumption rate of 110 gallons per capita per day (gpcd). For a 2002 estimated service area population of 4,627, the estimated annual water use was 570 (±171) acre-feet. The uncertainty is estimated as 30 percent of the total.

Private Water Systems – The estimated 2002 population served by private water systems on the Navajo Nation was 712. Assuming a consumptive use rate of 110

gcpd, the annual water use for 2002 was 88 (±26) acre-feet. The uncertainty is estimated as 30 percent of the total.

Individual Wells – According to census data from the Division of Community Development of the Navajo Nation, approximately 17 percent of the study area's population on the reservation (about 7,290 persons in 2002) receives a domestic water supply from individual wells. A consumptive use of 110 gpcd was derived as being a reasonable water use rate. Based on these figures, the annual consumptive use was 898 (±269) acre-feet for 2002.

TOTAL MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

The total municipal and industrial consumptive use, displayed in table 7, is the sum of the individual components discussed in the previous sections. Municipal and industrial water consumption represents approximately 86 percent of the total use in the study area.

Table 7.—Total municipal and industrial consumptive use, 2002

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
THERMAL ELECTRIC POWER		
Navajo Generating Station	28,415	852
OTHER		
Page, AZ and Vicinity		
City of Page	1,848	83
Le Chee	86	3
Greenhaven Water Company	101	7
Arizona Department of Transportation	16	5
Navajo Indian Reservation		
Community Water Systems		
NTUA Water Systems	864	123
BIA Water Systems	260	13
Navajo WOM	570	171
Private Water Systems	88	26
Individual Wells	898	269
TOTAL	33,145	923

It is questionable whether all the water pumped from wells should be considered a depletion to the Colorado River System; however, it is assumed that 100 percent of the water pumped is considered lost to the system. It is proposed that a future joint study be completed by Reclamation, the State of Arizona, and the Navajo Nation to estimate what

percentage of water pumped could actually be attributed to the Colorado River System and would have affected the river flows for a particular year.

RECREATION, FISH AND WILDLIFE

The recreation, fish and wildlife consumptive uses include evaporation from reservoirs used exclusively for fish & wildlife purposes as well as acreages irrigated for wildlife feeding. Consumptive use at National and State parks is also accounted for.

GLEN CANYON NATIONAL RECREATION AREA

Colorado River water is used by the Glen Canyon National Recreation Area (GCNRA) at Wahweap and Lees Ferry. The recreational area at Wahweap gets its water supply from a series of wells on the shore of Lake Powell. Pumping records for both Wahweap and Lees Ferry show 369 (±11) acre-feet of water withdrawn during 2002. The uncertainty is estimated at 3 percent. This water was used for domestic purposes at the campgrounds, picnic areas, and trailer parks. It was also used to irrigate approximately 60 acres of Bermuda grass and cottonwood trees. The domestic waste water is treated and the effluent is allowed to evaporate from two lines evaporation ponds with a total surface area of 16.7 acres.

Based on estimates of evaporation and consumptive use by the plants, there is some water which is unaccounted for and is assumed to be leakage from the delivery system, the evaporation pond, or deep percolation from irrigation application. However, since these water losses are difficult to quantify and verify, the losses were charged as consumptive uses. Therefore, net consumptive use of water is estimated to be equal to the quantity of water pumped.

RESERVOIR EVAPORATION

A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled “1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River” and are shown in table 8.

Table 8. —Recreation, fish and wildlife reservoir evaporation, 2002

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE AREA USED (ACRES)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Tsaile	260	260	35	5.47	29.53	640
Wheatfields	272	272	32	5.47	26.53	601
TOTAL	532	532	—	—	—	1,241

Efforts are made to maintain a nearly full condition and to minimize water surface fluctuations in reservoirs managed for a fishery. Under average operating conditions, the

water surface area of a reservoir used primarily for fishing is assumed to be equal to a normal water surface area. It is assumed that, in 2002, these reservoirs filled in the spring and were maintained at the normal pool level.

This method of evaporation estimation was used because continuous useful water level records for all reservoirs from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs.

For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for reservoir evaporation for calendar year 2002 are shown in table 8. The total evaporative losses in 2002 are 1,241 (±372) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent.

TOTAL RECREATION, FISH AND WILDLIFE

The total recreation, fish and wildlife consumptive use, displayed in table 9, is the sum of the individual components discussed in the previous sections. Recreation, fish and wildlife water consumption represents approximately 4 percent of the total use in the study area.

Table 9.—Total recreation, fish and wildlife consumptive use, 2002

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Glen Canyon National Recreation Area	369	11
Reservoir Evaporation	1,241	372
TOTAL	1,610	373

RESERVOIR EVAPORATION

Reservoir evaporation losses make up about 6 percent of the total water uses and losses in the study area. A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 10. These reservoirs are used primarily for irrigation.

Table 10.—Reservoir evaporation, 2002

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE ACRES USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Many Farms	1,800	503	—	56	5.47	50.53	2120
Marsh Pass	40	8	38%	40	4.33	35.67	23
Round Rock	83	29	71%	57	6.23	50.77	124
Walker Creek	30	13	87%	59	6.99	52.01	56
Others	38	10	53%	55	5.35	49.65	42
TOTAL	1,991	564	—	—	—	—	2,365

Reservoirs used primarily for irrigation experience large fluctuations in water levels and, correspondingly, large variations in surface area. Reservoir level records and elevation – area curves were available at Many Farms, but not for the remaining reservoirs in table 10. For the reservoirs with no records from which surface area could be accurately computed, the average evaporative surface area was estimated as one-half the water surface area of a full reservoir. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average evaporative surface area.

Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses. The computed values for reservoir evaporation for 2002 are shown in table 10. The total evaporative losses in 2002 are 2,365 ($\pm$709) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent of the total evaporation.

CONCLUSIONS

This report assesses the total consumptive use of the Arizona portion of the Upper Colorado River System surface water systems, depletion of ground water, and evaporative losses. Clearly, the amounts of water used by the Navajo Generating Station, City of Page, and Wahweap and Lees Ferry recreation areas are direct depletions of water from the Upper Colorado River System, but the situation is not as clear for other consumptive uses and losses occurring in other sections of the study area. For example, the source of water used by the Navajo Nation for domestic and municipal purposes is from wells, some exceeding 1,000 feet in depth. For our purposes here, it is considered to be consumed and a depletion to the Colorado River System. But this may not actually result in a reduction of Colorado River stream flows in the same year that the withdrawal occurs. Little knowledge and information exists of ground water movement and

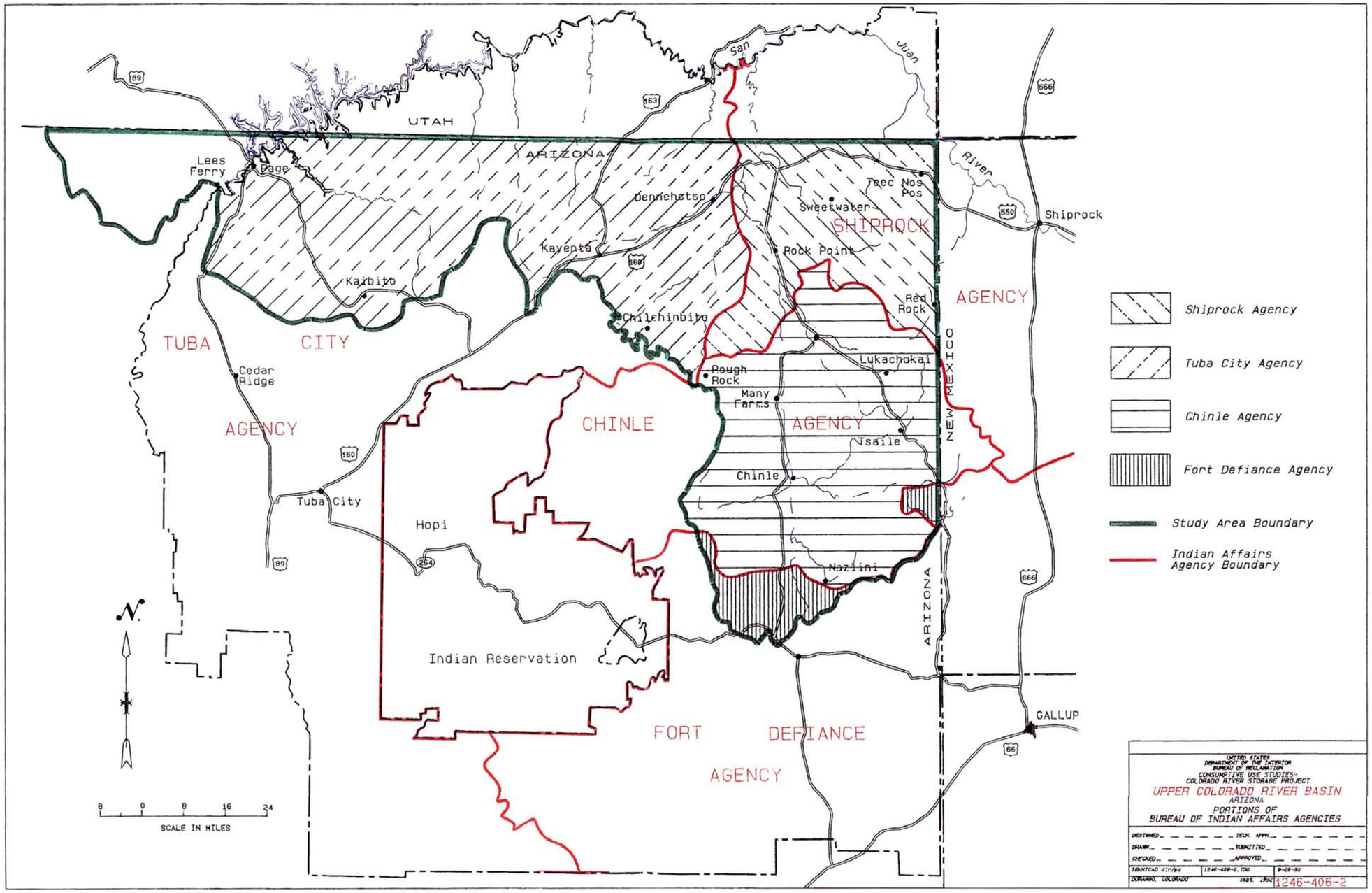
subsurface flow rates in the study area that are accurate descriptions of the effects on river flows.

Although the water diverted for agricultural purposes is considered as consumptive use in this report, a portion of the remaining surface water on the Navajo Nation, excess to needs, does evaporate before reaching the Colorado River. An attempt has not been made for this report to quantify these losses.

Uncertainties in estimating uses and losses exist, and the degree of variation in the figures is presented. Fortunately, the areas with the highest degree of uncertainty account for only a small percentage of the total consumptive use. The largest component, use by the Navajo Generating Station, is also the most accurately monitored. The total annual value for estimated consumptive use of water within the Arizona portion of the Upper Colorado River Basin for 2002 was 38,468 acre-feet, as shown in table 11.

Table 11.—Consumptive use for Arizona portion of Upper Colorado River Basin for 2002

USE CATEGORY	TOTAL CONSUMPTIVE USE (ACRE-FEET)	UNCERTAINTY	PERCENT OF TOTAL
Agriculture	1,347	279	4
Municipal & Industrial	33,145	923	86
Recreation, Fish & Wildlife	1,610	373	4
Reservoir Evaporation	2,365	709	6
TOTAL	38,468	1,254	100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NEW MEXICO
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Page
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Kayenta
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Chilchinbito
Teec Nos Pos
Sweetwater
Rock Point
Red Rock
Lukachukai
Rough Rock
Many Farms
Tsaile
Chinle
Nazlini
Shiprock
Cedar Ridge
Tuba City
Hopi
Indian Reservation
GALLUP
San Juan River
TUBA CITY AGENCY
CHINLE AGENCY
SHIPROCK AGENCY
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Shiprock Agency
Tuba City Agency
Chinle Agency
Fort Defiance Agency
Study Area Boundary
Indian Affairs Agency Boundary
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CONSUMPTIVE USE STUDIES-
COLORADO RIVER STORAGE PROJECT
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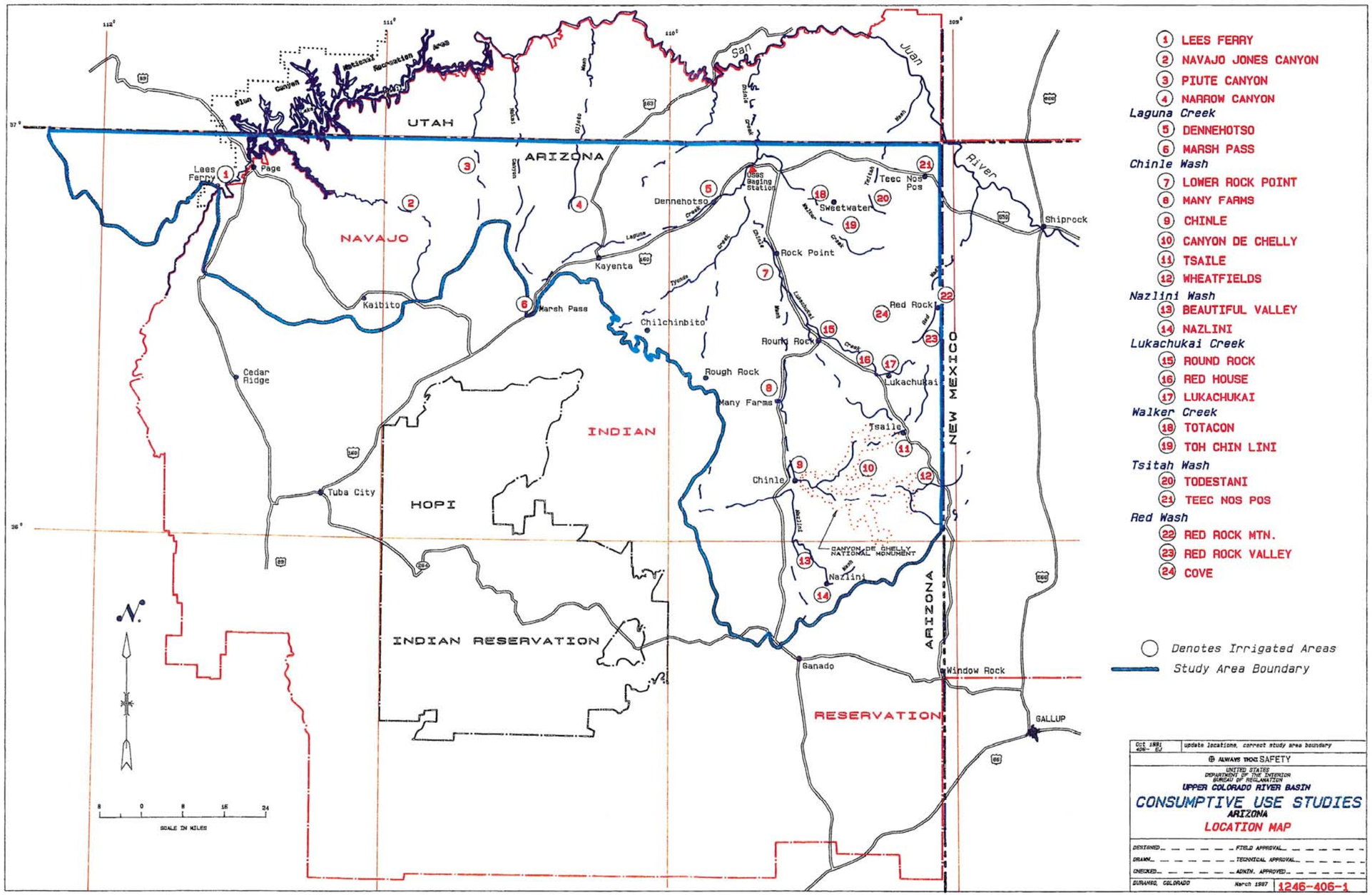
1 LEES FERRY
2 NAVAJO JONES CANYON
3 PIUTE CANYON
4 NARROW CANYON
Laguna Creek
5 DENNEHOTSO
6 MARSH PASS
Chinle Wash
7 LOWER ROCK POINT
8 MANY FARMS
9 CHINLE
10 CANYON DE CHELLY
11 TSAILE
12 WHEATFIELDS
Nazlini Wash
13 BEAUTIFUL VALLEY
14 NAZLINI
Lukachukai Creek
15 ROUND ROCK
16 RED HOUSE
17 LUKACHUKAI
Walker Creek
18 TOTACON
19 TOH CHIN LINI
Tsitah Wash
20 TODESTANI
21 TEEC NOS POS
Red Wash
22 RED ROCK MTN.
23 RED ROCK VALLEY
24 COVE
Denotes Irrigated Areas
Study Area Boundary
UTAH
ARIZONA
NAVAJO
INDIAN
HOPI
INDIAN RESERVATION
RESERVATION
NEW MEXICO
ARIZONA
San Juan River
Lees Ferry
Page
Kaibito
Cedar Ridge
Tuba City
Marsh Pass
Kayenta
Dennehotso
USGS Gaging Station
Sweetwater
Teec Nos Pos
Shiprock
Rock Point
Red Rock
Chilchinbito
Round Rock
Rough Rock
Many Farms
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CANYON DE CHELLY NATIONAL MONUMENT
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SCALE IN MILES
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Oct 1981 update locations, correct study area boundary
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
UPPER COLORADO RIVER BASIN
CONSUMPTIVE USE STUDIES
ARIZONA
LOCATION MAP
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FIELD APPROVAL
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TECHNICAL APPROVAL
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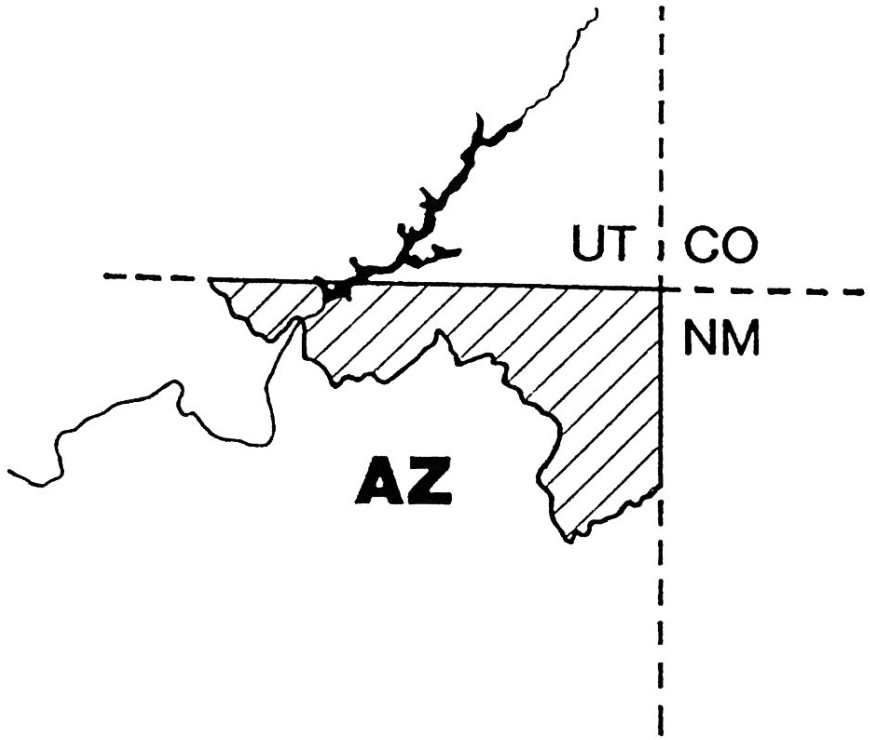
DURANGO, COLORADO
March 1987
1246-406-1

RECLAMATION

Managing Water in the West

Consumptive Uses and Losses

Arizona Portion of the Upper Colorado River Basin
Calendar Year 2003

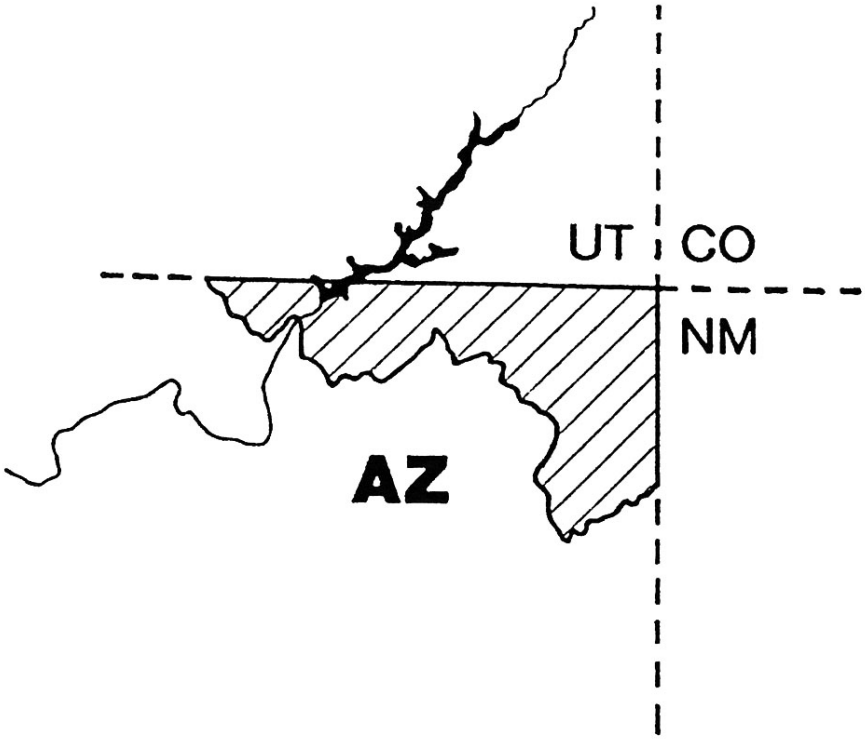


U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

October 2009

Consumptive Uses and Losses

Arizona Portion of the Upper Colorado River Basin
Calendar Year 2003



U.S. Department of the Interior
Bureau of Reclamation
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Tables

CONSUMPTIVE USES AND LOSSES

ARIZONA PORTION OF THE UPPER COLORADO RIVER BASIN

CALENDAR YEAR 2003

AUTHORITY

This report was prepared in compliance with Public Law 90-537, Section 601 (b)(1), dated September 30, 1968, which directs the Secretary of the Interior to "make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis." Additionally, this report is in compliance with Section 49 of the Navajo Project Participation Agreement dated September 30, 1969, which states in part: "The Secretary of the Interior further agrees to make the reports required by Section 601 (b)(1) of Public Law 90-537 as they pertain to Arizona's Upper Basin uses annually rather than every five years. Within fifteen days following the completion of said reports, the Secretary of the Interior shall furnish copies of such reports to the Co-Tenants, the Navajo Tribe, each of the Upper Basin States, and the Upper Colorado River Commission."

SUMMARY

The total consumptive use and loss value for the Arizona portion of the Upper Colorado River Basin for calendar year 2003 was 36,604 ($\pm$1,257) acre-feet.

STUDY AREA DESCRIPTION

The Arizona portion of the Upper Colorado River Basin covers approximately 6,900 square miles in the north-east corner of Arizona, as shown on the location map (Drawing 1246-406-1). The climate of the 5,900 square mile area to the west of the Chuska and Carrizo Mountains is largely arid to semiarid, with mean annual precipitation ranging from 6 to 12 inches and with summertime temperatures often reaching 100 degrees Fahrenheit (^{o}F). The potential evaporation rate is high and exceeds mean annual precipitation, with gross lake evaporation values of up to 55 inches per year or more. Elevations in the western portion range from 3200 feet on the Colorado River at Lees Ferry to over 8000 feet on the northern edge of the Black Mesa and across the Zilnez and Skeleton Mesas, back down to 5280 feet in the Chinle Valley, and back up to about 6500 feet on the western edge of the Chuska Mountains. Much of the western part

of the study area is starkly beautiful southwestern desert country with mesas and canyons intertwined across a pastoral landscape. By contrast, the eastern 1,000 square miles is largely mountainous, with elevations rising to nearly 10,000 feet and mean annual precipitation reaching 30 inches. The mountainous land responds with grass meadows interspersed with conifer forest of mostly ponderosa pine.

Except for Page, Arizona; a small area around Lees Ferry; and a portion of the Paria Plateau administered by the Bureau of Land Management; the study area lies entirely within the Navajo Nation. According to census data, 48,613 persons were living within the area in 2000, and of these 41,804 resided on the Navajo Nation.

The largest cities are Page and Chinle, with 2000 populations of 6,809 and 5,366, respectively. Other major communities and their populations include Dennehotso (734), Kaibeto (1,607), Kayenta (4,922), LeChee (1,606), Lukachukai (1,565), Many Farms (1,548), Rock Point (724), Teec Nos Pos (799), and Tsaile (1,078). Subsistence in the region is derived principally from livestock grazing, farming, tourist-related industries, employment at the Navajo Generating Station (NGS), which consumes 60 to 70 percent of the water used or lost in the study area every year. Agriculture accounted for 4 percent of the total water use; municipal and industrial about 85 percent; recreation, fish and wildlife, about 4 percent; and reservoir evaporation, 7 percent.

AGRICULTURAL CONSUMPTIVE USE

Agricultural consumptive use is divided into three categories: irrigation, stock pond, and livestock. Irrigation use includes all use related to irrigating crops including the incidental losses. Stock pond use is the evaporation that occurs from stock ponds and livestock use is the water consumed by livestock.

IRRIGATION USES

Within the Arizona portion of the Upper Colorado River Basin, historically 23 irrigated areas were scattered across the Navajo Nation plus a small amount of land near Lees Ferry irrigated by the National Park Service. Currently, only 15 irrigated areas are in production. An accurate assessment of consumptive use on the irrigated land is difficult due to poor quality of information, such as the exact number of acres under irrigation, the cropping pattern for each irrigated area, site climatological conditions, and the amount s of water actually diverted. In many cases, during the latter part of the irrigation season, farmers have to rely on dry land farming since there is little water available in the streams. This means that the crops do not receive their full water requirement.

For this report, the U.S. Department of Agriculture, Soil Conservation Service's (SCS) Modified Blaney-Criddle ET estimation model was used for computing irrigated crop consumptive use. This model, along with appropriate crop-growth stage coefficients and the method for computing effective precipitation, is described in SCS's *Irrigation Water Requirements Technical Release No. 21* (TR 21). Information required for applying this model includes mean monthly temperature and precipitation values, growing season data for each crop type, and the total number of acres planted by crop at each site. With the

exception of Teec Nos Pos, Canyon de Chelly, Lukachukai, and Lees Ferry, no climatological data exist for the irrigation sites, and site values must be generated from data collected at surrounding established weather stations. Growing season dates depend largely on the judgment of the local inhabitants and are, therefore, not known. Although several reports are available with published values for irrigated acres, it is unclear if these values are meant to represent potential irrigated acres, acres irrigated in the past, acres for which farming permits have been issued, or actual acres currently under irrigation.

The crop acreage used to estimate consumptive use by irrigated crops for the year 2003 is shown in table 1. These values were determined from direct field examination by a party composed of representatives from the State of Arizona and the Navajo Nation.

Table 1.—Total irrigated acreage, 2003

PROJECT	CORN (ACRES)	ALFALFA (ACRES)	GRASS PASTURE (ACRES)	SPRING GRAINS (ACRES)	SMALL VEGETABLES (ACRES)	ORCHARD (ACRES)	TOTAL (ACRES)
CHINLE AGENCY							
Canyon de Chelly	0.36	0.00	0.00	3.03	2.26	0.00	5.65
Lukachukai	39.09	7.69	0.00	7.50	5.98	2.07	62.33
Nazlini	0.00	0.00	0.00	0.00	1.79	0.74	2.53
Rough Rock	30.00	0.00	11.87	0.00	12.43	0.00	54.30
Tsaile	23.72	5.27	15.67	5.73	5.42	0.00	55.81
Wheatfields	0.00	60.80	0.00	0.00	0.00	0.00	60.80
TOTAL	93.17	73.76	27.54	16.26	27.88	2.81	241.42
SHIPROCK AGENCY							
Red Rock Valley	26.22	0.00	10.19	5.12	10.22	0.00	51.75
Teec Nos Pos	20.00	0.00	0.00	0.00	3.67	0.00	23.67
Toh Chin Lini	0.00	0.00	0.00	0.00	3.90	13.67	17.57
Totacon	0.00	0.00	0.00	0.00	1.00	0.00	1.00
TOTAL	46.22	0.00	10.19	5.12	18.79	13.67	94.0
WESTERN NAVAJO AGENCY							
Dennehotso	1.82	0.00	38.70	0.00	0.00	0.00	40.52
Lees Ferry	0.00	0.00	1.00	0.00	0.00	2.00	3.00
Marsh Pass	7.02	3.31	0.00	0.00	1.99	0.00	12.32
Navajo Canyon	0.00	0.00	0.00	0.00	0.00	3.50	3.50
Paiute Canyon	2.64	0.00	0.00	0.00	3.86	0.00	6.50
TOTAL	11.48	3.31	39.70	0.00	5.85	5.50	65.84
GRAND TOTAL	150.87	77.07	77.43	21.38	52.52	21.98	401.25

Consumptive Uses and Losses

Several factors complicated the modeling of irrigation consumptive use. For example, the computer program used to model consumptive use assumes a full water supply; if shortages exist, as they often do in this semiarid study area, adjustments must be made. These adjustments are complicated because some of the projects have no storage water and may only have a reliable irrigation water supply during spring runoff. After spring runoff, farming becomes essentially dry land until rains in July and August provide intermittent flows for irrigation. Finally, no ditch diversion records are available to help estimate irrigation water supplies and shortages.

A full irrigation supply seldom exists at many of the projects. Generally, a full supply is available for Lees Ferry, Navajo Canyon, Tsaile, and Wheatfields projects because of adequate stream flows or because of available storage water. In years with average precipitation, it is estimated that Chinle Wash provides approximately 75 percent of the irrigation requirement. Precipitation in the area averages approximately 9.5 inches per year. Based on this information, it would require approximately 12.67 inches of precipitation to provide 100 percent of the irrigation requirement. The percent of crop water requirement met was computed as a ratio of annual precipitation to 12.67 inches. These values are found in table 2.

The percentage of crop water requirement met was multiplied by the total net crop water requirement to come up with the amount of crop consumptive use. Incidental irrigation losses, evaporation, and phreatophyte consumptive use along supply canals are estimated to be 5 percent of the consumptive use of the irrigated area and are added to the crop consumptive use value to develop a total consumptive use value.

A portion of the water used for irrigation at these sites may not be contributing to the Colorado River System since evaporation rates in the area are high and the nature of most of the drainage enhances evapotranspiration. A good example of such a drainage is Chinle Wash, which after it leaves Canyon de Chelly, becomes wide and sandy and is lined with willows, cottonwoods, and other phreatophytes.

The uncertainties in the irrigation consumptive use values displayed in table 2 are very large and are estimated as 40 percent of the total consumptive use. This estimate of possible error only reflects the uncertainty of consumptive use and does not account for any possible errors in the acreage estimates. The effective consumptive use for irrigation for 2003 was estimated to equal 465 acre-feet. Including the 5 percent for incidental losses, the irrigation related consumptive use is 488 ($\pm$195) acre-feet.

Table 2.—Net consumptive use values, 2003

PROJECT	CROP WATER REQUIREMENT (INCHES)	TOTAL IRRIGATED (ACRES)	TOTAL WATER REQUIRED (ACRE-FEET)	CROP WATER REQUIREMENT MET (%)	CROP WATER REQUIREMENT MET (ACRE-FEET)	TOTAL CONSUMPTIVE USE (ACRE-FEET)[1]
CHINLE AGENCY						
Canyon de Chelly	17.99	5.65	8	56%	5	5
Lukachukai	22.78	62.33	118	56%	67	70
Nazlini	19.67	2.53	4	56%	2	2
Rough Rock	23.89	54.30	108	51%	56	58
Tsaile	23.80	55.81	111	56%	62	66
Wheatfields	32.46	60.80	164	56%	93	97
TOTAL	—	241.42	514	—	285	299
SHIPROCK AGENCY						
Red Rock Valley	24.74	51.75	107	52%	55	58
Teec Nos Pos	27.55	23.67	54	47%	26	27
Toh Chin Lini	37.85	17.57	55	33%	18	19
Totacon	16.60	1.00	1	33%	0	0
TOTAL	—	93.99	218	—	100	105
WESTERN NAVAJO AGENCY						
Dennehotso	37.45	40.52	126	37%	47	50
Lees Ferry	55.82	3.00	14	100%	14	15
Marsh Pass	23.73	12.32	24	40%	10	10
Navajo Canyon	41.76	3.50	12	46%	6	6
Paiute Canyon	21.65	6.50	12	33%	4	4
TOTAL	—	65.84	189	—	80	84
GRAND TOTAL	—	401.25	921	—	465	488

[1] Total includes 5% addition for incidental losses.

STOCK POND EVAPORATION

Stock pond consumptive use is assumed to be the evaporation from the stock pond. It is also assumed that any consumptive use by natural vegetation prior to the construction of the stock ponds is limited to precipitation which is subtracted from the evaporation losses.

A compilation of the stock ponds in the study area, including their locations and the water surface areas when ponds are full, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 3. For an average year conditions, the stock pond evaporative surface area was estimated as one-third the water surface area that occurs when the ponds are full. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average water surface area. These values are found in table 3.

Table 3.—Stock pond evaporation, 2003

COUNTY	SURFACE AREA FULL (ACRES)	SURFACE AREA USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Coconino	80	18	68%	57	4.61	52.39	80
Navajo	40	8	60%	55	5.83	49.18	33
Apache	646	161	75%	53	6.57	46.44	621
TOTAL	766	187	—	—	—	—	734

This method of evaporation estimation was used because continuous useful water level records for all stock ponds from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual stock ponds. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation. It was assumed that any consumptive use by natural vegetation prior to construction of the stock ponds is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for stock pond evaporation for calendar year 2003 are shown in table 3. The total evaporative losses in 2003 are 734 ($\pm$220) acre-feet with the stock pond evaporation uncertainty being estimated as 30 percent.

LIVESTOCK WATER

The source of most livestock water in the study area is from wells, with windmill-operated pumps developed and maintained by Navajo Water Operations and Maintenance, and water collected in small surface ponds. The estimated number of

livestock in the area was obtained based on livestock tallies. It was estimated that horses and cattle consume 12 gallons per day; sheep and goats consume 2 gallons per day.

The number of animals for the Upper Colorado portion of each district is shown in table 4. The computed value for livestock consumptive use is 218 acre-feet. The uncertainty in this number is estimated as 30 percent of the total or ±65 acre-feet.

Table 4.—Number of livestock, 2003

AGENCY	CATTLE	HORSES	SHEEP	GOATS
Western Navajo District No. 1	2,079	328	2,398	1,263
Western Navajo District No. 2	709	81	1,339	898
Western Navajo District No. 8	1,910	169	2,960	2,069
Shiprock District No. 9	1,134	179	1,226	1,494
Chinle District No. 10	2,694	369	3,605	1,967
Chinle District No. 11	1,041	156	956	1,041
Shiprock District No. 12	897	84	1,075	827
Fort Defiance District No. 17	100	15	370	141
Fort Defiance District No. 18	248	23	329	145
TOTAL	10,812	1,404	14,257	9,844

TOTAL AGRICULTURAL CONSUMPTIVE USE

The total agricultural consumptive use, displayed in table 5, is the sum of the individual components discussed in the previous sections. Agricultural water consumption represents approximately 4 percent of the total use in the study area. Total degree of uncertainty was computed by taking the square root of the sum of the individual uncertainties squared; known as the quadratic sum. This method and nomenclature is used throughout this report. This method was used because a simple sum does not account for the partial cancellation of errors occurring when calculating the total uncertainty derived from individual values that are random and independent of each other. As previously discussed, the individual uncertainties were set as a percent of the consumptive use value.

Table 5.—Total agricultural consumptive use, 2003

CATEGORY	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Irrigation	488	195
Stock Ponds	734	220
Livestock	218	65
TOTAL	1,440	301

MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

Municipal and industrial consumptive use is divided into three categories: mineral resources, thermal electric power, and other. Mineral resources consumptive use includes water used for mineral production. No mineral resources consumptive use is reported in the study area. Thermal electric power consumptive use includes the water used at the power plants, and that used to transport material to the power plant (such as a coal slurry pipeline). Other consumptive use includes urban, rural, and industrial uses.

THERMAL ELECTRIC POWER

Thermal electric power consumptive use includes the water used in the power plant and the water used to transport material to the plant.

Navajo Generating Station

The water used by the NGS is pumped directly from Lake Powell and comprises over half of the total consumption in the study area. Since all NGS water use is metered, this quantity is among those most precisely known, with the maximum uncertainty in the metered quantities believed to be less than 3 percent. The actual quantity consumed, along with the estimated uncertainty for the calendar year 2003, was 26,284 (±789) acre-feet.

OTHER

The other consumptive use category includes the remaining use by urban, rural, and industries.

Page, AZ and Vicinity

***City of Page, AZ*. –** The city of Page pumps its domestic water directly from Lake Powell. The water pumped is metered, and the uncertainty of the pumped quantities was assumed to be less than 3 percent. A portion of the water pumped and treated by the City of Page, is supplied to the community of Le Chee on the Navajo Nation and is accounted for separately. The quantity supplied to the City of Page and its associated uncertainty for the calendar year 2003 was 2,550 (±76) acre-feet. Water returning to the waste water treatment plant is metered as well. The waste water for the City of Page is treated and is either evaporated from lined ponds or applied to the golf course, with a portion being returned to the Colorado River. The return flow is estimated to be 780 acre-feet. The net consumptive use is estimated to be 1,770 acre-feet (±80).

***Le Chee* –** The community of Le Chee is supplied and metered by the City of Page. Total water supplied for 2003 was 101 (±3) acre-feet. The uncertainty was estimated to be 3 percent.

Greenhaven Water Company – The Greenhaven Water Company derives its domestic water supply from wells. Well pumping records are available. According to these records, the total water pumped for 2003 was 105 (±7) acre-feet. The uncertainty was estimated to be 7 percent.

Arizona Department of Transportation Housing – The Arizona Department of Transportation operates a housing, maintenance, and administrative facility located on US Hwy 89, north of Page, AZ. This facility is supplied from wells that have no meters installed. It is estimated that the total water pumped for 2003 was 16 acre-feet with an uncertainty of 30 percent of this value or ±5 acre-feet.

Navajo Nation

Community Water Systems – Statistics from the Division of Community Development of the Navajo Nation reveal that various community water systems served 26,086, or about 83 percent of the 31,429 people residing within the study area in 1980. This percentage was used for 2003 resulting in 36,048 out of 43,431 people being served. These systems include those operated by the Navajo Tribal Utility Authority (NTUA), the BIA, and the Water Operations and Maintenance Department of the Navajo Nation, and some privately developed community water systems.

Table 6 shows the source of water and estimated population served by each source of water for people living on the Navajo Nation during 2003. All of the communities obtain their water supply from ground water.

Table 6.—Domestic water sources, 2003

SOURCE	PERCENTAGE OF POPULATION SERVED	NUMBER OF POPULATION SERVED[1]
Community Water Systems	83	36,048
NTUA	[2](60)	21,629
BIA	[2](25)	9,012
Navajo WOM	[2](13)	4,686
Private	[2](2)	721
Individual Wells	17	7,383
TOTAL[2]	100	43,431

[1] Estimated total population within the Upper Colorado River Basin portion of the Navajo Nation provided by Larry Rodgers, Demographer for the Division of Community Development of the Navajo Nation, letter DCDA-L94052, June 20, 1995.
[2] These numbers are a percentage of the Community Water Systems.

NTUA Water Systems – The cities and surrounding communities of Oak Springs, Red Valley, Sweetwater, Chinle , Rough Rock, Round Rock, Rock Point, Wheatfields, Lukachukai, Kayenta, Chilchinbeto, Dennehotso, and Kaibeto derive most of their domestic water supply from wells operated by NTUA. Well pumping records are

available. According to these records, the total water pumped for 2003 was 1,646 acre-feet with an uncertainty estimated to be 7 percent of this value or ±115 acre-feet.

The NTUA manages the raw waste water; portions of which flow to individual septic tanks, some to evaporation ponds, and some, such as for the cities of Chinle and Kayenta, flow to waste water treatment plants. Very little water, if any, is returned to the ground water system through leakage from the evaporation ponds, but there are losses from the main collection system. Effluent from the Chinle and Kayenta waste water treatment plants is metered. Under normal conditions, the effluent returns to the Colorado River System and is subtracted from the pumping totals to determine a net consumptive use. For 2003, Chinle's treatment plant effluent was 451 (±32) acre-feet, and Kayenta's effluent was 232 (±16) acre-feet. An estimated uncertainty of 7 percent was used for the effluent of these two plants. The total effluent of 683 acre-feet is subtracted from the NTUA pumping total of 1,646 acre-feet to arrive at a net consumptive use of 963 (±125) acre-feet.

BIA Water Systems – Wells developed and operated by the BIA serve numerous Navajo communities. These systems also serve BIA schools, hospitals, agency offices, and some housing on the Navajo Nation. Metered records for total amounts of water pumped from BIA wells were available for a portion of the Shiprock Agency, the Western Navajo Agency, and the Chinle Agency. Drawing 1246-406-2 shows the agency boundaries within the Upper Colorado River Basin. The uncertainty was estimated to be about 7 percent for all three agencies.

The BIA systems include sewage disposal units terminating in lined evaporation ponds with very little or no return water returning to the ground water system. Undoubtedly, some losses occur in distribution, but insufficient data currently exist to estimate these losses. The losses are probably less than the uncertainties for each of the reported values.

The BIA well data available for the Shiprock Agency include: Cove, Red Rock, and Teec Nos Pos. Total consumptive use values are 11 (±1) acre-feet.

Pumping records for the Western Navajo Agency include data for the following schools: Chilchinbeto Day School, Dennehotso Boarding School, Kaibeto Boarding School, and Kayenta Boarding School. Total consumptive use for the Western Navajo Agency was 172 (±12) acre-feet.

Well pumping records for the Chinle Agency include data for the following schools: Cottonwood Day School, Lukachukai School, and Rock Point School. Rough Rock School maintains its own records, but the data was included with the Chinle Agency data. Total consumptive use for the Chinle Agency was 65 (±5) acre-feet.

Navajo WOM Water Systems – Water use in 2003 by the Navajo WOM service areas was based on an assumed consumption rate of 110 gallons per capita per day (gpcd). For a 2003 estimated service area population of 4,686, the estimated annual water use was 577(±173) acre-feet. The uncertainty is estimated as 30 percent of the total.

Private Water Systems – The estimated 2003 population served by private water systems on the Navajo Nation was 721. Assuming a consumptive use rate of 110

gcpd, the annual water use for 2003 was 89 (±27) acre-feet. The uncertainty is estimated as 30 percent of the total.

Individual Wells – According to census data from the Division of Community Development of the Navajo Nation, approximately 17 percent of the study area's population on the reservation (about 7,383 persons in 2003) receives a domestic water supply from individual wells. A consumptive use of 110 gpcd was derived as being a reasonable water use rate. Based on these figures, the annual consumptive use was 910 (±273) acre-feet for 2003.

TOTAL MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

The total municipal and industrial consumptive use, displayed in table 7, is the sum of the individual components discussed in the previous sections. Municipal and industrial water consumption represents approximately 85 percent of the total use in the study area.

Table 7.—Total municipal and industrial consumptive use, 2003

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
THERMAL ELECTRIC POWER		
Navajo Generating Station	26,284	789
OTHER		
Page, AZ and Vicinity		
City of Page	1,770	80
Le Chee	101	3
Greenhaven Water Company	105	7
Arizona Department of Transportation	16	5
Navajo Indian Reservation		
Community Water Systems		
NTUA Water Systems	963	125
BIA Water Systems	248	13
Navajo WOM	577	173
Private Water Systems	89	27
Individual Wells	910	273
TOTAL	31,062	866

It is questionable whether all the water pumped from wells should be considered a depletion to the Colorado River System; however, it is assumed that 100 percent of the water pumped is considered lost to the system. It is proposed that a future joint study be completed by Reclamation, the State of Arizona, and the Navajo Nation to estimate what

percentage of water pumped could actually be attributed to the Colorado River System and would have affected the river flows for a particular year.

RECREATION, FISH AND WILDLIFE

The recreation, fish and wildlife consumptive uses include evaporation from reservoirs used exclusively for fish & wildlife purposes as well as acreages irrigated for wildlife feeding. Consumptive use at National and State parks is also accounted for.

GLEN CANYON NATIONAL RECREATION AREA

Colorado River water is used by the Glen Canyon National Recreation Area (GCNRA) at Wahweap and Lees Ferry. The recreational area at Wahweap gets its water supply from a series of wells on the shore of Lake Powell. Pumping records for both Wahweap and Lees Ferry show 318 (±10) acre-feet of water withdrawn during 2003. The uncertainty is estimated at 3 percent. This water was used for domestic purposes at the campgrounds, picnic areas, and trailer parks. It was also used to irrigate approximately 60 acres of Bermuda grass and cottonwood trees. The domestic waste water is treated and the effluent is allowed to evaporate from two lines evaporation ponds with a total surface area of 16.7 acres.

Based on estimates of evaporation and consumptive use by the plants, there is some water which is unaccounted for and is assumed to be leakage from the delivery system, the evaporation pond, or deep percolation from irrigation application. However, since these water losses are difficult to quantify and verify, the losses were charged as consumptive uses. Therefore, net consumptive use of water is estimated to be equal to the quantity of water pumped.

RESERVOIR EVAPORATION

A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled “1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River” and are shown in table 8.

Table 8. —Recreation, fish and wildlife reservoir evaporation, 2003

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE AREA USED (ACRES)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Tsaile	260	260	35	7.14	27.86	604
Wheatfields	272	272	32	7.14	24.86	563
TOTAL	532	532	—	—	—	1,167

Efforts are made to maintain a nearly full condition and to minimize water surface fluctuations in reservoirs managed for a fishery. Under average operating conditions, the

water surface area of a reservoir used primarily for fishing is assumed to be equal to a normal water surface area. It is assumed that, in 2003, these reservoirs filled in the spring and were maintained at the normal pool level.

This method of evaporation estimation was used because continuous useful water level records for all reservoirs from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs.

For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for reservoir evaporation for calendar year 2003 are shown in table 8. The total evaporative losses in 2003 are 1,167 (±350) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent.

TOTAL RECREATION, FISH AND WILDLIFE

The total recreation, fish and wildlife consumptive use, displayed in table 9, is the sum of the individual components discussed in the previous sections. Recreation, fish and wildlife water consumption represents approximately 4 percent of the total use in the study area.

Table 9.—Total recreation, fish and wildlife consumptive use, 2003

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Glen Canyon National Recreation Area	318	10
Reservoir Evaporation	1,167	350
TOTAL	1,485	350

RESERVOIR EVAPORATION

Reservoir evaporation losses make up about 7 percent of the total water uses and losses in the study area. A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 10. These reservoirs are used primarily for irrigation.

Table 10.—Reservoir evaporation, 2003

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE ACRES USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Many Farms	1,800	580	—	56	7.14	48.86	2360
Marsh Pass	40	10	52%	40	5.86	34.14	30
Round Rock	83	31	75%	57	6.57	50.44	130
Walker Creek	30	11	74%	59	5.99	53.01	49
Others	38	12	63%	55	6.35	48.65	48
TOTAL	1,991	644	—	—	—	—	2,617

Reservoirs used primarily for irrigation experience large fluctuations in water levels and, correspondingly, large variations in surface area. Reservoir level records and elevation – area curves were available at Many Farms, but not for the remaining reservoirs in table 10. For the reservoirs with no records from which surface area could be accurately computed, the average evaporative surface area was estimated as one-half the water surface area of a full reservoir. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average evaporative surface area.

Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses. The computed values for reservoir evaporation for 2003 are shown in table 10. The total evaporative losses in 2003 are 2,617 ($\pm$785) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent of the total evaporation.

CONCLUSIONS

This report assesses the total consumptive use of the Arizona portion of the Upper Colorado River System surface water systems, depletion of ground water, and evaporative losses. Clearly, the amounts of water used by the Navajo Generating Station, City of Page, and Wahweap and Lees Ferry recreation areas are direct depletions of water from the Upper Colorado River System, but the situation is not as clear for other consumptive uses and losses occurring in other sections of the study area. For example, the source of water used by the Navajo Nation for domestic and municipal purposes is from wells, some exceeding 1,000 feet in depth. For our purposes here, it is considered to be consumed and a depletion to the Colorado River System. But this may not actually result in a reduction of Colorado River stream flows in the same year that the withdrawal occurs. Little knowledge and information exists of ground water movement and

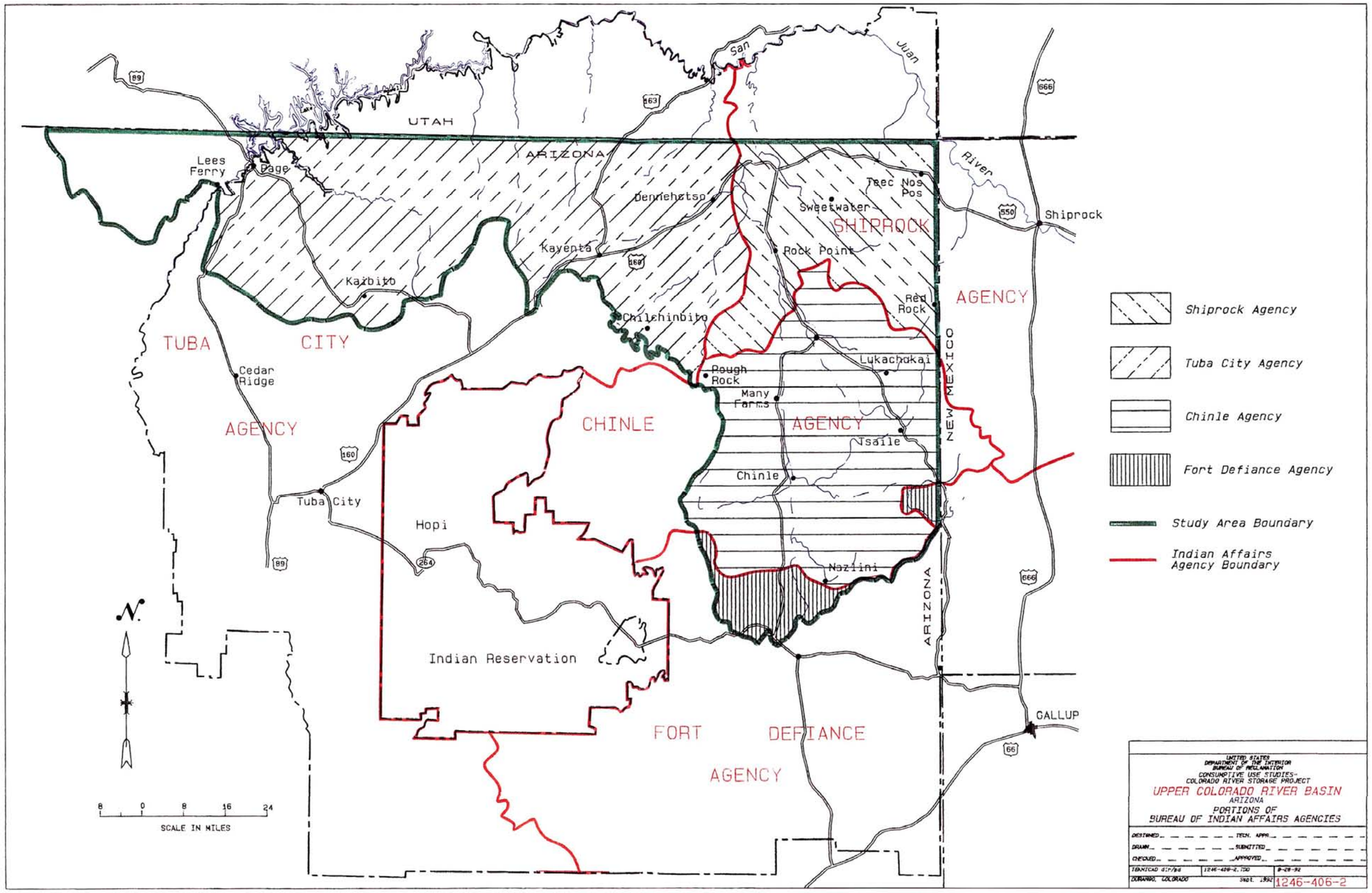
subsurface flow rates in the study area that are accurate descriptions of the effects on river flows.

Although the water diverted for agricultural purposes is considered as consumptive use in this report, a portion of the remaining surface water on the Navajo Nation, excess to needs, does evaporate before reaching the Colorado River. An attempt has not been made for this report to quantify these losses.

Uncertainties in estimating uses and losses exist, and the degree of variation in the figures is presented. Fortunately, the areas with the highest degree of uncertainty account for only a small percentage of the total consumptive use. The largest component, use by the Navajo Generating Station, is also the most accurately monitored. The total annual value for estimated consumptive use of water within the Arizona portion of the Upper Colorado River Basin for 2003 was 36,604 acre-feet, as shown in table 11.

Table 11.—Consumptive use for Arizona portion of Upper Colorado River Basin for 2003

USE CATEGORY	TOTAL CONSUMPTIVE USE (ACRE-FEET)	UNCERTAINTY	PERCENT OF TOTAL
Agriculture	1,440	301	4
Municipal & Industrial	31,062	866	85
Recreation, Fish & Wildlife	1,485	350	4
Reservoir Evaporation	2,617	785	7
TOTAL	36,604	1,257	100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ARIZONA
NEW MEXICO
Lees Ferry
Page
Kaibito
Kayenta
Dennehotso
Chilchinbito
Teec Nos Pos
Sweetwater
Rock Point
Red Rock
Lukachukai
Rough Rock
Many Farms
Tsaile
Chinle
Nazlini
Shiprock
Cedar Ridge
Tuba City
Hopi
Indian Reservation
GALLUP
San Juan River
TUBA CITY AGENCY
CHINLE AGENCY
SHIPROCK AGENCY
FORT DEFIANCE AGENCY
Shiprock Agency
Tuba City Agency
Chinle Agency
Fort Defiance Agency
Study Area Boundary
Indian Affairs Agency Boundary
N
8 0 8 16 24
SCALE IN MILES
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CONSUMPTIVE USE STUDIES-
COLORADO RIVER STORAGE PROJECT
UPPER COLORADO RIVER BASIN
ARIZONA
PORTIONS OF
BUREAU OF INDIAN AFFAIRS AGENCIES
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TECHNICAL DIV/BR
DENVER, COLORADO
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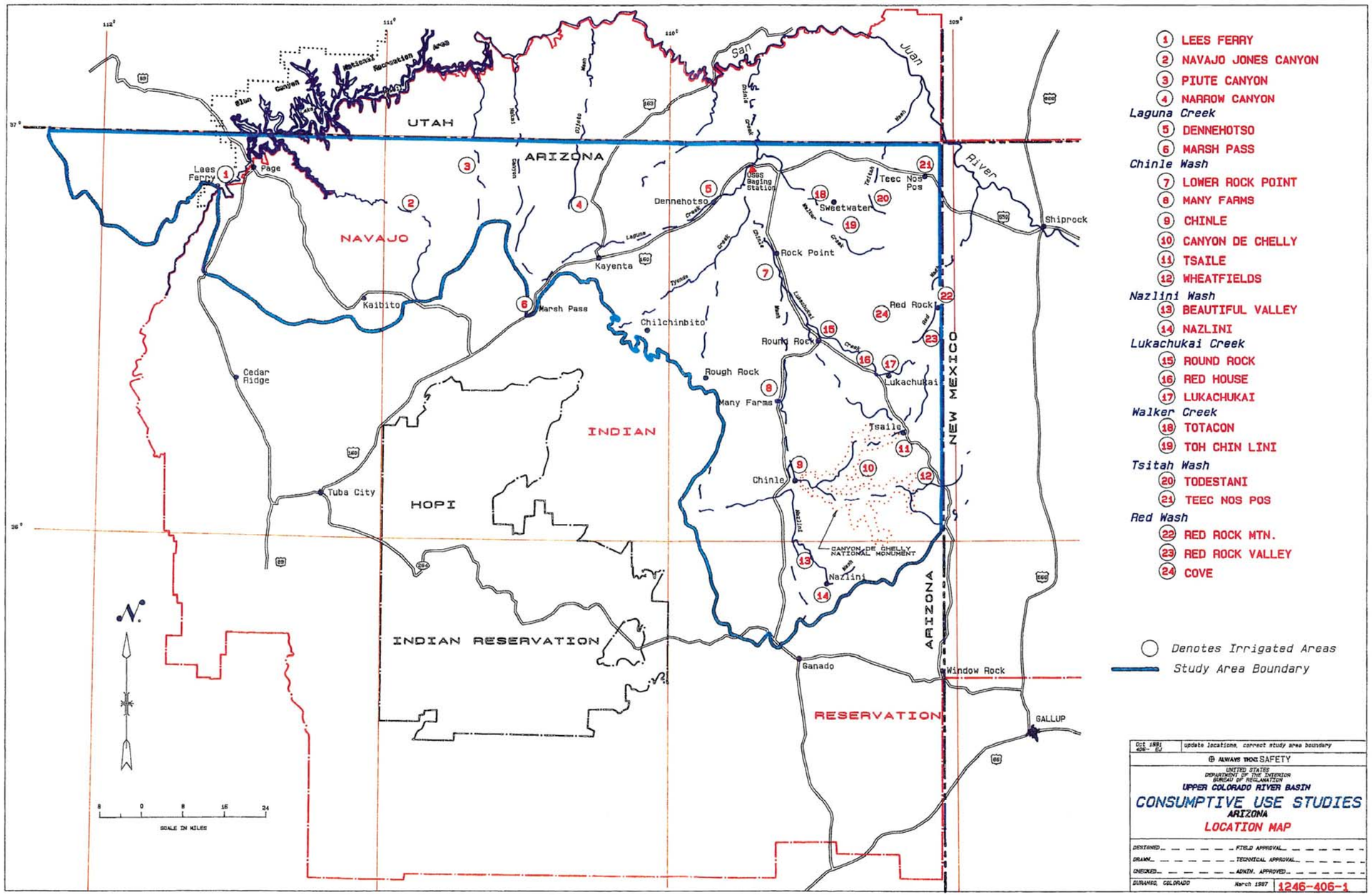
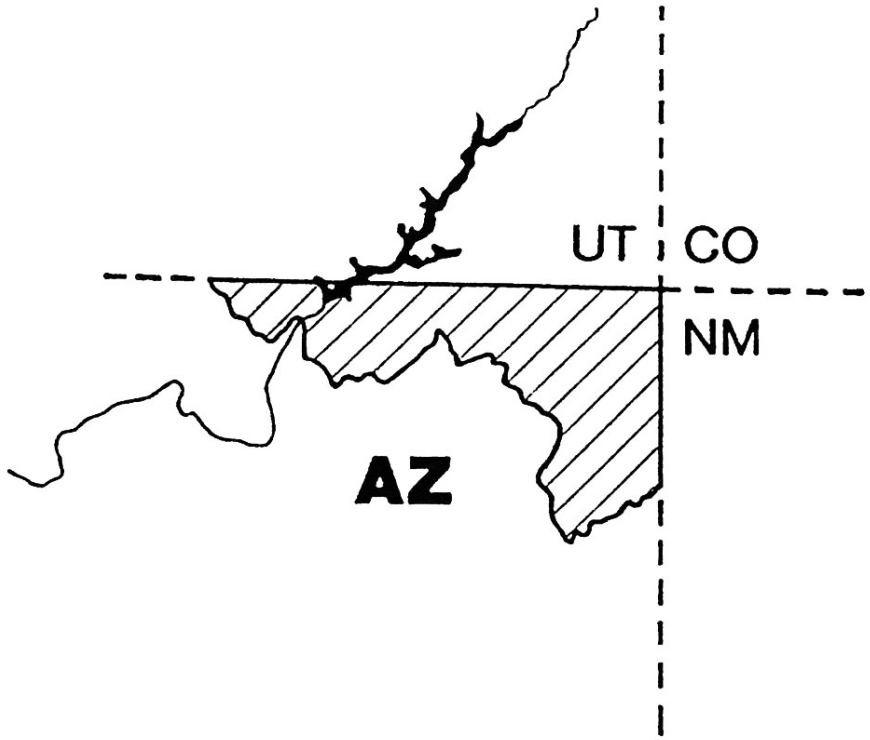

1 LEES FERRY
2 NAVAJO JONES CANYON
3 PIUTE CANYON
4 NARROW CANYON
Laguna Creek
5 DENNEHOTSO
6 MARSH PASS
Chinle Wash
7 LOWER ROCK POINT
8 MANY FARMS
9 CHINLE
10 CANYON DE CHELLY
11 TSAILE
12 WHEATFIELDS
Nazlini Wash
13 BEAUTIFUL VALLEY
14 NAZLINI
Lukachukai Creek
15 ROUND ROCK
16 RED HOUSE
17 LUKACHUKAI
Walker Creek
18 TOTACON
19 TOH CHIN LINI
Tsitah Wash
20 TODESTANI
21 TEEC NOS POS
Red Wash
22 RED ROCK MTN.
23 RED ROCK VALLEY
24 COVE
Denotes Irrigated Areas
Study Area Boundary
UTAH
ARIZONA
NAVAJO
INDIAN
HOPI
INDIAN RESERVATION
RESERVATION
NEW MEXICO
ARIZONA
San Juan River
Lees Ferry
Page
Kaibito
Cedar Ridge
Tuba City
Marsh Pass
Kayenta
Dennehotso
USGS Gaging Station
Sweetwater
Teec Nos Pos
Shiprock
Rock Point
Red Rock
Chilchinbito
Round Rock
Rough Rock
Many Farms
Lukachukai
Tsaile
Chinle
Nazlini
Ganado
Window Rock
GALLUP
CANYON DE CHELLY NATIONAL MONUMENT
N
SCALE IN MILES
8 0 8 16 24
Oct 1981 update locations, correct study area boundary
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
UPPER COLORADO RIVER BASIN
CONSUMPTIVE USE STUDIES
ARIZONA
LOCATION MAP
DESIGNED
FIELD APPROVAL
DRAWN
TECHNICAL APPROVAL
CHECKED
ADMIN. APPROVED
DURANGO, COLORADO
March 1987
1246-406-1

RECLAMATION

Managing Water in the West

Consumptive Uses and Losses

Arizona Portion of the Upper Colorado River Basin
Calendar Year 2004

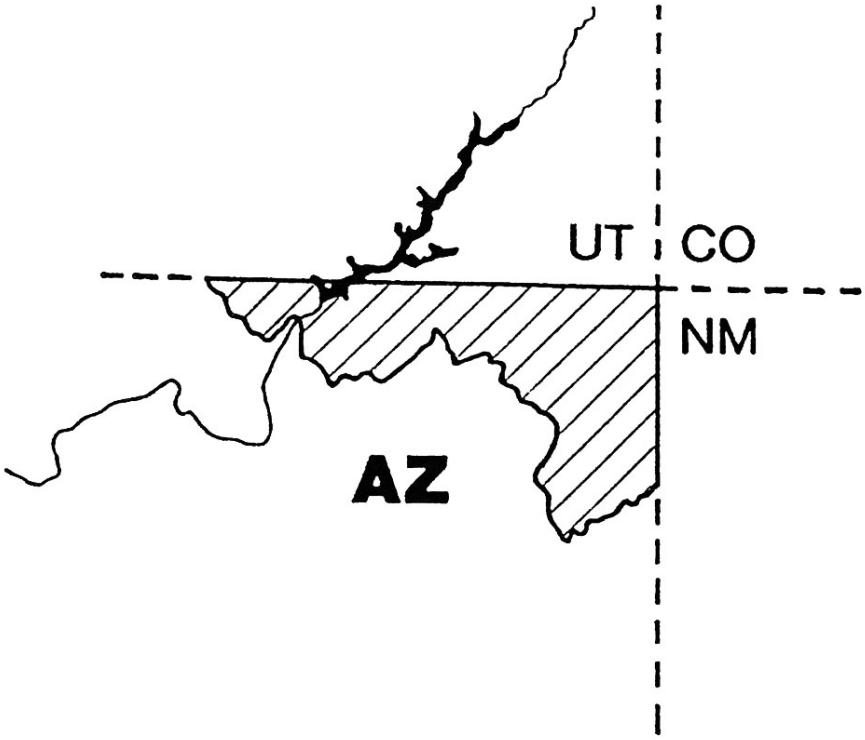


U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

October 2009

Consumptive Uses and Losses

Arizona Portion of the Upper Colorado River Basin
Calendar Year 2004



U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

October 2009

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Tables

CONSUMPTIVE USES AND LOSSES

ARIZONA PORTION OF THE UPPER COLORADO RIVER BASIN

CALENDAR YEAR 2004

AUTHORITY

This report was prepared in compliance with Public Law 90-537, Section 601 (b)(1), dated September 30, 1968, which directs the Secretary of the Interior to "make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis." Additionally, this report is in compliance with Section 49 of the Navajo Project Participation Agreement dated September 30, 1969, which states in part: "The Secretary of the Interior further agrees to make the reports required by Section 601 (b)(1) of Public Law 90-537 as they pertain to Arizona's Upper Basin uses annually rather than every five years. Within fifteen days following the completion of said reports, the Secretary of the Interior shall furnish copies of such reports to the Co-Tenants, the Navajo Tribe, each of the Upper Basin States, and the Upper Colorado River Commission."

SUMMARY

The total consumptive use and loss value for the Arizona portion of the Upper Colorado River Basin for calendar year 2004 was 37,521 ($\pm$1,272) acre-feet.

STUDY AREA DESCRIPTION

The Arizona portion of the Upper Colorado River Basin covers approximately 6,900 square miles in the north-east corner of Arizona, as shown on the location map (Drawing 1246-406-1). The climate of the 5,900 square mile area to the west of the Chuska and Carrizo Mountains is largely arid to semiarid, with mean annual precipitation ranging from 6 to 12 inches and with summertime temperatures often reaching 100 degrees Fahrenheit (^{o}F). The potential evaporation rate is high and exceeds mean annual precipitation, with gross lake evaporation values of up to 55 inches per year or more. Elevations in the western portion range from 3200 feet on the Colorado River at Lees Ferry to over 8000 feet on the northern edge of the Black Mesa and across the Zilnez and Skeleton Mesas, back down to 5280 feet in the Chinle Valley, and back up to about 6500 feet on the western edge of the Chuska Mountains. Much of the western part

of the study area is starkly beautiful southwestern desert country with mesas and canyons intertwined across a pastoral landscape. By contrast, the eastern 1,000 square miles is largely mountainous, with elevations rising to nearly 10,000 feet and mean annual precipitation reaching 30 inches. The mountainous land responds with grass meadows interspersed with conifer forest of mostly ponderosa pine.

Except for Page, Arizona; a small area around Lees Ferry; and a portion of the Paria Plateau administered by the Bureau of Land Management; the study area lies entirely within the Navajo Nation. According to census data, 48,613 persons were living within the area in 2000, and of these 41,804 resided on the Navajo Nation.

The largest cities are Page and Chinle, with 2000 populations of 6,809 and 5,366, respectively. Other major communities and their populations include Dennehotso (734), Kaibeto (1,607), Kayenta (4,922), LeChee (1,606), Lukachukai (1,565), Many Farms (1,548), Rock Point (724), Teec Nos Pos (799), and Tsaile (1,078). Subsistence in the region is derived principally from livestock grazing, farming, tourist-related industries, employment at the Navajo Generating Station (NGS), which consumes 60 to 70 percent of the water used or lost in the study area every year. Agriculture accounted for 5 percent of the total water use; municipal and industrial about 85 percent; recreation, fish and wildlife, about 3 percent; and reservoir evaporation, 7 percent.

AGRICULTURAL CONSUMPTIVE USE

Agricultural consumptive use is divided into three categories: irrigation, stock pond, and livestock. Irrigation use includes all use related to irrigating crops including the incidental losses. Stock pond use is the evaporation that occurs from stock ponds and livestock use is the water consumed by livestock.

IRRIGATION USES

Within the Arizona portion of the Upper Colorado River Basin, historically 23 irrigated areas were scattered across the Navajo Nation plus a small amount of land near Lees Ferry irrigated by the National Park Service. Currently, only 15 irrigated areas are in production. An accurate assessment of consumptive use on the irrigated land is difficult due to poor quality of information, such as the exact number of acres under irrigation, the cropping pattern for each irrigated area, site climatological conditions, and the amount s of water actually diverted. In many cases, during the latter part of the irrigation season, farmers have to rely on dry land farming since there is little water available in the streams. This means that the crops do not receive their full water requirement.

For this report, the U.S. Department of Agriculture, Soil Conservation Service's (SCS) Modified Blaney-Criddle ET estimation model was used for computing irrigated crop consumptive use. This model, along with appropriate crop-growth stage coefficients and the method for computing effective precipitation, is described in SCS's *Irrigation Water Requirements Technical Release No. 21* (TR 21). Information required for applying this model includes mean monthly temperature and precipitation values, growing season data for each crop type, and the total number of acres planted by crop at each site. With the

exception of Teec Nos Pos, Canyon de Chelly, Lukachukai, and Lees Ferry, no climatological data exist for the irrigation sites, and site values must be generated from data collected at surrounding established weather stations. Growing season dates depend largely on the judgment of the local inhabitants and are, therefore, not known. Although several reports are available with published values for irrigated acres, it is unclear if these values are meant to represent potential irrigated acres, acres irrigated in the past, acres for which farming permits have been issued, or actual acres currently under irrigation.

The crop acreage used to estimate consumptive use by irrigated crops for the year 2004 is shown in table 1. These values were determined from direct field examination by a party composed of representatives from the State of Arizona and the Navajo Nation.

Table 1.—Total irrigated acreage, 2004

PROJECT	CORN (ACRES)	ALFALFA (ACRES)	GRASS PASTURE (ACRES)	SPRING GRAINS (ACRES)	SMALL VEGETABLES (ACRES)	ORCHARD (ACRES)	TOTAL (ACRES)
CHINLE AGENCY							
Canyon de Chelly	0.36	0.00	0.00	3.03	2.26	0.00	5.65
Lukachukai	39.09	7.69	0.00	7.50	5.98	2.07	62.33
Nazlini	0.00	0.00	0.00	0.00	1.79	0.74	2.53
Rough Rock	30.00	0.00	11.87	0.00	12.43	0.00	54.30
Tsaile	23.72	5.27	15.67	5.73	5.42	0.00	55.81
Wheatfields	0.00	60.80	0.00	0.00	0.00	0.00	60.80
TOTAL	93.17	73.76	27.54	16.26	27.88	2.81	241.42
SHIPROCK AGENCY							
Red Rock Valley	26.22	0.00	10.19	5.12	10.22	0.00	51.75
Teec Nos Pos	20.00	0.00	0.00	0.00	3.67	0.00	23.67
Toh Chin Lini	0.00	0.00	0.00	0.00	3.90	13.67	17.57
Totacon	0.00	0.00	0.00	0.00	1.00	0.00	1.00
TOTAL	46.22	0.00	10.19	5.12	18.79	13.67	94.0
WESTERN NAVAJO AGENCY							
Dennehotso	1.82	0.00	38.70	0.00	0.00	0.00	40.52
Lees Ferry	0.00	0.00	1.00	0.00	0.00	2.00	3.00
Marsh Pass	7.02	3.31	0.00	0.00	1.99	0.00	12.32
Navajo Canyon	0.00	0.00	0.00	0.00	0.00	3.50	3.50
Paiute Canyon	2.64	0.00	0.00	0.00	3.86	0.00	6.50
TOTAL	11.48	3.31	39.70	0.00	5.85	5.50	65.84
GRAND TOTAL	150.87	77.07	77.43	21.38	52.52	21.98	401.25

Consumptive Uses and Losses

Several factors complicated the modeling of irrigation consumptive use. For example, the computer program used to model consumptive use assumes a full water supply; if shortages exist, as they often do in this semiarid study area, adjustments must be made. These adjustments are complicated because some of the projects have no storage water and may only have a reliable irrigation water supply during spring runoff. After spring runoff, farming becomes essentially dry land until rains in July and August provide intermittent flows for irrigation. Finally, no ditch diversion records are available to help estimate irrigation water supplies and shortages.

A full irrigation supply seldom exists at many of the projects. Generally, a full supply is available for Lees Ferry, Navajo Canyon, Tsaile, and Wheatfields projects because of adequate stream flows or because of available storage water. In years with average precipitation, it is estimated that Chinle Wash provides approximately 75 percent of the irrigation requirement. Precipitation in the area averages approximately 9.5 inches per year. Based on this information, it would require approximately 12.67 inches of precipitation to provide 100 percent of the irrigation requirement. The percent of crop water requirement met was computed as a ratio of annual precipitation to 12.67 inches. These values are found in table 2.

The percentage of crop water requirement met was multiplied by the total net crop water requirement to come up with the amount of crop consumptive use. Incidental irrigation losses, evaporation, and phreatophyte consumptive use along supply canals are estimated to be 5 percent of the consumptive use of the irrigated area and are added to the crop consumptive use value to develop a total consumptive use value.

A portion of the water used for irrigation at these sites may not be contributing to the Colorado River System since evaporation rates in the area are high and the nature of most of the drainage enhances evapotranspiration. A good example of such a drainage is Chinle Wash, which after it leaves Canyon de Chelly, becomes wide and sandy and is lined with willows, cottonwoods, and other phreatophytes.

The uncertainties in the irrigation consumptive use values displayed in table 2 are very large and are estimated as 40 percent of the total consumptive use. This estimate of possible error only reflects the uncertainty of consumptive use and does not account for any possible errors in the acreage estimates. The effective consumptive use for irrigation for 2004 was estimated to equal 553 acre-feet. Including the 5 percent for incidental losses, the irrigation related consumptive use is 580 ($\pm$232) acre-feet.

Table 2.—Net consumptive use values, 2004

PROJECT	CROP WATER REQUIREMENT (INCHES)	TOTAL IRRIGATED (ACRES)	TOTAL WATER REQUIRED (ACRE-FEET)	CROP WATER REQUIREMENT MET (%)	CROP WATER REQUIREMENT MET (ACRE-FEET)	TOTAL CONSUMPTIVE USE (ACRE-FEET)[1]
CHINLE AGENCY						
Canyon de Chelly	17.30	5.65	8	69%	6	6
Lukachukai	20.12	62.33	105	69%	72	76
Nazlini	17.40	2.53	4	69%	3	3
Rough Rock	20.56	54.30	93	94%	87	92
Tsaile	20.97	55.81	98	69%	67	70
Wheatfields	28.34	60.80	144	69%	99	104
TOTAL	—	241.42	450	—	333	350
SHIPROCK AGENCY						
Red Rock Valley	22.13	51.75	95	66%	63	66
Teec Nos Pos	24.52	23.67	48	63%	31	32
Toh Chin Lini	35.73	17.57	52	43%	23	24
Totacon	15.35	1.00	1	43%	1	1
TOTAL	—	93.99	197	—	117	123
WESTERN NAVAJO AGENCY						
Dennehotso	35.50	40.52	120	46%	55	58
Lees Ferry	48.00	3.00	12	100%	12	13
Marsh Pass	18.73	12.32	19	95%	18	19
Navajo Canyon	36.74	3.50	11	97%	10	11
Paiute Canyon	18.30	6.50	10	71%	7	7
TOTAL	—	65.84	172	—	103	108
GRAND TOTAL	—	401.25	820	—	553	580

[1] Total includes 5% addition for incidental losses.

STOCK POND EVAPORATION

Stock pond consumptive use is assumed to be the evaporation from the stock pond. It is also assumed that any consumptive use by natural vegetation prior to the construction of the stock ponds is limited to precipitation which is subtracted from the evaporation losses.

A compilation of the stock ponds in the study area, including their locations and the water surface areas when ponds are full, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 3. For an average year conditions, the stock pond evaporative surface area was estimated as one-third the water surface area that occurs when the ponds are full. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average water surface area. These values are found in table 3.

Table 3.—Stock pond evaporation, 2004

COUNTY	SURFACE AREA FULL (ACRES)	SURFACE AREA USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Coconino	80	27	100%	57	8.39	48.61	108
Navajo	40	13	100%	55	10.97	44.03	49
Apache	646	205	95%	53	8.37	44.64	761
TOTAL	766	245	—	—	—	—	918

This method of evaporation estimation was used because continuous useful water level records for all stock ponds from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual stock ponds. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation. It was assumed that any consumptive use by natural vegetation prior to construction of the stock ponds is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for stock pond evaporation for calendar year 2004 are shown in table 3. The total evaporative losses in 2004 are 918 ($\pm$275) acre-feet with the stock pond evaporation uncertainty being estimated as 30 percent.

LIVESTOCK WATER

The source of most livestock water in the study area is from wells, with windmill-operated pumps developed and maintained by Navajo Water Operations and Maintenance, and water collected in small surface ponds. The estimated number of

livestock in the area was obtained based on livestock tallies. It was estimated that horses and cattle consume 12 gallons per day; sheep and goats consume 2 gallons per day.

The number of animals for the Upper Colorado portion of each district is shown in table 4. The computed value for livestock consumptive use is 218 acre-feet. The uncertainty in this number is estimated as 30 percent of the total or ±65 acre-feet.

Table 4.—Number of livestock, 2004

AGENCY	CATTLE	HORSES	SHEEP	GOATS
Western Navajo District No. 1	2,079	328	2,398	1,263
Western Navajo District No. 2	709	81	1,339	898
Western Navajo District No. 8	1,910	169	2,960	2,069
Shiprock District No. 9	1,134	179	1,226	1,494
Chinle District No. 10	2,694	369	3,605	1,967
Chinle District No. 11	1,041	156	956	1,041
Shiprock District No. 12	897	84	1,075	827
Fort Defiance District No. 17	100	15	370	141
Fort Defiance District No. 18	248	23	329	145
TOTAL	10,812	1,404	14,257	9,844

TOTAL AGRICULTURAL CONSUMPTIVE USE

The total agricultural consumptive use, displayed in table 5, is the sum of the individual components discussed in the previous sections. Agricultural water consumption represents approximately 4 percent of the total use in the study area. Total degree of uncertainty was computed by taking the square root of the sum of the individual uncertainties squared; known as the quadratic sum. This method and nomenclature is used throughout this report. This method was used because a simple sum does not account for the partial cancellation of errors occurring when calculating the total uncertainty derived from individual values that are random and independent of each other. As previously discussed, the individual uncertainties were set as a percent of the consumptive use value.

Table 5.—Total agricultural consumptive use, 2004

CATEGORY	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Irrigation	580	232
Stock Ponds	918	275
Livestock	218	65
TOTAL	1,716	366

MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

Municipal and industrial consumptive use is divided into three categories: mineral resources, thermal electric power, and other. Mineral resources consumptive use includes water used for mineral production. No mineral resources consumptive use is reported in the study area. Thermal electric power consumptive use includes the water used at the power plants, and that used to transport material to the power plant (such as a coal slurry pipeline). Other consumptive use includes urban, rural, and industrial uses.

THERMAL ELECTRIC POWER

Thermal electric power consumptive use includes the water used in the power plant and the water used to transport material to the plant.

Navajo Generating Station

The water used by the NGS is pumped directly from Lake Powell and comprises over half of the total consumption in the study area. Since all NGS water use is metered, this quantity is among those most precisely known, with the maximum uncertainty in the metered quantities believed to be less than 3 percent. The actual quantity consumed, along with the estimated uncertainty for the calendar year 2004, was 27,375 (±821) acre-feet.

OTHER

The other consumptive use category includes the remaining use by urban, rural, and industries.

Page, AZ and Vicinity

***City of Page, AZ*. –** The city of Page pumps its domestic water directly from Lake Powell. The water pumped is metered, and the uncertainty of the pumped quantities was assumed to be less than 3 percent. A portion of the water pumped and treated by the City of Page, is supplied to the community of Le Chee on the Navajo Nation and is accounted for separately. The quantity supplied to the City of Page and its associated uncertainty for the calendar year 2004 was 2,283 (±68) acre-feet. Water returning to the waste water treatment plant is metered as well. The waste water for the City of Page is treated and is either evaporated from lined ponds or applied to the golf course, with a portion being returned to the Colorado River. The return flow is estimated to be 695 acre-feet. The net consumptive use is estimated to be 1,588 acre-feet (±72).

***Le Chee* –** The community of Le Chee is supplied and metered by the City of Page. Total water supplied for 2004 was 103 (±3) acre-feet. The uncertainty was estimated to be 3 percent.

Greenhaven Water Company – The Greenhaven Water Company derives its domestic water supply from wells. Well pumping records are available. According to these records, the total water pumped for 2004 was 87 (±6) acre-feet. The uncertainty was estimated to be 7 percent.

Arizona Department of Transportation Housing – The Arizona Department of Transportation operates a housing, maintenance, and administrative facility located on US Hwy 89, north of Page, AZ. This facility is supplied from wells that have no meters installed. It is estimated that the total water pumped for 2004 was 14 acre-feet with an uncertainty of 30 percent of this value or ±4 acre-feet.

Navajo Nation

Community Water Systems – Statistics from the Division of Community Development of the Navajo Nation reveal that various community water systems served 26,086, or about 83 percent of the 31,429 people residing within the study area in 1980. This percentage was used for 2004 resulting in 36,513 out of 43,991 people being served. These systems include those operated by the Navajo Tribal Utility Authority (NTUA), the BIA, and the Water Operations and Maintenance Department of the Navajo Nation, and some privately developed community water systems.

Table 6 shows the source of water and estimated population served by each source of water for people living on the Navajo Nation during 2004. All of the communities obtain their water supply from ground water.

Table 6.—Domestic water sources, 2004

SOURCE	PERCENTAGE OF POPULATION SERVED	NUMBER OF POPULATION SERVED[1]
Community Water Systems	83	36,513
NTUA	[2](60)	21,908
BIA	[2](25)	9,128
Navajo WOM	[2](13)	4,747
Private	[2](2)	730
Individual Wells	17	7,478
TOTAL[2]	100	43,991

[1] Estimated total population within the Upper Colorado River Basin portion of the Navajo Nation provided by Larry Rodgers, Demographer for the Division of Community Development of the Navajo Nation, letter DCDA-L94052, June 20, 1995.
[2] These numbers are a percentage of the Community Water Systems.

NTUA Water Systems – The cities and surrounding communities of Oak Springs, Red Valley, Sweetwater, Chinle , Rough Rock, Round Rock, Rock Point, Wheatfields, Lukachukai, Kayenta, Chilchinbeto, Dennehotso, and Kaibeto derive most of their domestic water supply from wells operated by NTUA. Well pumping records are

available. According to these records, the total water pumped for 2004 was 1,619 acre-feet with an uncertainty estimated to be 7 percent of this value or ±113 acre-feet.

The NTUA manages the raw waste water; portions of which flow to individual septic tanks, some to evaporation ponds, and some, such as for the cities of Chinle and Kayenta, flow to waste water treatment plants. Very little water, if any, is returned to the ground water system through leakage from the evaporation ponds, but there are losses from the main collection system. Effluent from the Chinle and Kayenta waste water treatment plants is metered. Under normal conditions, the effluent returns to the Colorado River System and is subtracted from the pumping totals to determine a net consumptive use. For 2004, Chinle's treatment plant effluent was 379 (±27) acre-feet, and Kayenta's effluent was 267 (±19) acre-feet. An estimated uncertainty of 7 percent was used for the effluent of these two plants. The total effluent of 645 acre-feet is subtracted from the NTUA pumping total of 1,619 acre-feet to arrive at a net consumptive use of 974 (±122) acre-feet.

BIA Water Systems – Wells developed and operated by the BIA serve numerous Navajo communities. These systems also serve BIA schools, hospitals, agency offices, and some housing on the Navajo Nation. Metered records for total amounts of water pumped from BIA wells were available for a portion of the Shiprock Agency, the Western Navajo Agency, and the Chinle Agency. Drawing 1246-406-2 shows the agency boundaries within the Upper Colorado River Basin. The uncertainty was estimated to be about 7 percent for all three agencies.

The BIA systems include sewage disposal units terminating in lined evaporation ponds with very little or no return water returning to the ground water system. Undoubtedly, some losses occur in distribution, but insufficient data currently exist to estimate these losses. The losses are probably less than the uncertainties for each of the reported values.

The BIA well data available for the Shiprock Agency include: Cove, Red Rock, and Teec Nos Pos. Total consumptive use values are 11 (±1) acre-feet.

Pumping records for the Western Navajo Agency include data for the following schools: Chilchinbeto Day School, Dennehotso Boarding School, Kaibeto Boarding School, and Kayenta Boarding School. Total consumptive use for the Western Navajo Agency was 169 (±12) acre-feet.

Well pumping records for the Chinle Agency include data for the following schools: Cottonwood Day School, Lukachukai School, and Rock Point School. Rough Rock School maintains its own records, but the data was included with the Chinle Agency data. Total consumptive use for the Chinle Agency was 69 (±5) acre-feet.

Navajo WOM Water Systems – Water use in 2004 by the Navajo WOM service areas was based on an assumed consumption rate of 110 gallons per capita per day (gpcd). For a 2004 estimated service area population of 4,747, the estimated annual water use was 585(±175) acre-feet. The uncertainty is estimated as 30 percent of the total.

Private Water Systems – The estimated 2004 population served by private water systems on the Navajo Nation was 730. Assuming a consumptive use rate of 110

gcpd, the annual water use for 2004 was 90 (±27) acre-feet. The uncertainty is estimated as 30 percent of the total.

Individual Wells – According to census data from the Division of Community Development of the Navajo Nation, approximately 17 percent of the study area's population on the reservation (about 7,478 persons in 2004) receives a domestic water supply from individual wells. A consumptive use of 110 gpcd was derived as being a reasonable water use rate. Based on these figures, the annual consumptive use was 921 (±276) acre-feet for 2004.

TOTAL MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

The total municipal and industrial consumptive use, displayed in table 7, is the sum of the individual components discussed in the previous sections. Municipal and industrial water consumption represents approximately 85 percent of the total use in the study area.

Table 7.—Total municipal and industrial consumptive use, 2004

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
THERMAL ELECTRIC POWER		
Navajo Generating Station	27,375	821
OTHER		
Page, AZ and Vicinity		
City of Page	1,588	72
Le Chee	103	3
Greenhaven Water Company	87	6
Arizona Department of Transportation	14	4
Navajo Indian Reservation		
Community Water Systems		
NTUA Water Systems	974	122
BIA Water Systems	249	13
Navajo WOM	585	175
Private Water Systems	90	27
Individual Wells	921	276
TOTAL	31,987	896

It is questionable whether all the water pumped from wells should be considered a depletion to the Colorado River System; however, it is assumed that 100 percent of the water pumped is considered lost to the system. It is proposed that a future joint study be completed by Reclamation, the State of Arizona, and the Navajo Nation to estimate what

percentage of water pumped could actually be attributed to the Colorado River System and would have affected the river flows for a particular year.

RECREATION, FISH AND WILDLIFE

The recreation, fish and wildlife consumptive uses include evaporation from reservoirs used exclusively for fish & wildlife purposes as well as acreages irrigated for wildlife feeding. Consumptive use at National and State parks is also accounted for.

GLEN CANYON NATIONAL RECREATION AREA

Colorado River water is used by the Glen Canyon National Recreation Area (GCNRA) at Wahweap and Lees Ferry. The recreational area at Wahweap gets its water supply from a series of wells on the shore of Lake Powell. Pumping records for both Wahweap and Lees Ferry show 198 (±6) acre-feet of water withdrawn during 2004. The uncertainty is estimated at 3 percent. This water was used for domestic purposes at the campgrounds, picnic areas, and trailer parks. It was also used to irrigate approximately 60 acres of Bermuda grass and cottonwood trees. The domestic waste water is treated and the effluent is allowed to evaporate from two lines evaporation ponds with a total surface area of 16.7 acres.

Based on estimates of evaporation and consumptive use by the plants, there is some water which is unaccounted for and is assumed to be leakage from the delivery system, the evaporation pond, or deep percolation from irrigation application. However, since these water losses are difficult to quantify and verify, the losses were charged as consumptive uses. Therefore, net consumptive use of water is estimated to be equal to the quantity of water pumped.

RESERVOIR EVAPORATION

A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled “1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River” and are shown in table 8.

Table 8. —Recreation, fish and wildlife reservoir evaporation, 2004

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE AREA USED (ACRES)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Tsaile	260	260	35	8.72	26.28	569
Wheatfields	272	272	32	8.72	23.28	528
TOTAL	532	532	—	—	—	1,097

Efforts are made to maintain a nearly full condition and to minimize water surface fluctuations in reservoirs managed for a fishery. Under average operating conditions, the

water surface area of a reservoir used primarily for fishing is assumed to be equal to a normal water surface area. It is assumed that, in 2004, these reservoirs filled in the spring and were maintained at the normal pool level.

This method of evaporation estimation was used because continuous useful water level records for all reservoirs from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs.

For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for reservoir evaporation for calendar year 2004 are shown in table 8. The total evaporative losses in 2004 are 1,097 (±329) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent.

TOTAL RECREATION, FISH AND WILDLIFE

The total recreation, fish and wildlife consumptive use, displayed in table 9, is the sum of the individual components discussed in the previous sections. Recreation, fish and wildlife water consumption represents approximately 3 percent of the total use in the study area.

Table 9.—Total recreation, fish and wildlife consumptive use, 2004

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Glen Canyon National Recreation Area	198	6
Reservoir Evaporation	1,097	329
TOTAL	1,295	329

RESERVOIR EVAPORATION

Reservoir evaporation losses make up about 7 percent of the total water uses and losses in the study area. A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 10. These reservoirs are used primarily for irrigation.

Table 10.—Reservoir evaporation, 2004

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE ACRES USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Many Farms	1,800	554	—	56	8.72	47.28	2185
Marsh Pass	40	20	100%	40	13.00	27.01	45
Round Rock	83	39	95%	57	8.37	48.64	160
Walker Creek	30	15	99%	59	8.01	50.99	63
Others	38	19	100%	55	10.56	44.44	70
TOTAL	1,991	648	—	—	—	—	2,523

Reservoirs used primarily for irrigation experience large fluctuations in water levels and, correspondingly, large variations in surface area. Reservoir level records and elevation – area curves were available at Many Farms, but not for the remaining reservoirs in table 10. For the reservoirs with no records from which surface area could be accurately computed, the average evaporative surface area was estimated as one-half the water surface area of a full reservoir. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average evaporative surface area.

Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses. The computed values for reservoir evaporation for 2004 are shown in table 10. The total evaporative losses in 2004 are 2,523 ($\pm$757) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent of the total evaporation.

CONCLUSIONS

This report assesses the total consumptive use of the Arizona portion of the Upper Colorado River System surface water systems, depletion of ground water, and evaporative losses. Clearly, the amounts of water used by the Navajo Generating Station, City of Page, and Wahweap and Lees Ferry recreation areas are direct depletions of water from the Upper Colorado River System, but the situation is not as clear for other consumptive uses and losses occurring in other sections of the study area. For example, the source of water used by the Navajo Nation for domestic and municipal purposes is from wells, some exceeding 1,000 feet in depth. For our purposes here, it is considered to be consumed and a depletion to the Colorado River System. But this may not actually result in a reduction of Colorado River stream flows in the same year that the withdrawal

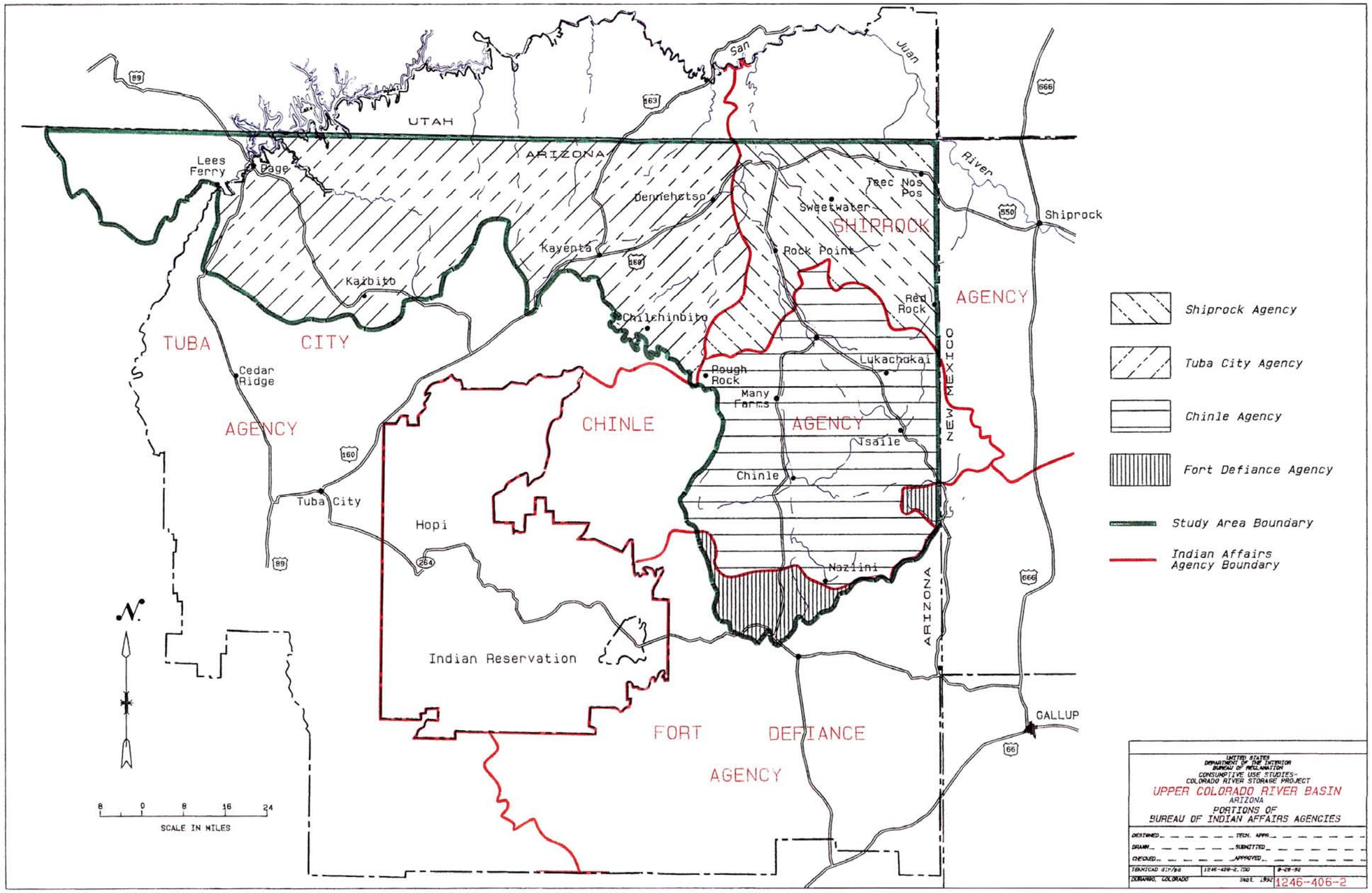
occurs. Little knowledge and information exists of ground water movement and subsurface flow rates in the study area that are accurate descriptions of the effects on river flows.

Although the water diverted for agricultural purposes is considered as consumptive use in this report, a portion of the remaining surface water on the Navajo Nation, excess to needs, does evaporate before reaching the Colorado River. An attempt has not been made for this report to quantify these losses.

Uncertainties in estimating uses and losses exist, and the degree of variation in the figures is presented. Fortunately, the areas with the highest degree of uncertainty account for only a small percentage of the total consumptive use. The largest component, use by the Navajo Generating Station, is also the most accurately monitored. The total annual value for estimated consumptive use of water within the Arizona portion of the Upper Colorado River Basin for 2004 was 37,521 acre-feet, as shown in table 11.

Table 11.—Consumptive use for Arizona portion of Upper Colorado River Basin for 2004

USE CATEGORY	TOTAL CONSUMPTIVE USE (ACRE-FEET)	UNCERTAINTY	PERCENT OF TOTAL
Agriculture	1,716	366	5
Municipal & Industrial	31,987	896	85
Recreation, Fish & Wildlife	1,295	329	3
Reservoir Evaporation	2,523	757	7
TOTAL	37,521	1,272	100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Page
Kaibito
Kayenta
Dennehotso
Chilchinbito
Teec Nos Pos
Sweetwater
Rock Point
Red Rock
Lukachukai
Rough Rock
Many Farms
Tsaile
Chinle
Nazlini
Shiprock
Cedar Ridge
Tuba City
Hopi
Indian Reservation
GALLUP
San Juan River
TUBA CITY AGENCY
CHINLE AGENCY
SHIPROCK AGENCY
FORT DEFIANCE AGENCY
Shiprock Agency
Tuba City Agency
Chinle Agency
Fort Defiance Agency
Study Area Boundary
Indian Affairs Agency Boundary
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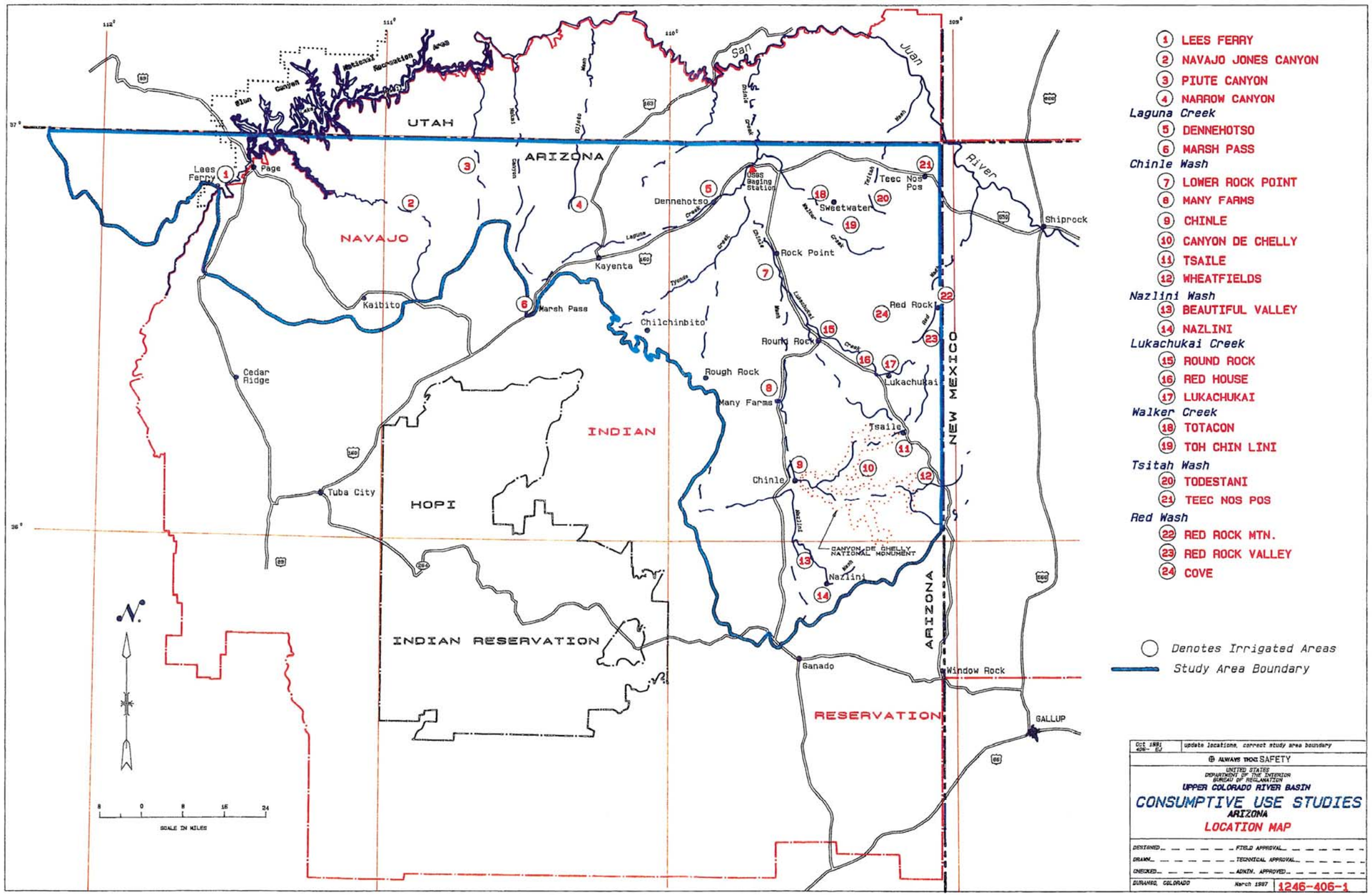
1 LEES FERRY
2 NAVAJO JONES CANYON
3 PIUTE CANYON
4 NARROW CANYON
Laguna Creek
5 DENNEHOTSO
6 MARSH PASS
Chinle Wash
7 LOWER ROCK POINT
8 MANY FARMS
9 CHINLE
10 CANYON DE CHELLY
11 TSAILE
12 WHEATFIELDS
Nazlini Wash
13 BEAUTIFUL VALLEY
14 NAZLINI
Lukachukai Creek
15 ROUND ROCK
16 RED HOUSE
17 LUKACHUKAI
Walker Creek
18 TOTACON
19 TOH CHIN LINI
Tsitah Wash
20 TODESTANI
21 TEEC NOS POS
Red Wash
22 RED ROCK MTN.
23 RED ROCK VALLEY
24 COVE
Denotes Irrigated Areas
Study Area Boundary
UTAH
ARIZONA
NAVAJO
INDIAN
HOPI
INDIAN RESERVATION
RESERVATION
NEW MEXICO
ARIZONA
San Juan River
Lees Ferry
Page
Kaibito
Cedar Ridge
Tuba City
Marsh Pass
Kayenta
Dennehotso
USGS Gaging Station
Sweetwater
Teec Nos Pos
Shiprock
Rock Point
Red Rock
Chilchinbito
Round Rock
Rough Rock
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UPPER COLORADO RIVER BASIN
CONSUMPTIVE USE STUDIES
ARIZONA
LOCATION MAP
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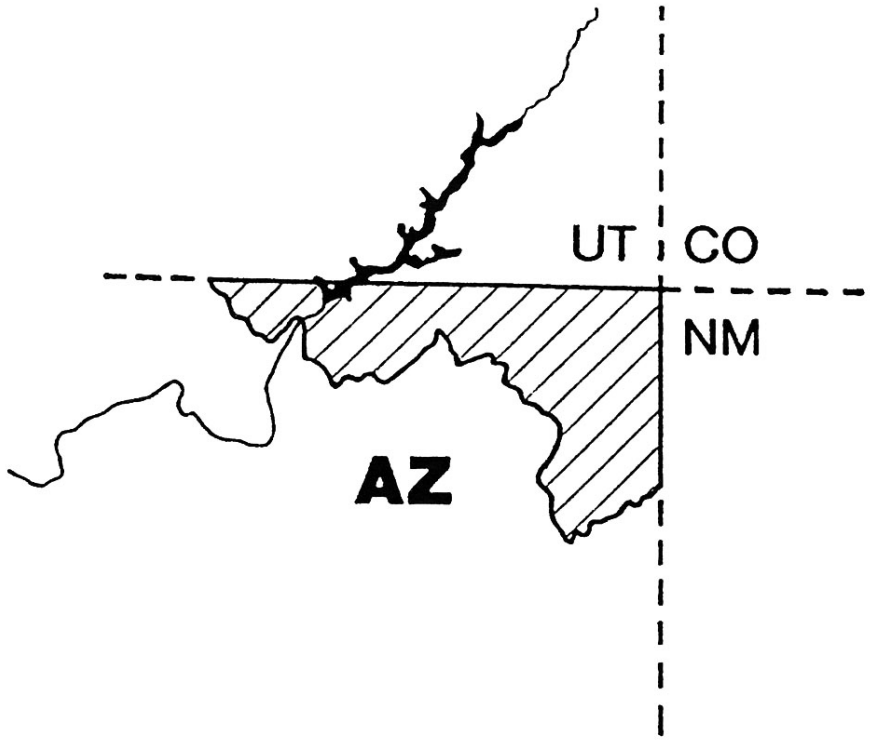
DURANGO, COLORADO
March 1987
1246-406-1

RECLAMATION

Managing Water in the West

Consumptive Uses and Losses

Arizona Portion of the Upper Colorado River Basin
Calendar Year 2005

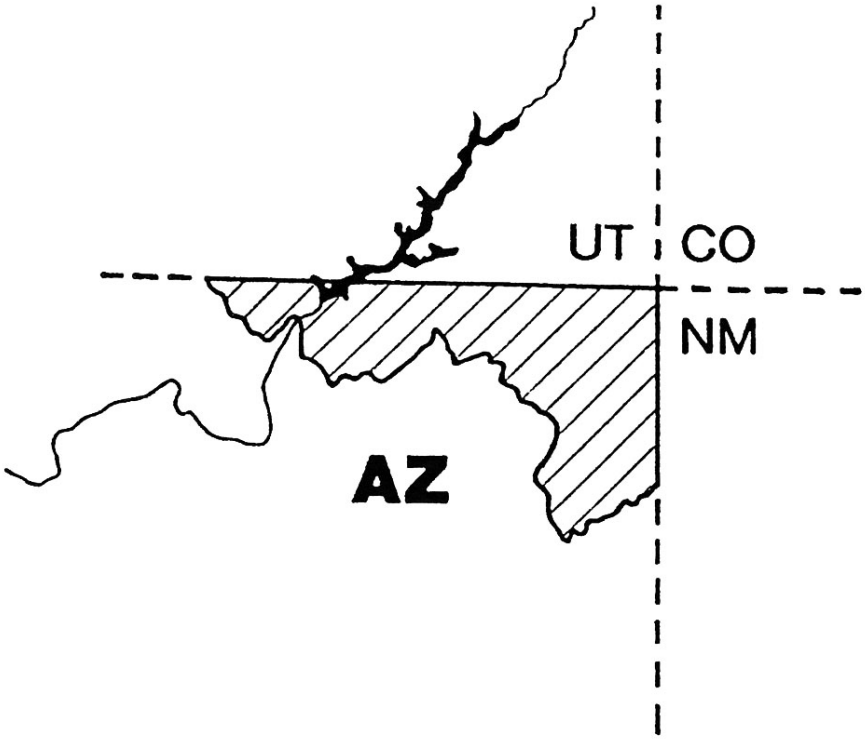


U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

October 2009

Consumptive Uses and Losses

Arizona Portion of the Upper Colorado River Basin
Calendar Year 2005



U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

October 2009

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Tables

CONSUMPTIVE USES AND LOSSES

ARIZONA PORTION OF THE UPPER COLORADO RIVER BASIN

CALENDAR YEAR 2005

AUTHORITY

This report was prepared in compliance with Public Law 90-537, Section 601 (b)(1), dated September 30, 1968, which directs the Secretary of the Interior to "make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis." Additionally, this report is in compliance with Section 49 of the Navajo Project Participation Agreement dated September 30, 1969, which states in part: "The Secretary of the Interior further agrees to make the reports required by Section 601 (b)(1) of Public Law 90-537 as they pertain to Arizona's Upper Basin uses annually rather than every five years. Within fifteen days following the completion of said reports, the Secretary of the Interior shall furnish copies of such reports to the Co-Tenants, the Navajo Tribe, each of the Upper Basin States, and the Upper Colorado River Commission."

SUMMARY

The total consumptive use and loss value for the Arizona portion of the Upper Colorado River Basin for calendar year 2005 was 36,456 ($\pm$1,236) acre-feet.

STUDY AREA DESCRIPTION

The Arizona portion of the Upper Colorado River Basin covers approximately 6,900 square miles in the north-east corner of Arizona, as shown on the location map (Drawing 1246-406-1). The climate of the 5,900 square mile area to the west of the Chuska and Carrizo Mountains is largely arid to semiarid, with mean annual precipitation ranging from 6 to 12 inches and with summertime temperatures often reaching 100 degrees Fahrenheit (^{o}F). The potential evaporation rate is high and exceeds mean annual precipitation, with gross lake evaporation values of up to 55 inches per year or more. Elevations in the western portion range from 3200 feet on the Colorado River at Lees Ferry to over 8000 feet on the northern edge of the Black Mesa and across the Zilnez and Skeleton Mesas, back down to 5280 feet in the Chinle Valley, and back up to about 6500 feet on the western edge of the Chuska Mountains. Much of the western part

of the study area is starkly beautiful southwestern desert country with mesas and canyons intertwined across a pastoral landscape. By contrast, the eastern 1,000 square miles is largely mountainous, with elevations rising to nearly 10,000 feet and mean annual precipitation reaching 30 inches. The mountainous land responds with grass meadows interspersed with conifer forest of mostly ponderosa pine.

Except for Page, Arizona; a small area around Lees Ferry; and a portion of the Paria Plateau administered by the Bureau of Land Management; the study area lies entirely within the Navajo Nation. According to census data, 48,613 persons were living within the area in 2000, and of these 41,804 resided on the Navajo Nation.

The largest cities are Page and Chinle, with 2000 populations of 6,809 and 5,366, respectively. Other major communities and their populations include Dennehotso (734), Kaibeto (1,607), Kayenta (4,922), LeChee (1,606), Lukachukai (1,565), Many Farms (1,548), Rock Point (724), Teec Nos Pos (799), and Tsaile (1,078). Subsistence in the region is derived principally from livestock grazing, farming, tourist-related industries, employment at the Navajo Generating Station (NGS), which consumes 60 to 70 percent of the water used or lost in the study area every year. Agriculture accounted for 4 percent of the total water use; municipal and industrial about 85 percent; recreation, fish and wildlife, about 4 percent; and reservoir evaporation, 7 percent.

AGRICULTURAL CONSUMPTIVE USE

Agricultural consumptive use is divided into three categories: irrigation, stock pond, and livestock. Irrigation use includes all use related to irrigating crops including the incidental losses. Stock pond use is the evaporation that occurs from stock ponds and livestock use is the water consumed by livestock.

IRRIGATION USES

Within the Arizona portion of the Upper Colorado River Basin, historically 23 irrigated areas were scattered across the Navajo Nation plus a small amount of land near Lees Ferry irrigated by the National Park Service. Currently, only 15 irrigated areas are in production. An accurate assessment of consumptive use on the irrigated land is difficult due to poor quality of information, such as the exact number of acres under irrigation, the cropping pattern for each irrigated area, site climatological conditions, and the amount s of water actually diverted. In many cases, during the latter part of the irrigation season, farmers have to rely on dry land farming since there is little water available in the streams. This means that the crops do not receive their full water requirement.

For this report, the U.S. Department of Agriculture, Soil Conservation Service's (SCS) Modified Blaney-Criddle ET estimation model was used for computing irrigated crop consumptive use. This model, along with appropriate crop-growth stage coefficients and the method for computing effective precipitation, is described in SCS's *Irrigation Water Requirements Technical Release No. 21* (TR 21). Information required for applying this model includes mean monthly temperature and precipitation values, growing season data for each crop type, and the total number of acres planted by crop at each site. With the

exception of Teec Nos Pos, Canyon de Chelly, Lukachukai, and Lees Ferry, no climatological data exist for the irrigation sites, and site values must be generated from data collected at surrounding established weather stations. Growing season dates depend largely on the judgment of the local inhabitants and are, therefore, not known. Although several reports are available with published values for irrigated acres, it is unclear if these values are meant to represent potential irrigated acres, acres irrigated in the past, acres for which farming permits have been issued, or actual acres currently under irrigation.

The crop acreage used to estimate consumptive use by irrigated crops for the year 2005 is shown in table 1. These values were determined from direct field examination by a party composed of representatives from the State of Arizona and the Navajo Nation.

Table 1.—Total irrigated acreage, 2005

PROJECT	CORN (ACRES)	ALFALFA (ACRES)	GRASS PASTURE (ACRES)	SPRING GRAINS (ACRES)	SMALL VEGETABLES (ACRES)	ORCHARD (ACRES)	TOTAL (ACRES)
CHINLE AGENCY							
Canyon de Chelly	0.36	0.00	0.00	3.03	2.26	0.00	5.65
Lukachukai	39.09	7.69	0.00	7.50	5.98	2.07	62.33
Nazlini	0.00	0.00	0.00	0.00	1.79	0.74	2.53
Rough Rock	30.00	0.00	11.87	0.00	12.43	0.00	54.30
Tsaile	23.72	5.27	15.67	5.73	5.42	0.00	55.81
Wheatfields	0.00	60.80	0.00	0.00	0.00	0.00	60.80
TOTAL	93.17	73.76	27.54	16.26	27.88	2.81	241.42
SHIPROCK AGENCY							
Red Rock Valley	26.22	0.00	10.19	5.12	10.22	0.00	51.75
Teec Nos Pos	20.00	0.00	0.00	0.00	3.67	0.00	23.67
Toh Chin Lini	0.00	0.00	0.00	0.00	3.90	13.67	17.57
Totacon	0.00	0.00	0.00	0.00	1.00	0.00	1.00
TOTAL	46.22	0.00	10.19	5.12	18.79	13.67	94.0
WESTERN NAVAJO AGENCY							
Dennehotso	1.82	0.00	38.70	0.00	0.00	0.00	40.52
Lees Ferry	0.00	0.00	1.00	0.00	0.00	2.00	3.00
Marsh Pass	7.02	3.31	0.00	0.00	1.99	0.00	12.32
Navajo Canyon	0.00	0.00	0.00	0.00	0.00	3.50	3.50
Paiute Canyon	2.64	0.00	0.00	0.00	3.86	0.00	6.50
TOTAL	11.48	3.31	39.70	0.00	5.85	5.50	65.84
GRAND TOTAL	150.87	77.07	77.43	21.38	52.52	21.98	401.25

Consumptive Uses and Losses

Several factors complicated the modeling of irrigation consumptive use. For example, the computer program used to model consumptive use assumes a full water supply; if shortages exist, as they often do in this semiarid study area, adjustments must be made. These adjustments are complicated because some of the projects have no storage water and may only have a reliable irrigation water supply during spring runoff. After spring runoff, farming becomes essentially dry land until rains in July and August provide intermittent flows for irrigation. Finally, no ditch diversion records are available to help estimate irrigation water supplies and shortages.

A full irrigation supply seldom exists at many of the projects. Generally, a full supply is available for Lees Ferry, Navajo Canyon, Tsaile, and Wheatfields projects because of adequate stream flows or because of available storage water. In years with average precipitation, it is estimated that Chinle Wash provides approximately 75 percent of the irrigation requirement. Precipitation in the area averages approximately 9.5 inches per year. Based on this information, it would require approximately 12.67 inches of precipitation to provide 100 percent of the irrigation requirement. The percent of crop water requirement met was computed as a ratio of annual precipitation to 12.67 inches. These values are found in table 2.

The percentage of crop water requirement met was multiplied by the total net crop water requirement to come up with the amount of crop consumptive use. Incidental irrigation losses, evaporation, and phreatophyte consumptive use along supply canals are estimated to be 5 percent of the consumptive use of the irrigated area and are added to the crop consumptive use value to develop a total consumptive use value.

A portion of the water used for irrigation at these sites may not be contributing to the Colorado River System since evaporation rates in the area are high and the nature of most of the drainage enhances evapotranspiration. A good example of such a drainage is Chinle Wash, which after it leaves Canyon de Chelly, becomes wide and sandy and is lined with willows, cottonwoods, and other phreatophytes.

The uncertainties in the irrigation consumptive use values displayed in table 2 are very large and are estimated as 40 percent of the total consumptive use. This estimate of possible error only reflects the uncertainty of consumptive use and does not account for any possible errors in the acreage estimates. The effective consumptive use for irrigation for 2005 was estimated to equal 580 acre-feet. Including the 5 percent for incidental losses, the irrigation related consumptive use is 609 ($\pm$244) acre-feet.

Table 2.—Net consumptive use values, 2005

PROJECT	CROP WATER REQUIREMENT (INCHES)	TOTAL IRRIGATED (ACRES)	TOTAL WATER REQUIRED (ACRE-FEET)	CROP WATER REQUIREMENT MET (%)	CROP WATER REQUIREMENT MET (ACRE-FEET)	TOTAL CONSUMPTIVE USE (ACRE-FEET)[1]
CHINLE AGENCY						
Canyon de Chelly	16.26	5.65	8	75%	6	6
Lukachukai	18.87	62.33	98	75%	74	78
Nazlini	16.59	2.53	3	75%	3	3
Rough Rock	20.12	54.30	91	97%	88	92
Tsaile	19.92	55.81	93	75%	70	73
Wheatfields	27.87	60.80	141	75%	106	112
TOTAL	—	241.42	434	—	346	364
SHIPROCK AGENCY						
Red Rock Valley	21.80	51.75	94	62%	58	61
Teec Nos Pos	24.51	23.67	48	48%	23	24
Toh Chin Lini	35.06	17.57	51	52%	27	28
Totacon	15.38	1.00	1	52%	1	1
TOTAL	—	93.99	195	—	109	114
WESTERN NAVAJO AGENCY						
Dennehotso	33.42	40.52	113	66%	74	78
Lees Ferry	50.93	3.00	13	100%	13	13
Marsh Pass	18.74	12.32	19	100%	19	20
Navajo Canyon	36.95	3.50	11	96%	10	11
Paiute Canyon	18.29	6.50	10	87%	9	9
TOTAL	—	65.84	166	—	125	131
GRAND TOTAL	—	401.25	795	—	580	609

[1] Total includes 5% addition for incidental losses.

STOCK POND EVAPORATION

Stock pond consumptive use is assumed to be the evaporation from the stock pond. It is also assumed that any consumptive use by natural vegetation prior to the construction of the stock ponds is limited to precipitation which is subtracted from the evaporation losses.

A compilation of the stock ponds in the study area, including their locations and the water surface areas when ponds are full, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 3. For an average year conditions, the stock pond evaporative surface area was estimated as one-third the water surface area that occurs when the ponds are full. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average water surface area. These values are found in table 3.

Table 3.—Stock pond evaporation, 2005

COUNTY	SURFACE AREA FULL (ACRES)	SURFACE AREA USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Coconino	80	27	100%	57	9.09	47.91	106
Navajo	40	13	100%	55	12.39	42.61	47
Apache	646	191	89%	53	7.82	45.19	720
TOTAL	766	231	—	—	—	—	873

This method of evaporation estimation was used because continuous useful water level records for all stock ponds from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual stock ponds. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation. It was assumed that any consumptive use by natural vegetation prior to construction of the stock ponds is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for stock pond evaporation for calendar year 2005 are shown in table 3. The total evaporative losses in 2005 are 873 ($\pm$262) acre-feet with the stock pond evaporation uncertainty being estimated as 30 percent.

LIVESTOCK WATER

The source of most livestock water in the study area is from wells, with windmill-operated pumps developed and maintained by Navajo Water Operations and Maintenance, and water collected in small surface ponds. The estimated number of

livestock in the area was obtained based on livestock tallies. It was estimated that horses and cattle consume 12 gallons per day; sheep and goats consume 2 gallons per day.

The number of animals for the Upper Colorado portion of each district is shown in table 4. The computed value for livestock consumptive use is 218 acre-feet. The uncertainty in this number is estimated as 30 percent of the total or ±65 acre-feet.

Table 4.—Number of livestock, 2005

AGENCY	CATTLE	HORSES	SHEEP	GOATS
Western Navajo District No. 1	2,079	328	2,398	1,263
Western Navajo District No. 2	709	81	1,339	898
Western Navajo District No. 8	1,910	169	2,960	2,069
Shiprock District No. 9	1,134	179	1,226	1,494
Chinle District No. 10	2,694	369	3,605	1,967
Chinle District No. 11	1,041	156	956	1,041
Shiprock District No. 12	897	84	1,075	827
Fort Defiance District No. 17	100	15	370	141
Fort Defiance District No. 18	248	23	329	145
TOTAL	10,812	1,404	14,257	9,844

TOTAL AGRICULTURAL CONSUMPTIVE USE

The total agricultural consumptive use, displayed in table 5, is the sum of the individual components discussed in the previous sections. Agricultural water consumption represents approximately 4 percent of the total use in the study area. Total degree of uncertainty was computed by taking the square root of the sum of the individual uncertainties squared; known as the quadratic sum. This method and nomenclature is used throughout this report. This method was used because a simple sum does not account for the partial cancellation of errors occurring when calculating the total uncertainty derived from individual values that are random and independent of each other. As previously discussed, the individual uncertainties were set as a percent of the consumptive use value.

Table 5.—Total agricultural consumptive use, 2005

CATEGORY	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Irrigation	609	244
Stock Ponds	873	262
Livestock	218	65
TOTAL	1,701	364

MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

Municipal and industrial consumptive use is divided into three categories: mineral resources, thermal electric power, and other. Mineral resources consumptive use includes water used for mineral production. No mineral resources consumptive use is reported in the study area. Thermal electric power consumptive use includes the water used at the power plants, and that used to transport material to the power plant (such as a coal slurry pipeline). Other consumptive use includes urban, rural, and industrial uses.

THERMAL ELECTRIC POWER

Thermal electric power consumptive use includes the water used in the power plant and the water used to transport material to the plant.

Navajo Generating Station

The water used by the NGS is pumped directly from Lake Powell and comprises over half of the total consumption in the study area. Since all NGS water use is metered, this quantity is among those most precisely known, with the maximum uncertainty in the metered quantities believed to be less than 3 percent. The actual quantity consumed, along with the estimated uncertainty for the calendar year 2005, was 26,200 (±786) acre-feet.

OTHER

The other consumptive use category includes the remaining use by urban, rural, and industries.

Page, AZ and Vicinity

***City of Page, AZ*. –** The city of Page pumps its domestic water directly from Lake Powell. The water pumped is metered, and the uncertainty of the pumped quantities was assumed to be less than 3 percent. A portion of the water pumped and treated by the City of Page, is supplied to the community of Le Chee on the Navajo Nation and is accounted for separately. The quantity supplied to the City of Page and its associated uncertainty for the calendar year 2005 was 2,107 (±63) acre-feet. Water returning to the waste water treatment plant is metered as well. The waste water for the City of Page is treated and is either evaporated from lined ponds or applied to the golf course, with a portion being returned to the Colorado River. The return flow is estimated to be 395 acre-feet. The net consumptive use is estimated to be 1,712 acre-feet (±64).

***Le Chee* –** The community of Le Chee is supplied and metered by the City of Page. Total water supplied for 2005 was 98 (±3) acre-feet. The uncertainty was estimated to be 3 percent.

Greenhaven Water Company – The Greenhaven Water Company derives its domestic water supply from wells. Well pumping records are available. According to these records, the total water pumped for 2005 was 87 (±6) acre-feet. The uncertainty was estimated to be 7 percent.

Arizona Department of Transportation Housing – The Arizona Department of Transportation operates a housing, maintenance, and administrative facility located on US Hwy 89, north of Page, AZ. This facility is supplied from wells that have no meters installed. It is estimated that the total water pumped for 2005 was 14 acre-feet with an uncertainty of 30 percent of this value or ±4 acre-feet.

Navajo Nation

Community Water Systems – Statistics from the Division of Community Development of the Navajo Nation reveal that various community water systems served 26,086, or about 83 percent of the 31,429 people residing within the study area in 1980. This percentage was used for 2005 resulting in 36,987 out of 44,563 people being served. These systems include those operated by the Navajo Tribal Utility Authority (NTUA), the BIA, and the Water Operations and Maintenance Department of the Navajo Nation, and some privately developed community water systems.

Table 6 shows the source of water and estimated population served by each source of water for people living on the Navajo Nation during 2005. All of the communities obtain their water supply from ground water.

Table 6.—Domestic water sources, 2005

SOURCE	PERCENTAGE OF POPULATION SERVED	NUMBER OF POPULATION SERVED[1]
Community Water Systems	83	36,987
NTUA	[2](60)	22,192
BIA	[2](25)	9,247
Navajo WOM	[2](13)	4,808
Private	[2](2)	740
Individual Wells	17	7,576
TOTAL[2]	100	44,563

[1] Estimated total population within the Upper Colorado River Basin portion of the Navajo Nation provided by Larry Rodgers, Demographer for the Division of Community Development of the Navajo Nation, letter DCDA-L94052, June 20, 1995.
[2] These numbers are a percentage of the Community Water Systems.

NTUA Water Systems – The cities and surrounding communities of Oak Springs, Red Valley, Sweetwater, Chinle , Rough Rock, Round Rock, Rock Point, Wheatfields, Lukachukai, Kayenta, Chilchinbeto, Dennehotso, and Kaibeto derive most of their domestic water supply from wells operated by NTUA. Well pumping records are

available. According to these records, the total water pumped for 2005 was 1,619 acre-feet with an uncertainty estimated to be 7 percent of this value or ±113 acre-feet.

The NTUA manages the raw waste water; portions of which flow to individual septic tanks, some to evaporation ponds, and some, such as for the cities of Chinle and Kayenta, flow to waste water treatment plants. Very little water, if any, is returned to the ground water system through leakage from the evaporation ponds, but there are losses from the main collection system. Effluent from the Chinle and Kayenta waste water treatment plants is metered. Under normal conditions, the effluent returns to the Colorado River System and is subtracted from the pumping totals to determine a net consumptive use. For 2005, Chinle's treatment plant effluent was 379 (±27) acre-feet, and Kayenta's effluent was 267 (±19) acre-feet. An estimated uncertainty of 7 percent was used for the effluent of these two plants. The total effluent of 645 acre-feet is subtracted from the NTUA pumping total of 1,619 acre-feet to arrive at a net consumptive use of 974 (±122) acre-feet.

BIA Water Systems – Wells developed and operated by the BIA serve numerous Navajo communities. These systems also serve BIA schools, hospitals, agency offices, and some housing on the Navajo Nation. Metered records for total amounts of water pumped from BIA wells were available for a portion of the Shiprock Agency, the Western Navajo Agency, and the Chinle Agency. Drawing 1246-406-2 shows the agency boundaries within the Upper Colorado River Basin. The uncertainty was estimated to be about 7 percent for all three agencies.

The BIA systems include sewage disposal units terminating in lined evaporation ponds with very little or no return water returning to the ground water system. Undoubtedly, some losses occur in distribution, but insufficient data currently exist to estimate these losses. The losses are probably less than the uncertainties for each of the reported values.

The BIA well data available for the Shiprock Agency include: Cove, Red Rock, and Teec Nos Pos. Total consumptive use values are 11 (±1) acre-feet.

Pumping records for the Western Navajo Agency include data for the following schools: Chilchinbeto Day School, Dennehotso Boarding School, Kaibeto Boarding School, and Kayenta Boarding School. Total consumptive use for the Western Navajo Agency was 170 (±12) acre-feet.

Well pumping records for the Chinle Agency include data for the following schools: Cottonwood Day School, Lukachukai School, and Rock Point School. Rough Rock School maintains its own records, but the data was included with the Chinle Agency data. Total consumptive use for the Chinle Agency was 69 (±5) acre-feet.

Navajo WOM Water Systems – Water use in 2005 by the Navajo WOM service areas was based on an assumed consumption rate of 110 gallons per capita per day (gpcd). For a 2005 estimated service area population of 4,808, the estimated annual water use was 592 (±178) acre-feet. The uncertainty is estimated as 30 percent of the total.

Private Water Systems – The estimated 2005 population served by private water systems on the Navajo Nation was 740. Assuming a consumptive use rate of 110

gcpd, the annual water use for 2005 was 91 (±27) acre-feet. The uncertainty is estimated as 30 percent of the total.

Individual Wells – According to census data from the Division of Community Development of the Navajo Nation, approximately 17 percent of the study area's population on the reservation (about 7,576 persons in 2005) receives a domestic water supply from individual wells. A consumptive use of 110 gpcd was derived as being a reasonable water use rate. Based on these figures, the annual consumptive use was 933 (±280) acre-feet for 2005.

TOTAL MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

The total municipal and industrial consumptive use, displayed in table 7, is the sum of the individual components discussed in the previous sections. Municipal and industrial water consumption represents approximately 85 percent of the total use in the study area.

Table 7.—Total municipal and industrial consumptive use, 2005

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
THERMAL ELECTRIC POWER		
Navajo Generating Station	26,200	786
OTHER		
Page, AZ and Vicinity		
City of Page	1,712	64
Le Chee	98	3
Greenhaven Water Company	87	6
Arizona Department of Transportation	14	4
Navajo Indian Reservation		
Community Water Systems		
NTUA Water Systems	974	122
BIA Water Systems	250	13
Navajo WOM	592	178
Private Water Systems	91	27
Individual Wells	933	280
TOTAL	30,952	865

It is questionable whether all the water pumped from wells should be considered a depletion to the Colorado River System; however, it is assumed that 100 percent of the water pumped is considered lost to the system. It is proposed that a future joint study be completed by Reclamation, the State of Arizona, and the Navajo Nation to estimate what

percentage of water pumped could actually be attributed to the Colorado River System and would have affected the river flows for a particular year.

RECREATION, FISH AND WILDLIFE

The recreation, fish and wildlife consumptive uses include evaporation from reservoirs used exclusively for fish & wildlife purposes as well as acreages irrigated for wildlife feeding. Consumptive use at National and State parks is also accounted for.

GLEN CANYON NATIONAL RECREATION AREA

Colorado River water is used by the Glen Canyon National Recreation Area (GCNRA) at Wahweap and Lees Ferry. The recreational area at Wahweap gets its water supply from a series of wells on the shore of Lake Powell. Pumping records for both Wahweap and Lees Ferry show 280(±8) acre-feet of water withdrawn during 2005. The uncertainty is estimated at 3 percent. This water was used for domestic purposes at the campgrounds, picnic areas, and trailer parks. It was also used to irrigate approximately 60 acres of Bermuda grass and cottonwood trees. The domestic waste water is treated and the effluent is allowed to evaporate from two lines evaporation ponds with a total surface area of 16.7 acres.

Based on estimates of evaporation and consumptive use by the plants, there is some water which is unaccounted for and is assumed to be leakage from the delivery system, the evaporation pond, or deep percolation from irrigation application. However, since these water losses are difficult to quantify and verify, the losses were charged as consumptive uses. Therefore, net consumptive use of water is estimated to be equal to the quantity of water pumped.

RESERVOIR EVAPORATION

A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled “1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River” and are shown in table 8.

Table 8. —Recreation, fish and wildlife reservoir evaporation, 2005

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE AREA USED (ACRES)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Tsaile	260	260	35	9.54	25.46	552
Wheatfields	272	272	32	9.54	22.46	509
TOTAL	532	532	—	—	—	1,061

Efforts are made to maintain a nearly full condition and to minimize water surface fluctuations in reservoirs managed for a fishery. Under average operating conditions, the

water surface area of a reservoir used primarily for fishing is assumed to be equal to a normal water surface area. It is assumed that, in 2005, these reservoirs filled in the spring and were maintained at the normal pool level.

This method of evaporation estimation was used because continuous useful water level records for all reservoirs from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs.

For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for reservoir evaporation for calendar year 2005 are shown in table 8. The total evaporative losses in 2005 are 1,061 (±318) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent.

TOTAL RECREATION, FISH AND WILDLIFE

The total recreation, fish and wildlife consumptive use, displayed in table 9, is the sum of the individual components discussed in the previous sections. Recreation, fish and wildlife water consumption represents approximately 4 percent of the total use in the study area.

Table 9.—Total recreation, fish and wildlife consumptive use, 2005

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Glen Canyon National Recreation Area	280	8
Reservoir Evaporation	1,061	318
TOTAL	1,341	318

RESERVOIR EVAPORATION

Reservoir evaporation losses make up about 7 percent of the total water uses and losses in the study area. A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 10. These reservoirs are used primarily for irrigation.

Table 10.—Reservoir evaporation, 2005

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE ACRES USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Many Farms	1,800	554	—	56	9.54	46.46	2147
Marsh Pass	40	20	100%	40	13.65	26.35	44
Round Rock	83	37	89%	57	7.82	49.19	151
Walker Creek	30	11	75%	59	6.09	52.91	50
Others	38	19	100%	55	10.17	44.83	71
TOTAL	1,991	642	—	—	—	—	2,462

Reservoirs used primarily for irrigation experience large fluctuations in water levels and, correspondingly, large variations in surface area. Reservoir level records and elevation – area curves were available at Many Farms, but not for the remaining reservoirs in table 10. For the reservoirs with no records from which surface area could be accurately computed, the average evaporative surface area was estimated as one-half the water surface area of a full reservoir. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average evaporative surface area.

Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses. The computed values for reservoir evaporation for 2005 are shown in table 10. The total evaporative losses in 2005 are 2,462 ($\pm$739) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent of the total evaporation.

CONCLUSIONS

This report assesses the total consumptive use of the Arizona portion of the Upper Colorado River System surface water systems, depletion of ground water, and evaporative losses. Clearly, the amounts of water used by the Navajo Generating Station, City of Page, and Wahweap and Lees Ferry recreation areas are direct depletions of water from the Upper Colorado River System, but the situation is not as clear for other consumptive uses and losses occurring in other sections of the study area. For example, the source of water used by the Navajo Nation for domestic and municipal purposes is from wells, some exceeding 1,000 feet in depth. For our purposes here, it is considered to be consumed and a depletion to the Colorado River System. But this may not actually result in a reduction of Colorado River stream flows in the same year that the withdrawal

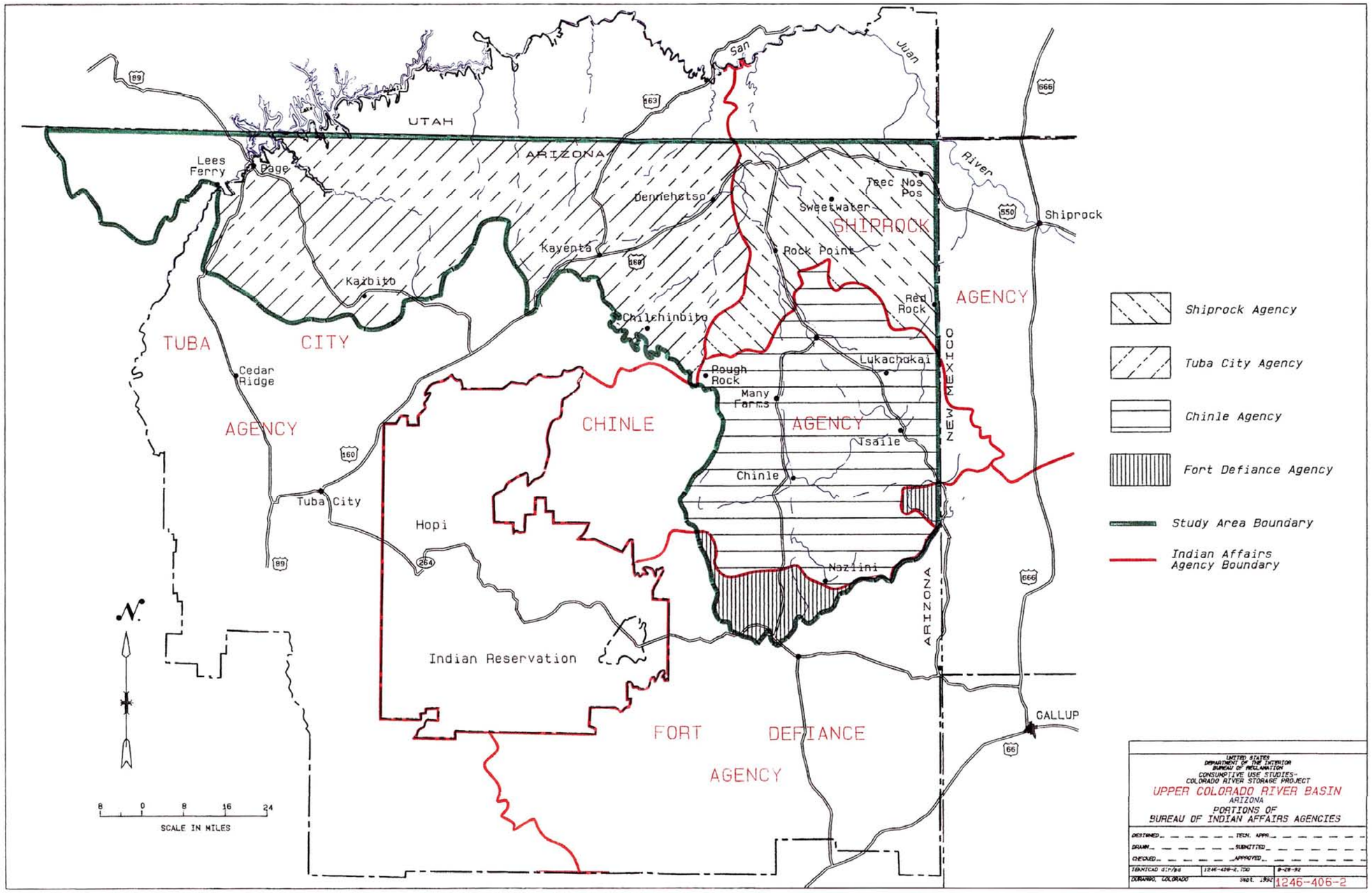
occurs. Little knowledge and information exists of ground water movement and subsurface flow rates in the study area that are accurate descriptions of the effects on river flows.

Although the water diverted for agricultural purposes is considered as consumptive use in this report, a portion of the remaining surface water on the Navajo Nation, excess to needs, does evaporate before reaching the Colorado River. An attempt has not been made for this report to quantify these losses.

Uncertainties in estimating uses and losses exist, and the degree of variation in the figures is presented. Fortunately, the areas with the highest degree of uncertainty account for only a small percentage of the total consumptive use. The largest component, use by the Navajo Generating Station, is also the most accurately monitored. The total annual value for estimated consumptive use of water within the Arizona portion of the Upper Colorado River Basin for 2005 was 36,135 acre-feet, as shown in table 11.

Table 11.—Consumptive use for Arizona portion of Upper Colorado River Basin for 2005

USE CATEGORY	TOTAL CONSUMPTIVE USE (ACRE-FEET)	UNCERTAINTY	PERCENT OF TOTAL
Agriculture	1,701	364	4
Municipal & Industrial	30,952	865	85
Recreation, Fish & Wildlife	1,341	318	4
Reservoir Evaporation	2,462	739	7
TOTAL	36,456	1,236	100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Page
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Kayenta
Dennehotso
Chilchinbito
Teec Nos Pos
Sweetwater
Rock Point
Red Rock
Lukachukai
Rough Rock
Many Farms
Tsaile
Chinle
Nazlini
Shiprock
Cedar Ridge
Tuba City
Hopi
Indian Reservation
GALLUP
San Juan River
TUBA CITY AGENCY
CHINLE AGENCY
SHIPROCK AGENCY
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Shiprock Agency
Tuba City Agency
Chinle Agency
Fort Defiance Agency
Study Area Boundary
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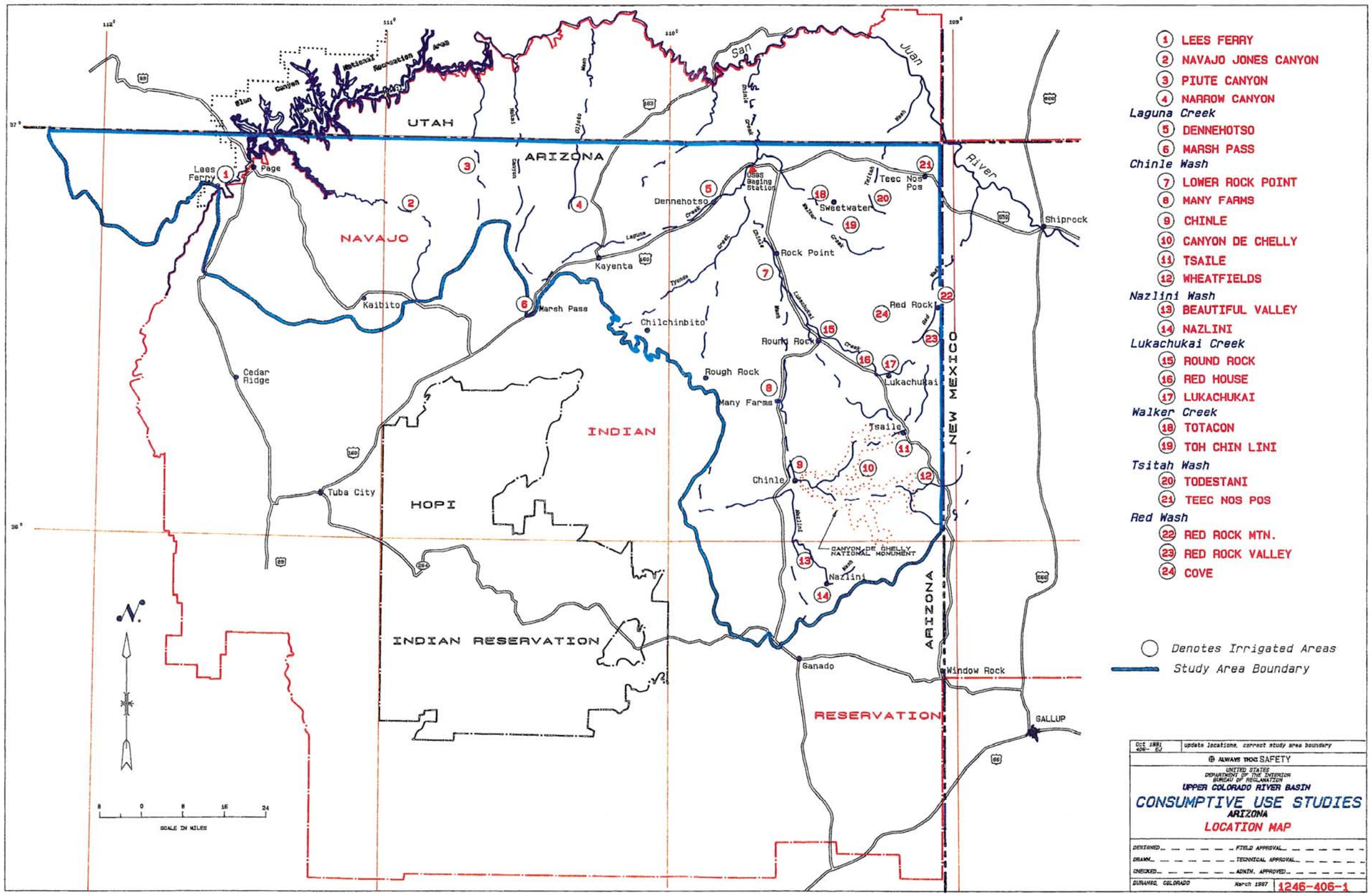
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3 PIUTE CANYON
4 NARROW CANYON
Laguna Creek
5 DENNEHOTSO
6 MARSH PASS
Chinle Wash
7 LOWER ROCK POINT
8 MANY FARMS
9 CHINLE
10 CANYON DE CHELLY
11 TSAILE
12 WHEATFIELDS
Nazlini Wash
13 BEAUTIFUL VALLEY
14 NAZLINI
Lukachukai Creek
15 ROUND ROCK
16 RED HOUSE
17 LUKACHUKAI
Walker Creek
18 TOTACON
19 TOH CHIN LINI
Tsitah Wash
20 TODESTANI
21 TEEC NOS POS
Red Wash
22 RED ROCK MTN.
23 RED ROCK VALLEY
24 COVE
Denotes Irrigated Areas
Study Area Boundary
UTAH
ARIZONA
NAVAJO
INDIAN
HOPI
INDIAN RESERVATION
RESERVATION
NEW MEXICO
ARIZONA
San Juan River
Lees Ferry
Page
Kaibito
Cedar Ridge
Tuba City
Marsh Pass
Kayenta
Dennehotso
USGS Gaging Station
Sweetwater
Teec Nos Pos
Shiprock
Rock Point
Red Rock
Chilchinbito
Round Rock
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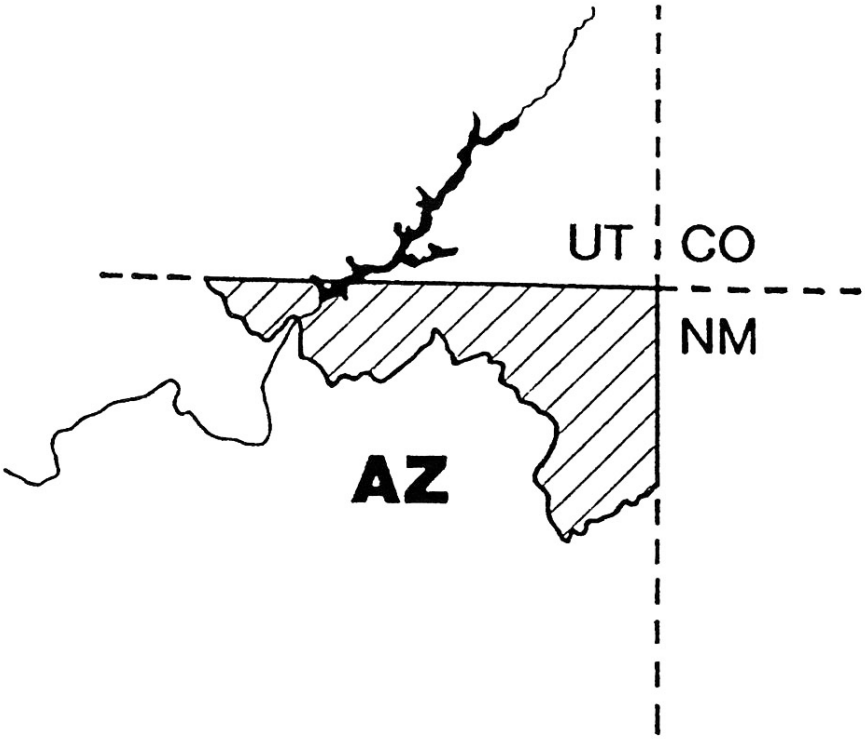
March 1987
1246-406-1

RECLAMATION

Managing Water in the West

Consumptive Uses and Losses: Final Estimate

Arizona Portion of the Upper Colorado River Basin Calendar Year 2006



U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

September 2014

RECLAMATION

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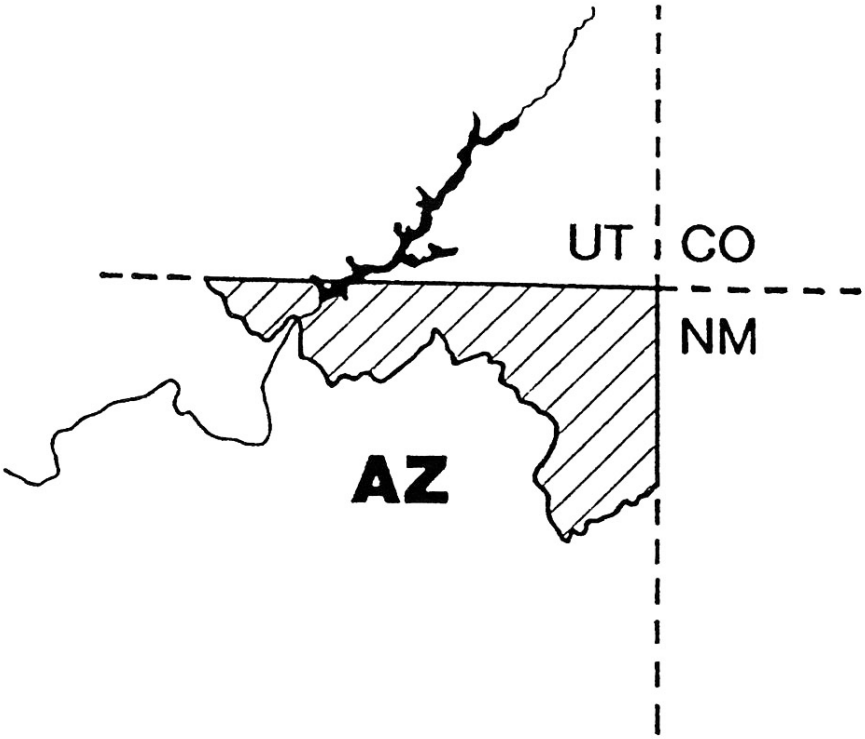

Prepared by: Alan Harrison – September 23, 2014

U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

September 2014

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ARIZONA PORTION
OF THE
UPPER COLORADO RIVER BASIN

CALENDAR YEAR
2006

AUTHORITY

This report was prepared in compliance with Public Law 90-537, Section 601 (b)(1), dated September 30, 1968, which directs the Secretary of the Interior to "make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis." Additionally, this report is in compliance with Section 49 of the Navajo Project Participation Agreement dated September 30, 1969, which states in part: "The Secretary of the Interior further agrees to make the reports required by Section 601 (b)(1) of Public Law 90-537 as they pertain to Arizona's Upper Basin uses annually rather than every five years. Within fifteen days following the completion of said reports, the Secretary of the Interior shall furnish copies of such reports to the Co-Tenants, the Navajo Tribe, each of the Upper Basin States, and the Upper Colorado River Commission."

SUMMARY

Based upon data made available for preparation of this document. the total consumptive use and loss value for the Arizona portion of the Upper Colorado River Basin for calendar year 2006 was 36,808 (±1,246) acre-feet. Reclamation prepares this estimate annually, final annual values for consumptive uses and losses for the northern Arizona portion of the Colorado River basin are published in the 5-year summary documents for the Upper Colorado River Basin

STUDY AREA DESCRIPTION

The Arizona portion of the Upper Colorado River Basin covers approximately 6,900 square miles in the north-east corner of Arizona, as shown on the location maps shown on pages 19 and 20 (Drawings 1246-406-1, 1246-406-2). The climate of the 5,900 square mile area to the west of the Chuska and Carrizo Mountains is largely arid to semiarid, with mean annual precipitation ranging from 6 to 12 inches and with summertime temperatures often reaching 100 degrees Fahrenheit (^{o}F). The potential

evaporation rate is high and exceeds mean annual precipitation, with gross lake evaporation values of up to 55 inches per year or more. Elevations in the western portion range from 3200 feet on the Colorado River at Lees Ferry to over 8000 feet on the northern edge of the Black Mesa and across the Zilnez and Skeleton Mesas, back down to 5280 feet in the Chinle Valley, and back up to about 6500 feet on the western edge of the Chuska Mountains. Much of the western part of the study area is starkly beautiful southwestern desert country with mesas and canyons intertwined across a pastoral landscape. By contrast, the eastern 1,000 square miles is largely mountainous, with elevations rising to nearly 10,000 feet and mean annual precipitation reaching 30 inches. The mountainous land responds with grass meadows interspersed with conifer forest of mostly ponderosa pine.

Except for Page, Arizona; a small area around Lees Ferry; and a portion of the Paria Plateau administered by the Bureau of Land Management; the study area lies entirely within the Navajo Nation. Based on straight-line interpolation of 2000 and 2010 census data for the area, it is estimated that approximately 48,174 persons were living within the study area in 2006, and of these an estimated 41,102 resided on the Navajo Nation.

The largest cities are Page and Chinle, with 2000 populations of 6,809 and 5,366, respectively. Other major communities and their populations include Dennehotso (734), Kaibeto (1,607), Kayenta (4,922), LeChee (1,606), Lukachukai (1,565), Many Farms (1,548), Rock Point (724), Teec Nos Pos (799), and Tsaile (1,078). Subsistence in the region is derived principally from livestock grazing, farming, tourist-related industries, employment at the Navajo Generating Station (NGS), which consumed 72 percent of the water used or lost in the study area. Agriculture accounted for 4 percent of the total water use; municipal and industrial about 85 percent; recreation, fish and wildlife, about 4 percent; and reservoir evaporation, 7 percent.

AGRICULTURAL CONSUMPTIVE USE

Agricultural consumptive use is divided into three categories: irrigation, stock pond, and livestock. Irrigation use includes all use related to irrigating crops including the incidental losses. Stock pond use is the evaporation that occurs from stock ponds and livestock use is the water consumed by livestock.

IRRIGATION USES

Within the Arizona portion of the Upper Colorado River Basin, historically 23 irrigated areas were scattered across the Navajo Nation plus a small amount of land near Lees Ferry irrigated by the National Park Service. Currently, only 16 irrigated areas are in production. An accurate assessment of consumptive use on the irrigated land is difficult due to poor quality of information, such as the exact number of acres under irrigation, the cropping pattern for each irrigated area, site climatological conditions, and the amounts of water actually diverted. In many cases, during the latter part of the irrigation season, farmers have to rely on dry land farming since there is little water available in the streams. This means that the crops do not receive their full water requirement.

For this report, the U.S. Department of Agriculture, Soil Conservation Service's (SCS) Modified Blaney-Criddle ET estimation model was used for computing irrigated crop consumptive use. This model, along with appropriate crop-growth stage coefficients and the method for computing effective precipitation, is described in SCS's *Irrigation Water Requirements Technical Release No. 21* (TR 21). Information required for applying this model includes mean monthly temperature and precipitation values, growing season data for each crop type, and the total number of acres planted by crop at each site. With the exception of Teec Nos Pos, Canyon de Chelly, Lukachukai, and Lees Ferry, no climatological data exist for the irrigation sites, and site values must be generated from data collected at surrounding established weather stations. Growing season dates depend largely on the judgment of the local inhabitants and are, therefore, not known. Although several reports are available with published values for irrigated acres, it is unclear if these values are meant to represent potential irrigated acres, acres irrigated in the past, acres for which farming permits have been issued, or actual acres currently under irrigation.

The crop acreage used to estimate consumptive use by irrigated crops for the year 2006 is shown in table 1. These values were determined from direct field examination by a party composed of representatives from the State of Arizona and the Navajo Nation.

Table 1.—Total irrigated acreage, 2006

PROJECT	CORN (ACRES)	ALFALFA (ACRES)	GRASS PASTURE (ACRES)	SPRING GRAINS (ACRES)	SMALL VEGETABLES (ACRES)	ORCHARD (ACRES)	TOTAL (ACRES)
CHINLE AGENCY							
Canyon de Chelly	0.36	0.00	0.00	3.03	2.26	0.00	5.65
Lukachukai	39.09	7.69	0.00	7.50	5.98	2.07	62.33
Many Farms	42.90	7.20	26.50	0.70	7.20	0.00	84.50
Nazlini	0.00	0.00	0.00	0.00	1.79	0.74	2.53
Rough Rock	30.00	0.00	11.87	0.00	12.43	0.00	54.30
Tsaile	23.72	5.27	15.67	5.73	5.42	0.00	55.81
Wheatfields	0.00	60.80	0.00	0.00	0.00	0.00	60.80
TOTAL	136.07	80.96	54.04	16.96	35.08	2.81	325.92
SHIPROCK AGENCY							
Red Rock Valley	26.22	0.00	10.19	5.12	10.22	0.00	51.75
Teec Nos Pos	20.00	0.00	0.00	0.00	3.67	0.00	23.67
Toh Chin Lini	0.00	0.00	0.00	0.00	3.90	13.67	17.57
Totacon	0.00	0.00	0.00	0.00	1.00	0.00	1.00
TOTAL	46.22	0.00	10.19	5.12	18.79	13.67	93.99
WESTERN NAVAJO AGENCY							
Dennehotso	1.82	0.00	38.70	0.00	0.00	0.00	40.52
Lees Ferry	0.00	0.00	1.00	0.00	0.00	2.00	3.00
Marsh Pass	7.02	3.31	0.00	0.00	1.99	0.00	12.32
Navajo Canyon	0.00	0.00	0.00	0.00	0.00	3.50	3.50
Paiute Canyon	2.64	0.00	0.00	0.00	3.86	0.00	6.50
TOTAL	11.48	3.31	39.70	0.00	5.85	5.50	65.84
GRAND TOTAL	193.77	84.27	103.93	22.08	59.72	21.98	485.75

Several factors complicated the modeling of irrigation consumptive use. For example, the computer program used to model consumptive use assumes a full water supply; if shortages exist, as they often do in this semiarid study area, adjustments must be made. These adjustments are complicated because some of the projects have no storage water and may only have a reliable irrigation water supply during spring runoff. After spring runoff, farming becomes essentially dry land until rains in July and August provide

intermittent flows for irrigation. Finally, no ditch diversion records are available to help estimate irrigation water supplies and shortages.

A full irrigation supply seldom exists at many of the projects. Generally, a full supply is available for Lees Ferry, Navajo Canyon, Tsaile, and Wheatfields projects because of adequate stream flows or because of available storage water. In years with average precipitation, it is estimated that Chinle Wash provides approximately 61 percent of the irrigation requirement. Precipitation in the area averages approximately 9.5 inches per year. Based on this information, it would require approximately 13.21 inches of precipitation to provide 100 percent of the irrigation requirement. The percent of crop water requirement met was computed as a ratio of annual precipitation to 13.21 inches. These values are found in table 2.

The percentage of crop water requirement met was multiplied by the total net crop water requirement to come up with the amount of crop consumptive use. Incidental irrigation losses, evaporation, and phreatophyte consumptive use along supply canals are estimated to be 5 percent of the consumptive use of the irrigated area and are added to the crop consumptive use value to develop a total consumptive use value.

A portion of the water used for irrigation at these sites may not be contributing to the Colorado River System since evaporation rates in the area are high and the nature of most of the drainage enhances evapotranspiration. A good example of such a drainage is Chinle Wash, which after it leaves Canyon de Chelly, becomes wide and sandy and is lined with willows, cottonwoods, and other phreatophytes.

The uncertainties in the irrigation consumptive use values displayed in table 2 are very large and are estimated as 40 percent of the total consumptive use. This estimate of possible error only reflects the uncertainty of consumptive use and does not account for any possible errors in the acreage estimates. The effective consumptive use for irrigation for 2006 was estimated to equal 545 acre-feet. Including the 5 percent for incidental losses, the irrigation related consumptive use is 572 ($\pm$229) acre-feet.

Table 2.—Net consumptive use values, 2006

PROJECT	CROP WATER REQUIREMEN T (INCHES)	TOTAL IRRIGATED (ACRES)	TOTAL WATER REQUIRED (ACRE-FEET)	CROP WATER REQUIREMENT MET (%)	CROP WATER REQUIREMENT MET (ACRE-FEET)	TOTAL CONSUMPTIVE USE (ACRE-FEET)[1]
CHINLE AGENCY						
Canyon de Chelly	16.38	5.65	8	61%	5	5
Lukachukai	17.59	62.33	91	61%	56	59
Many Farms	25.16	84.50	177	61%	108	114
Nazlini	16.05	2.53	3	61%	2	2
Rough Rock	18.08	54.30	82	80%	66	69
Tsaile	18.89	55.81	88	61%	54	56
Wheatfields	27.35	60.80	139	61%	85	89
TOTAL	139.49	325.92	588	—	375	393
SHIPROCK AGENCY						
Red Rock Valley	18.70	51.75	81	52%	42	44
Teec Nos Pos	25.83	23.67	51	42%	22	23
Toh Chin Lini	37.13	17.57	54	35%	19	20
Totacon	15.75	1.00	1	35%	1	1
TOTAL	97.41	93.99	187	—	83	87
WESTERN NAVAJO AGENCY						
Dennehotso	31.81	40.52	107	44%	48	50
Lees Ferry	43.43	3.00	11	100%	11	11
Marsh Pass	19.76	12.32	20	82%	17	17
Navajo Canyon	30.97	3.50	9	74%	7	7
Paiute Canyon	17.09	6.50	9	64%	6	6
TOTAL	143.06	65.84	157	—	88	92
GRAND TOTAL	379.97	485.75	932	—	545	572

[1] Total includes 5% addition for incidental losses.

STOCK POND EVAPORATION

Stock pond consumptive use is assumed to be the evaporation from the stock pond. It is also assumed that any consumptive use by natural vegetation prior to the construction of the stock ponds is limited to precipitation which is subtracted from the evaporation losses.

A compilation of the stock ponds in the study area, including their locations and the water surface areas when ponds are full, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 3. For an average year conditions, the stock pond evaporative surface area was estimated as one-third the water surface area that occurs when the ponds are full. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average water surface area. These values are found in table 3.

Table 3.—Stock pond evaporation, 2006

COUNTY	SURFACE AREA FULL (ACRES)	SURFACE AREA USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Coconino	80	27	100%	57	6.77	50.23	112
Navajo	40	13	94%	55	9.19	45.82	48
Apache	646	160	74%	53	6.56	46.45	620
TOTAL	766	200	—	—	—	—	780

This method of evaporation estimation was used because continuous useful water level records for all stock ponds from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual stock ponds. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation. It was assumed that any consumptive use by natural vegetation prior to construction of the stock ponds is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for stock pond evaporation for calendar year 2006 are shown in table 3. The total evaporative losses in 2006 are 780 ($\pm$234) acre-feet with the stock pond evaporation uncertainty being estimated as 30 percent.

LIVESTOCK WATER

The source of most livestock water in the study area is from wells, with windmill-operated pumps developed and maintained by Navajo Water Operations and

Maintenance, and water collected in small surface ponds. The estimated number of livestock in the area was obtained based on livestock tallies. It was estimated that horses and cattle consume 12 gallons per day; sheep and goats consume 2 gallons per day.

The number of animals for the Upper Colorado portion of each district is shown in table 4. The computed value for livestock consumptive use is 218 acre-feet. The uncertainty in this number is estimated as 30 percent of the total or ±65 acre-feet.

Table 4.—Number of livestock, 2006

AGENCY	CATTLE	HORSES	SHEEP	GOATS
Western Navajo District No. 1	2,079	328	2,398	1,263
Western Navajo District No. 2	709	81	1,339	898
Western Navajo District No. 8	1,910	169	2,960	2,069
Shiprock District No. 9	1,134	179	1,226	1,494
Chinle District No. 10	2,694	369	3,605	1,967
Chinle District No. 11	1,041	156	956	1,041
Shiprock District No. 12	897	84	1,075	827
Fort Defiance District No. 17	100	15	370	141
Fort Defiance District No. 18	248	23	329	145
TOTAL	10,812	1,404	14,257	9,844

TOTAL AGRICULTURAL CONSUMPTIVE USE

The total agricultural consumptive use, displayed in table 5, is the sum of the individual components discussed in the previous sections. Agricultural water consumption represents approximately 4 percent of the total use in the study area. Total degree of uncertainty was computed by taking the square root of the sum of the individual uncertainties squared; known as the quadratic sum. This method and nomenclature is used throughout this report. This method was used because a simple sum does not account for the partial cancellation of errors occurring when calculating the total uncertainty derived from individual values that are random and independent of each other. As previously discussed, the individual uncertainties were set as a percent of the consumptive use value.

Table 5.—Total agricultural consumptive use, 2006

CATEGORY	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Irrigation	572	229
Stock Ponds	780	234
Livestock	218	65
TOTAL	1,571	334

MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

Municipal and industrial consumptive use is divided into three categories: mineral resources, thermal electric power, and other. Mineral resources consumptive use includes water used for mineral production. No mineral resources consumptive use is reported in the study area. Thermal electric power consumptive use includes the water used at the power plants, and that used to transport material to the power plant (such as a coal slurry pipeline). Other consumptive use includes urban, rural, and industrial uses.

THERMAL ELECTRIC POWER

Thermal electric power consumptive use includes the water used in the power plant and the water used to transport material to the plant.

Navajo Generating Station

The water used by the NGS is pumped directly from Lake Powell and comprises over half of the total consumption in the study area. Since all NGS water use is metered, this quantity is among those most precisely known, with the maximum uncertainty in the metered quantities believed to be less than 3 percent. The actual quantity consumed, along with the estimated uncertainty for the calendar year 2006, was 26,660 (±800) acre-feet.

OTHER

The other consumptive use category includes the remaining use by urban, rural, and industries.

Page, AZ and Vicinity

City of Page, AZ. – The city of Page pumps its domestic water directly from Lake Powell. The water pumped is metered, and the uncertainty of the pumped quantities was assumed to be less than 3 percent. A portion of the water pumped and treated by the City

of Page, is supplied to the community of Le Chee on the Navajo Nation and is accounted for separately. The quantity supplied to the City of Page and its associated uncertainty for the calendar year 2006 was 2,262 (±68) acre-feet. Water returning to the waste water treatment plant is metered as well. The waste water for the City of Page is treated and is either evaporated from lined ponds or applied to the golf course, with a portion being returned to the Colorado River. The return flow is estimated to be 624 acre-feet. The net consumptive use is estimated to be 1,638 acre-feet (±70).

Le Chee – The community of Le Chee is supplied and metered by the City of Page. Total water supplied for 2006 was 97 (±3) acre-feet. The uncertainty was estimated to be 3 percent.

Greenhaven Water Company – The Greenhaven Water Company derives its domestic water supply from wells. Well pumping records are available. According to these records, the total water pumped for 2006 was 121 (±8) acre-feet. The uncertainty was estimated to be 7 percent.

Arizona Department of Transportation Housing – The Arizona Department of Transportation operates a housing, maintenance, and administrative facility located on US Hwy 89, north of Page, AZ. This facility is supplied from wells that have no meters installed. It is estimated that the total water pumped for 2006 was 12 acre-feet with an uncertainty of 30 percent of this value or ±4 acre-feet.

Navajo Nation

Community Water Systems – Statistics from the Division of Community Development of the Navajo Nation reveal that various community water systems served 26,086, or about 83 percent of the 31,429 people residing within the study area in 1980. This percentage was used for 2006 resulting in 34,115 out of 41,102 people being served. These systems include those operated by the Navajo Tribal Utility Authority (NTUA), the BIA, and the Water Operations and Maintenance Department of the Navajo Nation, and some privately developed community water systems.

Table 6 shows the source of water and estimated population served by each source of water for people living on the Navajo Nation during 2006. All of the communities obtain their water supply from ground water.

Table 6.—Domestic water sources, 2006

SOURCE	PERCENTAGE OF POPULATION SERVED	NUMBER OF POPULATION SERVED[1]
Community Water Systems	83	34,115
NTUA	[2](60)	20,469
BIA	[2](25)	8,529
Navajo WOM	[2](13)	4,435
Private	[2](2)	682
Individual Wells	17	6,987
TOTAL[2]	100	41,102

[1] Estimated total population within the Upper Colorado River Basin portion of the Navajo Nation provided by Larry Rodgers, Demographer for the Division of Community Development of the Navajo Nation, letter DCDA-L94052, June 20, 1995.
[2] These numbers are a percentage of the Community Water Systems.

NTUA Water Systems – The cities and surrounding communities of Oak Springs, Red Valley, Sweetwater, Chinle , Rough Rock, Round Rock, Rock Point, Wheatfields, Lukachukai, Kayenta, Chilchinbeto, Dennehotso, and Kaibeto derive most of their domestic water supply from wells operated by NTUA. Well pumping records are available. According to these records, the total water pumped for 2006 was 1,619 acre-feet with an uncertainty estimated to be 7 percent of this value or ±113 acre-feet.

The NTUA manages the raw waste water; portions of which flow to individual septic tanks, some to evaporation ponds, and some, such as for the cities of Chinle and Kayenta, flow to waste water treatment plants. Very little water, if any, is returned to the ground water system through leakage from the evaporation ponds, but there are losses from the main collection system. Effluent from the Chinle and Kayenta waste water treatment plants is metered. Under normal conditions, the effluent returns to the Colorado River System and is subtracted from the pumping totals to determine a net consumptive use. For 2006, Chinle's treatment plant effluent was 379 (±27) acre-feet, and Kayenta's effluent was 267 (±19) acre-feet. An estimated uncertainty of 7 percent was used for the effluent of these two plants. The total effluent of 645 acre-feet is subtracted from the NTUA pumping total of 1,619 acre-feet to arrive at a net consumptive use of 974 (±122) acre-feet.

BIA Water Systems – Wells developed and operated by the BIA serve numerous Navajo communities. These systems also serve BIA schools, hospitals, agency offices, and some housing on the Navajo Nation. Metered records for total amounts of water pumped from BIA wells were available for a portion of the Shiprock Agency, the Western Navajo Agency, and the Chinle Agency. Drawing 1246-406-2 shows the agency boundaries within the Upper Colorado River Basin. The uncertainty was estimated to be about 7 percent for all three agencies.

The BIA systems include sewage disposal units terminating in lined evaporation ponds with very little or no return water returning to the ground water system. Undoubtedly, some losses occur in distribution, but insufficient data currently exist to estimate these losses. The losses are probably less than the uncertainties for each of the reported values.

The BIA well data available for the Shiprock Agency include: Cove, Red Rock, and Teec Nos Pos. Total consumptive use values are 11 (±1) acre-feet.

Pumping records for the Western Navajo Agency include data for the following schools: Chilchinbeto Day School, Dennehotso Boarding School, Kaibeto Boarding School, and Kayenta Boarding School. Total consumptive use for the Western Navajo Agency was 171 (±12) acre-feet.

Well pumping records for the Chinle Agency include data for the following schools: Cottonwood Day School, Lukachukai School, and Rock Point School. Rough Rock School maintains its own records, but the data was included with the Chinle Agency data. Total consumptive use for the Chinle Agency was 69 (±5) acre-feet.

Navajo WOM Water Systems – Water use in 2006 by the Navajo WOM service areas was based on an assumed consumption rate of 110 gallons per capita per day (gpcd). For a 2006 estimated service area population of 4,435, the estimated annual water use was 546 (±164) acre-feet. The uncertainty is estimated as 30 percent of the total.

Private Water Systems – The estimated 2006 population served by private water systems on the Navajo Nation was 682. Assuming a consumptive use rate of 110 gcpd, the annual water use for 2006 was 84 (±25) acre-feet. The uncertainty is estimated as 30 percent of the total.

Individual Wells – According to census data from the Division of Community Development of the Navajo Nation, approximately 17 percent of the study area's population on the reservation (about 6,987 persons in 2006) receives a domestic water supply from individual wells. A consumptive use of 110 gpcd was derived as being a reasonable water use rate. Based on these figures, the annual consumptive use was 861 (±258) acre-feet for 2006.

TOTAL MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

The total municipal and industrial consumptive use, displayed in table 7, is the sum of the individual components discussed in the previous sections. Municipal and industrial water consumption represents approximately 85 percent of the total use in the study area.

Table 7.—Total municipal and industrial consumptive use, 2006

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
THERMAL ELECTRIC POWER		
Navajo Generating Station	26,660	800
OTHER		
Page, AZ and Vicinity		
City of Page	1,638	70
Le Chee	97	3
Greenhaven Water Company	121	8
Arizona Department of Transportation	12	4
Navajo Indian Reservation		
Community Water Systems		
NTUA Water Systems	974	122
BIA Water Systems	261	13
Navajo WOM	546	164
Private Water Systems	84	25
Individual Wells	861	258
TOTAL	31,244	868

It is questionable whether all the water pumped from wells should be considered a depletion to the Colorado River System; however, it is assumed that 100 percent of the water pumped is considered lost to the system. It is proposed that a future joint study be completed by Reclamation, the State of Arizona, and the Navajo Nation to estimate what percentage of water pumped could actually be attributed to the Colorado River System and would have affected the river flows for a particular year.

RECREATION, FISH AND WILDLIFE

The recreation, fish and wildlife consumptive uses include evaporation from reservoirs used exclusively for fish & wildlife purposes as well as acreages irrigated for wildlife feeding. Consumptive use related to recreation at National parks is also addressed.

GLEN CANYON NATIONAL RECREATION AREA

Colorado River water is used by the Glen Canyon National Recreation Area (GCNRA) at Wahweap and Lees Ferry. The recreational area at Wahweap gets its water supply from a series of wells on the shore of Lake Powell. Pumping records for both Wahweap Marina, and Lees Ferry show 338 ($\pm$10) acre-feet of water withdrawn during 2006. The uncertainty is estimated at 3 percent. This water was used for domestic purposes at the

campgrounds, picnic areas, and trailer parks. It was also used to irrigate approximately 60 acres of Bermuda grass and cottonwood trees. The domestic waste water is treated and the effluent is allowed to evaporate from two lined evaporation ponds with a total surface area of 16.7 acres.

Based on estimates of evaporation and consumptive use by the plants, there is some water which is unaccounted for and is assumed to be leakage from the delivery system, the evaporation pond, or deep percolation from irrigation application. However, since these water losses are difficult to quantify and verify, the losses were charged as consumptive uses. Therefore, net consumptive use of water is estimated to be equal to the quantity of water pumped.

RESERVOIR EVAPORATION

A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 8.

Table 8. —Recreation, fish and wildlife reservoir evaporation, 2006

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE AREA USED (ACRES)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Tsaile	260	260	35	7.73	27.27	591
Wheatfields	272	272	32	7.73	24.27	550
TOTAL	532	532	—	—	—	1,141

Efforts are made to maintain a nearly full condition and to minimize water surface fluctuations in reservoirs managed for a fishery. Under average operating conditions, the water surface area of a reservoir used primarily for fishing is assumed to be equal to a normal water surface area. It is assumed that, in 2006, these reservoirs filled in the spring and were maintained at the normal pool level.

This method of evaporation estimation was used because continuous useful water level records for all reservoirs from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs.

For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for reservoir evaporation for calendar year 2006 are shown in table 8. The total evaporative losses in 2006 are 1,141 ($\pm$342) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent.

TOTAL RECREATION, FISH AND WILDLIFE

The total recreation, fish and wildlife consumptive use, displayed in table 9, is the sum of the individual components discussed in the previous sections. Recreation, fish and wildlife water consumption represents approximately 4 percent of the total use in the study area.

Table 9.—Total recreation, fish and wildlife consumptive use, 2006

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Glen Canyon National Recreation Area	338	10
Reservoir Evaporation	1,141	342
TOTAL	1,479	342

RESERVOIR EVAPORATION

Reservoir evaporation losses make up about 7 percent of the total water uses and losses in the study area. A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled “1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River” and are shown in table 10. These reservoirs are used primarily for irrigation.

Table 10.—Reservoir evaporation, 2006

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE ACRES USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Many Farms	1,800	554	81%	56	7.73	48.27	2230
Marsh Pass	40	19	97%	40	10.90	29.10	47
Round Rock	83	31	74%	57	6.56	50.45	130
Walker Creek	30	10	67%	59	5.38	53.62	45
Others	38	16	85%	55	8.57	46.43	62
TOTAL	1,991	631	—	—	—	—	2,514

Reservoirs used primarily for irrigation experience large fluctuations in water levels and, correspondingly, large variations in surface area. Reservoir level records and elevation – area curves were available at Many Farms, but not for the remaining reservoirs in table 10. For the reservoirs with no records from which surface area could be accurately computed, the average evaporative surface area was estimated as one-half the water

surface area of a full reservoir. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average evaporative surface area.

Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses. The computed values for reservoir evaporation for 2007 are shown in table 10. The total evaporative losses in 2006 are 2,514 (±754) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent of the total evaporation.

CONCLUSIONS

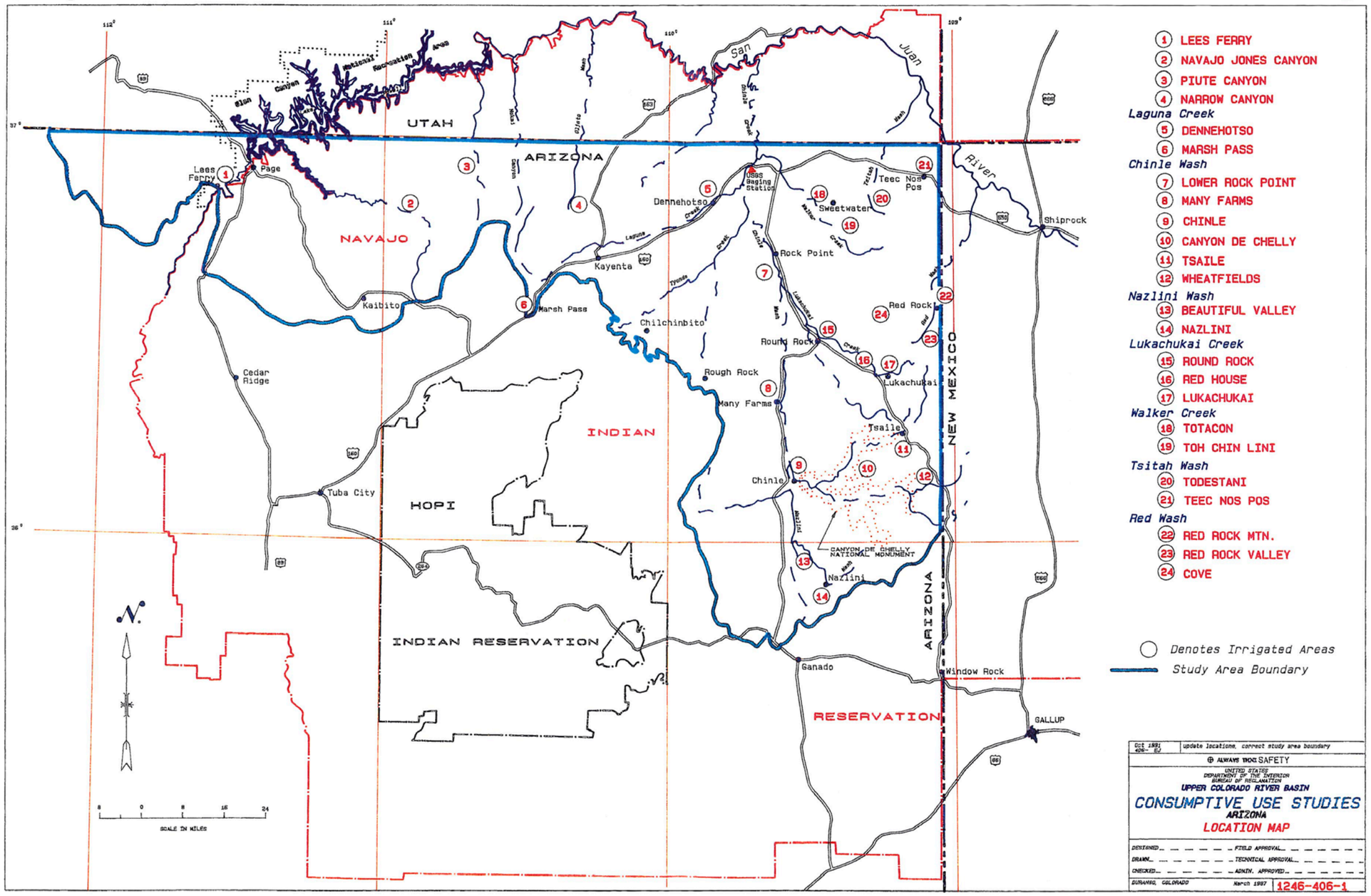
This report assesses the total consumptive use of the Arizona portion of the Upper Colorado River System surface water systems, depletion of ground water, and evaporative losses. Clearly, the amounts of water used by the Navajo Generating Station, City of Page, and Wahweap and Lees Ferry recreation areas are direct depletions of water from the Upper Colorado River System, but the situation is not as clear for other consumptive uses and losses occurring in other sections of the study area. For example, the source of water used by the Navajo Nation for domestic and municipal purposes is from wells, some exceeding 1,000 feet in depth. For our purposes here, it is considered to be consumed and a depletion to the Colorado River System. But this may not actually result in a reduction of Colorado River stream flows in the same year that the withdrawal occurs. Little knowledge and information exists of ground water movement and subsurface flow rates in the study area that are accurate descriptions of the effects on river flows.

Although the water diverted for agricultural purposes is considered as consumptive use in this report, a portion of the remaining surface water on the Navajo Nation, excess to needs, does evaporate before reaching the Colorado River. No attempt has been made for this report to quantify these losses.

Uncertainties in estimating uses and losses exist, and the degree of variation in the figures is presented. Fortunately, the areas with the highest degree of uncertainty account for only a small percentage of the total consumptive use. The largest component, use by the Navajo Generating Station, is also the most accurately monitored. The total annual value for estimated consumptive use of water within the Arizona portion of the Upper Colorado River Basin for 2006 was 36,808 acre-feet, as shown in table 11.

Table 11.—Consumptive use for Arizona portion of Upper Colorado River Basin for 2006

USE CATEGORY	TOTAL CONSUMPTIVE USE (ACRE-FEET)	UNCERTAINTY	PERCENT OF TOTAL
Agriculture	1,571	334	4
Municipal & Industrial	31,244	868	85
Recreation, Fish & Wildlife	1,479	342	4
Reservoir Evaporation	2,514	754	7
TOTAL	36,808	1,246	100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ARIZONA
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INDIAN
HOPI
INDIAN RESERVATION
RESERVATION
NEW MEXICO
ARIZONA
Lees Ferry
Page
Kaibito
Cedar Ridge
Tuba City
Marsh Pass
Kayenta
Dennehotso
Chilchinbito
Rough Rock
Many Farms
Chinle
Rock Point
Round Rock
Sweetwater
Tsaile
Lukachukai
Red Rock
Teec Nos Pos
Shiprock
Nazlini
Ganado
Window Rock
GALLUP
CANYON DE CHELLY NATIONAL MONUMENT
SCALE IN MILES
1 LEES FERRY
2 NAVAJO JONES CANYON
3 PIUTE CANYON
4 NARROW CANYON
Laguna Creek
5 DENNEHOTSO
6 MARSH PASS
Chinle Wash
7 LOWER ROCK POINT
8 MANY FARMS
9 CHINLE
10 CANYON DE CHELLY
11 TSAILE
12 WHEATFIELDS
Nazlini Wash
13 BEAUTIFUL VALLEY
14 NAZLINI
Lukachukai Creek
15 ROUND ROCK
16 RED HOUSE
17 LUKACHUKAI
Walker Creek
18 TOTACON
19 TOH CHIN LINI
Tsitah Wash
20 TODESTANI
21 TEEC NOS POS
Red Wash
22 RED ROCK MTN.
23 RED ROCK VALLEY
24 COVE
Denotes Irrigated Areas
Study Area Boundary
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BUREAU OF RECLAMATION
UPPER COLORADO RIVER BASIN
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ARIZONA
LOCATION MAP
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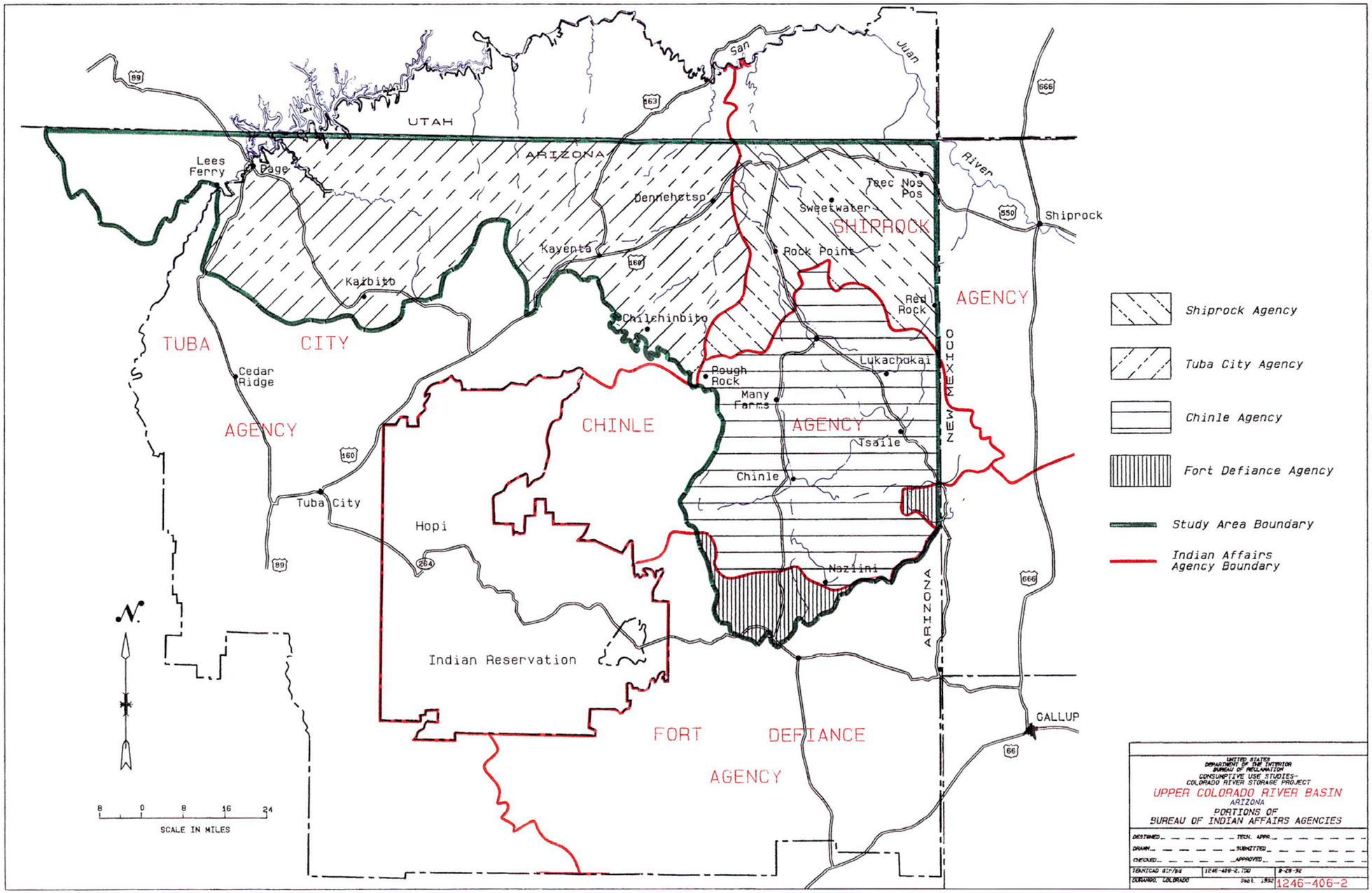
1246-406-1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Teec Nos Pos
Sweetwater
Rock Point
Red Rock
Lukachukai
Rough Rock
Many Farms
Tsaile
Chinle
Nazlini
Shiprock
San Juan River
TUBA CITY AGENCY
Cedar Ridge
Tuba City
CHINLE AGENCY
SHIPROCK AGENCY
Hopi
Indian Reservation
FORT DEFIANCE AGENCY
GALLUP
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8 0 8 16 24
SCALE IN MILES
Shiprock Agency
Tuba City Agency
Chinle Agency
Fort Defiance Agency
Study Area Boundary
Indian Affairs Agency Boundary
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CONSUMPTIVE USE STUDIES-
COLORADO RIVER STORAGE PROJECT
UPPER COLORADO RIVER BASIN
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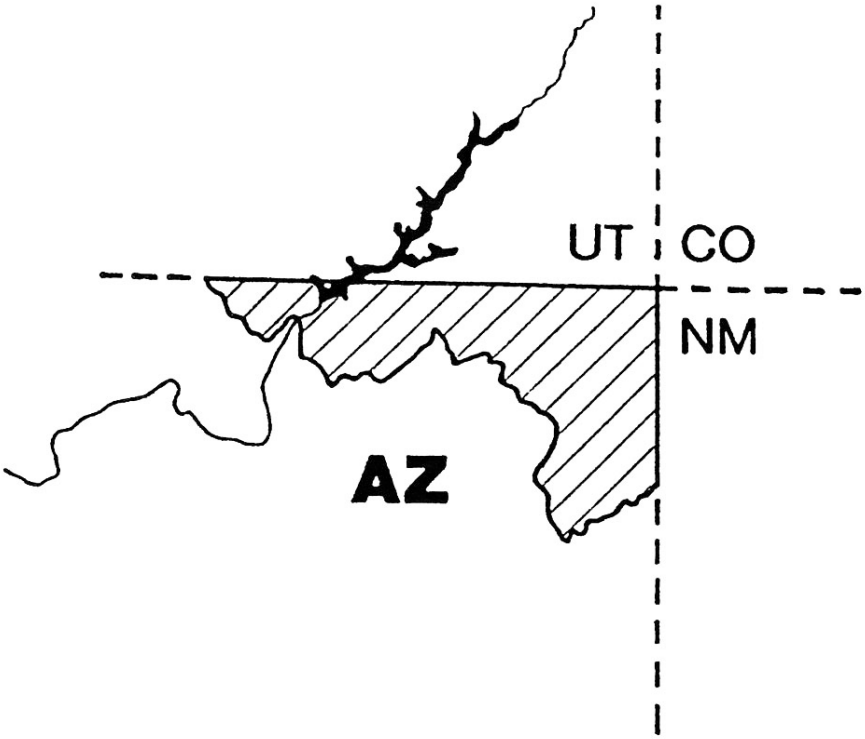
RECLAMATION

Managing Water in the West

Consumptive Uses and Losses: Final Estimate

Arizona Portion of the Upper Colorado River Basin Calendar Year 2007



U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

September 2014

RECLAMATION

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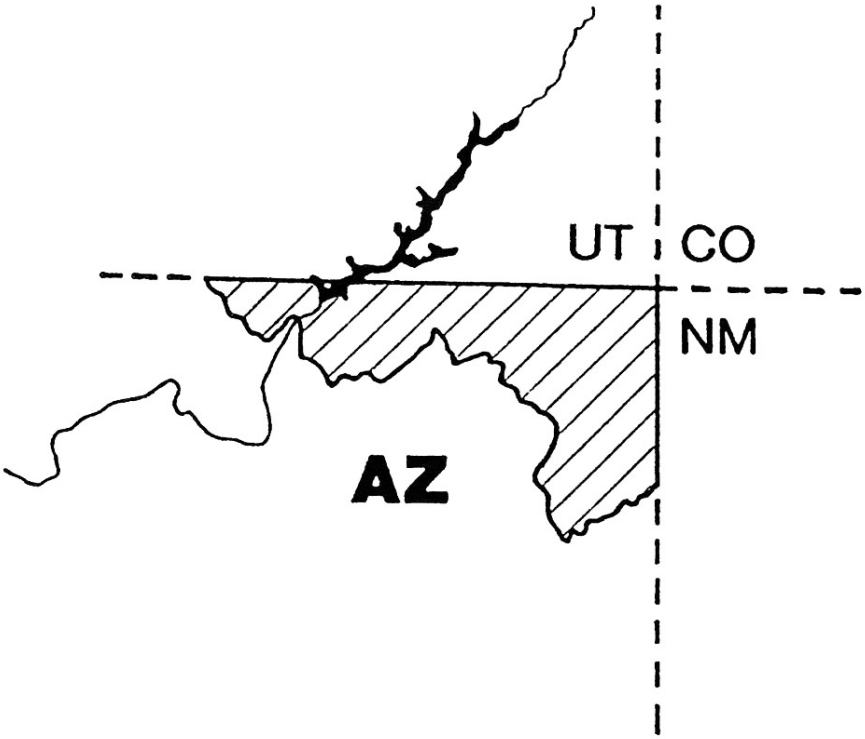

Prepared by: Alan Harrison – September 23, 2014

U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

September 2014

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ARIZONA PORTION
OF THE
UPPER COLORADO RIVER BASIN

CALENDAR YEAR
2007

AUTHORITY

This report was prepared in compliance with Public Law 90-537, Section 601 (b)(1), dated September 30, 1968, which directs the Secretary of the Interior to "make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis." Additionally, this report is in compliance with Section 49 of the Navajo Project Participation Agreement dated September 30, 1969, which states in part: "The Secretary of the Interior further agrees to make the reports required by Section 601 (b)(1) of Public Law 90-537 as they pertain to Arizona's Upper Basin uses annually rather than every five years. Within fifteen days following the completion of said reports, the Secretary of the Interior shall furnish copies of such reports to the Co-Tenants, the Navajo Tribe, each of the Upper Basin States, and the Upper Colorado River Commission."

SUMMARY

Based upon data made available for preparation of this document. the total consumptive use and loss value for the Arizona portion of the Upper Colorado River Basin for calendar year 2007 was 36,709 (±1,290) acre-feet. Reclamation prepares this estimate annually, final annual values for consumptive uses and losses for the northern Arizona portion of the Colorado River basin are published in the 5-year summary documents for the Upper Colorado River Basin

STUDY AREA DESCRIPTION

The Arizona portion of the Upper Colorado River Basin covers approximately 6,900 square miles in the north-east corner of Arizona, as shown on the location maps shown on pages 19 and 20 (Drawings 1246-406-1, 1246-406-2). The climate of the 5,900 square mile area to the west of the Chuska and Carrizo Mountains is largely arid to semiarid, with mean annual precipitation ranging from 6 to 12 inches and with summertime temperatures often reaching 100 degrees Fahrenheit (^{o}F). The potential

evaporation rate is high and exceeds mean annual precipitation, with gross lake evaporation values of up to 55 inches per year or more. Elevations in the western portion range from 3200 feet on the Colorado River at Lees Ferry to over 8000 feet on the northern edge of the Black Mesa and across the Zilnez and Skeleton Mesas, back down to 5280 feet in the Chinle Valley, and back up to about 6500 feet on the western edge of the Chuska Mountains. Much of the western part of the study area is starkly beautiful southwestern desert country with mesas and canyons intertwined across a pastoral landscape. By contrast, the eastern 1,000 square miles is largely mountainous, with elevations rising to nearly 10,000 feet and mean annual precipitation reaching 30 inches. The mountainous land responds with grass meadows interspersed with conifer forest of mostly ponderosa pine.

Except for Page, Arizona; a small area around Lees Ferry; and a portion of the Paria Plateau administered by the Bureau of Land Management; the study area lies entirely within the Navajo Nation. Based on straight-line interpolation of 2000 and 2010 census data for the area, it is estimated that approximately 47,947 persons were living within the study area in 2007, and of these an estimated 40,831 resided on the Navajo Nation.

The largest cities are Page and Chinle, with 2000 populations of 6,809 and 5,366, respectively. Other major communities and their populations include Dennehotso (734), Kaibeto (1,607), Kayenta (4,922), LeChee (1,606), Lukachukai (1,565), Many Farms (1,548), Rock Point (724), Teec Nos Pos (799), and Tsaile (1,078). Subsistence in the region is derived principally from livestock grazing, farming, tourist-related industries, employment at the Navajo Generating Station (NGS), which consumed 75 percent of the water used or lost in the study area. Agriculture accounted for 6 percent of the total water use; municipal and industrial about 84 percent; recreation, fish and wildlife, about 4 percent; and reservoir evaporation, 7 percent.

AGRICULTURAL CONSUMPTIVE USE

Agricultural consumptive use is divided into three categories: irrigation, stock pond, and livestock. Irrigation use includes all use related to irrigating crops including the incidental losses. Stock pond use is the evaporation that occurs from stock ponds and livestock use is the water consumed by livestock.

IRRIGATION USES

Within the Arizona portion of the Upper Colorado River Basin, historically 23 irrigated areas were scattered across the Navajo Nation plus a small amount of land near Lees Ferry irrigated by the National Park Service. Currently, only 16 irrigated areas are in production. An accurate assessment of consumptive use on the irrigated land is difficult due to poor quality of information, such as the exact number of acres under irrigation, the cropping pattern for each irrigated area, site climatological conditions, and the amount s of water actually diverted. In many cases, during the latter part of the irrigation season, farmers have to rely on dry land farming since there is little water available in the streams. This means that the crops do not receive their full water requirement.

For this report, the U.S. Department of Agriculture, Soil Conservation Service's (SCS) Modified Blaney-Criddle ET estimation model was used for computing irrigated crop consumptive use. This model, along with appropriate crop-growth stage coefficients and the method for computing effective precipitation, is described in SCS's *Irrigation Water Requirements Technical Release No. 21* (TR 21). Information required for applying this model includes mean monthly temperature and precipitation values, growing season data for each crop type, and the total number of acres planted by crop at each site. With the exception of Teec Nos Pos, Canyon de Chelly, Lukachukai, and Lees Ferry, no climatological data exist for the irrigation sites, and site values must be generated from data collected at surrounding established weather stations. Growing season dates depend largely on the judgment of the local inhabitants and are, therefore, not known. Although several reports are available with published values for irrigated acres, it is unclear if these values are meant to represent potential irrigated acres, acres irrigated in the past, acres for which farming permits have been issued, or actual acres currently under irrigation.

The crop acreage used to estimate consumptive use by irrigated crops for the year 2007 is shown in table 1. These values were determined from direct field examination by a party composed of representatives from the State of Arizona and the Navajo Nation.

Table 1.—Total irrigated acreage, 2007

PROJECT	CORN (ACRES)	ALFALFA (ACRES)	GRASS PASTURE (ACRES)	SPRING GRAINS (ACRES)	SMALL VEGETABLES (ACRES)	ORCHARD (ACRES)	TOTAL (ACRES)
CHINLE AGENCY							
Canyon de Chelly	0.36	0.00	0.00	3.03	2.26	0.00	5.65
Lukachukai	39.09	7.69	0.00	7.50	5.98	2.07	62.33
Many Farms	98.30	16.40	60.70	1.60	16.40	0.00	193.40
Nazlini	0.00	0.00	0.00	0.00	1.79	0.74	2.53
Rough Rock	30.00	0.00	11.87	0.00	12.43	0.00	54.30
Tsaile	23.72	5.27	15.67	5.73	5.42	0.00	55.81
Wheatfields	0.00	60.80	0.00	0.00	0.00	0.00	60.80
TOTAL	191.47	90.16	88.24	17.86	44.28	2.81	434.82
SHIPROCK AGENCY							
Red Rock Valley	26.22	0.00	10.19	5.12	10.22	0.00	51.75
Teec Nos Pos	20.00	0.00	0.00	0.00	3.67	0.00	23.67
Toh Chin Lini	0.00	0.00	0.00	0.00	3.90	13.67	17.57
Totacon	0.00	0.00	0.00	0.00	1.00	0.00	1.00
TOTAL	46.22	0.00	10.19	5.12	18.79	13.67	93.99
WESTERN NAVAJO AGENCY							
Dennehotso	1.82	0.00	38.70	0.00	0.00	0.00	40.52
Lees Ferry	0.00	0.00	1.00	0.00	0.00	2.00	3.00
Marsh Pass	7.02	3.31	0.00	0.00	1.99	0.00	12.32
Navajo Canyon	0.00	0.00	0.00	0.00	0.00	3.50	3.50
Paiute Canyon	2.64	0.00	0.00	0.00	3.86	0.00	6.50
TOTAL	11.48	3.31	39.70	0.00	5.85	5.50	65.84
GRAND TOTAL	249.17	93.47	138.13	22.98	68.92	21.98	594.65

Several factors complicated the modeling of irrigation consumptive use. For example, the computer program used to model consumptive use assumes a full water supply; if shortages exist, as they often do in this semiarid study area, adjustments must be made. These adjustments are complicated because some of the projects have no storage water and may only have a reliable irrigation water supply during spring runoff. After spring runoff, farming becomes essentially dry land until rains in July and August provide intermittent flows for irrigation. Finally, no ditch diversion records are available to help estimate irrigation water supplies and shortages.

A full irrigation supply seldom exists at many of the projects. Generally, a full supply is available for Lees Ferry, Navajo Canyon, Tsaile, and Wheatfields projects because of adequate stream flows or because of available storage water. In years with average precipitation, it is estimated that Chinle Wash provides approximately 75 percent of the irrigation requirement. Precipitation in the area averages approximately 9.5 inches per year. Based on this information, it would require approximately 12.67 inches of precipitation to provide 100 percent of the irrigation requirement. The percent of crop water requirement met was computed as a ratio of annual precipitation to 12.67 inches. These values are found in table 2.

The percentage of crop water requirement met was multiplied by the total net crop water requirement to come up with the amount of crop consumptive use. Incidental irrigation losses, evaporation, and phreatophyte consumptive use along supply canals are estimated to be 5 percent of the consumptive use of the irrigated area and are added to the crop consumptive use value to develop a total consumptive use value.

A portion of the water used for irrigation at these sites may not be contributing to the Colorado River System since evaporation rates in the area are high and the nature of most of the drainage enhances evapotranspiration. A good example of such a drainage is Chinle Wash, which after it leaves Canyon de Chelly, becomes wide and sandy and is lined with willows, cottonwoods, and other phreatophytes.

The uncertainties in the irrigation consumptive use values displayed in table 2 are very large and are estimated as 40 percent of the total consumptive use. This estimate of possible error only reflects the uncertainty of consumptive use and does not account for any possible errors in the acreage estimates. The effective consumptive use for irrigation for 2007 was estimated to equal 913 acre-feet. Including the 5 percent for incidental losses, the irrigation related consumptive use is 958 ($\pm$383) acre-feet.

Table 2.—Net consumptive use values, 2007

PROJECT	CROP WATER REQUIREMENT (INCHES)	TOTAL IRRIGATED (ACRES)	TOTAL WATER REQUIRED (ACRE-FEET)	CROP WATER REQUIREMENT MET (%)	CROP WATER REQUIREMENT MET (ACRE-FEET)	TOTAL CONSUMPTIVE USE (ACRE-FEET)[1]
CHINLE AGENCY						
Canyon de Chelly	27.93	5.65	13	74%	10	10.3
Lukachukai	21.74	62.33	113	74%	84	88.3
Many Farms	27.73	193.40	447	74%	333	349.3
Nazlini	19.85	2.53	4	74%	3	3.3
Rough Rock	24.21	54.30	110	72%	78	82.3
Tsaile	22.27	55.81	104	74%	77	81.0
Wheatfields	29.61	60.80	150	74%	112	117.3
TOTAL	173.34	434.82	940	—	697	731.7
SHIPROCK AGENCY						
Red Rock Valley	26.36	51.75	114	63%	71	74.9
Teec Nos Pos	31.88	23.67	63	51%	32	33.7
Toh Chin Lini	40.37	17.57	59	31%	18	19.1
Totacon	27.41	1.00	2	31%	1	0.7
TOTAL	126.03	93.99	238	—	122	128.5
WESTERN NAVAJO AGENCY						
Dennehotso	38.14	40.52	129	42%	55	57.4
Lees Ferry	45.27	3.00	11	100%	11	11.9
Marsh Pass	24.94	12.32	26	54%	14	14.5
Navajo Canyon	41.22	3.50	12	64%	8	8.1
Paiute Canyon	27.15	6.50	15	40%	6	6.1
TOTAL	176.72	65.84	192	—	93	98.1
GRAND TOTAL	476.09	594.65	1371	—	913	958.2

[1] Total includes 5% addition for incidental losses.

STOCK POND EVAPORATION

Stock pond consumptive use is assumed to be the evaporation from the stock pond. It is also assumed that any consumptive use by natural vegetation prior to the construction of the stock ponds is limited to precipitation which is subtracted from the evaporation losses.

A compilation of the stock ponds in the study area, including their locations and the water surface areas when ponds are full, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 3. For an average year conditions, the stock pond evaporative surface area was estimated as one-third the water surface area that occurs when the ponds are full. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average water surface area. These values are found in table 3.

Table 3.—Stock pond evaporation, 2007

COUNTY	SURFACE AREA FULL (ACRES)	SURFACE AREA USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Coconino	80	22	81%	57	5.49	51.51	93
Navajo	40	11	84%	55	8.15	46.86	44
Apache	646	194	90%	53	7.95	45.05	730
TOTAL	766	227	—	—	—	—	867

This method of evaporation estimation was used because continuous useful water level records for all stock ponds from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual stock ponds. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation. It was assumed that any consumptive use by natural vegetation prior to construction of the stock ponds is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for stock pond evaporation for calendar year 2007 are shown in table 3. The total evaporative losses in 2007 are 867 ($\pm$260) acre-feet with the stock pond evaporation uncertainty being estimated as 30 percent.

LIVESTOCK WATER

The source of most livestock water in the study area is from wells, with windmill-operated pumps developed and maintained by Navajo Water Operations and Maintenance, and water collected in small surface ponds. The estimated number of

livestock in the area was obtained based on livestock tallies. It was estimated that horses and cattle consume 12 gallons per day; sheep and goats consume 2 gallons per day.

The number of animals for the Upper Colorado portion of each district is shown in table 4. The computed value for livestock consumptive use is 245 acre-feet. The uncertainty in this number is estimated as 30 percent of the total or ±74 acre-feet.

Table 4.—Number of livestock, 2007

AGENCY	CATTLE	HORSES	SHEEP	GOATS
Western Navajo District No. 1	1,487	510	2,256	1,289
Western Navajo District No. 2	858	165	1,271	975
Western Navajo District No. 8	2,362	401	4,003	2,455
Shiprock District No. 9	1,513	419	2,099	2,317
Chinle District No. 10	1,625	464	2,574	1,324
Chinle District No. 11	688	181	722	544
Shiprock District No. 12	1,252	239	1,919	1,005
Fort Defiance District No. 17	407	162	1,598	497
Fort Defiance District No. 18	664	171	1,020	259
TOTAL	10,856	2,712	17,462	10,665

TOTAL AGRICULTURAL CONSUMPTIVE USE

The total agricultural consumptive use, displayed in table 5, is the sum of the individual components discussed in the previous sections. Agricultural water consumption represents approximately 6 percent of the total use in the study area. Total degree of uncertainty was computed by taking the square root of the sum of the individual uncertainties squared; known as the quadratic sum. This method and nomenclature is used throughout this report. This method was used because a simple sum does not account for the partial cancellation of errors occurring when calculating the total uncertainty derived from individual values that are random and independent of each other. As previously discussed, the individual uncertainties were set as a percent of the consumptive use value.

Table 5.—Total agricultural consumptive use, 2007

CATEGORY	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Irrigation	958	383
Stock Ponds	867	260
Livestock	245	74
TOTAL	2,070	469

MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

Municipal and industrial consumptive use is divided into three categories: mineral resources, thermal electric power, and other. Mineral resources consumptive use includes water used for mineral production. No mineral resources consumptive use is reported in the study area. Thermal electric power consumptive use includes the water used at the power plants, and that used to transport material to the power plant (such as a coal slurry pipeline). Other consumptive use includes urban, rural, and industrial uses.

THERMAL ELECTRIC POWER

Thermal electric power consumptive use includes the water used in the power plant and the water used to transport material to the plant.

Navajo Generating Station

The water used by the NGS is pumped directly from Lake Powell and comprises over half of the total consumption in the study area. Since all NGS water use is metered, this quantity is among those most precisely known, with the maximum uncertainty in the metered quantities believed to be less than 3 percent. The actual quantity consumed, along with the estimated uncertainty for the calendar year 2007, was 27,604 (±828) acre-feet.

OTHER

The other consumptive use category includes the remaining use by urban, rural, and industries.

Page, AZ and Vicinity

City of Page, AZ. – The city of Page pumps its domestic water directly from Lake Powell. The water pumped is metered, and the uncertainty of the pumped quantities was assumed to be less than 3 percent. A portion of the water pumped and treated by the City

of Page, is supplied to the community of Le Chee on the Navajo Nation and is accounted for separately. The quantity supplied to the City of Page and its associated uncertainty for the calendar year 2007 was 2,321 (±70) acre-feet. Water returning to the waste water treatment plant is metered as well. The waste water for the City of Page is treated and is either evaporated from lined ponds or applied to the golf course, with a portion being returned to the Colorado River. The return flow is estimated to be 1,919 acre-feet. The net consumptive use is estimated to be 402 acre-feet (±90).

Le Chee – The community of Le Chee is supplied and metered by the City of Page. Total water supplied for 2007 was 95 (±3) acre-feet. The uncertainty was estimated to be 3 percent.

Greenhaven Water Company – The Greenhaven Water Company derives its domestic water supply from wells. Well pumping records are available. According to these records, the total water pumped for 2007 was 121 (±8) acre-feet. The uncertainty was estimated to be 7 percent.

Arizona Department of Transportation Housing – The Arizona Department of Transportation operates a housing, maintenance, and administrative facility located on US Hwy 89, north of Page, AZ. This facility is supplied from wells that have no meters installed. It is estimated that the total water pumped for 2007 was 9 acre-feet with an uncertainty of 30 percent of this value or ±3 acre-feet.

Navajo Nation

Community Water Systems – Statistics from the Division of Community Development of the Navajo Nation reveal that various community water systems served 26,086, or about 83 percent of the 31,429 people residing within the study area in 1980. This percentage was used for 2007 resulting in 33,890 out of 40,831 people being served. These systems include those operated by the Navajo Tribal Utility Authority (NTUA), the BIA, and the Water Operations and Maintenance Department of the Navajo Nation, and some privately developed community water systems.

Table 6 shows the source of water and estimated population served by each source of water for people living on the Navajo Nation during 2007. All of the communities obtain their water supply from ground water.

Table 6.—Domestic water sources, 2007

SOURCE	PERCENTAGE OF POPULATION SERVED	NUMBER OF POPULATION SERVED[1]
Community Water Systems	83	33,890
NTUA	[2](60)	20,334
BIA	[2](25)	8,472
Navajo WOM	[2](13)	4,406
Private	[2](2)	678
Individual Wells	17	6,941
TOTAL[2]	100	40,831

[1] Estimated total population within the Upper Colorado River Basin portion of the Navajo Nation provided by Larry Rodgers, Demographer for the Division of Community Development of the Navajo Nation, letter DCDA-L94052, June 20, 1995.
[2] These numbers are a percentage of the Community Water Systems.

NTUA Water Systems – The cities and surrounding communities of Oak Springs, Red Valley, Sweetwater, Chinle , Rough Rock, Round Rock, Rock Point, Wheatfields, Lukachukai, Kayenta, Chilchinbeto, Dennehotso, and Kaibeto derive most of their domestic water supply from wells operated by NTUA. Well pumping records are sometimes available from the NTUA. If the records are not available, estimates based on the previous years data are used. According to these records, the total water pumped for 2007 was 1,454 acre-feet with an uncertainty estimated to be 7 percent of this value or ±102 acre-feet.

The NTUA manages the raw waste water; portions of which flow to individual septic tanks, some to evaporation ponds, and some, such as for the cities of Chinle and Kayenta, flow to waste water treatment plants. Very little water, if any, is returned to the ground water system through leakage from the evaporation ponds, but there are losses from the main collection system. Effluent from the Chinle and Kayenta waste water treatment plants is metered. Under normal conditions, the effluent returns to the Colorado River System and is subtracted from the pumping totals to determine a net consumptive use. For 2007, Chinle's treatment plant effluent was 379 (±27) acre-feet, and Kayenta's effluent was 267 (±19) acre-feet. An estimated uncertainty of 7 percent was used for the effluent of these two plants. The total effluent of 645 acre-feet is subtracted from the NTUA pumping total of 1,454 acre-feet to arrive at a net consumptive use of 809 (±111) acre-feet.

BIA Water Systems – Wells developed and operated by the BIA serve numerous Navajo communities. These systems also serve BIA schools, hospitals, agency offices, and some housing on the Navajo Nation. Metered records for total amounts of water pumped from BIA wells are sometimes available for a portion of the Shiprock Agency, the Western Navajo Agency, and the Chinle Agency. If current data was not available, estimates based on the previous year data was used. Drawing 1246-406-2 shows the agency boundaries within the Upper Colorado River Basin. The uncertainty was estimated to be about 7 percent for all three agencies.

The BIA systems include sewage disposal units terminating in lined evaporation ponds with very little or no return water returning to the ground water system. Undoubtedly,

some losses occur in distribution, but insufficient data currently exist to estimate these losses. The losses are probably less than the uncertainties for each of the reported values.

The BIA well data available for the Shiprock Agency include: Cove, Red Rock, and Teec Nos Pos. Total consumptive use values are 11 (±1) acre-feet.

Pumping records for the Western Navajo Agency include data for the following schools: Chilchinbeto Day School, Dennehotso Boarding School, Kaibeto Boarding School, and Kayenta Boarding School. Total consumptive use for the Western Navajo Agency was 177 (±12) acre-feet.

Well pumping records for the Chinle Agency include data for the following schools: Cottonwood Day School, Lukachukai School, and Rock Point School. Rough Rock School maintains its own records, but the data was included with the Chinle Agency data. Total consumptive use for the Chinle Agency was 69 (±5) acre-feet.

Navajo WOM Water Systems – Water use in 2007 by the Navajo WOM service areas was based on an assumed consumption rate of 110 gallons per capita per day (gpcd). For a 2007 estimated service area population of 4,406, the estimated annual water use was 543 (±163) acre-feet. The uncertainty is estimated as 30 percent of the total.

Private Water Systems – The estimated 2007 population served by private water systems on the Navajo Nation was 678. Assuming a consumptive use rate of 110 gcpd, the annual water use for 2007 was 84 (±25) acre-feet. The uncertainty is estimated as 30 percent of the total.

Individual Wells – According to census data from the Division of Community Development of the Navajo Nation, approximately 17 percent of the study area's population on the reservation (about 6,941 persons in 2007) receives a domestic water supply from individual wells. A consumptive use of 110 gpcd was derived as being a reasonable water use rate. Based on these figures, the annual consumptive use was 855 (±257) acre-feet for 2007.

TOTAL MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

The total municipal and industrial consumptive use, displayed in table 7, is the sum of the individual components discussed in the previous sections. Municipal and industrial water consumption represents approximately 84 percent of the total use in the study area.

Table 7.—Total municipal and industrial consumptive use, 2007

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
THERMAL ELECTRIC POWER		
Navajo Generating Station	27,604	828
OTHER		
Page, AZ and Vicinity		
City of Page	402	90
Le Chee	95	3
Greenhaven Water Company	121	8
Arizona Department of Transportation	9	3
Navajo Indian Reservation		
Community Water Systems		
NTUA Water Systems	809	111
BIA Water Systems	257	13
Navajo WOM	543	163
Private Water Systems	84	25
Individual Wells	855	257
TOTAL	30,778	894

It is questionable whether all the water pumped from wells should be considered a depletion to the Colorado River System; however, it is assumed that 100 percent of the water pumped is considered lost to the system. It is proposed that a future joint study be completed by Reclamation, the State of Arizona, and the Navajo Nation to estimate what percentage of water pumped could actually be attributed to the Colorado River System and would have affected the river flows for a particular year.

RECREATION, FISH AND WILDLIFE

The recreation, fish and wildlife consumptive uses include evaporation from reservoirs used exclusively for fish & wildlife purposes as well as acreages irrigated for wildlife feeding. Consumptive use related to recreation at National parks is also addressed.

GLEN CANYON NATIONAL RECREATION AREA

Colorado River water is used by the Glen Canyon National Recreation Area (GCNRA) at Wahweap and Lees Ferry. The recreational area at Wahweap gets its water supply from a

series of wells on the shore of Lake Powell. Pumping records for both Wahweap Marina, and Lees Ferry show 338 (±10) acre-feet of water withdrawn during 2007. The uncertainty is estimated at 3 percent. This water was used for domestic purposes at the campgrounds, picnic areas, and trailer parks. It was also used to irrigate approximately 60 acres of Bermuda grass and cottonwood trees. The domestic waste water is treated and the effluent is allowed to evaporate from two lined evaporation ponds with a total surface area of 16.7 acres.

Based on estimates of evaporation and consumptive use by the plants, there is some water which is unaccounted for and is assumed to be leakage from the delivery system, the evaporation pond, or deep percolation from irrigation application. However, since these water losses are difficult to quantify and verify, the losses were charged as consumptive uses. Therefore, net consumptive use of water is estimated to be equal to the quantity of water pumped.

RESERVOIR EVAPORATION

A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 8.

Table 8. —Recreation, fish and wildlife reservoir evaporation, 2007

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE AREA USED (ACRES)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Tsaile	260	260	35	9.43	25.57	554
Wheatfields	272	272	32	9.43	22.57	512
TOTAL	532	532	—	—	—	1,066

Efforts are made to maintain a nearly full condition and to minimize water surface fluctuations in reservoirs managed for a fishery. Under average operating conditions, the water surface area of a reservoir used primarily for fishing is assumed to be equal to a normal water surface area. It is assumed that, in 2007, these reservoirs filled in the spring and were maintained at the normal pool level.

This method of evaporation estimation was used because continuous useful water level records for all reservoirs from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs.

For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for reservoir evaporation for calendar year 2007 are shown in table 8. The total evaporative losses in 2007 are 1,066 (±320) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent.

TOTAL RECREATION, FISH AND WILDLIFE

The total recreation, fish and wildlife consumptive use, displayed in table 9, is the sum of the individual components discussed in the previous sections. Recreation, fish and wildlife water consumption represents approximately 4 percent of the total use in the study area.

Table 9.—Total recreation, fish and wildlife consumptive use, 2007

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Glen Canyon National Recreation Area	338	10
Reservoir Evaporation	1066	320
TOTAL	1,404	320

RESERVOIR EVAPORATION

Reservoir evaporation losses make up about 7 percent of the total water uses and losses in the study area. A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled “1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River” and are shown in table 10. These reservoirs are used primarily for irrigation.

Table 10.—Reservoir evaporation, 2007

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE ACRES USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Many Farms	1,800	554	99%	56	9.43	46.57	2152
Marsh Pass	40	15	75%	40	8.42	31.58	39
Round Rock	83	37	90%	57	7.95	49.05	153
Walker Creek	30	12	80%	59	6.47	52.53	53
Others	38	15	81%	55	8.21	46.79	60
TOTAL	1,991	634	—	—	—	—	2,457

Reservoirs used primarily for irrigation experience large fluctuations in water levels and, correspondingly, large variations in surface area. Reservoir level records and elevation – area curves were available at Many Farms, but not for the remaining reservoirs in table 10. For the reservoirs with no records from which surface area could be accurately computed, the average evaporative surface area was estimated as one-half the water surface area of a full reservoir. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average evaporative surface area.

Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses. The computed values for reservoir evaporation for 2007 are shown in table 10. The total evaporative losses in 2007 are 2,457 ($\pm$737) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent of the total evaporation.

CONCLUSIONS

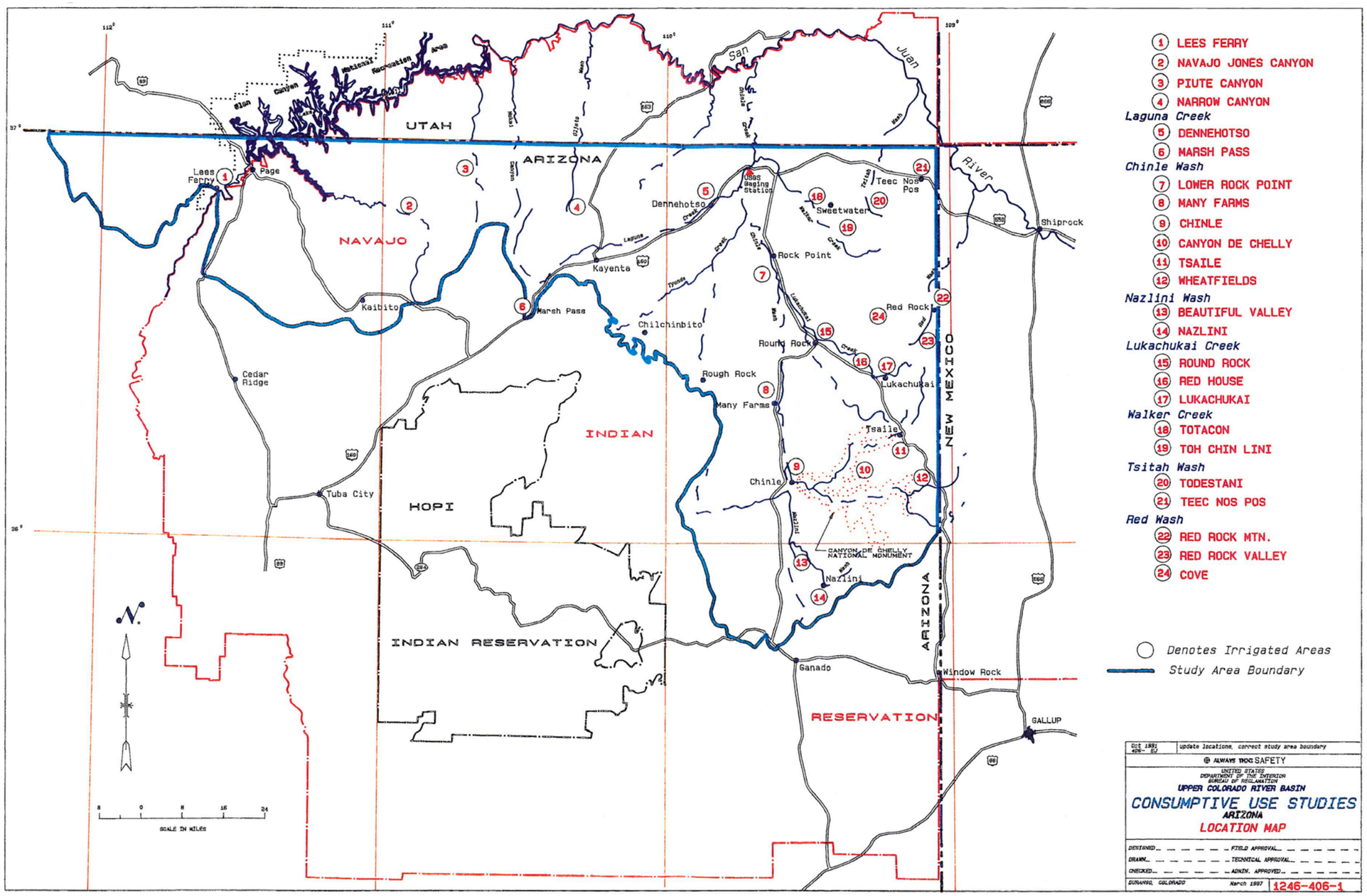
This report assesses the total consumptive use of the Arizona portion of the Upper Colorado River System surface water systems, depletion of ground water, and evaporative losses. Clearly, the amounts of water used by the Navajo Generating Station, City of Page, and Wahweap and Lees Ferry recreation areas are direct depletions of water from the Upper Colorado River System, but the situation is not as clear for other consumptive uses and losses occurring in other sections of the study area. For example, the source of water used by the Navajo Nation for domestic and municipal purposes is from wells, some exceeding 1,000 feet in depth. For our purposes here, it is considered to be consumed and a depletion to the Colorado River System. But this may not actually result in a reduction of Colorado River stream flows in the same year that the withdrawal occurs. Little knowledge and information exists of ground water movement and subsurface flow rates in the study area that are accurate descriptions of the effects on river flows.

Although the water diverted for agricultural purposes is considered as consumptive use in this report, a portion of the remaining surface water on the Navajo Nation, excess to needs, does evaporate before reaching the Colorado River. No attempt has been made for this report to quantify these losses.

Uncertainties in estimating uses and losses exist, and the degree of variation in the figures is presented. Fortunately, the areas with the highest degree of uncertainty account for only a small percentage of the total consumptive use. The largest component, use by the Navajo Generating Station, is also the most accurately monitored. The total annual value for estimated consumptive use of water within the Arizona portion of the Upper Colorado River Basin for 2007 was 36,709 acre-feet, as shown in table 11.

Table 11.—Consumptive use for Arizona portion of Upper Colorado River Basin for 2007

USE CATEGORY	TOTAL CONSUMPTIVE USE (ACRE-FEET)	UNCERTAINTY	PERCENT OF TOTAL
Agriculture	2070	469	5
Municipal & Industrial	30,778	894	84
Recreation, Fish & Wildlife	1,404	320	4
Reservoir Evaporation	2,457	737	7
TOTAL	36,709	1,290	100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NAVAJO
INDIAN
HOPI
INDIAN RESERVATION
RESERVATION
NEW MEXICO
ARIZONA
San Juan River
Lees Ferry
Page
Kaibito
Cedar Ridge
Tuba City
Marsh Pass
Kayenta
Dennehotso
USGS Gaging Station
Sweetwater
Teec Nos Pos
Rock Point
Chilchinbito
Round Rock
Rough Rock
Many Farms
Red Rock
Lukachukai
Tsaile
Chinle
Nazlini
CANYON DE CHELLY NATIONAL MONUMENT
Ganado
Window Rock
GALLUP
Shiprock
SCALE IN MILES
1 LEES FERRY
2 NAVAJO JONES CANYON
3 PIUTE CANYON
4 NARROW CANYON
Laguna Creek
5 DENNEHOTSO
6 MARSH PASS
Chinle Wash
7 LOWER ROCK POINT
8 MANY FARMS
9 CHINLE
10 CANYON DE CHELLY
11 TSAILE
12 WHEATFIELDS
Nazlini Wash
13 BEAUTIFUL VALLEY
14 NAZLINI
Lukachukai Creek
15 ROUND ROCK
16 RED HOUSE
17 LUKACHUKAI
Walker Creek
18 TOTACON
19 TOH CHIN LINI
Tsitah Wash
20 TODESTANI
21 TEEC NOS POS
Red Wash
22 RED ROCK MTN.
23 RED ROCK VALLEY
24 COVE
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Study Area Boundary
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BUREAU OF RECLAMATION
UPPER COLORADO RIVER BASIN
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ARIZONA
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TECHNICAL APPROVAL
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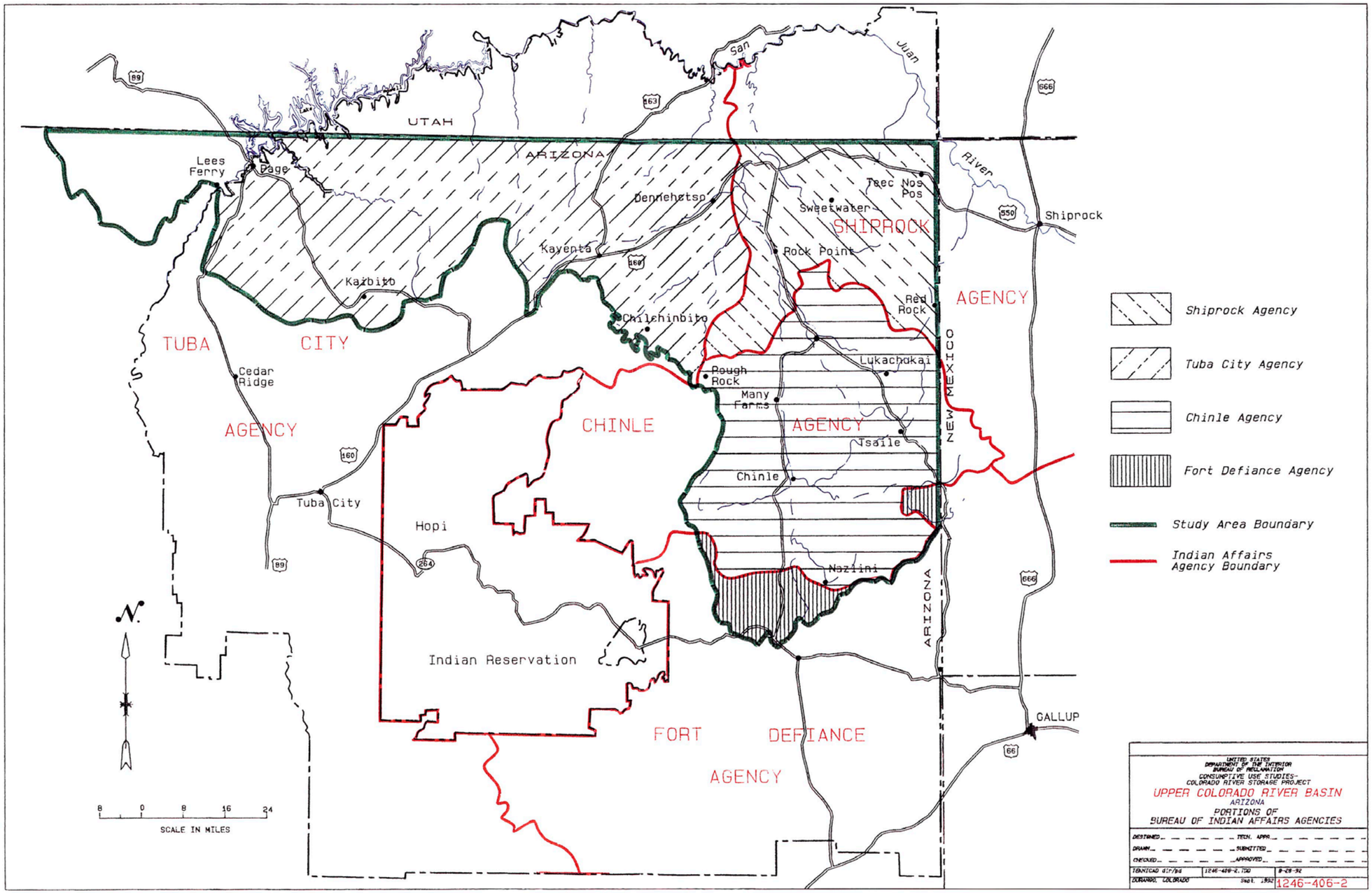
March 1987
1246-406-1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ARIZONA
NEW MEXICO
Lees Ferry
Page
Dennehotso
Kayenta
Kaibito
Chilchinbito
Teec Nos Pos
Sweetwater
Rock Point
Red Rock
Lukachukai
Rough Rock
Many Farms
Tsaile
Chinle
Nazlini
Shiprock
San Juan River
TUBA CITY AGENCY
Cedar Ridge
Tuba City
CHINLE AGENCY
SHIPROCK AGENCY
Hopi
Indian Reservation
FORT DEFIANCE AGENCY
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SCALE IN MILES
Shiprock Agency
Tuba City Agency
Chinle Agency
Fort Defiance Agency
Study Area Boundary
Indian Affairs Agency Boundary
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CONSUMPTIVE USE STUDIES-
COLORADO RIVER STORAGE PROJECT
UPPER COLORADO RIVER BASIN
ARIZONA
PORTIONS OF
BUREAU OF INDIAN AFFAIRS AGENCIES
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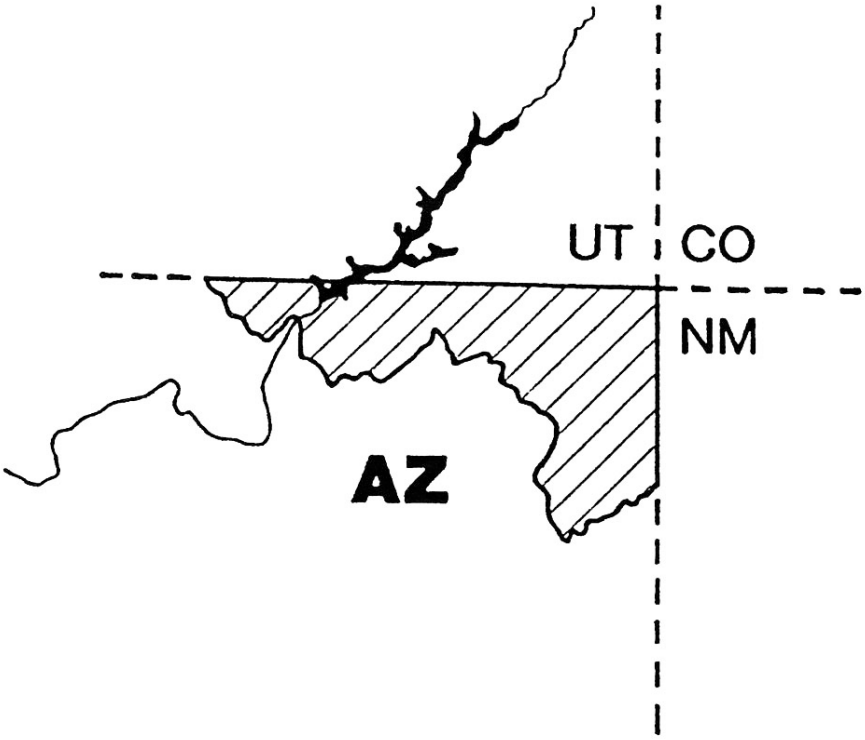
RECLAMATION

Managing Water in the West

Consumptive Uses and Losses: Final Estimate

Arizona Portion of the Upper Colorado River Basin Calendar Year 2008



U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

September 2014

RECLAMATION

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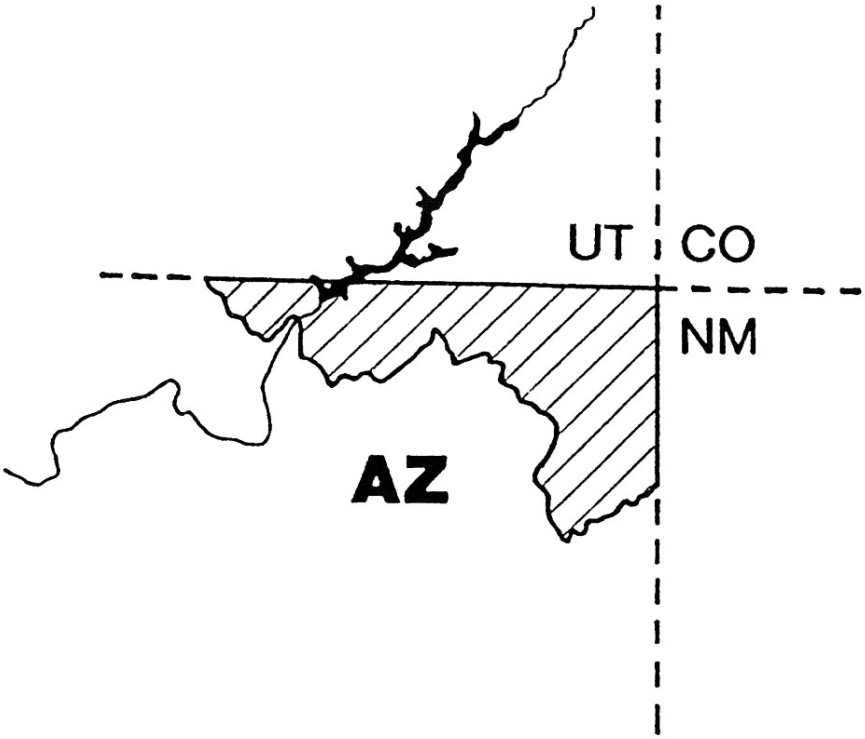

Prepared by: Alan Harrison – September 23, 2014

U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

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UPPER COLORADO RIVER BASIN

CALENDAR YEAR
2008

AUTHORITY

This report was prepared in compliance with Public Law 90-537, Section 601 (b)(1), dated September 30, 1968, which directs the Secretary of the Interior to "make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis." Additionally, this report is in compliance with Section 49 of the Navajo Project Participation Agreement dated September 30, 1969, which states in part: "The Secretary of the Interior further agrees to make the reports required by Section 601 (b)(1) of Public Law 90-537 as they pertain to Arizona's Upper Basin uses annually rather than every five years. Within fifteen days following the completion of said reports, the Secretary of the Interior shall furnish copies of such reports to the Co-Tenants, the Navajo Tribe, each of the Upper Basin States, and the Upper Colorado River Commission."

SUMMARY

Based upon data made available for preparation of this document. the total consumptive use and loss value for the Arizona portion of the Upper Colorado River Basin for calendar year 2008 was 35,709 (±1280) acre-feet. Reclamation prepares this estimate annually, final annual values for consumptive uses and losses for the northern Arizona portion of the Colorado River basin are published in the 5-year summary documents for the Upper Colorado River Basin

STUDY AREA DESCRIPTION

The Arizona portion of the Upper Colorado River Basin covers approximately 6,900 square miles in the north-east corner of Arizona, as shown on the location maps shown on pages 19 and 20 (Drawings 1246-406-1, 1246-406-2). The climate of the 5,900 square mile area to the west of the Chuska and Carrizo Mountains is largely arid to semiarid, with mean annual precipitation ranging from 6 to 12 inches and with summertime temperatures often reaching 100 degrees Fahrenheit (^{o}F). The potential

evaporation rate is high and exceeds mean annual precipitation, with gross lake evaporation values of up to 55 inches per year or more. Elevations in the western portion range from 3200 feet on the Colorado River at Lees Ferry to over 8000 feet on the northern edge of the Black Mesa and across the Zilnez and Skeleton Mesas, back down to 5280 feet in the Chinle Valley, and back up to about 6500 feet on the western edge of the Chuska Mountains. Much of the western part of the study area is starkly beautiful southwestern desert country with mesas and canyons intertwined across a pastoral landscape. By contrast, the eastern 1,000 square miles is largely mountainous, with elevations rising to nearly 10,000 feet and mean annual precipitation reaching 30 inches. The mountainous land responds with grass meadows interspersed with conifer forest of mostly ponderosa pine.

Except for Page, Arizona; a small area around Lees Ferry; and a portion of the Paria Plateau administered by the Bureau of Land Management; the study area lies entirely within the Navajo Nation. Based on straight-line interpolation of 2000 and 2010 census data for the area, it is estimated that approximately 47,719 persons were living within the study area in 2008, and of these an estimated 40,559 resided on the Navajo Nation.

The largest cities are Page and Chinle, with 2000 populations of 6,809 and 5,366, respectively. Other major communities and their populations include Dennehotso (734), Kaibeto (1,607), Kayenta (4,922), LeChee (1,606), Lukachukai (1,565), Many Farms (1,548), Rock Point (724), Teec Nos Pos (799), and Tsaile (1,078). Subsistence in the region is derived principally from livestock grazing, farming, tourist-related industries, employment at the Navajo Generating Station (NGS), which consumes 75 percent of the water used or lost in the study area. Agriculture accounted for 6 percent of the total water use; municipal and industrial about 83 percent; recreation, fish and wildlife, about 4 percent; and reservoir evaporation, 7 percent.

AGRICULTURAL CONSUMPTIVE USE

Agricultural consumptive use is divided into three categories: irrigation, stock pond, and livestock. Irrigation use includes all use related to irrigating crops including the incidental losses. Stock pond use is the evaporation that occurs from stock ponds and livestock use is the water consumed by livestock.

IRRIGATION USES

Within the Arizona portion of the Upper Colorado River Basin, historically 23 irrigated areas were scattered across the Navajo Nation plus a small amount of land near Lees Ferry irrigated by the National Park Service. Currently, only 16 irrigated areas are in production. An accurate assessment of consumptive use on the irrigated land is difficult due to poor quality of information, such as the exact number of acres under irrigation, the cropping pattern for each irrigated area, site climatological conditions, and the amount s of water actually diverted. In many cases, during the latter part of the irrigation season, farmers have to rely on dry land farming since there is little water available in the streams. This means that the crops do not receive their full water requirement.

For this report, the U.S. Department of Agriculture, Soil Conservation Service's (SCS) Modified Blaney-Criddle ET estimation model was used for computing irrigated crop consumptive use. This model, along with appropriate crop-growth stage coefficients and the method for computing effective precipitation, is described in SCS's *Irrigation Water Requirements Technical Release No. 21* (TR 21). Information required for applying this model includes mean monthly temperature and precipitation values, growing season data for each crop type, and the total number of acres planted by crop at each site. With the exception of Teec Nos Pos, Canyon de Chelly, Lukachukai, and Lees Ferry, no climatological data exist for the irrigation sites, and site values must be generated from data collected at surrounding established weather stations. Growing season dates depend largely on the judgment of the local inhabitants and are, therefore, not known. Although several reports are available with published values for irrigated acres, it is unclear if these values are meant to represent potential irrigated acres, acres irrigated in the past, acres for which farming permits have been issued, or actual acres currently under irrigation.

The crop acreage used to estimate consumptive use by irrigated crops for the year 2008 is shown in table 1. These values were determined from direct field examination by a party composed of representatives from the State of Arizona and the Navajo Nation.

Table 1.—Total irrigated acreage, 2008

PROJECT	CORN (ACRES)	ALFALFA (ACRES)	GRASS PASTURE (ACRES)	SPRING GRAINS (ACRES)	SMALL VEGETABLES (ACRES)	ORCHARD (ACRES)	TOTAL (ACRES)
CHINLE AGENCY							
Canyon de Chelly	0.36	0.00	0.00	3.03	2.26	0.00	5.65
Lukachukai	39.09	7.69	0.00	7.50	5.98	2.07	62.33
Many Farms	108.47	18.10	66.98	1.77	18.10	0.00	213.40
Nazlini	0.00	0.00	0.00	0.00	1.79	0.74	2.53
Rough Rock	30.00	0.00	11.87	0.00	12.43	0.00	54.30
Tsaile	23.72	5.27	15.67	5.73	5.42	0.00	55.81
Wheatfields	0.00	60.80	0.00	0.00	0.00	0.00	60.80
TOTAL	201.64	91.86	94.52	18.03	45.98	2.81	454.82
SHIPROCK AGENCY							
Red Rock Valley	26.22	0.00	10.19	5.12	10.22	0.00	51.75
Teec Nos Pos	20.00	0.00	0.00	0.00	3.67	0.00	23.67
Toh Chin Lini	0.00	0.00	0.00	0.00	3.90	13.67	17.57
Totacon	0.00	0.00	0.00	0.00	1.00	0.00	1.00
TOTAL	46.22	0.00	10.19	5.12	18.79	13.67	93.99
WESTERN NAVAJO AGENCY							
Dennehotso	1.82	0.00	38.70	0.00	0.00	0.00	40.52
Lees Ferry	0.00	0.00	1.00	0.00	0.00	2.00	3.00
Marsh Pass	7.02	3.31	0.00	0.00	1.99	0.00	12.32
Navajo Canyon	0.00	0.00	0.00	0.00	0.00	3.50	3.50
Paiute Canyon	2.64	0.00	0.00	0.00	3.86	0.00	6.50
TOTAL	11.48	3.31	39.70	0.00	5.85	5.50	65.84
GRAND TOTAL	259.34	95.17	144.41	23.15	70.62	21.98	614.65

Several factors complicated the modeling of irrigation consumptive use. For example, the computer program used to model consumptive use assumes a full water supply; if shortages exist, as they often do in this semiarid study area, adjustments must be made. These adjustments are complicated because some of the projects have no storage water and may only have a reliable irrigation water supply during spring runoff. After spring runoff, farming becomes essentially dry land until rains in July and August provide intermittent flows for irrigation. Finally, no ditch diversion records are available to help estimate irrigation water supplies and shortages.

A full irrigation supply seldom exists at many of the projects. Generally, a full supply is available for Lees Ferry, Navajo Canyon, Tsaile, and Wheatfields projects because of adequate stream flows or because of available storage water. In years with average precipitation, it is estimated that Chinle Wash provides approximately 75 percent of the irrigation requirement. Precipitation in the area averages approximately 9.5 inches per year. Based on this information, it would require approximately 12.67 inches of precipitation to provide 100 percent of the irrigation requirement. The percent of crop water requirement met was computed as a ratio of annual precipitation to 12.67 inches. These values are found in table 2.

The percentage of crop water requirement met was multiplied by the total net crop water requirement to come up with the amount of crop consumptive use. Incidental irrigation losses, evaporation, and phreatophyte consumptive use along supply canals are estimated to be 5 percent of the consumptive use of the irrigated area and are added to the crop consumptive use value to develop a total consumptive use value.

A portion of the water used for irrigation at these sites may not be contributing to the Colorado River System since evaporation rates in the area are high and the nature of most of the drainage enhances evapotranspiration. A good example of such a drainage is Chinle Wash, which after it leaves Canyon de Chelly, becomes wide and sandy and is lined with willows, cottonwoods, and other phreatophytes.

The uncertainties in the irrigation consumptive use values displayed in table 2 are very large and are estimated as 40 percent of the total consumptive use. This estimate of possible error only reflects the uncertainty of consumptive use and does not account for any possible errors in the acreage estimates. The effective consumptive use for irrigation for 2008 was estimated to equal 1030 acre-feet. Including the 5 percent for incidental losses, the irrigation related consumptive use is 1082 ($\pm$433) acre-feet.

Table 2.—Net consumptive use values, 2008

PROJECT	CROP WATER REQUIREMENT (INCHES)	TOTAL IRRIGATED (ACRES)	TOTAL WATER REQUIRED (ACRE-FEET)	CROP WATER REQUIREMENT MET (%)	CROP WATER REQUIREMENT MET (ACRE-FEET)	TOTAL CONSUMPTIVE USE (ACRE-FEET)[1]
CHINLE AGENCY						
Canyon de Chelly	25.26	5.65	12	82%	10	10.2
Lukachukai	21.75	62.33	113	82%	92	97.0
Many Farms	25.27	213.40	449	82%	368	386.0
Nazlini	19.81	2.53	4	82%	3	3.6
Rough Rock	20.61	54.30	93	100%	93	97.9
Tsaile	22.52	55.81	105	82%	86	89.9
Wheatfields	29.25	60.80	148	82%	121	127.3
TOTAL	164.48	545.82	925		773	811.9
SHIPROCK AGENCY						
Red Rock Valley	25.16	51.75	109	82%	89	93.3
Teec Nos Pos	29.03	23.67	57	82%	47	49.3
Toh Chin Lini	38.63	17.57	57	41%	23	24.4
Totacon	26.32	1.00	2	41%	1	0.9
TOTAL	119.15	93.99	225		160	167.9
WESTERN NAVAJO AGENCY						
Dennehotso	38.16	40.52	129	41%	53	55.3
Lees Ferry	43.79	3.00	11	100%	11	11.5
Marsh Pass	19.74	12.32	20	93%	19	19.8
Navajo Canyon	36.16	3.50	11	62%	7	6.9
Paiute Canyon	23.16	6.50	13	62%	8	8.2
TOTAL	161.00	65.84	183		97	101.7
GRAND TOTAL	444.62	614.64	1332		1030	1081.6

[1] Total includes 5% addition for incidental losses.

STOCK POND EVAPORATION

Stock pond consumptive use is assumed to be the evaporation from the stock pond. It is also assumed that any consumptive use by natural vegetation prior to the construction of the stock ponds is limited to precipitation which is subtracted from the evaporation losses.

A compilation of the stock ponds in the study area, including their locations and the water surface areas when ponds are full, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 3. For an average year conditions, the stock pond evaporative surface area was estimated as one-third the water surface area that occurs when the ponds are full. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average water surface area. These values are found in table 3.

Table 3.—Stock pond evaporation, 2008

COUNTY	SURFACE AREA FULL (ACRES)	SURFACE AREA USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Coconino	80	19	72	57	4.8	52.2	83
Navajo	40	13	100	55	10.8	44.2	49
Apache	646	215	100	53	10.4	42.6	765
TOTAL	766	248					897

This method of evaporation estimation was used because continuous useful water level records for all stock ponds from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual stock ponds. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation. It was assumed that any consumptive use by natural vegetation prior to construction of the stock ponds is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for stock pond evaporation for calendar year 2008 are shown in table 3. The total evaporative losses in 2008 are 897 ($\pm$269) acre-feet with the stock pond evaporation uncertainty being estimated as 30 percent.

LIVESTOCK WATER

The source of most livestock water in the study area is from wells, with windmill-operated pumps developed and maintained by Navajo Water Operations and Maintenance, and water collected in small surface ponds. The estimated number of

livestock in the area was obtained based on livestock tallies. It was estimated that horses and cattle consume 12 gallons per day; sheep and goats consume 2 gallons per day.

The number of animals for the Upper Colorado portion of each district is shown in table 4. The computed value for livestock consumptive use is 278 acre-feet. The uncertainty in this number is estimated as 30 percent of the total or ±83 acre-feet.

Table 4.—Number of livestock, 2008

AGENCY	CATTLE	HORSES	SHEEP	GOATS
Western Navajo District No. 1	2,310	545	2,855	1,642
Western Navajo District No. 2	1,029	165	1,859	1,247
Western Navajo District No. 8	2,626	340	4,292	2,980
Shiprock District No. 9	1,825	419	2,102	2,477
Chinle District No. 10	1,808	372	2,711	1,417
Chinle District No. 11	704	150	686	692
Shiprock District No. 12	1,478	195	1,898	1,293
Fort Defiance District No. 17	429	108	1,498	495
Fort Defiance District No. 18	810	122	1,085	391
TOTAL	13,019	2,416	18,986	12,634

TOTAL AGRICULTURAL CONSUMPTIVE USE

The total agricultural consumptive use, displayed in table 5, is the sum of the individual components discussed in the previous sections. Agricultural water consumption represents approximately 6 percent of the total use in the study area. Total degree of uncertainty was computed by taking the square root of the sum of the individual uncertainties squared; known as the quadratic sum. This method and nomenclature is used throughout this report. This method was used because a simple sum does not account for the partial cancellation of errors occurring when calculating the total uncertainty derived from individual values that are random and independent of each other. As previously discussed, the individual uncertainties were set as a percent of the consumptive use value.

Table 5.—Total agricultural consumptive use, 2008

CATEGORY	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Irrigation	1,082	433
Stock Ponds	897	269
Livestock	278	83
TOTAL	2,257	516

MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

Municipal and industrial consumptive use is divided into three categories: mineral resources, thermal electric power, and other. Mineral resources consumptive use includes water used for mineral production. No mineral resources consumptive use is reported in the study area. Thermal electric power consumptive use includes the water used at the power plants, and that used to transport material to the power plant (such as a coal slurry pipeline). Other consumptive use includes urban, rural, and industrial uses.

THERMAL ELECTRIC POWER

Thermal electric power consumptive use includes the water used in the power plant and the water used to transport material to the plant.

Navajo Generating Station

The water used by the NGS is pumped directly from Lake Powell and comprises over half of the total consumption in the study area. Since all NGS water use is metered, this quantity is among those most precisely known, with the maximum uncertainty in the metered quantities believed to be less than 3 percent. The actual quantity consumed, along with the estimated uncertainty for the calendar year 2008, was 26,334 (±790) acre-feet.

OTHER

The other consumptive use category includes the remaining use by urban, rural, and industries.

Page, AZ and Vicinity

City of Page, AZ. – The city of Page pumps its domestic water directly from Lake Powell. The water pumped is metered, and the uncertainty of the pumped quantities was assumed to be less than 3 percent. A portion of the water pumped and treated by the City

of Page, is supplied to the community of Le Chee on the Navajo Nation and is accounted for separately. The quantity supplied to the City of Page and its associated uncertainty for the calendar year 2008 was 2,310 (±69) acre-feet. Water returning to the waste water treatment plant is metered as well. The waste water for the City of Page is treated and is either evaporated from lined ponds or applied to the golf course, with a portion being returned to the Colorado River. The return flow is estimated to be 1,919 acre-feet. The net consumptive use is estimated to be 391 acre-feet (±90).

Le Chee – The community of Le Chee is supplied and metered by the City of Page. Total water supplied for 2008 was 95 (±3) acre-feet. The uncertainty was estimated to be 3 percent.

Greenhaven Water Company – The Greenhaven Water Company derives its domestic water supply from wells. Well pumping records are available. According to these records, the total water pumped for 2008 was 121 (±8) acre-feet. The uncertainty was estimated to be 7 percent.

Arizona Department of Transportation Housing – The Arizona Department of Transportation operates a housing, maintenance, and administrative facility located on US Hwy 89, north of Page, AZ. This facility is supplied from wells that have no meters installed. It is estimated that the total water pumped for 2008 was 8 acre-feet with an uncertainty of 30 percent of this value or ±2 acre-feet.

Navajo Nation

Community Water Systems – Statistics from the Division of Community Development of the Navajo Nation reveal that various community water systems served 26,086, or about 83 percent of the 31,429 people residing within the study area in 1980. This percentage was used for 2008 resulting in 33,664 out of 40,559 people being served. These systems include those operated by the Navajo Tribal Utility Authority (NTUA), the BIA, and the Water Operations and Maintenance Department of the Navajo Nation, and some privately developed community water systems.

Table 6 shows the source of water and estimated population served by each source of water for people living on the Navajo Nation during 2008. All of the communities obtain their water supply from ground water.

Table 6.—Domestic water sources, 2008

SOURCE	PERCENTAGE OF POPULATION SERVED	NUMBER OF POPULATION SERVED[1]
Community Water Systems	83	33,664
NTUA	[2](60)	20,199
BIA	[2](25)	8,416
Navajo WOM	[2](13)	4,376
Private	[2](2)	673
Individual Wells	17	6,895
TOTAL[2]	100	40,559

[1] Estimated total population within the Upper Colorado River Basin portion of the Navajo Nation provided by Larry Rodgers, Demographer for the Division of Community Development of the Navajo Nation, letter DCDA-L94052, June 20, 1995.
[2] These numbers are a percentage of the Community Water Systems.

NTUA Water Systems – The cities and surrounding communities of Oak Springs, Red Valley, Sweetwater, Chinle , Rough Rock, Round Rock, Rock Point, Wheatfields, Lukachukai, Kayenta, Chilchinbeto, Dennehotso, and Kaibeto derive most of their domestic water supply from wells operated by NTUA. Well pumping records are available. According to these records, the total water pumped for 2008 was 1,619 acre-feet with an uncertainty estimated to be 7 percent of this value or ±113 acre-feet.

The NTUA manages the raw waste water; portions of which flow to individual septic tanks, some to evaporation ponds, and some, such as for the cities of Chinle and Kayenta, flow to waste water treatment plants. Very little water, if any, is returned to the ground water system through leakage from the evaporation ponds, but there are losses from the main collection system. Effluent from the Chinle and Kayenta waste water treatment plants is metered. Under normal conditions, the effluent returns to the Colorado River System and is subtracted from the pumping totals to determine a net consumptive use. For 2008, Chinle's treatment plant effluent was 379 (±27) acre-feet, and Kayenta's effluent was 267 (±19) acre-feet. An estimated uncertainty of 7 percent was used for the effluent of these two plants. The total effluent of 645 acre-feet is subtracted from the NTUA pumping total of 1,619 acre-feet to arrive at a net consumptive use of 974 (±122) acre-feet.

BIA Water Systems – Wells developed and operated by the BIA serve numerous Navajo communities. These systems also serve BIA schools, hospitals, agency offices, and some housing on the Navajo Nation. Metered records for total amounts of water pumped from BIA wells were available for a portion of the Shiprock Agency, the Western Navajo Agency, and the Chinle Agency. Drawing 1246-406-2 shows the agency boundaries within the Upper Colorado River Basin. The uncertainty was estimated to be about 7 percent for all three agencies.

The BIA systems include sewage disposal units terminating in lined evaporation ponds with very little or no return water returning to the ground water system. Undoubtedly, some losses occur in distribution, but insufficient data currently exist to estimate these losses. The losses are probably less than the uncertainties for each of the reported values.

The BIA well data available for the Shiprock Agency include: Cove, Red Rock, and Teec Nos Pos. Total consumptive use values are 11 (±1) acre-feet.

Pumping records for the Western Navajo Agency include data for the following schools: Chilchinbeto Day School, Dennehotso Boarding School, Kaibeto Boarding School, and Kayenta Boarding School. Total consumptive use for the Western Navajo Agency was 172 (±12) acre-feet.

Well pumping records for the Chinle Agency include data for the following schools: Cottonwood Day School, Lukachukai School, and Rock Point School. Rough Rock School maintains its own records, but the data was included with the Chinle Agency data. Total consumptive use for the Chinle Agency was 69 (±5) acre-feet.

Navajo WOM Water Systems – Water use in 2008 by the Navajo WOM service areas was based on an assumed consumption rate of 110 gallons per capita per day (gpcd). For a 2008 estimated service area population of 4,376, the estimated annual water use was 539 (±162) acre-feet. The uncertainty is estimated as 30 percent of the total.

Private Water Systems – The estimated 2008 population served by private water systems on the Navajo Nation was 673. Assuming a consumptive use rate of 110 gcpd, the annual water use for 2008 was 83 (±25) acre-feet. The uncertainty is estimated as 30 percent of the total.

Individual Wells – According to census data from the Division of Community Development of the Navajo Nation, approximately 17 percent of the study area's population on the reservation (about 6,895 persons in 2008) receives a domestic water supply from individual wells. A consumptive use of 110 gpcd was derived as being a reasonable water use rate. Based on these figures, the annual consumptive use was 850 (±255) acre-feet for 2008.

TOTAL MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

The total municipal and industrial consumptive use, displayed in table 7, is the sum of the individual components discussed in the previous sections. Municipal and industrial water consumption represents approximately 83 percent of the total use in the study area.

Table 7.—Total municipal and industrial consumptive use, 2008

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
THERMAL ELECTRIC POWER		
Navajo Generating Station	26,334	790
OTHER		
Page, AZ and Vicinity		
City of Page	391	90
Le Chee	95	3
Greenhaven Water Company	121	8
Arizona Department of Transportation	8	2
Navajo Indian Reservation		
Community Water Systems		
NTUA Water Systems	974	122
BIA Water Systems	252	13
Navajo WOM	539	162
Private Water Systems	83	25
Individual Wells	850	255
TOTAL	29,647	860

It is questionable whether all the water pumped from wells should be considered a depletion to the Colorado River System; however, it is assumed that 100 percent of the water pumped is considered lost to the system. It is proposed that a future joint study be completed by Reclamation, the State of Arizona, and the Navajo Nation to estimate what percentage of water pumped could actually be attributed to the Colorado River System and would have affected the river flows for a particular year.

RECREATION, FISH AND WILDLIFE

The recreation, fish and wildlife consumptive uses include evaporation from reservoirs used exclusively for fish & wildlife purposes as well as acreages irrigated for wildlife feeding. Consumptive use related to recreation at National parks is also addressed.

GLEN CANYON NATIONAL RECREATION AREA

Colorado River water is used by the Glen Canyon National Recreation Area (GCNRA) at Wahweap and Lees Ferry. The recreational area at Wahweap gets its water supply from a series of wells on the shore of Lake Powell. Pumping records for both Wahweap Marina, and Lees Ferry show 338 ($\pm$10) acre-feet of water withdrawn during 2008. The uncertainty is estimated at 3 percent. This water was used for domestic purposes at the

campgrounds, picnic areas, and trailer parks. It was also used to irrigate approximately 60 acres of Bermuda grass and cottonwood trees. The domestic waste water is treated and the effluent is allowed to evaporate from two lined evaporation ponds with a total surface area of 16.7 acres.

Based on estimates of evaporation and consumptive use by the plants, there is some water which is unaccounted for and is assumed to be leakage from the delivery system, the evaporation pond, or deep percolation from irrigation application. However, since these water losses are difficult to quantify and verify, the losses were charged as consumptive uses. Therefore, net consumptive use of water is estimated to be equal to the quantity of water pumped.

RESERVOIR EVAPORATION

A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 8.

Table 8. —Recreation, fish and wildlife reservoir evaporation, 2008

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE AREA USED (ACRES)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Tsaile	260	260	35	10.36	24.64	534
Wheatfields	272	272	32	10.36	21.64	491
TOTAL	532	532				1,024

Efforts are made to maintain a nearly full condition and to minimize water surface fluctuations in reservoirs managed for a fishery. Under average operating conditions, the water surface area of a reservoir used primarily for fishing is assumed to be equal to a normal water surface area. It is assumed that, in 2008, these reservoirs filled in the spring and were maintained at the normal pool level.

This method of evaporation estimation was used because continuous useful water level records for all reservoirs from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs.

For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for reservoir evaporation for calendar year 2008 are shown in table 8. The total evaporative losses in 2008 are 1,024 ($\pm$307) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent.

TOTAL RECREATION, FISH AND WILDLIFE

The total recreation, fish and wildlife consumptive use, displayed in table 9, is the sum of the individual components discussed in the previous sections. Recreation, fish and wildlife water consumption represents approximately 4 percent of the total use in the study area.

Table 9.—Total recreation, fish and wildlife consumptive use, 2008

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Glen Canyon National Recreation Area	338	10
Reservoir Evaporation	1024	307
TOTAL	1,363	307

RESERVOIR EVAPORATION

Reservoir evaporation losses make up about 7 percent of the total water uses and losses in the study area. A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 10. These reservoirs are used primarily for irrigation.

Table 10.—Reservoir evaporation, 2008

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE ACRES USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Many Farms	1,800	554	100%	56	10.36	45.64	2,109
Marsh Pass	40	20	100%	40	13.30	26.71	45
Round Rock	83	42	100%	57	10.38	46.63	151
Walker Creek	30	15	100%	59	10.39	48.61	61
Others	38	19	100%	55	12.15	42.85	68
TOTAL	1,991	650					2,443

Reservoirs used primarily for irrigation experience large fluctuations in water levels and, correspondingly, large variations in surface area. Reservoir level records and elevation – area curves were available at Many Farms, but not for the remaining reservoirs in table 10. For the reservoirs with no records from which surface area could be accurately computed, the average evaporative surface area was estimated as one-half the water

surface area of a full reservoir. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average evaporative surface area.

Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses. The computed values for reservoir evaporation for 2008 are shown in table 10. The total evaporative losses in 2008 are 2,443 ($\pm$733) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent of the total evaporation.

CONCLUSIONS

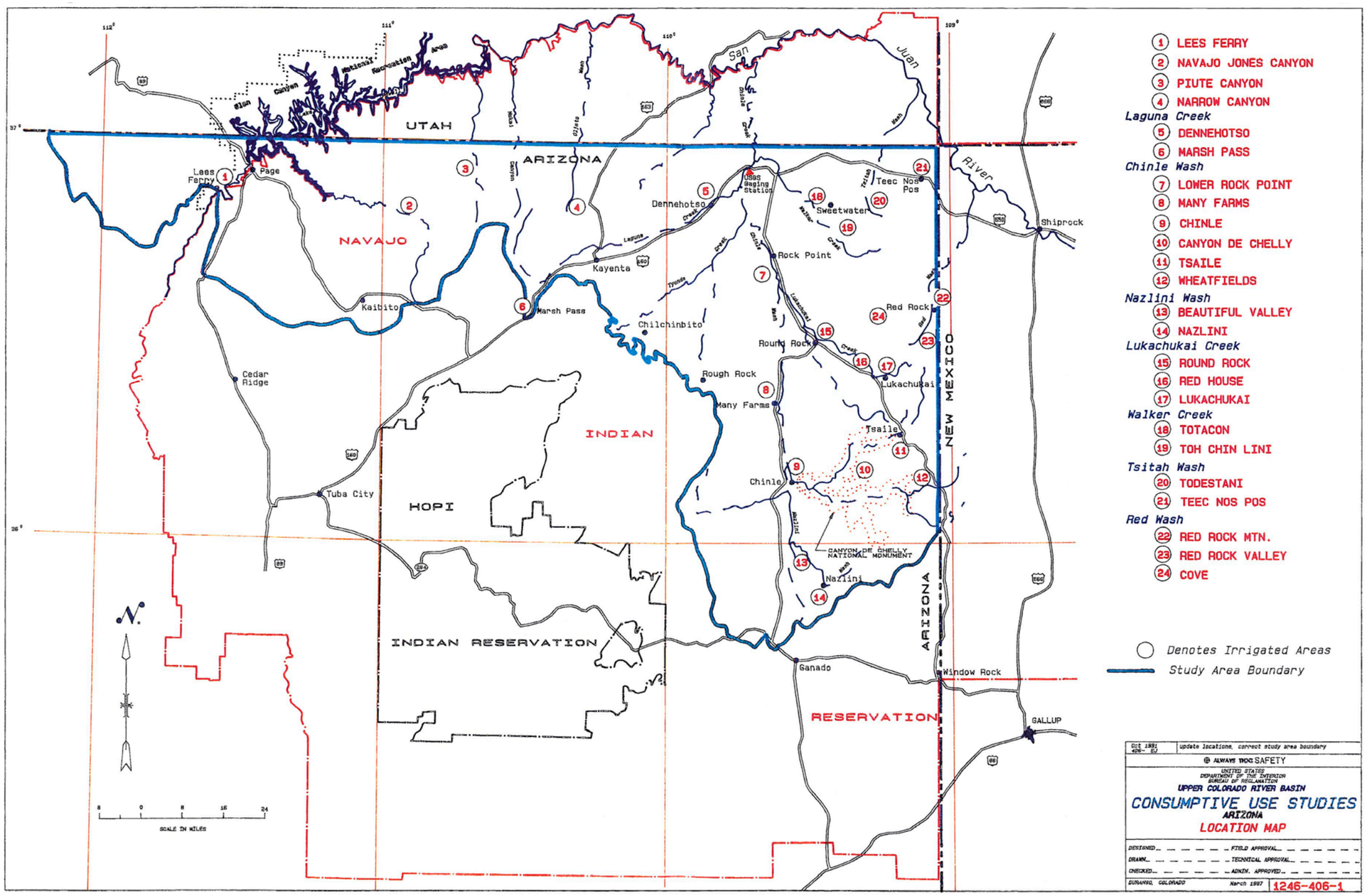
This report assesses the total consumptive use of the Arizona portion of the Upper Colorado River System surface water systems, depletion of ground water, and evaporative losses. Clearly, the amounts of water used by the Navajo Generating Station, City of Page, and Wahweap and Lees Ferry recreation areas are direct depletions of water from the Upper Colorado River System, but the situation is not as clear for other consumptive uses and losses occurring in other sections of the study area. For example, the source of water used by the Navajo Nation for domestic and municipal purposes is from wells, some exceeding 1,000 feet in depth. For our purposes here, it is considered to be consumed and a depletion to the Colorado River System. But this may not actually result in a reduction of Colorado River stream flows in the same year that the withdrawal occurs. Little knowledge and information exists of ground water movement and subsurface flow rates in the study area that are accurate descriptions of the effects on river flows.

Although the water diverted for agricultural purposes is considered as consumptive use in this report, a portion of the remaining surface water on the Navajo Nation, excess to needs, does evaporate before reaching the Colorado River. No attempt has been made for this report to quantify these losses.

Uncertainties in estimating uses and losses exist, and the degree of variation in the figures is presented. Fortunately, the areas with the highest degree of uncertainty account for only a small percentage of the total consumptive use. The largest component, use by the Navajo Generating Station, is also the most accurately monitored. The total annual value for estimated consumptive use of water within the Arizona portion of the Upper Colorado River Basin for 2008 was 35,709 acre-feet, as shown in table 11.

Table 11.—Consumptive use for Arizona portion of Upper Colorado River Basin for 2008

USE CATEGORY	TOTAL CONSUMPTIVE USE (ACRE-FEET)	UNCERTAINTY	PERCENT OF TOTAL
Agriculture	2,257	516	6
Municipal & Industrial	29,647	860	83
Recreation, Fish & Wildlife	1,363	307	4
Reservoir Evaporation	2,443	733	7
TOTAL	35,709	1,280	100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Cedar Ridge
Tuba City
Marsh Pass
Kayenta
Dennehotso
USGS Gaging Station
Sweetwater
Teec Nos Pos
Rock Point
Chilchinbito
Round Rock
Rough Rock
Many Farms
Red Rock
Lukachukai
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Ganado
Window Rock
GALLUP
Shiprock
SCALE IN MILES
1 LEES FERRY
2 NAVAJO JONES CANYON
3 PIUTE CANYON
4 NARROW CANYON
Laguna Creek
5 DENNEHOTSO
6 MARSH PASS
Chinle Wash
7 LOWER ROCK POINT
8 MANY FARMS
9 CHINLE
10 CANYON DE CHELLY
11 TSAILE
12 WHEATFIELDS
Nazlini Wash
13 BEAUTIFUL VALLEY
14 NAZLINI
Lukachukai Creek
15 ROUND ROCK
16 RED HOUSE
17 LUKACHUKAI
Walker Creek
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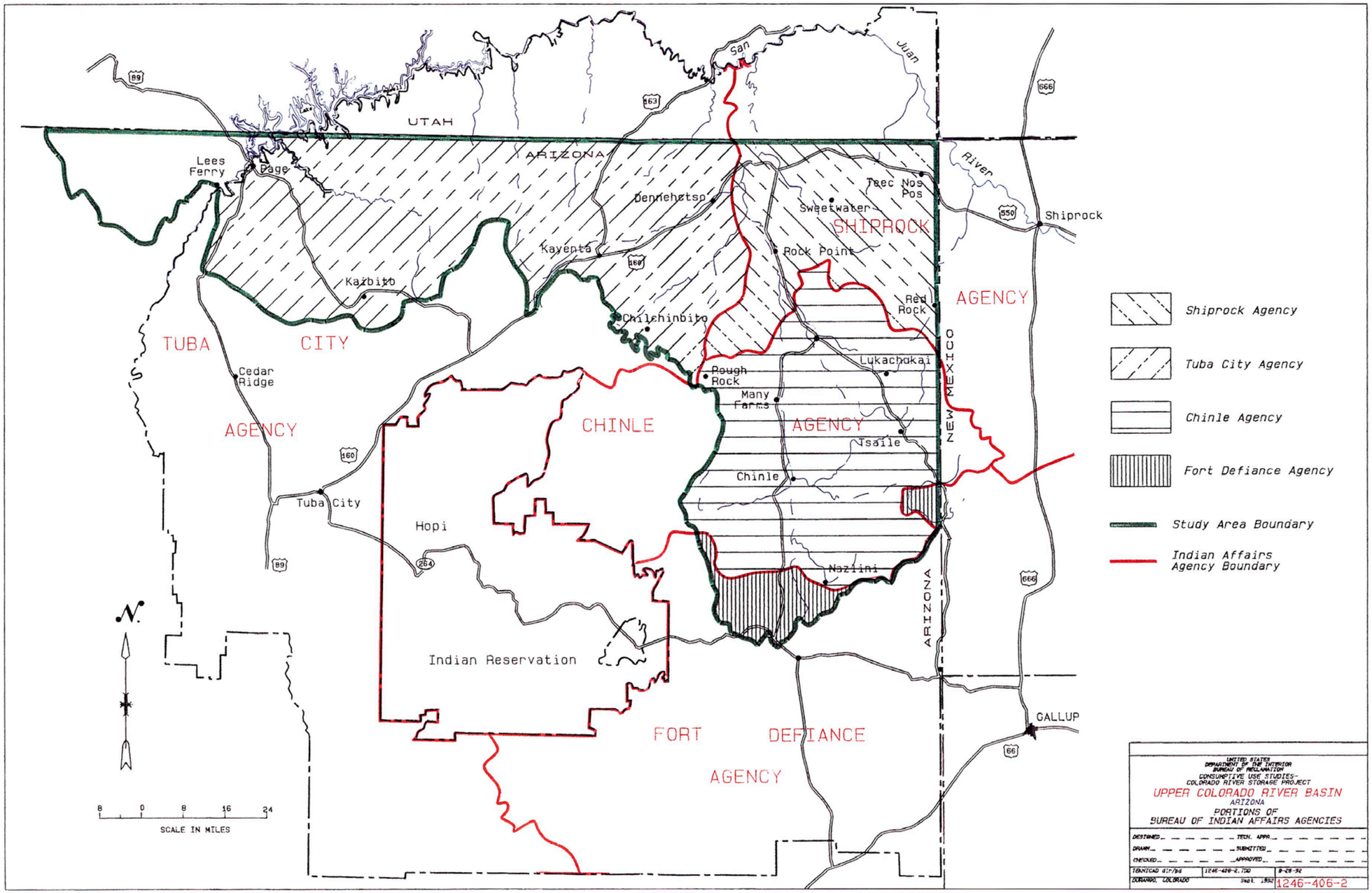
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Lukachukai
Rough Rock
Many Farms
Tsaile
Chinle
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Shiprock
San Juan River
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Cedar Ridge
Tuba City
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Tuba City Agency
Chinle Agency
Fort Defiance Agency
Study Area Boundary
Indian Affairs Agency Boundary
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BUREAU OF RECLAMATION
CONSUMPTIVE USE STUDIES-
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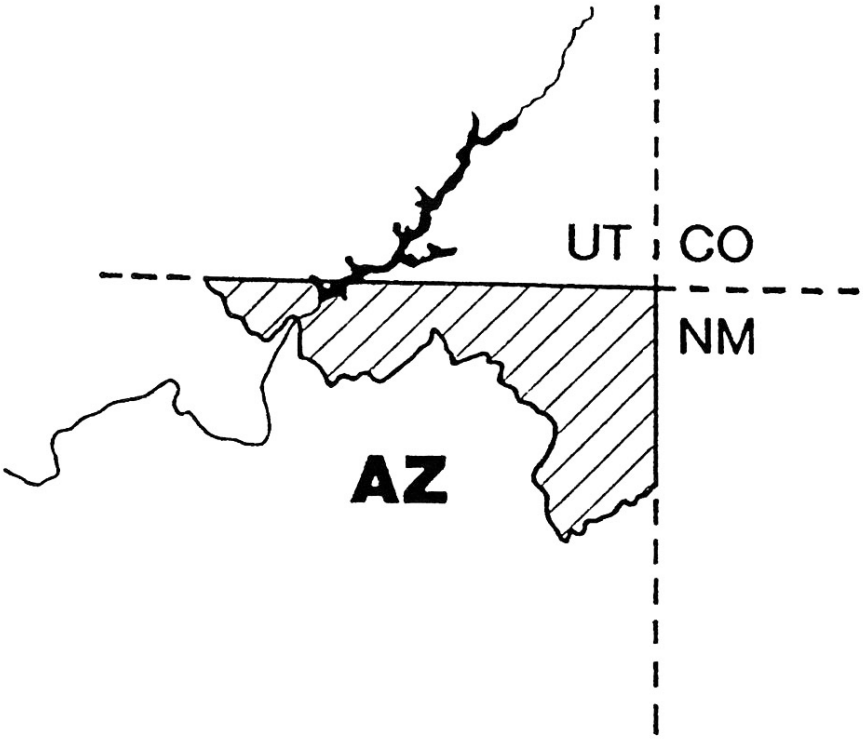
RECLAMATION

Managing Water in the West

Consumptive Uses and Losses: Final Estimate

Arizona Portion of the Upper Colorado River Basin Calendar Year 2009



U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

September 2014

RECLAMATION

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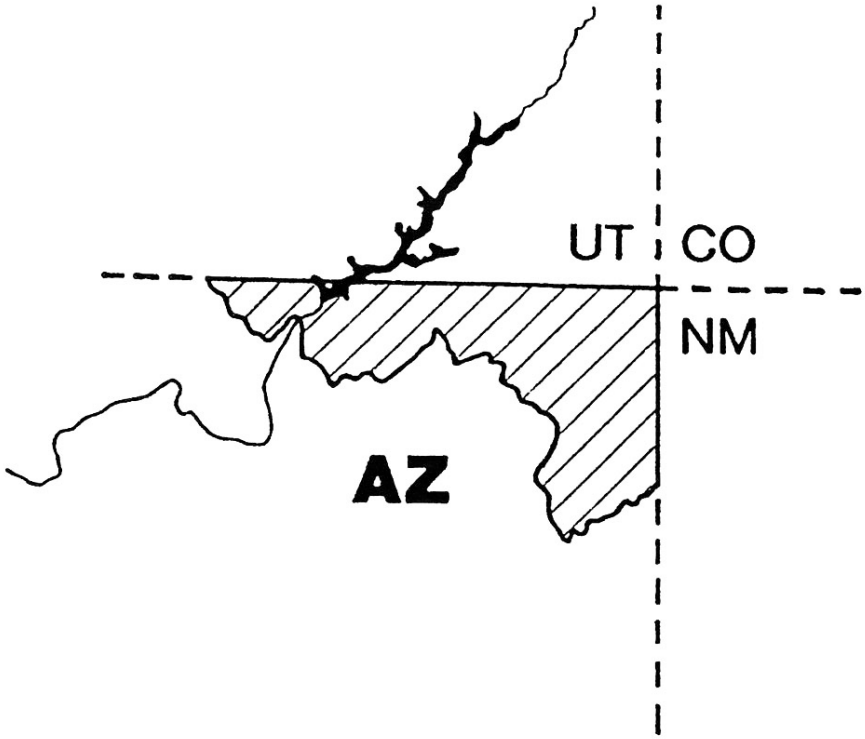

Prepared by: Alan Harrison – September 23, 2014

U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

September 2014

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UPPER COLORADO RIVER BASIN

CALENDAR YEAR
2009

AUTHORITY

This report was prepared in compliance with Public Law 90-537, Section 601 (b)(1), dated September 30, 1968, which directs the Secretary of the Interior to "make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis." Additionally, this report is in compliance with Section 49 of the Navajo Project Participation Agreement dated September 30, 1969, which states in part: "The Secretary of the Interior further agrees to make the reports required by Section 601 (b)(1) of Public Law 90-537 as they pertain to Arizona's Upper Basin uses annually rather than every five years. Within fifteen days following the completion of said reports, the Secretary of the Interior shall furnish copies of such reports to the Co-Tenants, the Navajo Tribe, each of the Upper Basin States, and the Upper Colorado River Commission."

SUMMARY

Based upon data made available for preparation of this document. the total consumptive use and loss value for the Arizona portion of the Upper Colorado River Basin for calendar year 2009 was 35,937 (±1262) acre-feet. Reclamation prepares this estimate annually, final annual values for consumptive uses and losses for the northern Arizona portion of the Colorado River basin are published in the 5-year summary documents for the Upper Colorado River Basin

STUDY AREA DESCRIPTION

The Arizona portion of the Upper Colorado River Basin covers approximately 6,900 square miles in the north-east corner of Arizona, as shown on the location maps shown on pages 19 and 20 (Drawings 1246-406-1, 1246-406-2). The climate of the 5,900 square mile area to the west of the Chuska and Carrizo Mountains is largely arid to semiarid, with mean annual precipitation ranging from 6 to 12 inches and with summertime temperatures often reaching 100 degrees Fahrenheit (^{o}F). The potential

evaporation rate is high and exceeds mean annual precipitation, with gross lake evaporation values of up to 55 inches per year or more. Elevations in the western portion range from 3200 feet on the Colorado River at Lees Ferry to over 8000 feet on the northern edge of the Black Mesa and across the Zilnez and Skeleton Mesas, back down to 5280 feet in the Chinle Valley, and back up to about 6500 feet on the western edge of the Chuska Mountains. Much of the western part of the study area is starkly beautiful southwestern desert country with mesas and canyons intertwined across a pastoral landscape. By contrast, the eastern 1,000 square miles is largely mountainous, with elevations rising to nearly 10,000 feet and mean annual precipitation reaching 30 inches. The mountainous land responds with grass meadows interspersed with conifer forest of mostly ponderosa pine.

Except for Page, Arizona; a small area around Lees Ferry; and a portion of the Paria Plateau administered by the Bureau of Land Management; the study area lies entirely within the Navajo Nation. Based on straight-line interpolation of 2000 and 2010 census data for the area, it is estimated that approximately 47,492 persons were living within the study area in 2009, and of these an estimated 40,289 resided on the Navajo Nation.

The largest cities are Page and Chinle, with 2000 populations of 6,809 and 5,366, respectively. Other major communities and their populations include Dennehotso (734), Kaibeto (1,607), Kayenta (4,922), LeChee (1,606), Lukachukai (1,565), Many Farms (1,548), Rock Point (724), Teec Nos Pos (799), and Tsaile (1,078). Subsistence in the region is derived principally from livestock grazing, farming, tourist-related industries, employment at the Navajo Generating Station (NGS), which consumes 83 percent of the water used or lost in the study area. Agriculture accounted for 5 percent of the total water use; municipal and industrial about 83 percent; recreation, fish and wildlife, about 4 percent; and reservoir evaporation, 7 percent.

AGRICULTURAL CONSUMPTIVE USE

Agricultural consumptive use is divided into three categories: irrigation, stock pond, and livestock. Irrigation use includes all use related to irrigating crops including the incidental losses. Stock pond use is the evaporation that occurs from stock ponds and livestock use is the water consumed by livestock.

IRRIGATION USES

Within the Arizona portion of the Upper Colorado River Basin, historically 23 irrigated areas were scattered across the Navajo Nation plus a small amount of land near Lees Ferry irrigated by the National Park Service. Currently, only 16 irrigated areas are in production. An accurate assessment of consumptive use on the irrigated land is difficult due to poor quality of information, such as the exact number of acres under irrigation, the cropping pattern for each irrigated area, site climatological conditions, and the amounts of water actually diverted. In many cases, during the latter part of the irrigation season, farmers have to rely on dry land farming since there is little water available in the streams. This means that the crops do not receive their full water requirement.

For this report, the U.S. Department of Agriculture, Soil Conservation Service's (SCS) Modified Blaney-Criddle ET estimation model was used for computing irrigated crop consumptive use. This model, along with appropriate crop-growth stage coefficients and the method for computing effective precipitation, is described in SCS's *Irrigation Water Requirements Technical Release No. 21* (TR 21). Information required for applying this model includes mean monthly temperature and precipitation values, growing season data for each crop type, and the total number of acres planted by crop at each site. With the exception of Teec Nos Pos, Canyon de Chelly, Lukachukai, and Lees Ferry, no climatological data exist for the irrigation sites, and site values must be generated from data collected at surrounding established weather stations. Growing season dates depend largely on the judgment of the local inhabitants and are, therefore, not known. Although several reports are available with published values for irrigated acres, it is unclear if these values are meant to represent potential irrigated acres, acres irrigated in the past, acres for which farming permits have been issued, or actual acres currently under irrigation.

The crop acreage used to estimate consumptive use by irrigated crops for the year 2009 is shown in table 1. These values were determined from direct field examination by a party composed of representatives from the State of Arizona and the Navajo Nation.

Table 1.—Total irrigated acreage, 2009

PROJECT	CORN (ACRES)	ALFALFA (ACRES)	GRASS PASTURE (ACRES)	SPRING GRAINS (ACRES)	SMALL VEGETABLES (ACRES)	ORCHARD (ACRES)	TOTAL (ACRES)
CHINLE AGENCY							
Canyon de Chelly	0.36	0.00	0.00	3.03	2.26	0.00	5.65
Lukachukai	39.09	7.69	0.00	7.50	5.98	2.07	62.33
Many Farms	118.63	19.79	73.25	1.93	19.79	0.00	233.40
Nazlini	0.00	0.00	0.00	0.00	1.79	0.74	2.53
Rough Rock	30.00	0.00	11.87	0.00	12.43	0.00	54.30
Tsaile	23.72	5.27	15.67	5.73	5.42	0.00	55.81
Wheatfields	0.00	60.80	0.00	0.00	0.00	0.00	60.80
TOTAL	211.80	93.55	100.79	18.19	47.67	2.81	474.82
SHIPROCK AGENCY							
Red Rock Valley	26.22	0.00	10.19	5.12	10.22	0.00	51.75
Teec Nos Pos	20.00	0.00	0.00	0.00	3.67	0.00	23.67
Toh Chin Lini	0.00	0.00	0.00	0.00	3.90	13.67	17.57
Totacon	0.00	0.00	0.00	0.00	1.00	0.00	1.00
TOTAL	46.22	0.00	10.19	5.12	18.79	13.67	93.99
WESTERN NAVAJO AGENCY							
Dennehotso	1.82	0.00	38.70	0.00	0.00	0.00	40.52
Lees Ferry	0.00	0.00	1.00	0.00	0.00	2.00	3.00
Marsh Pass	7.02	3.31	0.00	0.00	1.99	0.00	12.32
Navajo Canyon	0.00	0.00	0.00	0.00	0.00	3.50	3.50
Paiute Canyon	2.64	0.00	0.00	0.00	3.86	0.00	6.50
TOTAL	11.48	3.31	39.70	0.00	5.85	5.50	65.84
GRAND TOTAL	269.50	96.86	150.68	23.31	72.31	21.98	634.65

Several factors complicated the modeling of irrigation consumptive use. For example, the computer program used to model consumptive use assumes a full water supply; if shortages exist, as they often do in this semiarid study area, adjustments must be made. These adjustments are complicated because some of the projects have no storage water and may only have a reliable irrigation water supply during spring runoff. After spring runoff, farming becomes essentially dry land until rains in July and August provide intermittent flows for irrigation. Finally, no ditch diversion records are available to help estimate irrigation water supplies and shortages.

A full irrigation supply seldom exists at many of the projects. Generally, a full supply is available for Lees Ferry, Navajo Canyon, Tsaile, and Wheatfields projects because of adequate stream flows or because of available storage water. In years with average precipitation, it is estimated that Chinle Wash provides approximately 75 percent of the irrigation requirement. Precipitation in the area averages approximately 9.5 inches per year. Based on this information, it would require approximately 12.67 inches of precipitation to provide 100 percent of the irrigation requirement. The percent of crop water requirement met was computed as a ratio of annual precipitation to 12.67 inches. These values are found in table 2.

The percentage of crop water requirement met was multiplied by the total net crop water requirement to come up with the amount of crop consumptive use. Incidental irrigation losses, evaporation, and phreatophyte consumptive use along supply canals are estimated to be 5 percent of the consumptive use of the irrigated area and are added to the crop consumptive use value to develop a total consumptive use value.

A portion of the water used for irrigation at these sites may not be contributing to the Colorado River System since evaporation rates in the area are high and the nature of most of the drainage enhances evapotranspiration. A good example of such a drainage is Chinle Wash, which after it leaves Canyon de Chelly, becomes wide and sandy and is lined with willows, cottonwoods, and other phreatophytes.

The uncertainties in the irrigation consumptive use values displayed in table 2 are very large and are estimated as 40 percent of the total consumptive use. This estimate of possible error only reflects the uncertainty of consumptive use and does not account for any possible errors in the acreage estimates. The effective consumptive use for irrigation for 2009 was estimated to equal 695 acre-feet. Including the 5 percent for incidental losses, the irrigation related consumptive use is 729 ($\pm$292) acre-feet.

Table 2.—Net consumptive use values, 2009

PROJECT	CROP WATER REQUIREMENT (INCHES)	TOTAL IRRIGATED (ACRES)	TOTAL WATER REQUIRED (ACRE-FEET)	CROP WATER REQUIREMENT MET (%)	CROP WATER REQUIREMENT MET (ACRE-FEET)	TOTAL CONSUMPTIVE USE (ACRE-FEET)[1]
CHINLE AGENCY						
Canyon de Chelly	26.79	5.65	13	51%	6	6.8
Lukachukai	22.27	62.33	116	51%	59	62.2
Many Farms	27.21	233.40	529	51%	291	284.8
Nazlini	20.06	2.53	4	51%	2	2.3
Rough Rock	23.57	54.30	107	56%	60	62.6
Tsaile	22.82	55.81	106	51%	54	57.1
Wheatfields	29.18	60.80	148	51%	76	79.6
TOTAL	171.88	474.82	1022		529	555.3
SHIPROCK AGENCY						
Red Rock Valley	26.05	51.75	112	51%	57	60.2
Teec Nos Pos	29.95	23.67	59	51%	30	31.5
Toh Chin Lini	38.79	17.57	57	25%	14	15.2
Totacon	26.00	1.00	2	25%	1	0.6
TOTAL	120.79	93.99	230		102	107.5
WESTERN NAVAJO AGENCY						
Dennehotso	37.19	40.52	126	26%	32	33.8
Lees Ferry	43.41	3.00	11	100%	11	11.4
Marsh Pass	23.88	12.32	25	45%	11	11.7
Navajo Canyon	38.81	3.50	11	45%	5	5.3
Paiute Canyon	26.00	6.50	14	30%	4	4.5
TOTAL	169.29	65.84	186		63	66.6
GRAND TOTAL	461.97	634.65	1439		695	729.5

[1] Total includes 5% addition for incidental losses.

STOCK POND EVAPORATION

Stock pond consumptive use is assumed to be the evaporation from the stock pond. It is also assumed that any consumptive use by natural vegetation prior to the construction of the stock ponds is limited to precipitation which is subtracted from the evaporation losses.

A compilation of the stock ponds in the study area, including their locations and the water surface areas when ponds are full, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 3. For an average year condition, the stock pond evaporative surface area was estimated as one-third the water surface area that occurs when the ponds are full. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average water surface area. These values are found in table 3.

Table 3.—Stock pond evaporation, 2009

COUNTY	SURFACE AREA FULL (ACRES)	SURFACE AREA USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Coconino	80	20	73	57	4.93	52.07	85
Navajo	40	9	69	55	6.73	48.27	37
Apache	646	158	73	53	6.47	46.53	613
TOTAL	766	187					735

This method of evaporation estimation was used because continuous useful water level records for all stock ponds from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual stock ponds. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation. It was assumed that any consumptive use by natural vegetation prior to construction of the stock ponds is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for stock pond evaporation for calendar year 2009 are shown in table 3. The total evaporative losses in 2009 are 735 ($\pm$220) acre-feet with the stock pond evaporation uncertainty being estimated as 30 percent.

LIVESTOCK WATER

The source of most livestock water in the study area is from wells, with windmill-operated pumps developed and maintained by Navajo Water Operations and Maintenance, and water collected in small surface ponds. The estimated number of

livestock in the area was obtained based on livestock tallies. It was estimated that horses and cattle consume 12 gallons per day; sheep and goats consume 2 gallons per day.

The number of animals for the Upper Colorado portion of each district is shown in table 4. The computed value for livestock consumptive use is 461 acre-feet. The uncertainty in this number is estimated as 30 percent of the total or ±138 acre-feet.

Table 4.—Number of livestock, 2009

AGENCY	CATTLE	HORSES	SHEEP	GOATS
Western Navajo District No. 1	1181	204	1950	983
Western Navajo District No. 2	891	198	1304	1008
Western Navajo District No. 8	4957	2996	6598	5050
Shiprock District No. 9	2035	941	2621	2839
Chinle District No. 10	2750	1589	3699	2449
Chinle District No. 11	1300	793	1334	1156
Shiprock District No. 12	3649	2636	4316	3402
Fort Defiance District No. 17	335	90	1526	425
Fort Defiance District No. 18	643	150	999	238
TOTAL	17741	9597	24347	17550

TOTAL AGRICULTURAL CONSUMPTIVE USE

The total agricultural consumptive use, displayed in table 5, is the sum of the individual components discussed in the previous sections. Agricultural water consumption represents approximately 6 percent of the total use in the study area. Total degree of uncertainty was computed by taking the square root of the sum of the individual uncertainties squared; known as the quadratic sum. This method and nomenclature is used throughout this report. This method was used because a simple sum does not account for the partial cancellation of errors occurring when calculating the total uncertainty derived from individual values that are random and independent of each other. As previously discussed, the individual uncertainties were set as a percent of the consumptive use value.

Table 5.—Total agricultural consumptive use, 2009

CATEGORY	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Irrigation	729	292
Stock Ponds	735	220
Livestock	461	138
TOTAL	1,926	391

MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

Municipal and industrial consumptive use is divided into three categories: mineral resources, thermal electric power, and other. Mineral resources consumptive use includes water used for mineral production. No mineral resources consumptive use is reported in the study area. Thermal electric power consumptive use includes the water used at the power plants, and that used to transport material to the power plant (such as a coal slurry pipeline). Other consumptive use includes urban, rural, and industrial uses.

THERMAL ELECTRIC POWER

Thermal electric power consumptive use includes the water used in the power plant and the water used to transport material to the plant.

Navajo Generating Station

The water used by the NGS is pumped directly from Lake Powell and comprises over half of the total consumption in the study area. Since all NGS water use is metered, this quantity is among those most precisely known, with the maximum uncertainty in the metered quantities believed to be less than 3 percent. The actual quantity consumed, along with the estimated uncertainty for the calendar year 2009, was 26,073 (±782) acre-feet.

OTHER

The other consumptive use category includes the remaining use by urban, rural, and industries.

Page, AZ and Vicinity

City of Page, AZ. – The city of Page pumps its domestic water directly from Lake Powell. The water pumped is metered, and the uncertainty of the pumped quantities was assumed to be less than 3 percent. A portion of the water pumped and treated by the City

of Page, is supplied to the community of Le Chee on the Navajo Nation and is accounted for separately. The quantity supplied to the City of Page and its associated uncertainty for the calendar year 2009 was 2,240 (±67) acre-feet. Water returning to the waste water treatment plant is metered as well. The waste water for the City of Page is treated and is either evaporated from lined ponds or applied to the golf course, with a portion being returned to the Colorado River. The return flow is estimated to be 1,922 acre-feet. The net consumptive use is estimated to be 318 acre-feet (±89).

Le Chee – The community of Le Chee is supplied and metered by the City of Page. Total water supplied for 2009 was 95 (±3) acre-feet. The uncertainty was estimated to be 3 percent.

Greenhaven Water Company – The Greenhaven Water Company derives its domestic water supply from wells. Well pumping records are available. According to these records, the total water pumped for 2009 was 121 (±8) acre-feet. The uncertainty was estimated to be 7 percent.

Arizona Department of Transportation Housing – The Arizona Department of Transportation operates a housing, maintenance, and administrative facility located on US Hwy 89, north of Page, AZ. This facility is supplied from wells that have no meters installed. It is estimated that the total water pumped for 2009 was 8 acre-feet with an uncertainty of 30 percent of this value or ±2 acre-feet.

Navajo Nation

Community Water Systems – Statistics from the Division of Community Development of the Navajo Nation reveal that various community water systems served 26,086, or about 83 percent of the 31,429 people residing within the study area in 1980. This percentage was used for 2009 resulting in 33,440 out of 40,289 people being served. These systems include those operated by the Navajo Tribal Utility Authority (NTUA), the BIA, and the Water Operations and Maintenance Department of the Navajo Nation, and some privately developed community water systems.

Table 6 shows the source of water and estimated population served by each source of water for people living on the Navajo Nation during 2009. All of the communities obtain their water supply from ground water.

Table 6.—Domestic water sources, 2009

SOURCE	PERCENTAGE OF POPULATION SERVED	NUMBER OF POPULATION SERVED[1]
Community Water Systems	83	33,440
NTUA	[2](60)	20,064
BIA	[2](25)	8,360
Navajo WOM	[2](13)	4,347
Private	[2](2)	669
Individual Wells	17	6,849
TOTAL[2]	100	40,289

[1] Estimated total population within the Upper Colorado River Basin portion of the Navajo Nation provided by Larry Rodgers, Demographer for the Division of Community Development of the Navajo Nation, letter DCDA-L94052, June 20, 1995.
[2] These numbers are a percentage of the Community Water Systems.

NTUA Water Systems – The cities and surrounding communities of Oak Springs, Red Valley, Sweetwater, Chinle , Rough Rock, Round Rock, Rock Point, Wheatfields, Lukachukai, Kayenta, Chilchinbeto, Dennehotso, and Kaibeto derive most of their domestic water supply from wells operated by NTUA. Well pumping records are available. According to these records, the total water pumped for 2009 was 1,619 acre-feet with an uncertainty estimated to be 7 percent of this value or ±113 acre-feet.

The NTUA manages the raw waste water; portions of which flow to individual septic tanks, some to evaporation ponds, and some, such as for the cities of Chinle and Kayenta, flow to waste water treatment plants. Very little water, if any, is returned to the ground water system through leakage from the evaporation ponds, but there are losses from the main collection system. Effluent from the Chinle and Kayenta waste water treatment plants is metered. Under normal conditions, the effluent returns to the Colorado River System and is subtracted from the pumping totals to determine a net consumptive use. For 2009, Chinle's treatment plant effluent was 14.6 (±1.0) acre-feet, and Kayenta's effluent was 6.9 (±0.5) acre-feet. An estimated uncertainty of 7 percent was used for the effluent of these two plants. The total effluent of 22 acre-feet is subtracted from the NTUA pumping total of 1,619 acre-feet to arrive at a net consumptive use of 1,598 (±113) acre-feet.

BIA Water Systems – Wells developed and operated by the BIA serve numerous Navajo communities. These systems also serve BIA schools, hospitals, agency offices, and some housing on the Navajo Nation. Metered records for total amounts of water pumped from BIA wells were available for a portion of the Shiprock Agency, the Western Navajo Agency, and the Chinle Agency. Drawing 1246-406-2 shows the agency boundaries within the Upper Colorado River Basin. The uncertainty was estimated to be about 7 percent for all three agencies.

The BIA systems include sewage disposal units terminating in lined evaporation ponds with very little or no return water returning to the ground water system. Undoubtedly, some losses occur in distribution, but insufficient data currently exist to estimate these losses. The losses are probably less than the uncertainties for each of the reported values.

The BIA well data available for the Shiprock Agency include: Cove, Red Rock, and Teec Nos Pos. Total consumptive use values are 11 (±1) acre-feet.

Pumping records for the Western Navajo Agency include data for the following schools: Chilchinbeto Day School, Dennehotso Boarding School, Kaibeto Boarding School, and Kayenta Boarding School. Total consumptive use for the Western Navajo Agency was 172 (±12) acre-feet.

Well pumping records for the Chinle Agency include data for the following schools: Cottonwood Day School, Lukachukai School, and Rock Point School. Rough Rock School maintains its own records, but the data was included with the Chinle Agency data. Total consumptive use for the Chinle Agency was 69 (±5) acre-feet.

Navajo WOM Water Systems – Water use in 2009 by the Navajo WOM service areas was based on an assumed consumption rate of 110 gallons per capita per day (gpcd). For a 2009 estimated service area population of 4,347, the estimated annual water use was 536 (±161) acre-feet. The uncertainty is estimated as 30 percent of the total.

Private Water Systems – The estimated 2009 population served by private water systems on the Navajo Nation was 669. Assuming a consumptive use rate of 110 gcpd, the annual water use for 2009 was 82 (±25) acre-feet. The uncertainty is estimated as 30 percent of the total.

Individual Wells – According to census data from the Division of Community Development of the Navajo Nation, approximately 17 percent of the study area's population on the reservation (about 6,849 persons in 2009) receives a domestic water supply from individual wells. A consumptive use of 110 gpcd was derived as being a reasonable water use rate. Based on these figures, the annual consumptive use was 844 (±253) acre-feet for 2009.

TOTAL MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

The total municipal and industrial consumptive use, displayed in table 7, is the sum of the individual components discussed in the previous sections. Municipal and industrial water consumption represents approximately 83 percent of the total use in the study area.

Table 7.—Total municipal and industrial consumptive use, 2009

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
THERMAL ELECTRIC POWER		
Navajo Generating Station	26,073	782
OTHER		
Page, AZ and Vicinity		
City of Page	318	89
Le Chee	95	3
Greenhaven Water Company	121	8
Arizona Department of Transportation	8	2
Navajo Indian Reservation		
Community Water Systems		
NTUA Water Systems	1,598	113
BIA Water Systems	252	13
Navajo WOM	536	161
Private Water Systems	82	25
Individual Wells	844	253
TOTAL	29,927	850

It is questionable whether all the water pumped from wells should be considered a depletion to the Colorado River System; however, it is assumed that 100 percent of the water pumped is considered lost to the system. It is proposed that a future joint study be completed by Reclamation, the State of Arizona, and the Navajo Nation to estimate what percentage of water pumped could actually be attributed to the Colorado River System and would have affected the river flows for a particular year.

RECREATION, FISH AND WILDLIFE

The recreation, fish and wildlife consumptive uses include evaporation from reservoirs used exclusively for fish & wildlife purposes as well as acreages irrigated for wildlife feeding. Consumptive use related to recreation at National parks is also addressed.

GLEN CANYON NATIONAL RECREATION AREA

Colorado River water is used by the Glen Canyon National Recreation Area (GCNRA) at Wahweap and Lees Ferry. The recreational area at Wahweap gets its water supply from a series of wells on the shore of Lake Powell. Pumping records for both Wahweap Marina, and Lees Ferry show 334 ($\pm$10) acre-feet of water withdrawn during 2009. The uncertainty is estimated at 3 percent. This water was used for domestic purposes at the

campgrounds, picnic areas, and trailer parks. It was also used to irrigate approximately 60 acres of Bermuda grass and cottonwood trees. The domestic waste water is treated and the effluent is allowed to evaporate from two lined evaporation ponds with a total surface area of 16.7 acres.

Based on estimates of evaporation and consumptive use by the plants, there is some water which is unaccounted for and is assumed to be leakage from the delivery system, the evaporation pond, or deep percolation from irrigation application. However, since these water losses are difficult to quantify and verify, the losses were charged as consumptive uses. Therefore, net consumptive use of water is estimated to be equal to the quantity of water pumped.

RESERVOIR EVAPORATION

A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 8.

Table 8. —Recreation, fish and wildlife reservoir evaporation, 2009

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE AREA USED (ACRES)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Tsaile	260	260	35	6.49	28.51	618
Wheatfields	272	272	32	6.49	25.51	578
TOTAL	532	532				1,196

Efforts are made to maintain a nearly full condition and to minimize water surface fluctuations in reservoirs managed for a fishery. Under average operating conditions, the water surface area of a reservoir used primarily for fishing is assumed to be equal to a normal water surface area. It is assumed that, in 2009, these reservoirs filled in the spring and were maintained at the normal pool level.

This method of evaporation estimation was used because continuous useful water level records for all reservoirs from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs.

For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for reservoir evaporation for calendar year 2009 are shown in table 8. The total evaporative losses in 2009 are 1,196 ($\pm$359) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent.

TOTAL RECREATION, FISH AND WILDLIFE

The total recreation, fish and wildlife consumptive use, displayed in table 9, is the sum of the individual components discussed in the previous sections. Recreation, fish and wildlife water consumption represents approximately 4 percent of the total use in the study area.

Table 9.—Total recreation, fish and wildlife consumptive use, 2009

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Glen Canyon National Recreation Area	334	10
Reservoir Evaporation	1,196	359
TOTAL	1,529	359

RESERVOIR EVAPORATION

Reservoir evaporation losses make up about 7 percent of the total water uses and losses in the study area. A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 10. These reservoirs are used primarily for irrigation.

Table 10.—Reservoir evaporation, 2009

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE ACRES USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Many Farms	1,800	554	68%	56	6.49	49.51	2,288
Marsh Pass	40	13	64%	40	7.19	32.81	35
Round Rock	83	30	73%	57	6.47	50.53	128
Walker Creek	30	12	80%	59	6.44	52.56	52
Others	38	13	68%	55	6.86	48.14	52
TOTAL	1,991	623					2,555

Reservoirs used primarily for irrigation experience large fluctuations in water levels and, correspondingly, large variations in surface area. Reservoir level records and elevation – area curves were available at Many Farms, but not for the remaining reservoirs in table 10. For the reservoirs with no records from which surface area could be accurately computed, the average evaporative surface area was estimated as one-half the water

surface area of a full reservoir. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average evaporative surface area.

Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses. The computed values for reservoir evaporation for 2008 are shown in table 10. The total evaporative losses in 2009 are 2,555 (±766) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent of the total evaporation.

CONCLUSIONS

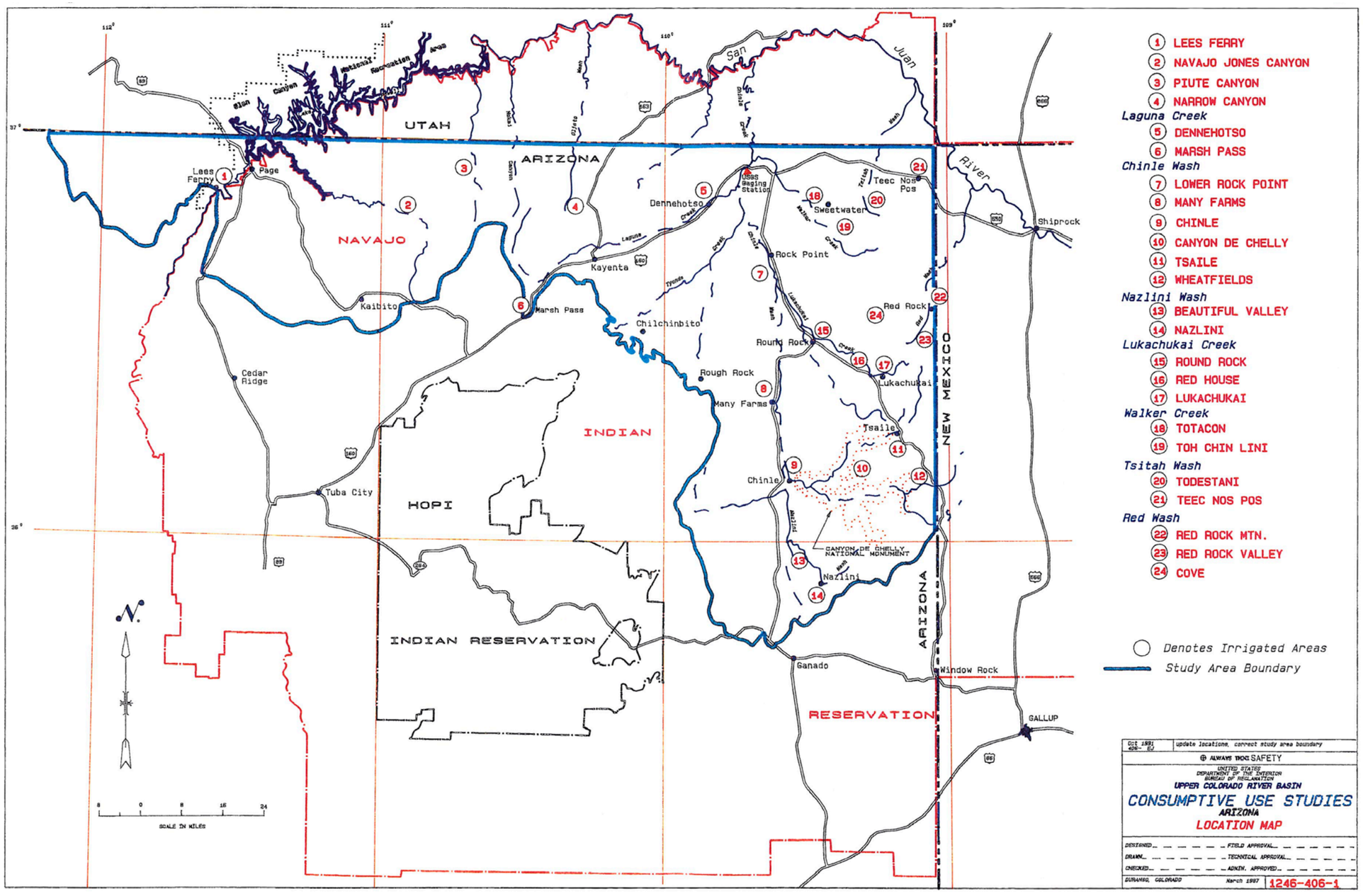
This report assesses the total consumptive use of the Arizona portion of the Upper Colorado River System surface water systems, depletion of ground water, and evaporative losses. Clearly, the amounts of water used by the Navajo Generating Station, City of Page, and Wahweap and Lees Ferry recreation areas are direct depletions of water from the Upper Colorado River System, but the situation is not as clear for other consumptive uses and losses occurring in other sections of the study area. For example, the source of water used by the Navajo Nation for domestic and municipal purposes is from wells, some exceeding 1,000 feet in depth. For our purposes here, it is considered to be consumed and a depletion to the Colorado River System. But this may not actually result in a reduction of Colorado River stream flows in the same year that the withdrawal occurs. Little knowledge and information exists of ground water movement and subsurface flow rates in the study area that are accurate descriptions of the effects on river flows.

Although the water diverted for agricultural purposes is considered as consumptive use in this report, a portion of the remaining surface water on the Navajo Nation, excess to needs, does evaporate before reaching the Colorado River. No attempt has been made for this report to quantify these losses.

Uncertainties in estimating uses and losses exist, and the degree of variation in the figures is presented. Fortunately, the areas with the highest degree of uncertainty account for only a small percentage of the total consumptive use. The largest component, use by the Navajo Generating Station, is also the most accurately monitored. The total annual value for estimated consumptive use of water within the Arizona portion of the Upper Colorado River Basin for 2009 was 35,937 acre-feet, as shown in table 11.

Table 11.—Consumptive use for Arizona portion of Upper Colorado River Basin for 2009

USE CATEGORY	TOTAL CONSUMPTIVE USE (ACRE-FEET)	UNCERTAINTY	PERCENT OF TOTAL
Agriculture	1,926	391	5.4
Municipal & Industrial	29,927	850	83.3
Recreation, Fish & Wildlife	1,529	359	4.3
Reservoir Evaporation	2,555	766	7.0
TOTAL	35,937	1,262	100


UTAH
ARIZONA
NAVAJO
INDIAN
HOPI
INDIAN RESERVATION
RESERVATION
NEW MEXICO
ARIZONA
Lees Ferry
Page
Kaibito
Cedar Ridge
Tuba City
Marsh Pass
Kayenta
Dennehotso
Chilchinbito
Rough Rock
Many Farms
Chinle
Rock Point
Round Rock
Sweetwater
Tsaile
Lukachukai
Red Rock
Teec Nos Pos
Shiprock
Ganado
Window Rock
GALLUP
CANYON DE CHELLY NATIONAL MONUMENT
Nazlini
San Juan River
SCALE IN MILES
1 LEES FERRY
2 NAVAJO JONES CANYON
3 PIUTE CANYON
4 NARROW CANYON
Laguna Creek
5 DENNEHOTSO
6 MARSH PASS
Chinle Wash
7 LOWER ROCK POINT
8 MANY FARMS
9 CHINLE
10 CANYON DE CHELLY
11 TSAILE
12 WHEATFIELDS
Nazlini Wash
13 BEAUTIFUL VALLEY
14 NAZLINI
Lukachukai Creek
15 ROUND ROCK
16 RED HOUSE
17 LUKACHUKAI
Walker Creek
18 TOTACON
19 TOH CHIN LINI
Tsitah Wash
20 TODESTANI
21 TEEC NOS POS
Red Wash
22 RED ROCK MTN.
23 RED ROCK VALLEY
24 COVE
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BUREAU OF RECLAMATION
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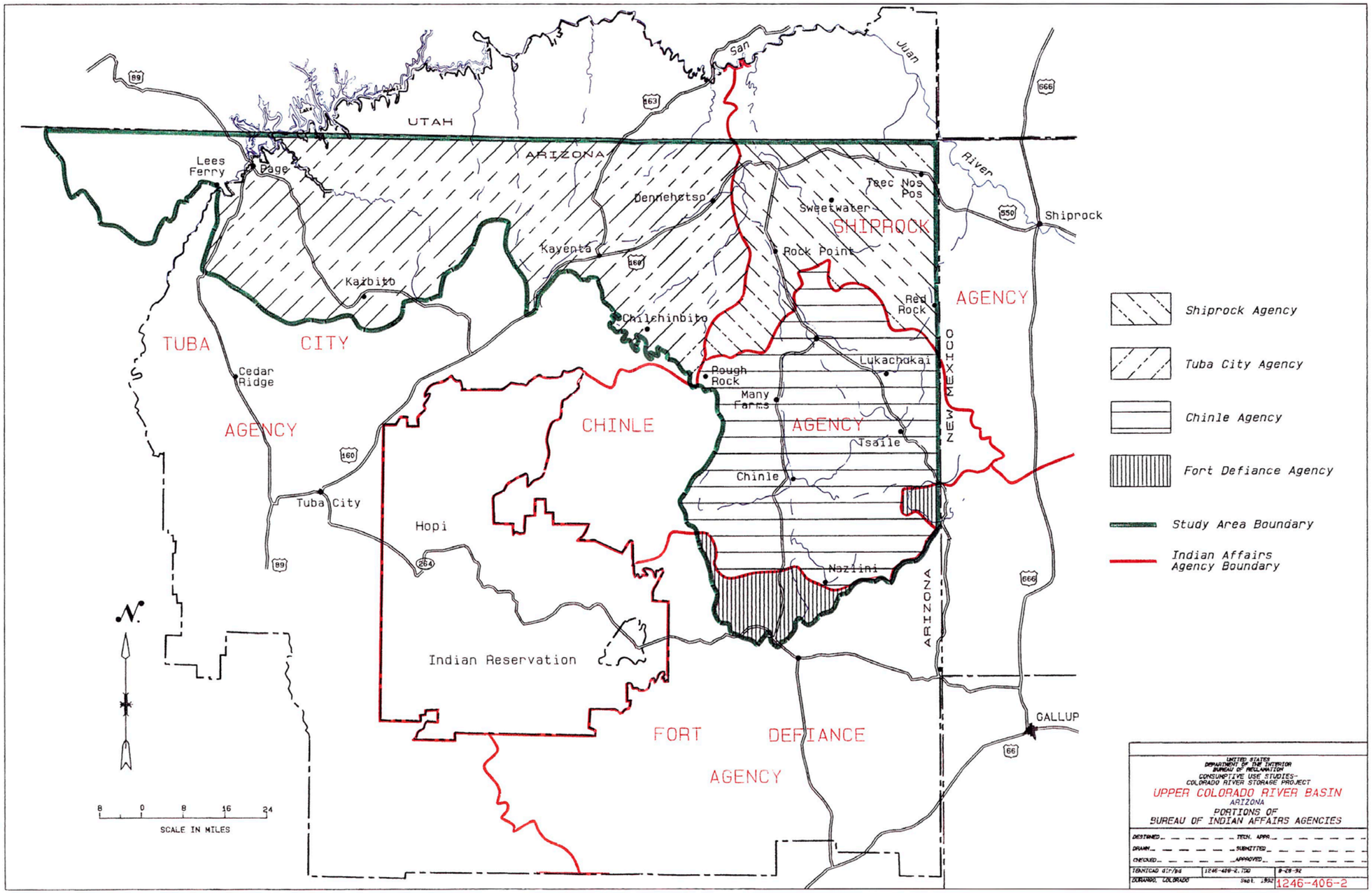
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Sweetwater
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Red Rock
AGENCY
Shiprock
Lukachukai
Rough Rock
Many Farms
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Chinle Agency
Fort Defiance Agency
Study Area Boundary
Indian Affairs Agency Boundary
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UNITED STATES
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BUREAU OF RECLAMATION
CONSUMPTIVE USE STUDIES-
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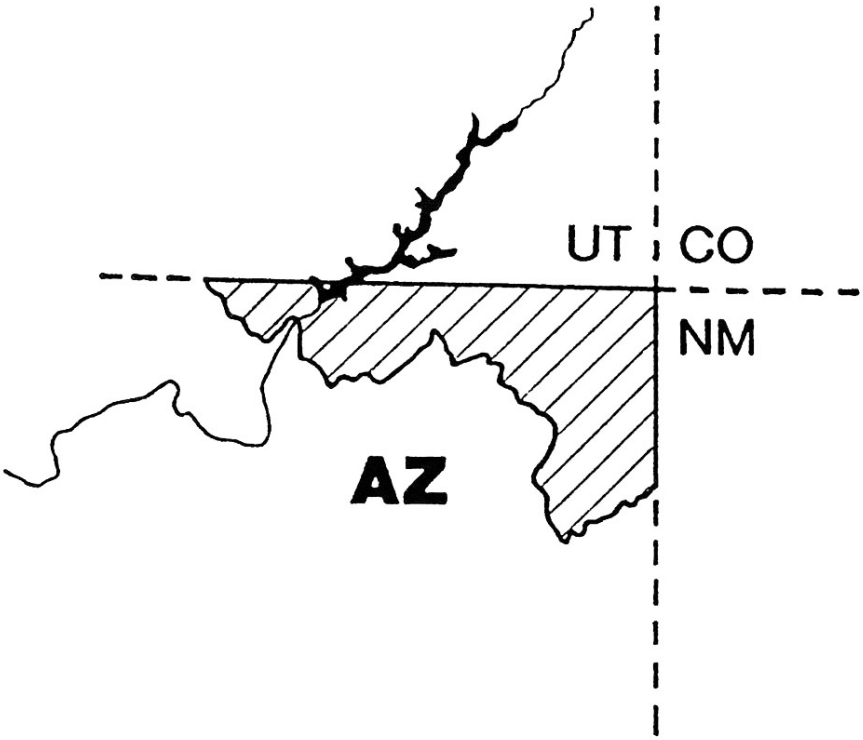
RECLAMATION

Managing Water in the West

Consumptive Uses and Losses: Final Estimate

Arizona Portion of the Upper Colorado River Basin Calendar Year 2010



U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

September 2014

RECLAMATION

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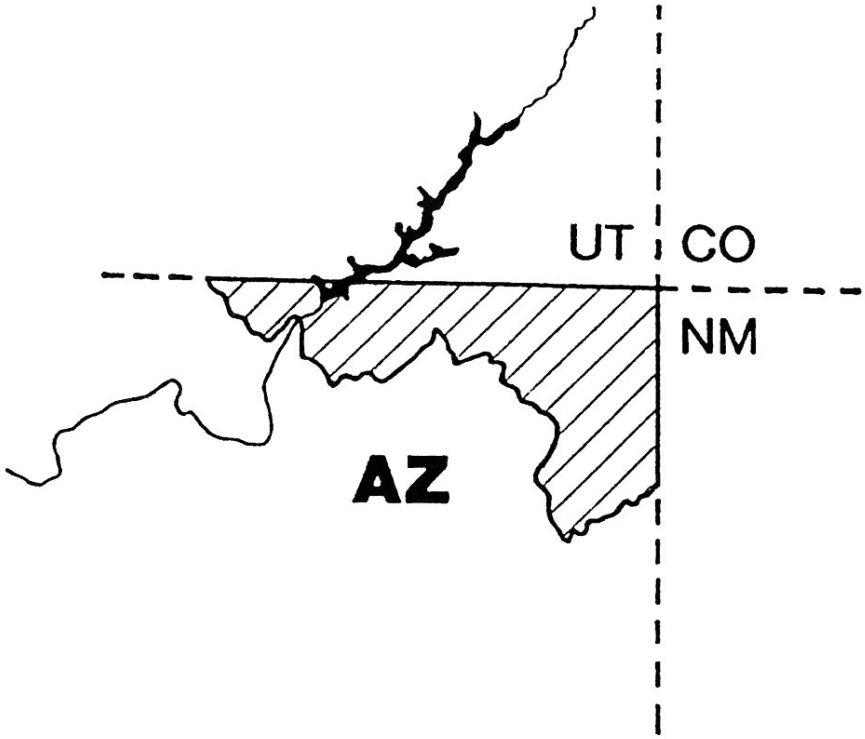

Prepared by: Alan Harrison – September 23, 2014

U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

September 2014

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UPPER COLORADO RIVER BASIN

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AUTHORITY

This report was prepared in compliance with Public Law 90-537, Section 601 (b)(1), dated September 30, 1968, which directs the Secretary of the Interior to "make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis." Additionally, this report is in compliance with Section 49 of the Navajo Project Participation Agreement dated September 30, 1969, which states in part: "The Secretary of the Interior further agrees to make the reports required by Section 601 (b)(1) of Public Law 90-537 as they pertain to Arizona's Upper Basin uses annually rather than every five years. Within fifteen days following the completion of said reports, the Secretary of the Interior shall furnish copies of such reports to the Co-Tenants, the Navajo Tribe, each of the Upper Basin States, and the Upper Colorado River Commission."

SUMMARY

Based upon data made available for preparation of this document. the total consumptive use and loss value for the Arizona portion of the Upper Colorado River Basin for calendar year 2010 was 35,150 (±1,241) acre-feet. Reclamation prepares this estimate annually, final annual values for consumptive uses and losses for the northern Arizona portion of the Colorado River basin are published in the 5-year summary documents for the Upper Colorado River Basin

STUDY AREA DESCRIPTION

The Arizona portion of the Upper Colorado River Basin covers approximately 6,900 square miles in the north-east corner of Arizona, as shown on the location maps shown on pages 19 and 20 (Drawings 1246-406-1, 1246-406-2). The climate of the 5,900 square mile area to the west of the Chuska and Carrizo Mountains is largely arid to semiarid, with mean annual precipitation ranging from 6 to 12 inches and with summertime temperatures often reaching 100 degrees Fahrenheit (^{o}F). The potential

evaporation rate is high and exceeds mean annual precipitation, with gross lake evaporation values of up to 55 inches per year or more. Elevations in the western portion range from 3200 feet on the Colorado River at Lees Ferry to over 8000 feet on the northern edge of the Black Mesa and across the Zilnez and Skeleton Mesas, back down to 5280 feet in the Chinle Valley, and back up to about 6500 feet on the western edge of the Chuska Mountains. Much of the western part of the study area is starkly beautiful southwestern desert country with mesas and canyons intertwined across a pastoral landscape. By contrast, the eastern 1,000 square miles is largely mountainous, with elevations rising to nearly 10,000 feet and mean annual precipitation reaching 30 inches. The mountainous land responds with grass meadows interspersed with conifer forest of mostly ponderosa pine.

Except for Page, Arizona; a small area around Lees Ferry; and a portion of the Paria Plateau administered by the Bureau of Land Management; the study area lies entirely within the Navajo Nation. Based 2010 census data for the area, it is estimated that approximately 47,265 persons were living within the study area in 2010, and of these an estimated 40,018 resided on the Navajo Nation.

The largest cities are Page and Chinle, with 2000 populations of 6,809 and 5,366, respectively. Other major communities and their populations include Dennehotso (734), Kaibeto (1,607), Kayenta (4,922), LeChee (1,606), Lukachukai (1,565), Many Farms (1,548), Rock Point (724), Teec Nos Pos (799), and Tsaile (1,078). Subsistence in the region is derived principally from livestock grazing, farming, tourist-related industries, employment at the Navajo Generating Station (NGS), which consumes 73 percent of the water used or lost in the study area. Agriculture accounted for about 8 percent of the total water use; municipal and industrial about 82 percent; recreation, fish and wildlife, about 3 percent; and reservoir evaporation, about 7 percent.

AGRICULTURAL CONSUMPTIVE USE

Agricultural consumptive use is divided into three categories: irrigation, stock pond, and livestock. Irrigation use includes all use related to irrigating crops including the incidental losses. Stock pond use is the evaporation that occurs from stock ponds and livestock use is the water consumed by livestock.

IRRIGATION USES

Within the Arizona portion of the Upper Colorado River Basin, historically 23 irrigated areas were scattered across the Navajo Nation plus a small amount of land near Lees Ferry irrigated by the National Park Service. Currently, only 16 irrigated areas are in production. An accurate assessment of consumptive use on the irrigated land is difficult due to poor quality of information, such as the exact number of acres under irrigation, the cropping pattern for each irrigated area, site climatological conditions, and the amount s of water actually diverted. In many cases, during the latter part of the irrigation season, farmers have to rely on dry land farming since there is little water available in the streams. This means that the crops do not receive their full water requirement.

For this report, the U.S. Department of Agriculture, Soil Conservation Service's (SCS) Modified Blaney-Criddle ET estimation model was used for computing irrigated crop consumptive use. This model, along with appropriate crop-growth stage coefficients and the method for computing effective precipitation, is described in SCS's *Irrigation Water Requirements Technical Release No. 21* (TR 21). Information required for applying this model includes mean monthly temperature and precipitation values, growing season data for each crop type, and the total number of acres planted by crop at each site. With the exception of Teec Nos Pos, Canyon de Chelly, Lukachukai, and Lees Ferry, no climatological data exist for the irrigation sites, and site values must be generated from data collected at surrounding established weather stations. Growing season dates depend largely on the judgment of the local inhabitants and are, therefore, not known. Although several reports are available with published values for irrigated acres, it is unclear if these values are meant to represent potential irrigated acres, acres irrigated in the past, acres for which farming permits have been issued, or actual acres currently under irrigation.

The crop acreage used to estimate consumptive use by irrigated crops for the year 2010 is shown in table 1. These values were determined from direct field examination by a party composed of representatives from the State of Arizona and the Navajo Nation.

Table 1.—Total irrigated acreage, 2010

PROJECT	CORN (ACRES)	ALFALFA (ACRES)	GRASS PASTURE (ACRES)	SPRING GRAINS (ACRES)	SMALL VEGETABLES (ACRES)	ORCHARD (ACRES)	TOTAL (ACRES)
CHINLE AGENCY							
Canyon de Chelly	0.36	0.00	0.00	3.03	2.26	0.00	5.65
Lukachukai	39.09	7.69	0.00	7.50	5.98	2.07	62.33
Many Farms	128.80	21.49	79.53	2.10	21.49	0.00	253.40
Nazlini	0.00	0.00	0.00	0.00	1.79	0.74	2.53
Rough Rock	30.00	0.00	11.87	0.00	12.43	0.00	54.30
Tsaile	23.72	5.27	15.67	5.73	5.42	0.00	55.81
Wheatfields	0.00	60.80	0.00	0.00	0.00	0.00	60.80
TOTAL	221.97	95.25	107.07	18.36	49.37	2.81	494.82
SHIPROCK AGENCY							
Red Rock Valley	26.22	0.00	10.19	5.12	10.22	0.00	51.75
Teec Nos Pos	20.00	0.00	0.00	0.00	3.67	0.00	23.67
Toh Chin Lini	0.00	0.00	0.00	0.00	3.90	13.67	17.57
Totacon	0.00	0.00	0.00	0.00	1.00	0.00	1.00
TOTAL	46.22	0.00	10.19	5.12	18.79	13.67	93.99
WESTERN NAVAJO AGENCY							
Dennehotso	1.82	0.00	38.70	0.00	0.00	0.00	40.52
Lees Ferry	0.00	0.00	1.00	0.00	0.00	2.00	3.00
Marsh Pass	7.02	3.31	0.00	0.00	1.99	0.00	12.32
Navajo Canyon	0.00	0.00	0.00	0.00	0.00	3.50	3.50
Paiute Canyon	2.64	0.00	0.00	0.00	3.86	0.00	6.50
TOTAL	11.48	3.31	39.70	0.00	5.85	5.50	65.84
GRAND TOTAL	279.67	98.56	156.96	23.48	74.01	21.98	654.65

Several factors complicated the modeling of irrigation consumptive use. For example, the computer program used to model consumptive use assumes a full water supply; if shortages exist, as they often do in this semiarid study area, adjustments must be made. These adjustments are complicated because some of the projects have no storage water and may only have a reliable irrigation water supply during spring runoff. After spring runoff, farming becomes essentially dry land until rains in July and August provide intermittent flows for irrigation. Finally, no ditch diversion records are available to help estimate irrigation water supplies and shortages.

A full irrigation supply seldom exists at many of the projects. Generally, a full supply is available for Lees Ferry, Navajo Canyon, Tsaile, and Wheatfields projects because of adequate stream flows or because of available storage water. In years with average precipitation, it is estimated that Chinle Wash provides approximately 75 percent of the irrigation requirement. Precipitation in the area averages approximately 9.5 inches per year. Based on this information, it would require approximately 12.67 inches of precipitation to provide 100 percent of the irrigation requirement. The percent of crop water requirement met was computed as a ratio of annual precipitation to 12.67 inches. These values are found in table 2.

The percentage of crop water requirement met was multiplied by the total net crop water requirement to come up with the amount of crop consumptive use. Incidental irrigation losses, evaporation, and phreatophyte consumptive use along supply canals are estimated to be 5 percent of the consumptive use of the irrigated area and are added to the crop consumptive use value to develop a total consumptive use value.

A portion of the water used for irrigation at these sites may not be contributing to the Colorado River System since evaporation rates in the area are high and the nature of most of the drainage enhances evapotranspiration. A good example of such a drainage is Chinle Wash, which after it leaves Canyon de Chelly, becomes wide and sandy and is lined with willows, cottonwoods, and other phreatophytes.

The uncertainties in the irrigation consumptive use values displayed in table 2 are very large and are estimated as 40 percent of the total consumptive use. This estimate of possible error only reflects the uncertainty of consumptive use and does not account for any possible errors in the acreage estimates. The effective consumptive use for irrigation for 2010 was estimated to equal 1,152 acre-feet. Including the 5 percent for incidental losses, the irrigation related consumptive use is 1,210 (±484) acre-feet.

Table 2.—Net consumptive use values, 2010

PROJECT	CROP WATER REQUIREMENT (INCHES)	TOTAL IRRIGATED (ACRES)	TOTAL WATER REQUIRED (ACRE-FEET)	CROP WATER REQUIREMENT MET (%)	CROP WATER REQUIREMENT MET (ACRE-FEET)	TOTAL CONSUMPTIVE USE (ACRE-FEET)[1]
CHINLE AGENCY						
Canyon de Chelly	23.71	5.65	11	97 %	11	11.3
Lukachukai	20.15	62.33	105	97%	101	106.2
Many Farms	24.28	253.40	513	97%	495	520.0
Nazlini	18.28	2.53	4	97%	4	3.9
Rough Rock	19.42	54.3	88	100%	88	92.3
Tsaile	20.84	55.81	97	97%	94	98.3
Wheatfields	27.44	60.80	139	97%	134	141.0
TOTAL	154.13	494.82	956		927	973.0
SHIPROCK AGENCY						
Red Rock Valley	22.67	51.75	98	81%	79	82.9
Teec Nos Pos	25.04	23.67	49	65%	32	33.6
Toh Chin Lini	34.67	17.57	51	32%	16	17.3
Totacon	22.92	1.00	2	32%	1	0.7
TOTAL	105.30	93.99	200		128	134.4
WESTERN NAVAJO AGENCY						
Dennehotso	34.28	40.52	116	48%	56	58.7
Lees Ferry	40.71	3.00	10	100%	10	10.7
Marsh Pass	18.27	12.32	19	83%	16	16.3
Navajo Canyon	35.07	3.50	10	87%	9	9.3
Paiute Canyon	22.84	6.50	12	55%	7	7.2
TOTAL	151.17	65.84	167		97	102.2
GRAND TOTAL	410.60	654.65	1323		1152	1209.6

[1] Total includes 5% addition for incidental losses.

STOCK POND EVAPORATION

Stock pond consumptive use is assumed to be the evaporation from the stock pond. It is also assumed that any consumptive use by natural vegetation prior to the construction of the stock ponds is limited to precipitation which is subtracted from the evaporation losses.

A compilation of the stock ponds in the study area, including their locations and the water surface areas when ponds are full, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 3. For an average year conditions, the stock pond evaporative surface area was estimated as one-third the water surface area that occurs when the ponds are full. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average water surface area. These values are found in table 3.

Table 3.—Stock pond evaporation, 2010

COUNTY	SURFACE AREA FULL (ACRES)	SURFACE AREA USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Coconino	80	27	100	57	10.38	46.62	104
Navajo	40	13	100	55	11.21	43.79	49
Apache	646	215	100	53	10.22	42.78	768
TOTAL	766	255					920

This method of evaporation estimation was used because continuous useful water level records for all stock ponds from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual stock ponds. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation. It was assumed that any consumptive use by natural vegetation prior to construction of the stock ponds is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for stock pond evaporation for calendar year 2010 are shown in table 3. The total evaporative losses in 2010 are 920 (±276) acre-feet with the stock pond evaporation uncertainty being estimated as 30 percent.

LIVESTOCK WATER

The source of most livestock water in the study area is from wells, with windmill-operated pumps developed and maintained by Navajo Water Operations and Maintenance, and water collected in small surface ponds. The estimated number of

livestock in the area was obtained based on livestock tallies. It was estimated that horses and cattle consume 12 gallons per day; sheep and goats consume 2 gallons per day.

The number of animals for the Upper Colorado portion of each district is shown in table 4. The computed value for livestock consumptive use is 533 acre-feet. The uncertainty in this number is estimated as 30 percent of the total or ±160 acre-feet.

Table 4.—Number of livestock, 2010

AGENCY	CATTLE	HORSES	SHEEP	GOATS
Western Navajo District No. 1	1,079	102	1,848	881
Western Navajo District No. 2	902	209	1,315	1,019
Western Navajo District No. 8	5,822	3,861	7,463	5,915
Shiprock District No. 9	2,209	1,115	2,795	3,013
Chinle District No. 10	3,125	1,964	4,074	2,824
Chinle District No. 11	1,504	997	1,538	1,360
Shiprock District No. 12	4,448	3,435	5,115	4,201
Fort Defiance District No. 17	311	66	1,502	401
Fort Defiance District No. 18	636	143	992	231
TOTAL	20,036	11,892	26,642	19,845

TOTAL AGRICULTURAL CONSUMPTIVE USE

The total agricultural consumptive use, displayed in table 5, is the sum of the individual components discussed in the previous sections. Agricultural water consumption represents approximately 8 percent of the total use in the study area. Total degree of uncertainty was computed by taking the square root of the sum of the individual uncertainties squared; known as the quadratic sum. This method and nomenclature is used throughout this report. This method was used because a simple sum does not account for the partial cancellation of errors occurring when calculating the total uncertainty derived from individual values that are random and independent of each other. As previously discussed, the individual uncertainties were set as a percent of the consumptive use value.

Table 5.—Total agricultural consumptive use, 2010

CATEGORY	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Irrigation	1,210	484
Stock Ponds	920	276
Livestock	533	160
TOTAL	2,663	580

MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

Municipal and industrial consumptive use is divided into three categories: mineral resources, thermal electric power, and other. Mineral resources consumptive use includes water used for mineral production. No mineral resources consumptive use is reported in the study area. Thermal electric power consumptive use includes the water used at the power plants, and that used to transport material to the power plant (such as a coal slurry pipeline). Other consumptive use includes urban, rural, and industrial uses.

THERMAL ELECTRIC POWER

Thermal electric power consumptive use includes the water used in the power plant and the water used to transport material to the plant.

Navajo Generating Station

The water used by the NGS is pumped directly from Lake Powell and comprises over half of the total consumption in the study area. Since all NGS water use is metered, this quantity is among those most precisely known, with the maximum uncertainty in the metered quantities believed to be less than 3 percent. The actual quantity consumed, along with the estimated uncertainty for the calendar year 2010, was 23,948 (±718) acre-feet.

OTHER

The other consumptive use category includes the remaining use by urban, rural, and industries.

Page, AZ and Vicinity

City of Page, AZ. – The city of Page pumps its domestic water directly from Lake Powell. The water pumped is metered, and the uncertainty of the pumped quantities was assumed to be less than 3 percent. A portion of the water pumped and treated by the City

of Page, is supplied to the community of Le Chee on the Navajo Nation and is accounted for separately. The quantity supplied to the City of Page and its associated uncertainty for the calendar year 2010 was 2,096 (±63) acre-feet. Water returning to the waste water treatment plant is metered as well. The waste water for the City of Page is treated and is either evaporated from lined ponds or applied to the golf course, with a portion being returned to the Colorado River. The return flow is estimated to be 637 acre-feet. The net consumptive use is estimated to be 1,459 acre-feet (±66).

Le Chee – The community of Le Chee is supplied and metered by the City of Page. Total water supplied for 2010 was 91 (±3) acre-feet. The uncertainty was estimated to be 3 percent.

Greenhaven Water Company – The Greenhaven Water Company derives its domestic water supply from wells. Well pumping records are available. According to these records, the total water pumped for 2010 was 121 (±8) acre-feet. The uncertainty was estimated to be 7 percent.

Arizona Department of Transportation Housing – The Arizona Department of Transportation operates a housing, maintenance, and administrative facility located on US Hwy 89, north of Page, AZ. This facility is supplied from wells that have no meters installed. It is estimated that the total water pumped for 2010 was 7 acre-feet with an uncertainty of 30 percent of this value or ±2 acre-feet.

Navajo Nation

Community Water Systems – Statistics from the Division of Community Development of the Navajo Nation reveal that various community water systems served 26,086, or about 83 percent of the 31,429 people residing within the study area in 1980. This percentage was used for 2010 resulting in 33,215 out of 40,018 people being served. These systems include those operated by the Navajo Tribal Utility Authority (NTUA), the BIA, and the Water Operations and Maintenance Department of the Navajo Nation, and some privately developed community water systems.

Table 6 shows the source of water and estimated population served by each source of water for people living on the Navajo Nation during 2010. All of the communities obtain their water supply from ground water.

Table 6.—Domestic water sources, 2010

SOURCE	PERCENTAGE OF POPULATION SERVED	NUMBER OF POPULATION SERVED[1]
Community Water Systems	83	33,215
NTUA	[2](60)	19,929
BIA	[2](25)	8,304
Navajo WOM	[2](13)	4,318
Private	[2](2)	664
Individual Wells	17	6,803
TOTAL[2]	100	40,018

[1] Estimated total population within the Upper Colorado River Basin portion of the Navajo Nation provided by Larry Rodgers, Demographer for the Division of Community Development of the Navajo Nation, letter DCDA-L94052, June 20, 1995.
[2] These numbers are a percentage of the Community Water Systems.

NTUA Water Systems – The cities and surrounding communities of Oak Springs, Red Valley, Sweetwater, Chinle , Rough Rock, Round Rock, Rock Point, Wheatfields, Lukachukai, Kayenta, Chilchinbeto, Dennehotso, and Kaibeto derive most of their domestic water supply from wells operated by NTUA. Well pumping records are available. According to these records, the total water pumped for 2010 was 1,619 acre-feet with an uncertainty estimated to be 7 percent of this value or ±113 acre-feet.

The NTUA manages the raw waste water; portions of which flow to individual septic tanks, some to evaporation ponds, and some, such as for the cities of Chinle and Kayenta, flow to waste water treatment plants. Very little water, if any, is returned to the ground water system through leakage from the evaporation ponds, but there are losses from the main collection system. Effluent from the Chinle and Kayenta waste water treatment plants is metered. Under normal conditions, the effluent returns to the Colorado River System and is subtracted from the pumping totals to determine a net consumptive use. For 2010, Chinle's treatment plant effluent was 13.6 (±1.0) acre-feet, and Kayenta's effluent was 9.7 (±0.7) acre-feet. An estimated uncertainty of 7 percent was used for the effluent of these two plants. The total effluent of 23 acre-feet is subtracted from the NTUA pumping total of 1,619 acre-feet to arrive at a net consumptive use of 1,596 (±113) acre-feet.

BIA Water Systems – Wells developed and operated by the BIA serve numerous Navajo communities. These systems also serve BIA schools, hospitals, agency offices, and some housing on the Navajo Nation. Metered records for total amounts of water pumped from BIA wells were available for a portion of the Shiprock Agency, the Western Navajo Agency, and the Chinle Agency. Drawing 1246-406-2 shows the agency boundaries within the Upper Colorado River Basin. The uncertainty was estimated to be about 7 percent for all three agencies.

The BIA systems include sewage disposal units terminating in lined evaporation ponds with very little or no return water returning to the ground water system. Undoubtedly, some losses occur in distribution, but insufficient data currently exist to estimate these losses. The losses are probably less than the uncertainties for each of the reported values.

The BIA well data available for the Shiprock Agency include: Cove, Red Rock, and Teec Nos Pos. Total consumptive use values are 11 (±1) acre-feet.

Pumping records for the Western Navajo Agency include data for the following schools: Chilchinbeto Day School, Dennehotso Boarding School, Kaibeto Boarding School, and Kayenta Boarding School. Total consumptive use for the Western Navajo Agency was 172 (±12) acre-feet.

Well pumping records for the Chinle Agency include data for the following schools: Cottonwood Day School, Lukachukai School, and Rock Point School. Rough Rock School maintains its own records, but the data was included with the Chinle Agency data. Total consumptive use for the Chinle Agency was 69 (±5) acre-feet.

Navajo WOM Water Systems – Water use in 2010 by the Navajo WOM service areas was based on an assumed consumption rate of 110 gallons per capita per day (gpcd). For a 2010 estimated service area population of 4,318, the estimated annual water use was 532 (±160) acre-feet. The uncertainty is estimated as 30 percent of the total.

Private Water Systems – The estimated 2010 population served by private water systems on the Navajo Nation was 664. Assuming a consumptive use rate of 110 gcpd, the annual water use for 2010 was 82 (±25) acre-feet. The uncertainty is estimated as 30 percent of the total.

Individual Wells – According to census data from the Division of Community Development of the Navajo Nation, approximately 17 percent of the study area's population on the reservation (about 6,803 persons in 2010) receives a domestic water supply from individual wells. A consumptive use of 110 gpcd was derived as being a reasonable water use rate. Based on these figures, the annual consumptive use was 838 (±251) acre-feet for 2010.

TOTAL MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

The total municipal and industrial consumptive use, displayed in table 7, is the sum of the individual components discussed in the previous sections. Municipal and industrial water consumption represents approximately 82 percent of the total use in the study area.

Table 7.—Total municipal and industrial consumptive use, 2010

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
THERMAL ELECTRIC POWER		
Navajo Generating Station	23,948	718
OTHER		
Page, AZ and Vicinity		
City of Page	1,459	66
Le Chee	91	3
Greenhaven Water Company	121	8
Arizona Department of Transportation	7	2
Navajo Indian Reservation		
Community Water Systems		
NTUA Water Systems	1,596	113
BIA Water Systems	252	13
Navajo WOM	532	160
Private Water Systems	82	25
Individual Wells	838	251
TOTAL	28,926	789

It is questionable whether all the water pumped from wells should be considered a depletion to the Colorado River System; however, it is assumed that 100 percent of the water pumped is considered lost to the system. It is proposed that a future joint study be completed by Reclamation, the State of Arizona, and the Navajo Nation to estimate what percentage of water pumped could actually be attributed to the Colorado River System and would have affected the river flows for a particular year.

RECREATION, FISH AND WILDLIFE

The recreation, fish and wildlife consumptive uses include evaporation from reservoirs used exclusively for fish & wildlife purposes as well as acreages irrigated for wildlife feeding. Consumptive use related to recreation at National parks is also addressed.

GLEN CANYON NATIONAL RECREATION AREA

Colorado River water is used by the Glen Canyon National Recreation Area (GCNRA) at Wahweap and Lees Ferry. The recreational area at Wahweap gets its water supply from a series of wells on the shore of Lake Powell. Pumping records for both Wahweap Marina, and Lees Ferry show 258 (±8) acre-feet of water withdrawn during 2010. The uncertainty is estimated at 3 percent. This water was used for domestic purposes at the

campgrounds, picnic areas, and trailer parks. It was also used to irrigate approximately 60 acres of Bermuda grass and cottonwood trees. The domestic waste water is treated and the effluent is allowed to evaporate from two lined evaporation ponds with a total surface area of 16.7 acres.

Based on estimates of evaporation and consumptive use by the plants, there is some water which is unaccounted for and is assumed to be leakage from the delivery system, the evaporation pond, or deep percolation from irrigation application. However, since these water losses are difficult to quantify and verify, the losses were charged as consumptive uses. Therefore, net consumptive use of water is estimated to be equal to the quantity of water pumped.

RESERVOIR EVAPORATION

A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 8.

Table 8. —Recreation, fish and wildlife reservoir evaporation, 2010

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE AREA USED (ACRES)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Tsaile	260	260	35	12.23	22.77	493
Wheatfields	272	272	32	12.23	19.77	448
TOTAL	532	532				941

Efforts are made to maintain a nearly full condition and to minimize water surface fluctuations in reservoirs managed for a fishery. Under average operating conditions, the water surface area of a reservoir used primarily for fishing is assumed to be equal to a normal water surface area. It is assumed that, in 2010, these reservoirs filled in the spring and were maintained at the normal pool level.

This method of evaporation estimation was used because continuous useful water level records for all reservoirs from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs.

For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for reservoir evaporation for calendar year 2010 are shown in table 8. The total evaporative losses in 2010 are 941 (±282) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent.

TOTAL RECREATION, FISH AND WILDLIFE

The total recreation, fish and wildlife consumptive use, displayed in table 9, is the sum of the individual components discussed in the previous sections. Recreation, fish and wildlife water consumption represents approximately 4 percent of the total use in the study area.

Table 9.—Total recreation, fish and wildlife consumptive use, 2010

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Glen Canyon National Recreation Area	258	8
Reservoir Evaporation	941	282
TOTAL	1,199	282

RESERVOIR EVAPORATION

Reservoir evaporation losses make up about 7 percent of the total water uses and losses in the study area. A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled “1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River” and are shown in table 10. These reservoirs are used primarily for irrigation.

Table 10.—Reservoir evaporation, 2010

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE ACRES USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Many Farms	1,800	554	100	56	12.23	43.77	2,022
Marsh Pass	40	20	100	40	12.59	27.41	46
Round Rock	83	42	100	57	10.22	46.78	162
Walker Creek	30	15	100	59	8.21	50.79	63
Others	38	19	100	55	11.48	43.52	69
TOTAL	1,991	650					2,362

Reservoirs used primarily for irrigation experience large fluctuations in water levels and, correspondingly, large variations in surface area. Reservoir level records and elevation – area curves were available at Many Farms, but not for the remaining reservoirs in table 10. For the reservoirs with no records from which surface area could be accurately computed, the average evaporative surface area was estimated as one-half the water

surface area of a full reservoir. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average evaporative surface area.

Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses. The computed values for reservoir evaporation for 2010 are shown in table 10. The total evaporative losses in 2010 are 2,362 (±709) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent of the total evaporation.

CONCLUSIONS

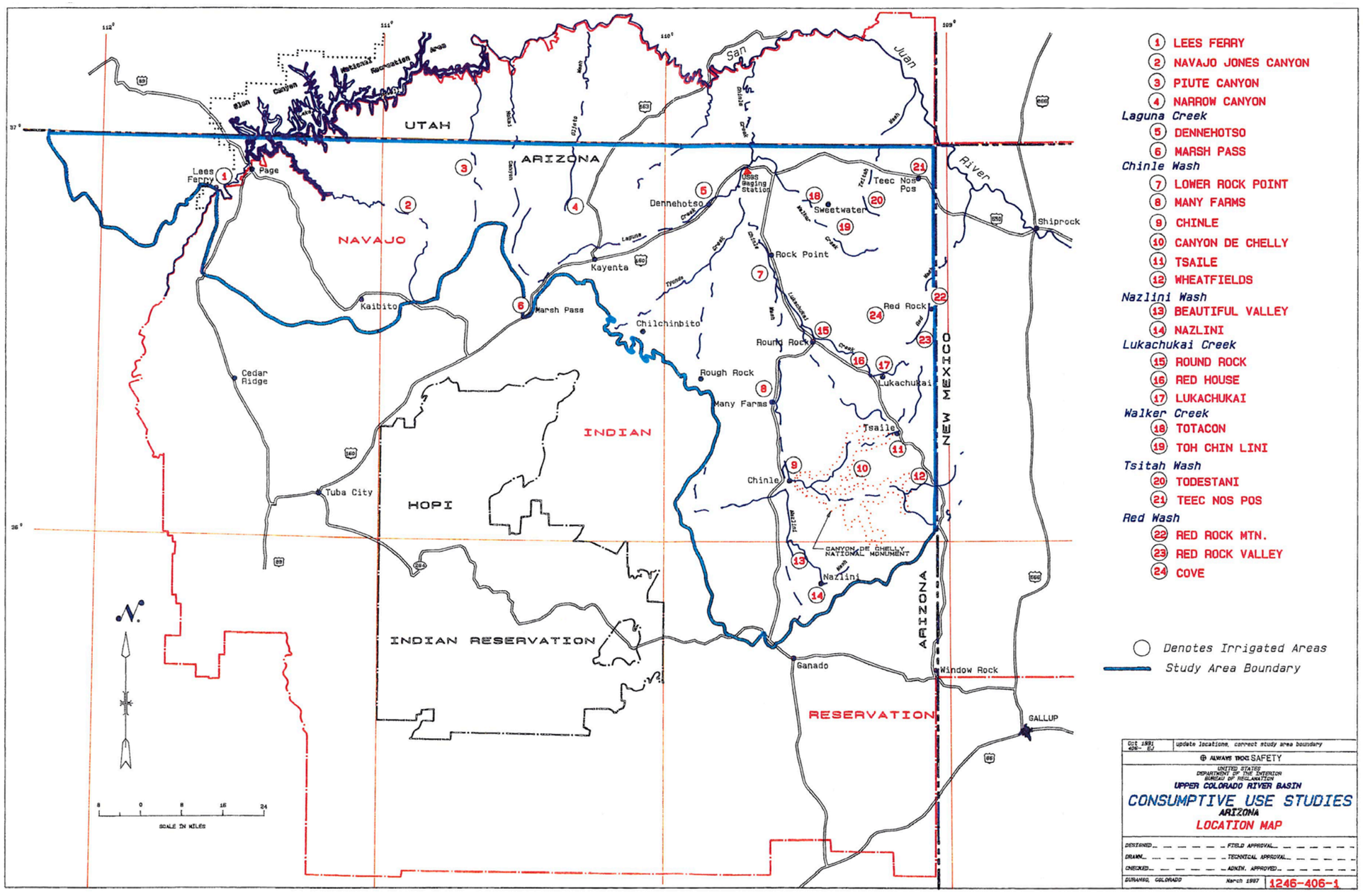
This report assesses the total consumptive use of the Arizona portion of the Upper Colorado River System surface water systems, depletion of ground water, and evaporative losses. Clearly, the amounts of water used by the Navajo Generating Station, City of Page, and Wahweap and Lees Ferry recreation areas are direct depletions of water from the Upper Colorado River System, but the situation is not as clear for other consumptive uses and losses occurring in other sections of the study area. For example, the source of water used by the Navajo Nation for domestic and municipal purposes is from wells, some exceeding 1,000 feet in depth. For our purposes here, it is considered to be consumed and a depletion to the Colorado River System. But this may not actually result in a reduction of Colorado River stream flows in the same year that the withdrawal occurs. Little knowledge and information exists of ground water movement and subsurface flow rates in the study area that are accurate descriptions of the effects on river flows.

Although the water diverted for agricultural purposes is considered as consumptive use in this report, a portion of the remaining surface water on the Navajo Nation, excess to needs, does evaporate before reaching the Colorado River. No attempt has been made for this report to quantify these losses.

Uncertainties in estimating uses and losses exist, and the degree of variation in the figures is presented. Fortunately, the areas with the highest degree of uncertainty account for only a small percentage of the total consumptive use. The largest component, use by the Navajo Generating Station, is also the most accurately monitored. The total annual value for estimated consumptive use of water within the Arizona portion of the Upper Colorado River Basin for 2010 was 35,150 acre-feet, as shown in table 11.

Table 11.—Consumptive use for Arizona portion of Upper Colorado River Basin for 2010

USE CATEGORY	TOTAL CONSUMPTIVE USE (ACRE-FEET)	UNCERTAINTY	PERCENT OF TOTAL
Agriculture	2,663	580	7.6
Municipal & Industrial	28,926	789	82.3
Recreation, Fish & Wildlife	1,199	282	3.4
Reservoir Evaporation	2,362	709	6.7
TOTAL	35,150	1,241	100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Page
Kaibito
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Tuba City
Marsh Pass
Kayenta
Dennehotso
Chilchinbito
Rough Rock
Many Farms
Chinle
Rock Point
Round Rock
Sweetwater
Tsaile
Lukachukai
Red Rock
Teec Nos Pos
Shiprock
Ganado
Window Rock
GALLUP
CANYON DE CHELLY NATIONAL MONUMENT
Nazlini
San Juan River
SCALE IN MILES
1 LEES FERRY
2 NAVAJO JONES CANYON
3 PIUTE CANYON
4 NARROW CANYON
Laguna Creek
5 DENNEHOTSO
6 MARSH PASS
Chinle Wash
7 LOWER ROCK POINT
8 MANY FARMS
9 CHINLE
10 CANYON DE CHELLY
11 TSAILE
12 WHEATFIELDS
Nazlini Wash
13 BEAUTIFUL VALLEY
14 NAZLINI
Lukachukai Creek
15 ROUND ROCK
16 RED HOUSE
17 LUKACHUKAI
Walker Creek
18 TOTACON
19 TOH CHIN LINI
Tsitah Wash
20 TODESTANI
21 TEEC NOS POS
Red Wash
22 RED ROCK MTN.
23 RED ROCK VALLEY
24 COVE
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BUREAU OF RECLAMATION
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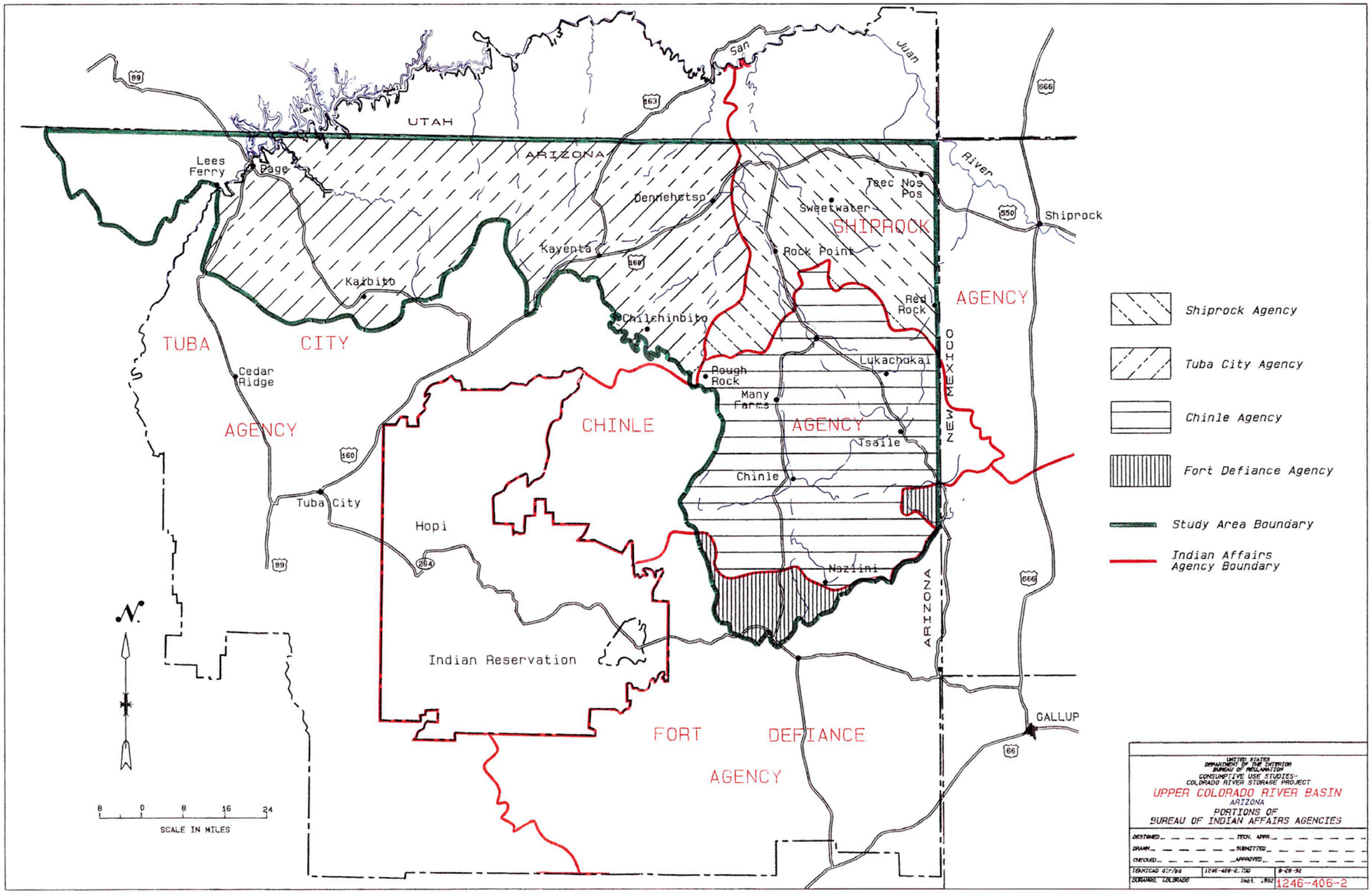
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Kaibito
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Teec Nos Pos
Sweetwater
SHIPROCK
Rock Point
Red Rock
AGENCY
Shiprock
Lukachukai
Rough Rock
Many Farms
Tsaile
Chinle
CHINLE
AGENCY
Nazlini
TUBA
CITY
Cedar Ridge
AGENCY
Tuba City
Hopi
Indian Reservation
FORT
DEFIANCE
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Study Area Boundary
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DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CONSUMPTIVE USE STUDIES-
COLORADO RIVER STORAGE PROJECT
UPPER COLORADO RIVER BASIN
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Sept. 1992
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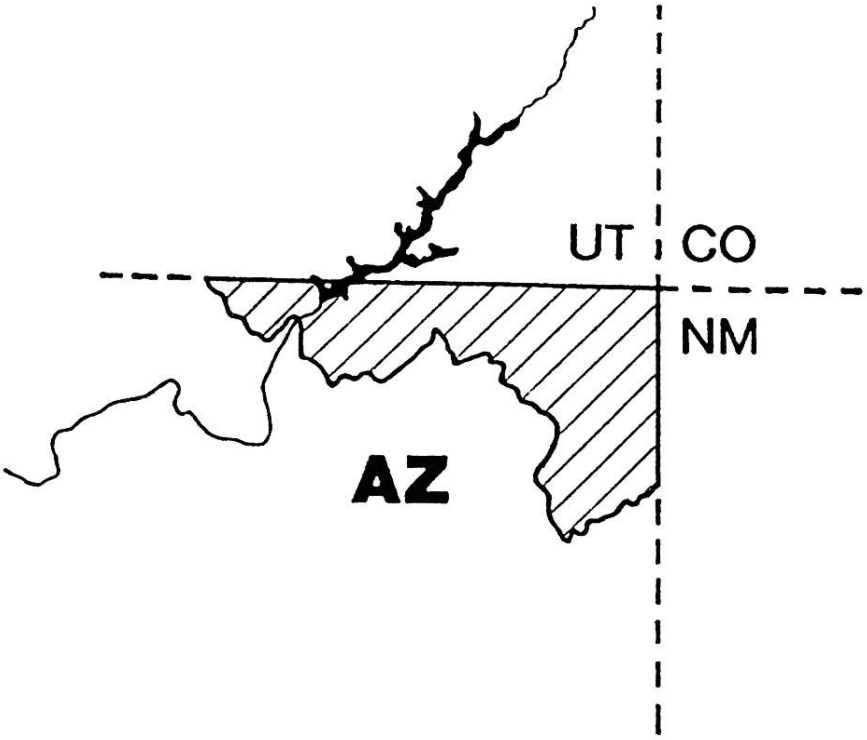
RECLAMATION

Managing Water in the West

Consumptive Uses and Losses: Provisional Estimate

Arizona Portion of the Upper Colorado River Basin Calendar Year 2011

Provisional Version revision dated: September 24, 2014



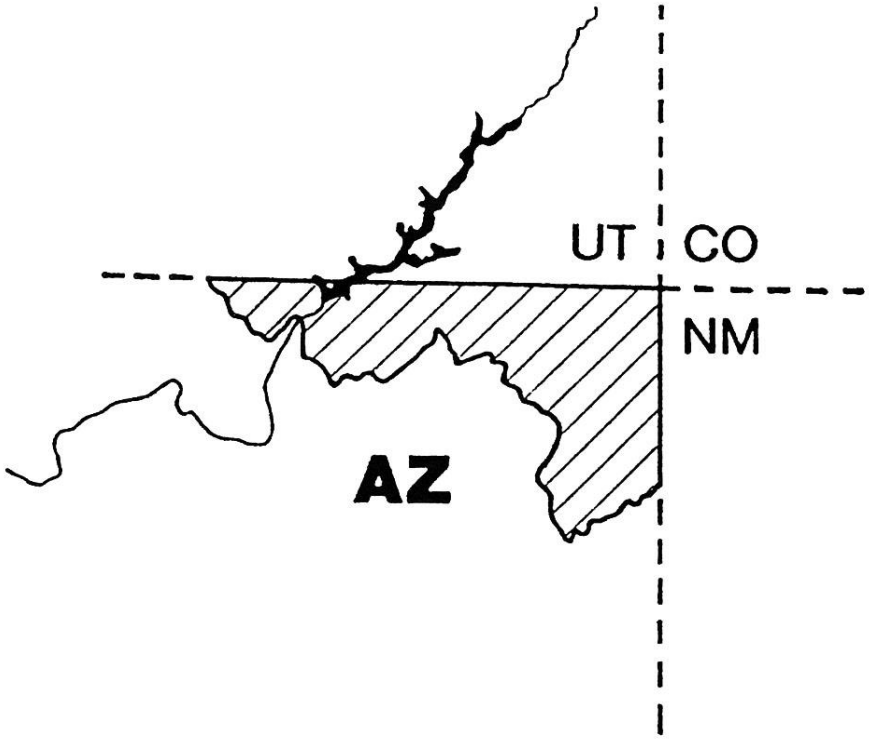
U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

November 2013
Revised September 2014

RECLAMATION
Managing Water in the West

Consumptive Uses and Losses: Provisional Estimate

Arizona Portion of the Upper Colorado River Basin
Calendar Year 2011



Prepared by: Alan Harrison – November 4, 2013
Revised by: Alan Harrison – September 24, 2014

U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

November 2013
Revised September 2014

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ARIZONA PORTION
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UPPER COLORADO RIVER BASIN

CALENDAR YEAR
2011

AUTHORITY

This report was prepared in compliance with Public Law 90-537, Section 601 (b)(1), dated September 30, 1968, which directs the Secretary of the Interior to "make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis." Additionally, this report is in compliance with Section 49 of the Navajo Project Participation Agreement dated September 30, 1969, which states in part: "The Secretary of the Interior further agrees to make the reports required by Section 601 (b)(1) of Public Law 90-537 as they pertain to Arizona's Upper Basin uses annually rather than every five years. Within fifteen days following the completion of said reports, the Secretary of the Interior shall furnish copies of such reports to the Co-Tenants, the Navajo Tribe, each of the Upper Basin States, and the Upper Colorado River Commission."

SUMMARY

Based upon data made available for preparation of this document. the total consumptive use and loss value for the Arizona portion of the Upper Colorado River Basin for calendar year 2011 was 34,878 (±1,253) acre-feet. Reclamation prepares this estimate annually, final annual values for consumptive uses and losses for the northern Arizona portion of the Colorado River basin are published in the 5-year summary documents for the Upper Colorado River Basin

STUDY AREA DESCRIPTION

The Arizona portion of the Upper Colorado River Basin covers approximately 6,900 square miles in the north-east corner of Arizona, as shown on the location maps shown on pages 19 and 20 (Drawings 1246-406-1, 1246-406-2). The climate of the 5,900 square mile area to the west of the Chuska and Carrizo Mountains is largely arid to semiarid, with mean annual precipitation ranging from 6 to 12 inches and with summertime temperatures often reaching 100 degrees Fahrenheit (^{o}F). The potential

evaporation rate is high and exceeds mean annual precipitation, with gross lake evaporation values of up to 55 inches per year or more. Elevations in the western portion range from 3200 feet on the Colorado River at Lees Ferry to over 8000 feet on the northern edge of the Black Mesa and across the Zilnez and Skeleton Mesas, back down to 5280 feet in the Chinle Valley, and back up to about 6500 feet on the western edge of the Chuska Mountains. Much of the western part of the study area is starkly beautiful southwestern desert country with mesas and canyons intertwined across a pastoral landscape. By contrast, the eastern 1,000 square miles is largely mountainous, with elevations rising to nearly 10,000 feet and mean annual precipitation reaching 30 inches. The mountainous land responds with grass meadows interspersed with conifer forest of mostly ponderosa pine.

Except for Page, Arizona; a small area around Lees Ferry; and a portion of the Paria Plateau administered by the Bureau of Land Management; the study area lies entirely within the Navajo Nation. Based on straight-line interpolation of 2000 and 2010 census data for the area, it is estimated that approximately 47,054 persons were living within the study area in 2011, and of these an estimated 39,763 resided on the Navajo Nation.

The largest cities are Page and Kayenta, with 2010 populations of 7,247 and 5,189, respectively. Other major communities and their populations include Dennehotso (746), Kaibeto (1,522), Chinle (4,518), LeChee (1,443), Lukachukai (1,701), Many Farms (1,348), Rock Point (642), Teec Nos Pos (730), and Tsaile (1,205). Subsistence in the region is derived principally from livestock grazing, farming, tourist-related industries, employment at the Navajo Generating Station (NGS), which consumes approximately 69 percent of the water used or lost in the study area every year. Agriculture accounted for about 7 percent of the total water use; municipal and industrial (including the Navajo Generating Station) about 82 percent; recreation, fish and wildlife, about 4 percent; and reservoir evaporation, about 7 percent.

AGRICULTURAL CONSUMPTIVE USE

Agricultural consumptive use is divided into three categories: irrigation, stock pond, and livestock. Irrigation use includes all use related to irrigating crops including the incidental losses. Stock pond use is the evaporation that occurs from stock ponds and livestock use is the water consumed by livestock.

IRRIGATION USES

Within the Arizona portion of the Upper Colorado River Basin, historically 23 irrigated areas were scattered across the Navajo Nation plus a small amount of land near Lees Ferry irrigated by the National Park Service. Currently, only 16 irrigated areas are in production. An accurate assessment of consumptive use on the irrigated land is difficult due to poor quality of information, such as the exact number of acres under irrigation, the cropping pattern for each irrigated area, site climatological conditions, and the amount s of water actually diverted. In many cases, during the latter part of the irrigation season, farmers have to rely on dry land farming since there is little water available in the streams. This means that the crops do not receive their full water requirement.

For this report, the U.S. Department of Agriculture, Soil Conservation Service's (SCS) Modified Blaney-Criddle evapotranspiration, without an elevation adjustment, estimation formula was used for computing irrigated crop consumptive use. This model, along with appropriate crop-growth stage coefficients and the method for computing effective precipitation, is described in SCS's *Irrigation Water Requirements Technical Release No. 21* (TR 21). Information required for applying this model includes mean monthly temperature and precipitation values, growing season data for each crop type, and the total number of acres planted by crop at each site. With the exception of Teec Nos Pos, Canyon de Chelly, Lukachukai, and Lees Ferry, no climatological data exist for the irrigation sites, and site values must be generated from data collected at surrounding established weather stations. Growing season dates depend largely on the judgment of the local inhabitants and are, therefore, not known. Although several reports are available with published values for irrigated acres, it is unclear if these values are meant to represent potential irrigated acres, acres irrigated in the past, acres for which farming permits have been issued, or actual acres currently under irrigation.

The crop acreage used to estimate consumptive use by irrigated crops for the year 2011 is shown in table 1. These values were estimated from previous direct field examination by a party composed of representatives from the State of Arizona and the Navajo Nation.

Table 1.—Total irrigated acreage, 2011

PROJECT	CORN (ACRES)	ALFALFA (ACRES)	GRASS PASTURE (ACRES)	SPRING GRAINS (ACRES)	SMALL VEGETABLES (ACRES)	ORCHARD (ACRES)	TOTAL (ACRES)
CHINLE AGENCY							
Canyon de Chelly	0.36	0.00	0.00	3.03	2.26	0.00	5.65
Lukachukai	39.09	7.69	0.00	7.50	5.98	2.07	62.33
Many Farms	138.96	23.18	85.81	2.26	23.18	0.00	273.40
Nazlini	0.00	0.00	0.00	0.00	1.79	0.74	2.53
Rough Rock	30.00	0.00	11.87	0.00	12.43	0.00	54.30
Tsaile	23.72	5.27	15.67	5.73	5.42	0.00	55.81
Wheatfields	0.00	60.80	0.00	0.00	0.00	0.00	60.80
TOTAL	232.13	96.94	113.35	18.52	51.06	2.81	514.82
SHIPROCK AGENCY							
Red Rock Valley	26.22	0.00	10.19	5.12	10.22	0.00	51.75
Teec Nos Pos	20.00	0.00	0.00	0.00	3.67	0.00	23.67
Toh Chin Lini	0.00	0.00	0.00	0.00	3.90	13.67	17.57
Totacon	0.00	0.00	0.00	0.00	1.00	0.00	1.00
TOTAL	46.22	0.00	10.19	5.12	18.79	13.67	93.99
WESTERN NAVAJO AGENCY							
Dennehotso	1.82	0.00	38.70	0.00	0.00	0.00	40.52
Lees Ferry	0.00	0.00	1.00	0.00	0.00	2.00	3.00
Marsh Pass	7.02	3.31	0.00	0.00	1.99	0.00	12.32
Navajo Canyon	0.00	0.00	0.00	0.00	0.00	3.50	3.50
Paiute Canyon	2.64	0.00	0.00	0.00	3.86	0.00	6.50
TOTAL	11.48	3.31	39.70	0.00	5.85	5.50	65.84
GRAND TOTAL	289.83	100.25	163.24	23.64	75.70	21.98	674.65

Several factors complicated the modeling of irrigation consumptive use. For example, the computer program used to model consumptive use assumes a full water supply; if shortages exist, as they often do in this semiarid study area, adjustments must be made. These adjustments are complicated because some of the projects have no storage water and may only have a reliable irrigation water supply during spring runoff. After spring runoff, farming becomes essentially dry land until rains in July and August provide intermittent flows for irrigation. Finally, no ditch diversion records are available to help estimate irrigation water supplies and shortages.

A full irrigation supply seldom exists at many of the projects. Generally, a full supply is available for Lees Ferry, Navajo Canyon, Tsaile, and Wheatfields projects because of adequate stream flows or because of available storage water. In years with average precipitation, it is estimated that Chinle Wash provides approximately 75 percent of the irrigation requirement. Precipitation in the area averages approximately 9.5 inches per year. Based on this information, it would require approximately 12.67 inches of precipitation to provide 100 percent of the irrigation requirement. The percent of crop water requirement met was computed as a ratio of annual precipitation to 12.67 inches. These values are found in table 2.

The percentage of crop water requirement met was multiplied by the total net crop water requirement to come up with the amount of crop consumptive use. Incidental irrigation losses, evaporation, and phreatophyte consumptive use along supply canals are estimated to be 5 percent of the consumptive use of the irrigated area and are added to the crop consumptive use value to develop a total consumptive use value.

A portion of the water used for irrigation at these sites may not be contributing to the Colorado River System since evaporation rates in the area are high and the nature of most of the drainage enhances evapotranspiration. A good example of such a drainage is Chinle Wash, which after it leaves Canyon de Chelly, becomes wide and sandy and is lined with willows, cottonwoods, and other phreatophytes.

The uncertainties in the irrigation consumptive use values displayed in table 2 are very large and are estimated as 40 percent of the total consumptive use. This estimate of possible error only reflects the uncertainty of consumptive use and does not account for any possible errors in the acreage estimates. The effective consumptive use for irrigation for 2011 was estimated to equal 966 acre-feet. Including the 5 percent for incidental losses, the irrigation related consumptive use is 1,014 (±406) acre-feet.

Table 2.—Net consumptive use values, 2011

PROJECT	CROP WATER REQUIREMENT (INCHES)	TOTAL IRRIGATED (ACRES)	TOTAL WATER REQUIRED (ACRE-FEET)	CROP WATER REQUIREMENT MET (%)	CROP WATER REQUIREMENT MET (ACRE-FEET)	TOTAL CONSUMPTIVE USE (ACRE-FEET)[1]
CHINLE AGENCY						
Canyon de Chelly	26.09	5.65	12	73%	9	9.4
Lukachukai	20.47	62.33	106	73%	77	81.1
Many Farms	26.26	273.40	598	73%	435	456.2
Nazlini	18.36	2.53	4	73%	3	3.0
Rough Rock	20.50	54.3	93	81%	75	78.5
Tsaile	21.12	55.81	98	73%	71	74.9
Wheatfields	27.68	60.80	140	73%	102	107.0
TOTAL	160.48	514.82	1,052		771	810.0
SHIPROCK AGENCY						
Red Rock Valley	24.06	51.75	104	65%	67	70.9
Teec Nos Pos	27.99	23.67	55	57%	32	33.3
Toh Chin Lini	37.18	17.57	54	29%	16	16.4
Totacon	24.93	1.00	2	29%	1	0.6
TOTAL	114.16	93.99	215		115	121.2
WESTERN NAVAJO AGENCY						
Dennehotso	36.88	40.52	125	36%	45	47.5
Lees Ferry	40.88	3.00	10	100%	10	10.7
Marsh Pass	18.72	12.32	19	66%	13	13.4
Navajo Canyon	35.48	3.50	10	53%	5	5.7
Paiute Canyon	23.01	6.50	12	44%	6	5.8
TOTAL	154.97	65.84	177		79	83.2
GRAND TOTAL	429.61	674.65	1,444		966	1,014.5

[1] Total includes 5% addition for incidental losses.

STOCK POND EVAPORATION

Stock pond consumptive use is assumed to be the evaporation from the stock pond. It is also assumed that any consumptive use by natural vegetation prior to the construction of the stock ponds is limited to precipitation which is subtracted from the evaporation losses.

A compilation of the stock ponds in the study area, including their locations and the water surface areas when ponds are full, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 3. For an average year conditions, the stock pond evaporative surface area was estimated as one-third the water surface area that occurs when the ponds are full. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average water surface area. These values are found in table 3.

Table 3.—Stock pond evaporation, 2011

COUNTY	SURFACE AREA FULL (ACRES)	SURFACE AREA USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Coconino	80	25	92	57	6.21	50.79	104
Navajo	40	11	82	55	7.97	47.04	42.7
Apache	646	202	94	53	8.24	44.76	751.7
TOTAL	766	237					898

This method of evaporation estimation was used because continuous useful water level records for all stock ponds from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual stock ponds. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation. It was assumed that any consumptive use by natural vegetation prior to construction of the stock ponds is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for stock pond evaporation for calendar year 2011 are shown in table 3. The total evaporative losses in 2011 are 898 (±270) acre-feet with the stock pond evaporation uncertainty being estimated as 30 percent.

LIVESTOCK WATER

The source of most livestock water in the study area is from wells, with windmill-operated pumps developed and maintained by Navajo Water Operations and Maintenance, and water collected in small surface ponds. The estimated number of

livestock in the area was estimated based on previous livestock tallies. It was estimated that horses and cattle consume 12 gallons per day; sheep and goats consume 2 gallons per day.

The number of animals for the Upper Colorado portion of each district is shown in table 4. The computed value for livestock consumptive use is 638 acre-feet. The uncertainty in this number is estimated as 30 percent of the total or ±192 acre-feet.

Table 4.—Number of livestock, 2011

AGENCY	CATTLE	HORSES	SHEEP	GOATS
Western Navajo District No. 1	784	45	1,676	760
Western Navajo District No. 2	946	247	1,264	1,037
Western Navajo District No. 8	7,147	5,319	8,943	7,231
Shiprock District No. 9	2,542	1,473	3,269	3,469
Chinle District No. 10	3,051	2,412	4,083	2,919
Chinle District No. 11	1,543	1,232	1,631	1,310
Shiprock District No. 12	5,795	4,793	6,579	5,472
Fort Defiance District No. 17	346	63	1,766	450
Fort Defiance District No. 18	721	164	1,152	237
TOTAL	22,877	15,749	30,364	22,884

TOTAL AGRICULTURAL CONSUMPTIVE USE

The total agricultural consumptive use, displayed in table 5, is the sum of the individual components discussed in the previous sections. Agricultural water consumption represents approximately 8 percent of the total use in the study area. Total degree of uncertainty was computed by taking the square root of the sum of the individual uncertainties squared; known as the quadratic sum. This method and nomenclature is used throughout this report. This method was used because a simple sum does not account for the partial cancellation of errors occurring when calculating the total uncertainty derived from individual values that are random and independent of each other. As previously discussed, the individual uncertainties were set as a percent of the consumptive use value.

Table 5.—Total agricultural consumptive use, 2011

CATEGORY	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Irrigation	1,014	406
Stock Ponds	898	270
Livestock	638	192
TOTAL	2,551	523

MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

Municipal and industrial consumptive use is divided into three categories: mineral resources, thermal electric power, and other. Mineral resources consumptive use includes water used for mineral production. No mineral resources consumptive use is reported in the study area. Thermal electric power consumptive use includes the water used at the power plants, and that used to transport material to the power plant (such as a coal slurry pipeline). Other consumptive use includes urban, rural, and industrial uses.

THERMAL ELECTRIC POWER

Thermal electric power consumptive use includes the water used in the power plant and the water used to transport material to the plant.

Navajo Generating Station

The water used by the NGS is pumped directly from Lake Powell and comprises over half of the total consumption in the study area. Since all NGS water use is metered, this quantity is among those most precisely known, with the maximum uncertainty in the metered quantities believed to be less than 3 percent. The actual quantity consumed, along with the estimated uncertainty for the calendar year 2011, was 24,221 (±727) acre-feet.

OTHER

The other consumptive use category includes the remaining use by urban, rural, and industries.

Page, AZ and Vicinity

City of Page, AZ. – The city of Page pumps its domestic water directly from Lake Powell. The water pumped is metered, and the uncertainty of the pumped quantities was assumed to be less than 3 percent. A portion of the water pumped and treated by the City

of Page, is supplied to the community of Le Chee on the Navajo Nation and is accounted for separately. The quantity supplied to the City of Page and its associated uncertainty for the calendar year 2011 was 2,219 (±67) acre-feet. Water returning to the waste water treatment plant is metered as well. The waste water for the City of Page is treated and is either evaporated from lined ponds or applied to the golf course, with a portion being returned to the Colorado River. The return flow is estimated to be 1,446 acre-feet. The net consumptive use is estimated to be 773 acre-feet (±79).

Le Chee – The community of Le Chee is supplied and metered by the City of Page. Total water supplied for 2011 was 94 (±3) acre-feet. The uncertainty was estimated to be 3 percent.

Greenhaven Water Company – The Greenhaven Water Company derives its domestic water supply from wells. Well pumping records are available. According to these records, the total water pumped for 2011 was 121 (±8) acre-feet. The uncertainty was estimated to be 7 percent.

Arizona Department of Transportation Housing – The Arizona Department of Transportation operates a housing, maintenance, and administrative facility located on US Hwy 89, north of Page, AZ. This facility is supplied from wells that have no meters installed. It is estimated that the total water pumped for 2011 was 7 acre-feet with an uncertainty of 30 percent of this value or ±2 acre-feet.

Navajo Nation

Community Water Systems – 1980 statistics from the Division of Community Development of the Navajo Nation reveal that various community water systems served 26,086, or about 83 percent of the 31,429 people residing within the study area at that time. Since additional estimates have not been repeated, this same percentage was used for 2011 resulting in 33,003 out of 39,763 people being served. These systems include those operated by the Navajo Tribal Utility Authority (NTUA), the BIA, and the Water Operations and Maintenance Department of the Navajo Nation, and some privately developed community water systems.

Table 6 shows the source of water and estimated population served by each source of water for people living on the Navajo Nation during 2011. All of the communities obtain their water supply from ground water.

Table 6.—Domestic water sources, 2011

SOURCE	PERCENTAGE OF POPULATION SERVED	NUMBER OF POPULATION SERVED[1]
Community Water Systems	83	33,003
NTUA	[2](60)	19,802
BIA	[2](25)	8,251
Navajo WOM	[2](13)	4,290
Private	[2](2)	660
Individual Wells	17	6,760
TOTAL	100	39,763

[1] Total population within the Upper Colorado River Basin portion of the Navajo Nation, estimated from 2010 US Census.
[2] These numbers are a percentage of the Community Water Systems.

NTUA Water Systems – The cities and surrounding communities of Oak Springs, Red Valley, Sweetwater, Chinle , Rough Rock, Round Rock, Rock Point, Wheatfields, Lukachukai, Kayenta, Chilchinbeto, Dennehotso, and Kaibeto derive most of their domestic water supply from wells operated by NTUA. Well pumping records are available. According to these records, the total water pumped for 2011 was 1,619 acre-feet with an uncertainty estimated to be 7 percent of this value or ±113 acre-feet.

The NTUA manages the raw waste water; portions of which flow to individual septic tanks, some to evaporation ponds, and some, such as for the cities of Chinle and Kayenta, flow to waste water treatment plants. Very little water, if any, is returned to the ground water system through leakage from the evaporation ponds, but there are losses from the main collection system. Effluent from the Chinle and Kayenta waste water treatment plants is metered. Under normal conditions, the effluent returns to the Colorado River System and is subtracted from the pumping totals to determine a net consumptive use. For 2011, Chinle's treatment plant effluent was 13.6 (±1.0) acre-feet, and Kayenta's effluent was 9.7 (±0.7) acre-feet. An estimated uncertainty of 7 percent was used for the effluent of these two plants. The total effluent of 23 acre-feet is subtracted from the NTUA pumping total of 1,619 acre-feet to arrive at a net consumptive use of 1,596 (±113) acre-feet.

BIA Water Systems – Wells developed and operated by the BIA serve numerous Navajo communities. These systems also serve BIA schools, hospitals, agency offices, and some housing on the Navajo Nation. Metered records for total amounts of water pumped from BIA wells were available for a portion of the Shiprock Agency, the Western Navajo Agency, and the Chinle Agency. Drawing 1246-406-2 shows the agency boundaries within the Upper Colorado River Basin. The uncertainty was estimated to be about 7 percent for all three agencies.

The BIA systems include sewage disposal units terminating in lined evaporation ponds with very little or no return water returning to the ground water system. Undoubtedly, some losses occur in distribution, but insufficient data currently exist to estimate these losses. The losses are probably less than the uncertainties for each of the reported values.

The BIA well data available for the Shiprock Agency include: Cove, Red Rock, and Teec Nos Pos. Total consumptive use values are 11 (±1) acre-feet.

Pumping records for the Western Navajo Agency include data for the following schools: Chilchinbeto Day School, Dennehotso Boarding School, Kaibeto Boarding School, and Kayenta Boarding School. Total consumptive use for the Western Navajo Agency was 172 (±12) acre-feet.

Well pumping records for the Chinle Agency include data for the following schools: Cottonwood Day School, Lukachukai School, and Rock Point School. Rough Rock School maintains its own records, but the data was included with the Chinle Agency data. Total consumptive use for the Chinle Agency was 69 (±5) acre-feet.

Navajo WOM Water Systems – Water use in 2011 by the Navajo WOM service areas was based on an assumed consumption rate of 110 gallons per capita per day (gpcd). For a 2011 estimated service area population of 4,290, the estimated annual water use was 529 (±159) acre-feet. The uncertainty is estimated as 30 percent of the total.

Private Water Systems – The estimated 2011 population served by private water systems on the Navajo Nation was 660. Assuming a consumptive use rate of 110 gcpd, the annual water use for 2011 was 81 (±24) acre-feet. The uncertainty is estimated as 30 percent of the total.

Individual Wells – According to census data from the Division of Community Development of the Navajo Nation, approximately 17 percent of the study area's population on the reservation (about 6,760 persons in 2011) receives a domestic water supply from individual wells. A consumptive use of 110 gpcd was derived as being a reasonable water use rate. Based on these figures, the annual consumptive use was 833 (±250) acre-feet for 2011.

TOTAL MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

The total municipal and industrial consumptive use, displayed in table 7, is the sum of the individual components discussed in the previous sections. Municipal and industrial water consumption represents approximately 82 percent of the total use in the study area.

Table 7.—Total municipal and industrial consumptive use, 2011

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
THERMAL ELECTRIC POWER		
Navajo Generating Station	24,221	727
OTHER		
Page, AZ and Vicinity		
City of Page	773	79
Le Chee	94	3
Greenhaven Water Company	121	8
Arizona Department of Transportation	7	2
Navajo Indian Reservation		
Community Water Systems		
NTUA Water Systems	1,596	113
BIA Water Systems	252	13
Navajo WOM	529	159
Private Water Systems	81	24
Individual Wells	833	250
TOTAL	28,506	797

It is questionable whether all the water pumped from wells should be considered a depletion to the Colorado River System; however, it is assumed that 100 percent of the water pumped is considered lost to the system. It is proposed that a future joint study be completed by Reclamation, the State of Arizona, and the Navajo Nation to estimate what percentage of water pumped could actually be attributed to the Colorado River System and would have affected the river flows for a particular year.

RECREATION, FISH AND WILDLIFE

The recreation, fish and wildlife consumptive uses include evaporation from reservoirs used exclusively for fish & wildlife purposes as well as acreages irrigated for wildlife feeding. Consumptive use related to recreation at National parks is also addressed.

GLEN CANYON NATIONAL RECREATION AREA

Colorado River water is used by the Glen Canyon National Recreation Area (GCNRA) at Wahweap and Lees Ferry. The recreational area at Wahweap gets its water supply from a series of wells on the shore of Lake Powell. Pumping records for both Wahweap Marina, and Lees Ferry show 257 (±8) acre-feet of water withdrawn during 2011. The uncertainty is estimated at 3 percent. This water was used for domestic purposes at the

campgrounds, picnic areas, and trailer parks. It was also used to irrigate approximately 60 acres of Bermuda grass and cottonwood trees. The domestic waste water is treated and the effluent is allowed to evaporate from two lined evaporation ponds with a total surface area of 16.7 acres.

Based on estimates of evaporation and consumptive use by the plants, there is some water which is unaccounted for and is assumed to be leakage from the delivery system, the evaporation pond, or deep percolation from irrigation application. However, since these water losses are difficult to quantify and verify, the losses were charged as consumptive uses. Therefore, net consumptive use of water is estimated to be equal to the quantity of water pumped.

RESERVOIR EVAPORATION

A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 8.

Table 8. —Recreation, fish and wildlife reservoir evaporation, 2011

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE AREA USED (ACRES)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Tsaile	260	260	35	9.20	25.8	559.0
Wheatfields	272	272	32	9.20	22.8	516.8
TOTAL	532	532				1,076

Efforts are made to maintain a nearly full condition and to minimize water surface fluctuations in reservoirs managed for a fishery. Under average operating conditions, the water surface area of a reservoir used primarily for fishing is assumed to be equal to a normal water surface area. It is assumed that, in 2011, these reservoirs filled in the spring and were maintained at the normal pool level.

This method of evaporation estimation was used because continuous useful water level records for all reservoirs from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs.

For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for reservoir evaporation for calendar year 2011 are shown in table 8. The total evaporative losses in 2011 are 1,076 (±323) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent.

TOTAL RECREATION, FISH AND WILDLIFE

The total recreation, fish and wildlife consumptive use, displayed in table 9, is the sum of the individual components discussed in the previous sections. Recreation, fish and wildlife water consumption represents approximately 4 percent of the total use in the study area.

Table 9.—Total recreation, fish and wildlife consumptive use, 2011

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Glen Canyon National Recreation Area	257	8
Reservoir Evaporation	1,076	323
TOTAL	1,332	323

RESERVOIR EVAPORATION

Reservoir evaporation losses make up about 7 percent of the total water uses and losses in the study area. A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 10. These reservoirs are used primarily for irrigation.

Table 10.—Reservoir evaporation, 2011

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE ACRES USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Many Farms	1,800	554	100	56	9.20	46.80	2163
Marsh Pass	40	17	100	40	9.60	30.40	43
Round Rock	83	39	100	57	8.24	48.76	158
Walker Creek	30	14	100	59	7.28	51.72	58
Others	38	17	100	55	9.24	45.76	66
TOTAL	1,991	641					2,488

Reservoirs used primarily for irrigation experience large fluctuations in water levels and, correspondingly, large variations in surface area. Reservoir level records and elevation – area curves were available at Many Farms, but not for the remaining reservoirs in table 10. For the reservoirs with no records from which surface area could be accurately computed, the average evaporative surface area was estimated as one-half the water

surface area of a full reservoir. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average evaporative surface area.

Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses. The computed values for reservoir evaporation for 2011 are shown in table 10. The total evaporative losses in 2011 are 2,488 (±746) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent of the total evaporation.

CONCLUSIONS

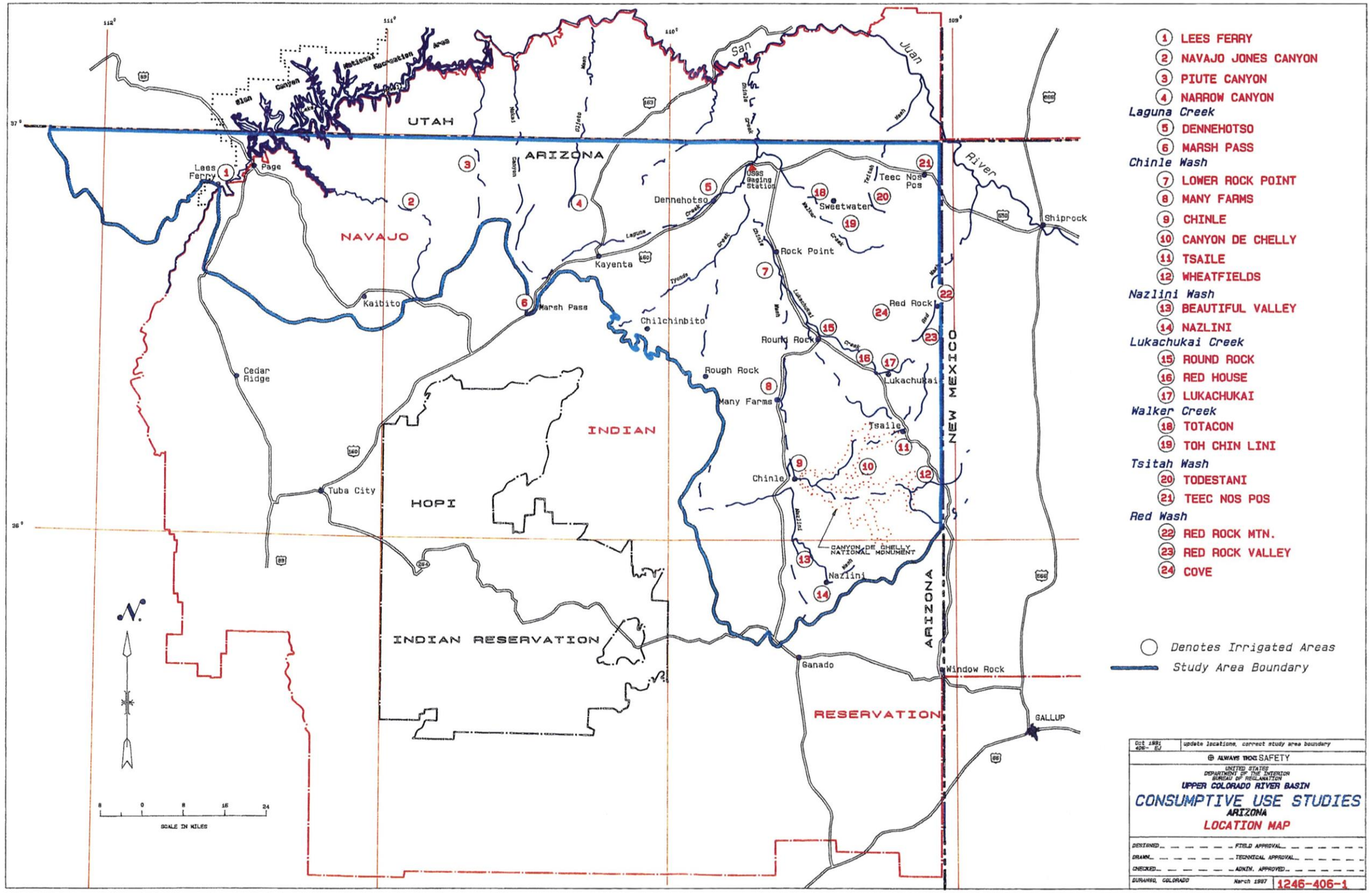
This report assesses the total consumptive use of the Arizona portion of the Upper Colorado River surface water systems, depletion of ground water, and evaporative losses. Clearly, the amounts of water used by the Navajo Generating Station, City of Page, and Wahweap and Lees Ferry recreation areas are direct depletions of water from the Upper Colorado River System, but the situation is not as clear for other consumptive uses and losses occurring in other sections of the study area. For example, the source of water used by the Navajo Nation for domestic and municipal purposes is from wells, some exceeding 1,000 feet in depth. For our purposes here, it is considered to be consumed and a depletion to the Colorado River System. But this may not actually result in a reduction of Colorado River stream flows in the same year that the withdrawal occurs, or at all. Little knowledge and information exists of ground water movement and subsurface flow rates in the study area that are accurate descriptions of the effects on river flows.

Although the water diverted for agricultural purposes is considered as consumptive use in this report, a portion of the remaining surface water on the Navajo Nation, excess to needs, does evaporate before reaching the Colorado River. No attempt has been made for this report to quantify these losses.

Uncertainties in estimating uses and losses exist, and the degree of variation in the figures is presented. Fortunately, the areas with the highest degree of uncertainty account for only a small percentage of the total consumptive use. The largest component, use by the Navajo Generating Station, is also the most accurately monitored. The total annual value for estimated consumptive use of water within the Arizona portion of the Upper Colorado River Basin for 2011 was 34,878 acre-feet, as shown in table 11.

Table 11.—Consumptive use for Arizona portion of Upper Colorado River Basin for 2011

USE CATEGORY	TOTAL CONSUMPTIVE USE (ACRE-FEET)	UNCERTAINTY	PERCENT OF TOTAL
Agriculture	2,551	523	7.3
Municipal & Industrial	28,506	797	81.7
Recreation, Fish & Wildlife	1,332	323	3.8
Reservoir Evaporation	2,488	746	7.1
TOTAL	34,878	1,253	100


1 LEES FERRY
2 NAVAJO JONES CANYON
3 PIUTE CANYON
4 NARROW CANYON
Laguna Creek
5 DENNEHOTSO
6 MARSH PASS
Chinle Wash
7 LOWER ROCK POINT
8 MANY FARMS
9 CHINLE
10 CANYON DE CHELLY
11 TSAILE
12 WHEATFIELDS
Nazlini Wash
13 BEAUTIFUL VALLEY
14 NAZLINI
Lukachukai Creek
15 ROUND ROCK
16 RED HOUSE
17 LUKACHUKAI
Walker Creek
18 TOTACON
19 TOH CHIN LINI
Tsitah Wash
20 TODESTANI
21 TEEC NOS POS
Red Wash
22 RED ROCK MTN.
23 RED ROCK VALLEY
24 COVE
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NEW MEXICO
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Page
Kaibito
Cedar Ridge
Tuba City
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Dennehotso
Chilchinbito
Rough Many Farms
Round Rock
Rock Point
Sweetwater
Tsaile
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Lukachukai
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Ganado
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LOCATION MAP
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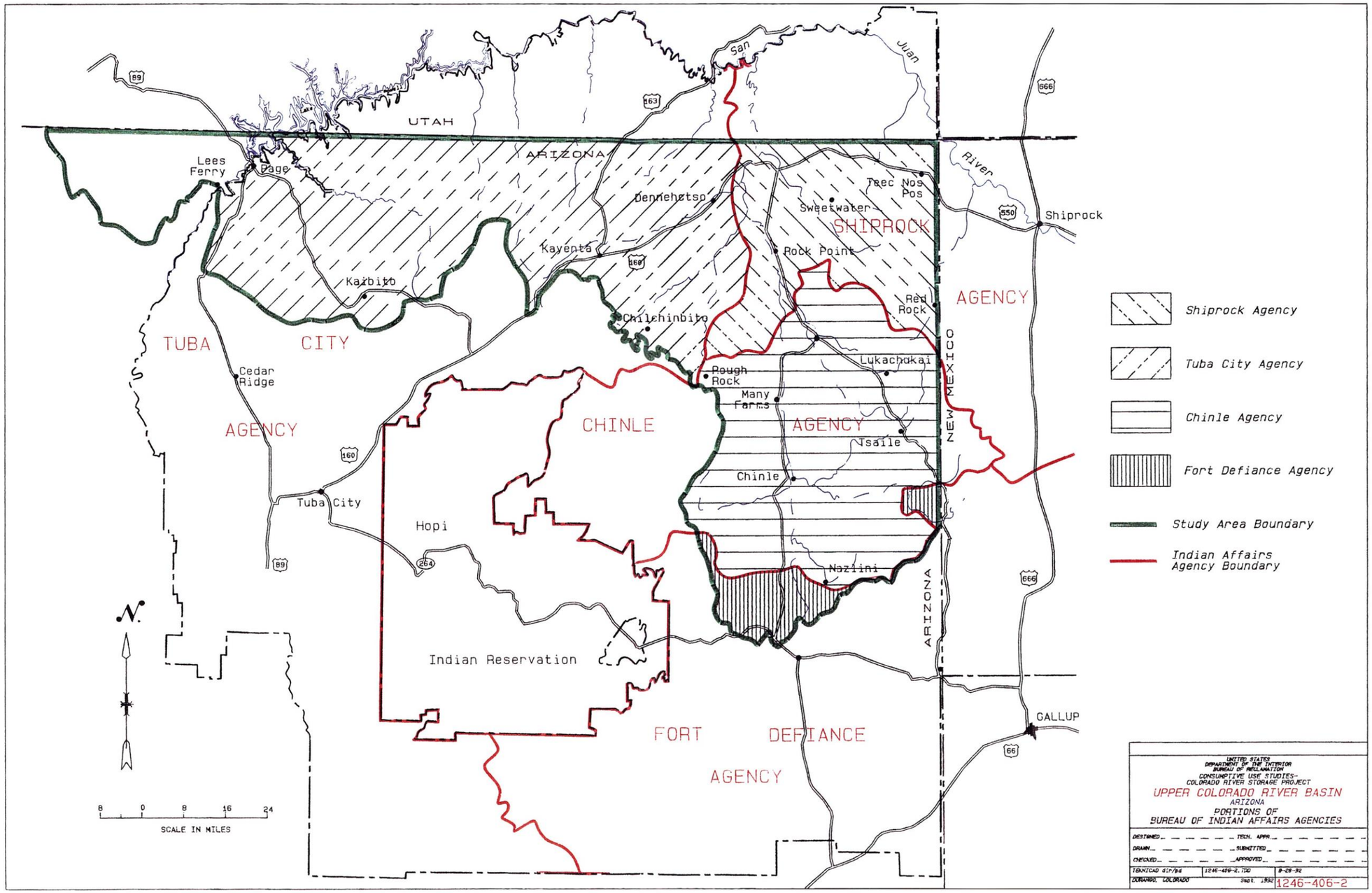
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Tsaile
Chinle
Nazlini
Cedar Ridge
Tuba City
Hopi
Indian Reservation
GALLUP
SHIPROCK
AGENCY
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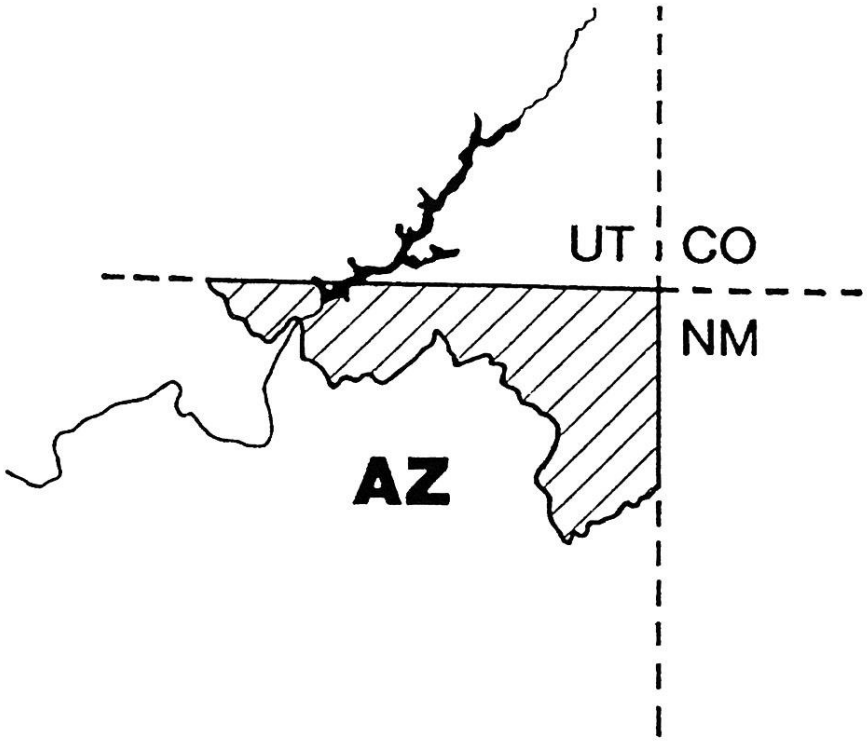
RECLAMATION

Managing Water in the West

Consumptive Uses and Losses: Provisional Estimate

Arizona Portion of the Upper Colorado River Basin Calendar Year 2012

Provisional Version dated: September 23, 2014



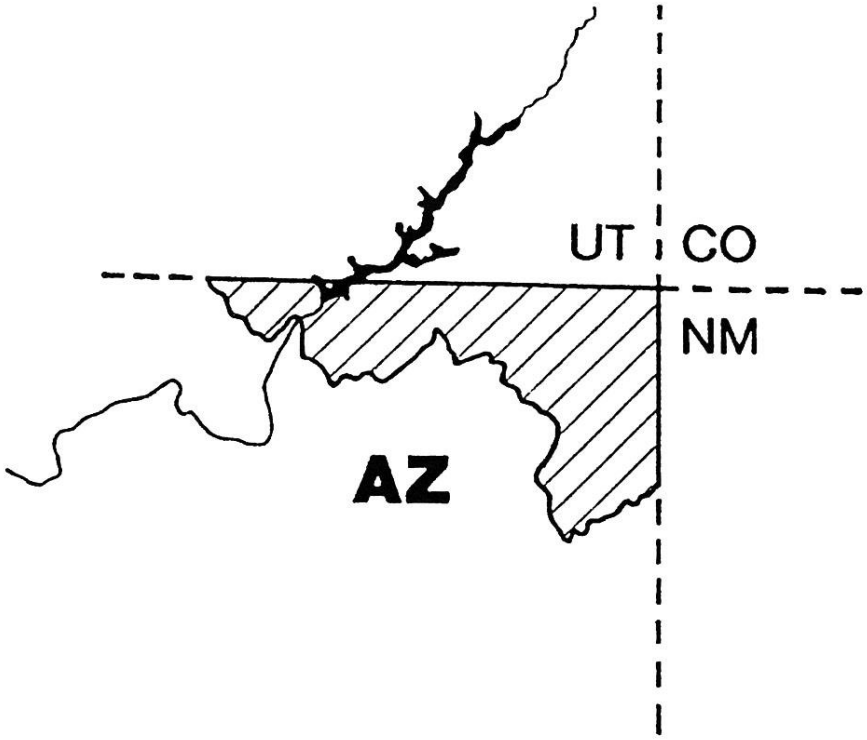
U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

September 2014

RECLAMATION
Managing Water in the West

Consumptive Uses and Losses: Provisional Estimate

Arizona Portion of the Upper Colorado River Basin
Calendar Year 2012



Prepared by: Alan Harrison – September 23, 2014

U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

September 2014

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ARIZONA PORTION
OF THE
UPPER COLORADO RIVER BASIN

CALENDAR YEAR
2012

AUTHORITY

This report was prepared in compliance with Public Law 90-537, Section 601 (b)(1), dated September 30, 1968, which directs the Secretary of the Interior to "make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis." Additionally, this report is in compliance with Section 49 of the Navajo Project Participation Agreement dated September 30, 1969, which states in part: "The Secretary of the Interior further agrees to make the reports required by Section 601 (b)(1) of Public Law 90-537 as they pertain to Arizona's Upper Basin uses annually rather than every five years. Within fifteen days following the completion of said reports, the Secretary of the Interior shall furnish copies of such reports to the Co-Tenants, the Navajo Tribe, each of the Upper Basin States, and the Upper Colorado River Commission."

SUMMARY

Based upon data made available for preparation of this document. the total consumptive use and loss value for the Arizona portion of the Upper Colorado River Basin for calendar year 2012 was 33,557 (±1,226) acre-feet. Reclamation prepares this estimate annually, final annual values for consumptive uses and losses for the northern Arizona portion of the Colorado River basin are published in the 5-year summary documents for the Upper Colorado River Basin

STUDY AREA DESCRIPTION

The Arizona portion of the Upper Colorado River Basin covers approximately 6,900 square miles in the north-east corner of Arizona, as shown on the location maps shown on pages 19 and 20 (Drawings 1246-406-1, 1246-406-2). The climate of the 5,900 square mile area to the west of the Chuska and Carrizo Mountains is largely arid to semiarid, with mean annual precipitation ranging from 6 to 12 inches and with summertime temperatures often reaching 100 degrees Fahrenheit (^{o}F). The potential

evaporation rate is high and exceeds mean annual precipitation, with gross lake evaporation values of up to 55 inches per year or more. Elevations in the western portion range from 3200 feet on the Colorado River at Lees Ferry to over 8000 feet on the northern edge of the Black Mesa and across the Zilnez and Skeleton Mesas, back down to 5280 feet in the Chinle Valley, and back up to about 6500 feet on the western edge of the Chuska Mountains. Much of the western part of the study area is starkly beautiful southwestern desert country with mesas and canyons intertwined across a pastoral landscape. By contrast, the eastern 1,000 square miles is largely mountainous, with elevations rising to nearly 10,000 feet and mean annual precipitation reaching 30 inches. The mountainous land responds with grass meadows interspersed with conifer forest of mostly ponderosa pine.

Except for Page, Arizona; a small area around Lees Ferry; and a portion of the Paria Plateau administered by the Bureau of Land Management; the study area lies entirely within the Navajo Nation. Based on straight-line interpolation of 2000 and 2010 census data for the area, it is estimated that approximately 46,867 persons were living within the study area in 2012, and of these an estimated 39,533 resided on the Navajo Nation.

The largest cities are Page and Kayenta, with 2010 populations of 7,247 and 5,189, respectively. Other major communities and their populations include Dennehotso (746), Kaibeto (1,522), Chinle (4,518), LeChee (1,443), Lukachukai (1,701), Many Farms (1,348), Rock Point (642), Teec Nos Pos (730), and Tsaile (1,205). Subsistence in the region is derived principally from livestock grazing, farming, tourist-related industries, employment at the Navajo Generating Station (NGS), which consumes approximately 71 percent of the water used or lost in the study area every year. Agriculture accounted for about 5 percent of the total water use; municipal and industrial (including the Navajo Generating Station) about 83 percent; recreation, fish and wildlife, about 5 percent; and reservoir evaporation, about 8 percent.

AGRICULTURAL CONSUMPTIVE USE

Agricultural consumptive use is divided into three categories: irrigation, stock pond, and livestock. Irrigation use includes all use related to irrigating crops including the incidental losses. Stock pond use is the evaporation that occurs from stock ponds and livestock use is the water consumed by livestock.

IRRIGATION USES

Within the Arizona portion of the Upper Colorado River Basin, historically 23 irrigated areas were scattered across the Navajo Nation plus a small amount of land near Lees Ferry irrigated by the National Park Service. Currently, only 16 irrigated areas are in production. An accurate assessment of consumptive use on the irrigated land is difficult due to poor quality of information, such as the exact number of acres under irrigation, the cropping pattern for each irrigated area, site climatological conditions, and the amount s of water actually diverted. In many cases, during the latter part of the irrigation season, farmers have to rely on dry land farming since there is little water available in the streams. This means that the crops do not receive their full water requirement.

For this report, the U.S. Department of Agriculture, Soil Conservation Service's (SCS) Modified Blaney-Criddle evapotranspiration, without an elevation adjustment, estimation formula was used for computing irrigated crop consumptive use. This model, along with appropriate crop-growth stage coefficients and the method for computing effective precipitation, is described in SCS's *Irrigation Water Requirements Technical Release No. 21* (TR 21). Information required for applying this model includes mean monthly temperature and precipitation values, growing season data for each crop type, and the total number of acres planted by crop at each site. With the exception of Teec Nos Pos, Canyon de Chelly, Lukachukai, and Lees Ferry, no climatological data exist for the irrigation sites, and site values must be generated from data collected at surrounding established weather stations. Growing season dates depend largely on the judgment of the local inhabitants and are, therefore, not known. Although several reports are available with published values for irrigated acres, it is unclear if these values are meant to represent potential irrigated acres, acres irrigated in the past, acres for which farming permits have been issued, or actual acres currently under irrigation.

The crop acreage used to estimate consumptive use by irrigated crops for the year 2012 is shown in table 1. These values were estimated from previous direct field examination by a party composed of representatives from the State of Arizona and the Navajo Nation.

Table 1.—Total irrigated acreage, 2012

PROJECT	CORN (ACRES)	ALFALFA (ACRES)	GRASS PASTURE (ACRES)	SPRING GRAINS (ACRES)	SMALL VEGETABLES (ACRES)	ORCHARD (ACRES)	TOTAL (ACRES)
CHINLE AGENCY							
Canyon de Chelly	0.36	0.00	0.00	3.03	2.26	0.00	5.65
Lukachukai	39.09	7.69	0.00	7.50	5.98	2.07	62.33
Many Farms	149.13	24.88	92.09	2.43	24.88	0.00	293.40
Nazlini	0.00	0.00	0.00	0.00	1.79	0.74	2.53
Rough Rock	30.00	0.00	11.87	0.00	12.43	0.00	54.30
Tsaile	23.72	5.27	15.67	5.73	5.42	0.00	55.81
Wheatfields	0.00	60.80	0.00	0.00	0.00	0.00	60.80
TOTAL	242.30	98.64	119.63	18.69	52.76	2.81	534.82
SHIPROCK AGENCY							
Red Rock Valley	26.22	0.00	10.19	5.12	10.22	0.00	51.75
Teec Nos Pos	20.00	0.00	0.00	0.00	3.67	0.00	23.67
Toh Chin Lini	0.00	0.00	0.00	0.00	3.90	13.67	17.57
Totacon	0.00	0.00	0.00	0.00	1.00	0.00	1.00
TOTAL	46.22	0.00	10.19	5.12	18.79	13.67	93.99
WESTERN NAVAJO AGENCY							
Dennehotso	1.82	0.00	38.70	0.00	0.00	0.00	40.52
Lees Ferry	0.00	0.00	1.00	0.00	0.00	2.00	3.00
Marsh Pass	7.02	3.31	0.00	0.00	1.99	0.00	12.32
Navajo Canyon	0.00	0.00	0.00	0.00	0.00	3.50	3.50
Paiute Canyon	2.64	0.00	0.00	0.00	3.86	0.00	6.50
TOTAL	11.48	3.31	39.70	0.00	5.85	5.50	65.84
GRAND TOTAL	300.00	101.95	169.52	23.81	77.4	21.98	694.65

Several factors complicated the modeling of irrigation consumptive use. For example, the computer program used to model consumptive use assumes a full water supply; if shortages exist, as they often do in this semiarid study area, adjustments must be made. These adjustments are complicated because some of the projects have no storage water and may only have a reliable irrigation water supply during spring runoff. After spring runoff, farming becomes essentially dry land until rains in July and August provide intermittent flows for irrigation. Finally, no ditch diversion records are available to help estimate irrigation water supplies and shortages.

A full irrigation supply seldom exists at many of the projects. Generally, a full supply is available for Lees Ferry, Navajo Canyon, Tsaile, and Wheatfields projects because of adequate stream flows or because of available storage water. In years with average precipitation, it is estimated that Chinle Wash provides approximately 75 percent of the irrigation requirement. Precipitation in the area averages approximately 9.5 inches per year. Based on this information, it would require approximately 12.67 inches of precipitation to provide 100 percent of the irrigation requirement. The percent of crop water requirement met was computed as a ratio of annual precipitation to 12.67 inches. These values are found in table 2.

The percentage of crop water requirement met was multiplied by the total net crop water requirement to come up with the amount of crop consumptive use. Incidental irrigation losses, evaporation, and phreatophyte consumptive use along supply canals are estimated to be 5 percent of the consumptive use of the irrigated area and are added to the crop consumptive use value to develop a total consumptive use value.

A portion of the water used for irrigation at these sites may not be contributing to the Colorado River System since evaporation rates in the area are high and the nature of most of the drainage enhances evapotranspiration. A good example of such a drainage is Chinle Wash, which after it leaves Canyon de Chelly, becomes wide and sandy and is lined with willows, cottonwoods, and other phreatophytes.

The uncertainties in the irrigation consumptive use values displayed in table 2 are very large and are estimated as 40 percent of the total consumptive use. This estimate of possible error only reflects the uncertainty of consumptive use and does not account for any possible errors in the acreage estimates. The effective consumptive use for irrigation for 2012 was estimated to equal 584 acre-feet. Including the 5 percent for incidental losses, the irrigation related consumptive use is 613 (±245) acre-feet.

Table 2.—Net consumptive use values, 2012

PROJECT	CROP WATER REQUIREMENT (INCHES)	TOTAL IRRIGATED (ACRES)	TOTAL WATER REQUIRED (ACRE-FEET)	CROP WATER REQUIREMENT MET (%)	CROP WATER REQUIREMENT MET (ACRE-FEET)	TOTAL CONSUMPTIVE USE (ACRE-FEET)[1]
CHINLE AGENCY						
Canyon de Chelly	30.92	5.65	15	30%	4	4.5
Lukachukai	31.43	62.33	163	30%	48	50.7
Many Farms	31.19	293.40	763	30%	226	237.1
Nazlini	28.43	2.53	6	30%	2	1.9
Rough Rock	24.41	54.3	110	56%	62	64.1
Tsaile	31.79	55.81	148	30%	44	46.0
Wheatfields	39.85	60.80	202	30%	60	62.8
TOTAL	218.02	534.82	1,407		446	468.0
SHIPROCK AGENCY						
Red Rock Valley	31.13	51.75	134	33%	45	47.1
Teec Nos Pos	31.30	23.67	62	37%	23	24.2
Toh Chin Lini	41.90	17.57	61	19%	11	12.0
Totacon	28.60	1.00	2	19%	0	0.5
TOTAL	132.94	93.99	260		80	83.8
WESTERN NAVAJO AGENCY						
Dennehotso	41.42	40.52	140	15%	21	21.7
Lees Ferry	42.12	3.00	11	100%	11	11.8
Marsh Pass	22.02	12.32	23	62%	14	14.7
Navajo Canyon	39.87	3.50	12	53%	6	6.5
Paiute Canyon	26.36	6.50	14	41%	6	6.2
TOTAL	174.79	65.84	200		58	61.0
GRAND TOTAL	525.74	694.65	1,866		584	612.7

[1] Total includes 5% addition for incidental losses.

STOCK POND EVAPORATION

Stock pond consumptive use is assumed to be the evaporation from the stock pond. It is also assumed that any consumptive use by natural vegetation prior to the construction of the stock ponds is limited to precipitation which is subtracted from the evaporation losses.

A compilation of the stock ponds in the study area, including their locations and the water surface areas when ponds are full, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 3. For an average year condition, the stock pond evaporative surface area was estimated as one-third the water surface area that occurs when the ponds are full. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average water surface area. These values are found in table 3.

Table 3.—Stock pond evaporation, 2012

COUNTY	SURFACE AREA FULL (ACRES)	SURFACE AREA USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Coconino	80	15	58	57	3.89	53.11	68.1
Navajo	40	10	73	55	7.12	47.88	38.9
Apache	646	104	48	53	4.24	48.77	420.9
TOTAL	766	129					528

This method of evaporation estimation was used because continuous useful water level records for all stock ponds from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual stock ponds. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation. It was assumed that any consumptive use by natural vegetation prior to construction of the stock ponds is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for stock pond evaporation for calendar year 2012 are shown in table 3. The total evaporative losses in 2012 are 528 (±158) acre-feet with the stock pond evaporation uncertainty being estimated as 30 percent.

LIVESTOCK WATER

The source of most livestock water in the study area is from wells, with windmill-operated pumps developed and maintained by Navajo Water Operations and Maintenance, and water collected in small surface ponds. The estimated number of

livestock in the area was estimated based on previous livestock tallies. It was estimated that horses and cattle consume 12 gallons per day; sheep and goats consume 2 gallons per day.

The number of animals for the Upper Colorado portion of each district is shown in table 4. The computed value for livestock consumptive use is 397 acre-feet. The uncertainty in this number is estimated as 30 percent of the total or ±119 acre-feet.

Table 4.—Number of livestock, 2012

AGENCY	CATTLE	HORSES	SHEEP	GOATS
Western Navajo District No. 1	149	78	1,644	695
Western Navajo District No. 2	1,308	123	1,337	1,593
Western Navajo District No. 8	5,722	1,145	9,193	5,869
Shiprock District No. 9	1,387	107	3,143	3,199
Chinle District No. 10	2,867	776	4,824	2,476
Chinle District No. 11	1,642	289	1,946	1,702
Shiprock District No. 12	4,258	797	6,713	3,525
Fort Defiance District No. 17	29	156	1,454	827
Fort Defiance District No. 18	0	195	978	0
TOTAL	17,362	3,666	31,232	19,886

TOTAL AGRICULTURAL CONSUMPTIVE USE

The total agricultural consumptive use, displayed in table 5, is the sum of the individual components discussed in the previous sections. Agricultural water consumption represents approximately 5 percent of the total use in the study area. Total degree of uncertainty was computed by taking the square root of the sum of the individual uncertainties squared; known as the quadratic sum. This method and nomenclature is used throughout this report. This method was used because a simple sum does not account for the partial cancellation of errors occurring when calculating the total uncertainty derived from individual values that are random and independent of each other. As previously discussed, the individual uncertainties were set as a percent of the consumptive use value.

Table 5.—Total agricultural consumptive use, 2012

CATEGORY	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Irrigation	613	245
Stock Ponds	528	158
Livestock	397	119
TOTAL	1538	315

MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

Municipal and industrial consumptive use is divided into three categories: mineral resources, thermal electric power, and other. Mineral resources consumptive use includes water used for mineral production. No mineral resources consumptive use is reported in the study area. Thermal electric power consumptive use includes the water used at the power plants, and that used to transport material to the power plant (such as a coal slurry pipeline). Other consumptive use includes urban, rural, and industrial uses.

THERMAL ELECTRIC POWER

Thermal electric power consumptive use includes the water used in the power plant and the water used to transport material to the plant.

Navajo Generating Station

The water used by the NGS is pumped directly from Lake Powell and comprises about 70 percent of the total consumption in the study area. Since all NGS water use is metered, this quantity is among those most precisely known, with the maximum uncertainty in the metered quantities believed to be less than 3 percent. The actual quantity consumed, along with the estimated uncertainty for the calendar year 2012, was 23,953 (±719) acre-feet.

OTHER

The other consumptive use category includes the remaining use by urban, rural, and industries.

Page, AZ and Vicinity

City of Page, AZ. – The city of Page pumps its domestic water directly from Lake Powell. The water pumped is metered, and the uncertainty of the pumped quantities was assumed to be less than 3 percent. A portion of the water pumped and treated by the City

of Page, is supplied to the community of Le Chee on the Navajo Nation and is accounted for separately. The quantity supplied to the City of Page and its associated uncertainty for the calendar year 2012 was 2,240 (±67) acre-feet. Water returning to the waste water treatment plant is metered as well. The waste water for the City of Page is treated and is either evaporated from lined ponds or applied to the golf course, with a portion being returned to the Colorado River. The return flow is estimated to be 1,922 acre-feet. The net consumptive use is estimated to be 318 acre-feet (±89).

Le Chee – The community of Le Chee is supplied and metered by the City of Page. Total water supplied for 2012 was 94 (±3) acre-feet. The uncertainty was estimated to be 3 percent.

Greenhaven Water Company – The Greenhaven Water Company derives its domestic water supply from wells. Well pumping records are available. According to these records, the total water pumped for 2012 was 121 (±8) acre-feet. The uncertainty was estimated to be 7 percent.

Arizona Department of Transportation Housing – The Arizona Department of Transportation operates a housing, maintenance, and administrative facility located on US Hwy 89, north of Page, AZ. This facility is supplied from wells that have no meters installed. It is estimated that the total water pumped for 2012 was 7 acre-feet with an uncertainty of 30 percent of this value or ±2 acre-feet.

Navajo Nation

Community Water Systems – 1980 statistics from the Division of Community Development of the Navajo Nation reveal that various community water systems served 26,086, or about 83 percent of the 31,429 people residing within the study area at that time. Since additional estimates have not been repeated, this same percentage was used for 2012 resulting in 32,812 out of 39,533 people being served. These systems include those operated by the Navajo Tribal Utility Authority (NTUA), the BIA, and the Water Operations and Maintenance Department of the Navajo Nation, and some privately developed community water systems.

Table 6 shows the source of water and estimated population served by each source of water for people living on the Navajo Nation during 2012. All of the communities obtain their water supply from ground water.

Table 6.—Domestic water sources, 2012

SOURCE	PERCENTAGE OF POPULATION SERVED	NUMBER OF POPULATION SERVED[1]
Community Water Systems	83	32,812
NTUA	[2](60)	19,687
BIA	[2](25)	8,203
Navajo WOM	[2](13)	4,256
Private	[2](2)	656
Individual Wells	17	6,721
TOTAL	100	39,533

[1] Total population within the Upper Colorado River Basin portion of the Navajo Nation, estimated from 2010 US Census.
[2] These numbers are a percentage of the Community Water Systems.

NTUA Water Systems – The cities and surrounding communities of Oak Springs, Red Valley, Sweetwater, Chinle , Rough Rock, Round Rock, Rock Point, Wheatfields, Lukachukai, Kayenta, Chilchinbeto, Dennehotso, and Kaibeto derive most of their domestic water supply from wells operated by NTUA. Well pumping records are available. According to these records, the total water pumped for 2012 was 1,596 acre-feet with an uncertainty estimated to be 7 percent of this value or ±113 acre-feet.

The NTUA manages the raw waste water; portions of which flow to individual septic tanks, some to evaporation ponds, and some, such as for the cities of Chinle and Kayenta, flow to waste water treatment plants. Very little water, if any, is returned to the ground water system through leakage from the evaporation ponds, but there are losses from the main collection system. Effluent from the Chinle and Kayenta waste water treatment plants is metered. Under normal conditions, the effluent returns to the Colorado River System and is subtracted from the pumping totals to determine a net consumptive use. For 2012, Chinle's treatment plant effluent was 13.6 (±1.0) acre-feet, and Kayenta's effluent was 9.7 (±0.7) acre-feet. An estimated uncertainty of 7 percent was used for the effluent of these two plants. The total effluent of 23 acre-feet is subtracted from the NTUA pumping total of 1,619 acre-feet to arrive at a net consumptive use of 1,596 (±113) acre-feet.

BIA Water Systems – Wells developed and operated by the BIA serve numerous Navajo communities. These systems also serve BIA schools, hospitals, agency offices, and some housing on the Navajo Nation. Metered records for total amounts of water pumped from BIA wells were available for a portion of the Shiprock Agency, the Western Navajo Agency, and the Chinle Agency. Drawing 1246-406-2 shows the agency boundaries within the Upper Colorado River Basin. The uncertainty was estimated to be about 7 percent for all three agencies.

The BIA systems include sewage disposal units terminating in lined evaporation ponds with very little or no return water returning to the ground water system. Undoubtedly, some losses occur in distribution, but insufficient data currently exist to estimate these losses. The losses are probably less than the uncertainties for each of the reported values.

The BIA well data available for the Shiprock Agency include: Cove, Red Rock, and Teec Nos Pos. Total consumptive use values are 11 (±1) acre-feet.

Pumping records for the Western Navajo Agency include data for the following schools: Chilchinbeto Day School, Dennehotso Boarding School, Kaibeto Boarding School, and Kayenta Boarding School. Total consumptive use for the Western Navajo Agency was 172 (±12) acre-feet.

Well pumping records for the Chinle Agency include data for the following schools: Cottonwood Day School, Lukachukai School, and Rock Point School. Rough Rock School maintains its own records, but the data was included with the Chinle Agency data. Total consumptive use for the Chinle Agency was 69 (±5) acre-feet.

Navajo WOM Water Systems – Water use in 2012 by the Navajo WOM service areas was based on an assumed consumption rate of 110 gallons per capita per day (gpcd). For a 2012 estimated service area population of 4,266, the estimated annual water use was 526 (±158) acre-feet. The uncertainty is estimated as 30 percent of the total.

Private Water Systems – The estimated 2012 population served by private water systems on the Navajo Nation was 656. Assuming a consumptive use rate of 110 gcpd, the annual water use for 2012 was 81 (±24) acre-feet. The uncertainty is estimated as 30 percent of the total.

Individual Wells – According to census data from the Division of Community Development of the Navajo Nation, approximately 17 percent of the study area's population on the reservation (about 6,721 persons in 2012) receives a domestic water supply from individual wells. A consumptive use of 110 gpcd was derived as being a reasonable water use rate. Based on these figures, the annual consumptive use was 828 (±248) acre-feet for 2012.

TOTAL MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

The total municipal and industrial consumptive use, displayed in table 7, is the sum of the individual components discussed in the previous sections. Municipal and industrial water consumption represents approximately 83 percent of the total use in the study area.

Table 7.—Total municipal and industrial consumptive use, 2012

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
THERMAL ELECTRIC POWER		
Navajo Generating Station	23,953	719
OTHER		
Page, AZ and Vicinity		
City of Page	318	89
Le Chee	94	3
Greenhaven Water Company	121	8
Arizona Department of Transportation	7	2
Navajo Indian Reservation		
Community Water Systems		
NTUA Water Systems	1,596	113
BIA Water Systems	252	13
Navajo WOM	526	158
Private Water Systems	81	24
Individual Wells	828	248
TOTAL	27,776	790

It is questionable whether all the water pumped from wells should be considered a depletion to the Colorado River System; however, it is assumed that 100 percent of the water pumped is considered lost to the system. It is proposed that a future joint study be completed by Reclamation, the State of Arizona, and the Navajo Nation to estimate what percentage of water pumped could actually be attributed to the Colorado River System and would have affected the river flows for a particular year.

RECREATION, FISH AND WILDLIFE

The recreation, fish and wildlife consumptive uses include evaporation from reservoirs used exclusively for fish & wildlife purposes as well as acreages irrigated for wildlife feeding. Consumptive use related to recreation at National parks is also addressed.

GLEN CANYON NATIONAL RECREATION AREA

Colorado River water is used by the Glen Canyon National Recreation Area (GCNRA) at Wahweap and Lees Ferry. The recreational area at Wahweap gets its water supply from a series of wells on the shore of Lake Powell. Pumping records for both Wahweap Marina, and Lees Ferry show 296 (±9) acre-feet of water withdrawn during 2012. The uncertainty is estimated at 3 percent. This water was used for domestic purposes at the

campgrounds, picnic areas, and trailer parks. It was also used to irrigate approximately 60 acres of Bermuda grass and cottonwood trees. The domestic waste water is treated and the effluent is allowed to evaporate from two lined evaporation ponds with a total surface area of 16.7 acres.

Based on estimates of evaporation and consumptive use by the plants, there is some water which is unaccounted for and is assumed to be leakage from the delivery system, the evaporation pond, or deep percolation from irrigation application. However, since these water losses are difficult to quantify and verify, the losses were charged as consumptive uses. Therefore, net consumptive use of water is estimated to be equal to the quantity of water pumped.

RECREATION – FISH & WILDLIFE RESERVOIR EVAPORATION

A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 8.

Table 8. —Recreation, fish and wildlife reservoir evaporation, 2012

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE AREA USED (ACRES)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Tsaile	260	260	35	3.75	31.25	677.1
Wheatfields	272	272	32	3.75	28.25	640.3
TOTAL	532	532				1,317

Efforts are made to maintain a nearly full condition and to minimize water surface fluctuations in reservoirs managed for a fishery. Under average operating conditions, the water surface area of a reservoir used primarily for fishing is assumed to be equal to a normal water surface area. It is assumed that, in 2012, these reservoirs filled in the spring and were maintained at the normal pool level.

This method of evaporation estimation was used because continuous useful water level records for all reservoirs from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs.

For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for reservoir evaporation for calendar year 2012 are shown in table 8. The total evaporative losses in 2012 are 1,317 (±395) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent.

TOTAL RECREATION, FISH AND WILDLIFE

The total recreation, fish and wildlife consumptive use, displayed in table 9, is the sum of the individual components discussed in the previous sections. Recreation, fish and wildlife water consumption represents approximately 4 percent of the total use in the study area.

Table 9.—Total recreation, fish and wildlife consumptive use, 2012

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Glen Canyon National Recreation Area	296	9
Reservoir Evaporation	1,317	395
TOTAL	1,614	395

IRRIGATION RESERVOIR EVAPORATION

Irrigation reservoir evaporation losses make up about 8 percent of the total water uses and losses in the study area. A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 10. These reservoirs are used primarily for irrigation.

Table 10.—Reservoir evaporation, 2012

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE ACRES USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Many Farms	1,800	554	39	56	3.75	52.25	2,414.3
Marsh Pass	40	16	78	40	8.80	31.21	40.6
Round Rock	83	20	48	57	4.24	52.77	87.8
Walker Creek	30	9	58	59	4.72	54.28	39.6
Others	38	12	62	55	6.29	48.71	47.9
TOTAL	1,991	611					2,630

Reservoirs used primarily for irrigation experience large fluctuations in water levels and, correspondingly, large variations in surface area. Reservoir level records and elevation – area curves were available at Many Farms, but not for the remaining reservoirs in table 10. For the reservoirs with no records from which surface area could be accurately computed, the average evaporative surface area was estimated as one-half the water

surface area of a full reservoir. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average evaporative surface area.

Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses. The computed values for reservoir evaporation for 2012 are shown in table 10. The total evaporative losses in 2012 are 2,630 (±789) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent of the total evaporation.

CONCLUSIONS

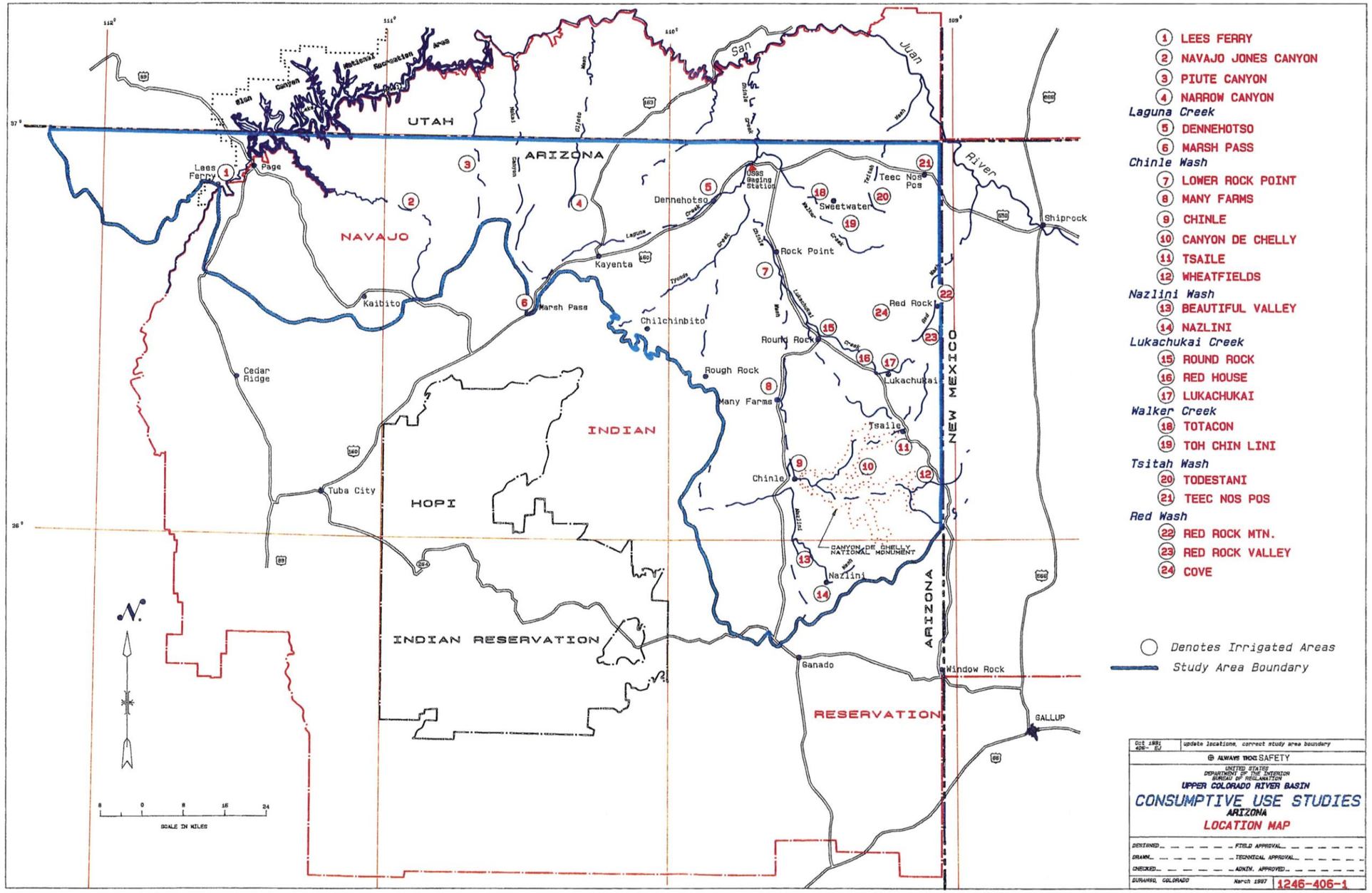
This report assesses the total consumptive use of the Arizona portion of the Upper Colorado River surface water systems, depletion of ground water, and evaporative losses. Clearly, the amounts of water used by the Navajo Generating Station, City of Page, and Wahweap and Lees Ferry recreation areas are direct depletions of water from the Upper Colorado River System, but the situation is not as clear for other consumptive uses and losses occurring in other sections of the study area. For example, the source of water used by the Navajo Nation for domestic and municipal purposes is from wells, some exceeding 1,000 feet in depth. For our purposes here, it is considered to be consumed and a depletion to the Colorado River System. But this may not actually result in a reduction of Colorado River stream flows in the same year that the withdrawal occurs, or at all. Little knowledge and information exists of ground water movement and subsurface flow rates in the study area that are accurate descriptions of the effects on river flows.

Although the water diverted for agricultural purposes is considered as consumptive use in this report, a portion of the remaining surface water on the Navajo Nation, excess to needs, does evaporate before reaching the Colorado River. No attempt has been made for this report to quantify these losses.

Uncertainties in estimating uses and losses exist, and the degree of variation in the figures is presented. Fortunately, the areas with the highest degree of uncertainty account for only a small percentage of the total consumptive use. The largest component, use by the Navajo Generating Station, is also the most accurately monitored. The total annual value for estimated consumptive use of water within the Arizona portion of the Upper Colorado River Basin for 2012 was 33,557 acre-feet, as shown in table 11.

Table 11.—Consumptive use for Arizona portion of Upper Colorado River Basin for 2012

USE CATEGORY	TOTAL CONSUMPTIVE USE (ACRE-FEET)	UNCERTAINTY	PERCENT OF TOTAL
Agriculture	1,538	315	4.58
Municipal & Industrial	27,776	790	82.77
Recreation, Fish & Wildlife	1,614	395	4.81
Reservoir Evaporation	2,630	789	7.84
TOTAL	33,557	1,226	100


1 LEES FERRY
2 NAVAJO JONES CANYON
3 PIUTE CANYON
4 NARROW CANYON
Laguna Creek
5 DENNEHOTSO
6 MARSH PASS
Chinle Wash
7 LOWER ROCK POINT
8 MANY FARMS
9 CHINLE
10 CANYON DE CHELLY
11 TSAILE
12 WHEATFIELDS
Nazlini Wash
13 BEAUTIFUL VALLEY
14 NAZLINI
Lukachukai Creek
15 ROUND ROCK
16 RED HOUSE
17 LUKACHUKAI
Walker Creek
18 TOTACON
19 TOH CHIN LINI
Tsitah Wash
20 TODESTANI
21 TEEC NOS POS
Red Wash
22 RED ROCK MTN.
23 RED ROCK VALLEY
24 COVE
Denotes Irrigated Areas
Study Area Boundary
UTAH
ARIZONA
NAVAJO
INDIAN
HOPI
INDIAN RESERVATION
RESERVATION
NEW MEXICO
ARIZONA
San Juan River
Lees Ferry
Page
Kaibito
Cedar Ridge
Tuba City
Marsh Pass
Kayenta
Dennehotso
USGS Gaging Station
Chilchinbito
Rough Rock
Many Farms
Chinle
Rock Point
Sweetwater
Teec Nos Pos
Round Rock
Red Rock
Lukachukai
Tsaile
CANYON DE CHELLY NATIONAL MONUMENT
Nazlini
Ganado
Window Rock
GALLUP
Shiprock
SCALE IN MILES
ALWAYS THOC SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
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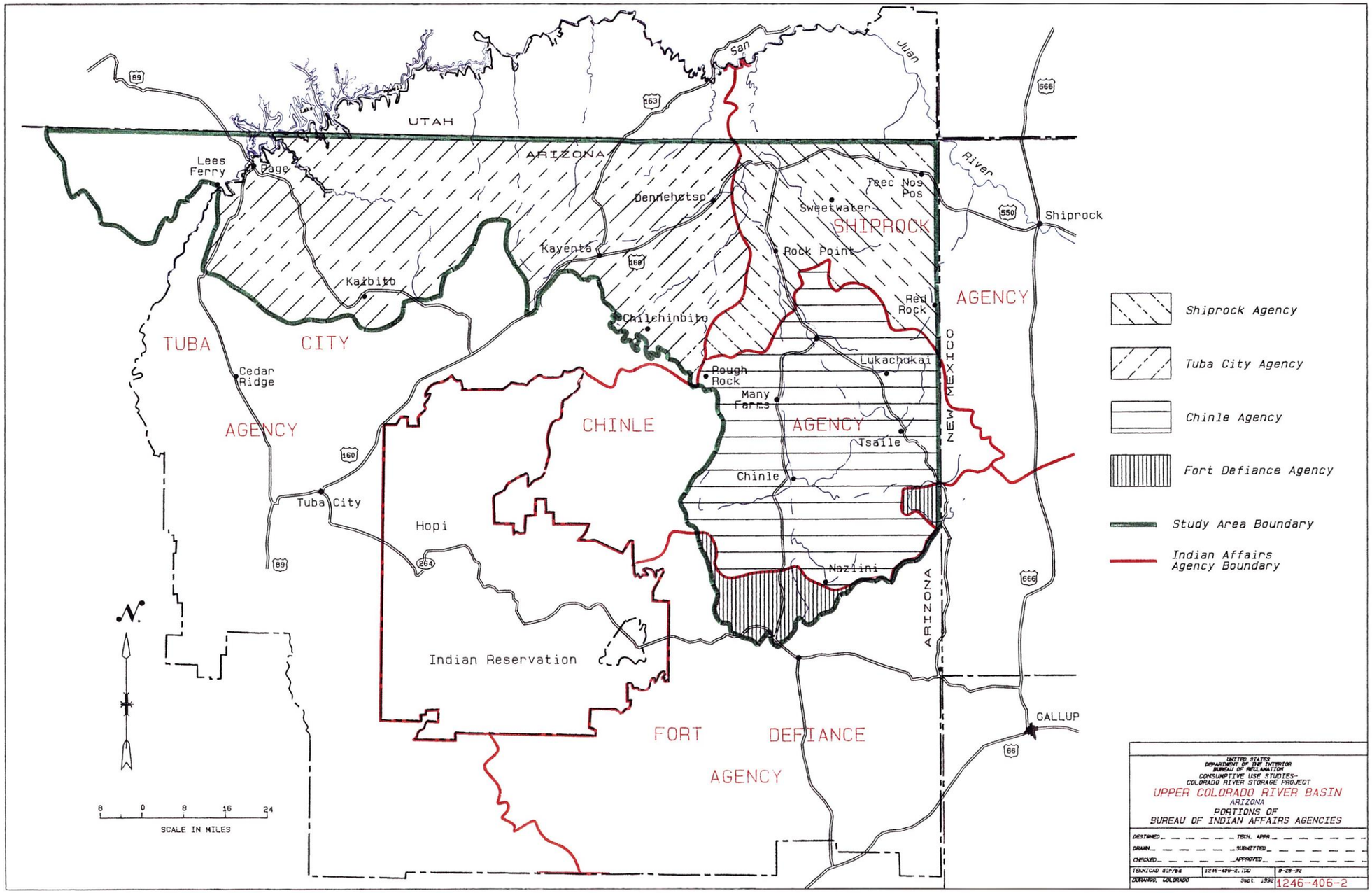
CONSUMPTIVE USE STUDIES
ARIZONA
LOCATION MAP
DENVER, COLORADO
March 1987
1246-406-1


UTAH
ARIZONA
NEW MEXICO
San Juan River
Lees Ferry
Page
Kaibito
Kayenta
Dennehotso
Chilchinbito
Tsec Nos Pos
Sweetwater
Rock Point
Red Rock
Shiprock
Lukachukai
Rough Rock
Many Farms
Tsaile
Chinle
Nazlini
Cedar Ridge
Tuba City
Hopi
Indian Reservation
GALLUP
TUBA CITY AGENCY
CHINLE AGENCY
SHIPROCK AGENCY
FORT DEFIANCE AGENCY
Shiprock Agency
Tuba City Agency
Chinle Agency
Fort Defiance Agency
Study Area Boundary
Indian Affairs Agency Boundary
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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CONSUMPTIVE USE STUDIES-
COLORADO RIVER STORAGE PROJECT
UPPER COLORADO RIVER BASIN
ARIZONA
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Sept. 1992
1246-406-2

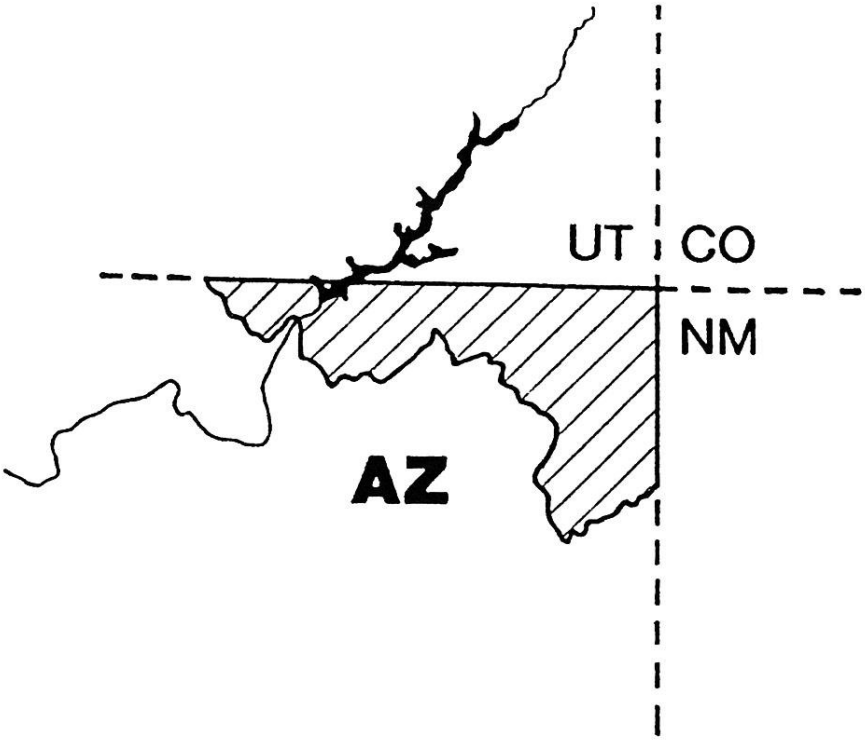
RECLAMATION

Managing Water in the West

Consumptive Uses and Losses: Provisional Estimate

Arizona Portion of the Upper Colorado River Basin Calendar Year 2013

Provisional Version dated: October 1, 2014



U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

October 2014

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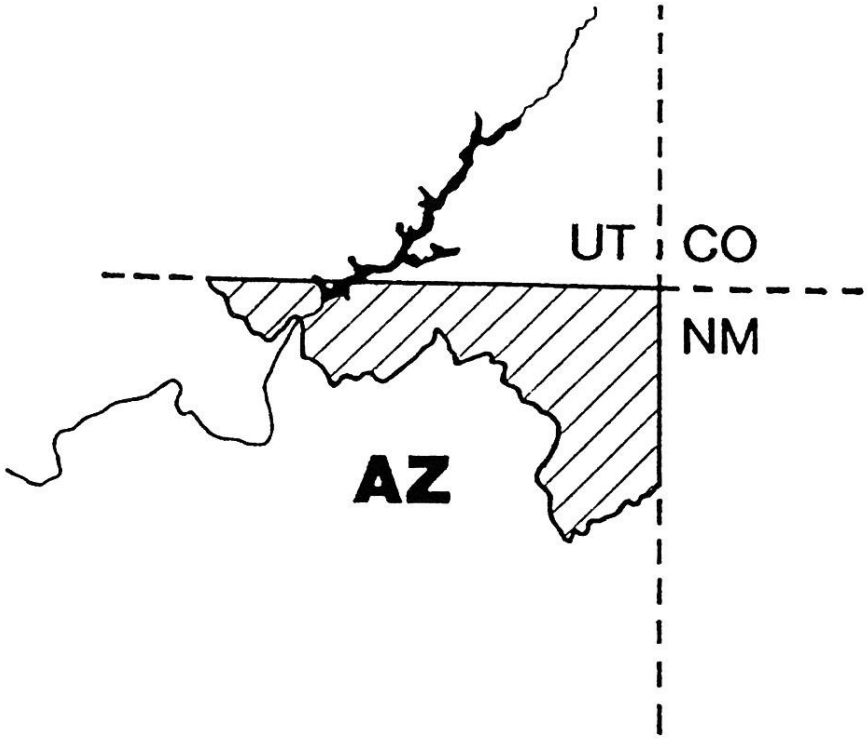

Prepared by: Alan Harrison – October 1, 2014

U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

October 2014

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ARIZONA PORTION
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UPPER COLORADO RIVER BASIN

CALENDAR YEAR
2013

AUTHORITY

This report was prepared in compliance with Public Law 90-537, Section 601 (b)(1), dated September 30, 1968, which directs the Secretary of the Interior to "make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis." Additionally, this report is in compliance with Section 49 of the Navajo Project Participation Agreement dated September 30, 1969, which states in part: "The Secretary of the Interior further agrees to make the reports required by Section 601 (b)(1) of Public Law 90-537 as they pertain to Arizona's Upper Basin uses annually rather than every five years. Within fifteen days following the completion of said reports, the Secretary of the Interior shall furnish copies of such reports to the Co-Tenants, the Navajo Tribe, each of the Upper Basin States, and the Upper Colorado River Commission."

SUMMARY

Based upon data made available for preparation of this document. the total consumptive use and loss value for the Arizona portion of the Upper Colorado River Basin for calendar year 2013 was 35,037 (±1,267) acre-feet. Reclamation prepares this estimate annually, final annual values for consumptive uses and losses for the northern Arizona portion of the Colorado River basin are published in the 5-year summary documents for the Upper Colorado River Basin

STUDY AREA DESCRIPTION

The Arizona portion of the Upper Colorado River Basin covers approximately 6,900 square miles in the north-east corner of Arizona, as shown on the location maps shown on pages 19 and 20 (Drawings 1246-406-1, 1246-406-2). The climate of the 5,900 square mile area to the west of the Chuska and Carrizo Mountains is largely arid to semiarid, with mean annual precipitation ranging from 6 to 12 inches and with summertime temperatures often reaching 100 degrees Fahrenheit (^{o}F). The potential

evaporation rate is high and exceeds mean annual precipitation, with gross lake evaporation values of up to 55 inches per year or more. Elevations in the western portion range from 3200 feet on the Colorado River at Lees Ferry to over 8000 feet on the northern edge of the Black Mesa and across the Zilnez and Skeleton Mesas, back down to 5280 feet in the Chinle Valley, and back up to about 6500 feet on the western edge of the Chuska Mountains. Much of the western part of the study area is starkly beautiful southwestern desert country with mesas and canyons intertwined across a pastoral landscape. By contrast, the eastern 1,000 square miles is largely mountainous, with elevations rising to nearly 10,000 feet and mean annual precipitation reaching 30 inches. The mountainous land responds with grass meadows interspersed with conifer forest of mostly ponderosa pine.

Except for Page, Arizona; a small area around Lees Ferry; and a portion of the Paria Plateau administered by the Bureau of Land Management; the study area lies entirely within the Navajo Nation. Based on straight-line interpolation of 2000 and 2010 census data for the area, it is estimated that approximately 46,693 persons were living within the study area in 2013, and of these an estimated 39,314 resided on the Navajo Nation.

The largest cities are Page and Kayenta, with 2010 populations of 7,247 and 5,189, respectively. Other major communities and their populations include Dennehotso (746), Kaibeto (1,522), Chinle (4,518), LeChee (1,443), Lukachukai (1,701), Many Farms (1,348), Rock Point (642), Teec Nos Pos (730), and Tsaile (1,205). Subsistence in the region is derived principally from livestock grazing, farming, tourist-related industries, employment at the Navajo Generating Station (NGS), which consumes approximately 71 percent of the water used or lost in the study area every year. Agriculture accounted for about 7 percent of the total water use; municipal and industrial (including the Navajo Generating Station) about 82 percent; recreation, fish and wildlife, about 4 percent; and reservoir evaporation, about 7 percent.

AGRICULTURAL CONSUMPTIVE USE

Agricultural consumptive use is divided into three categories: irrigation, stock pond, and livestock. Irrigation use includes all use related to irrigating crops including the incidental losses. Stock pond use is the evaporation that occurs from stock ponds and livestock use is the water consumed by livestock.

IRRIGATION USES

Within the Arizona portion of the Upper Colorado River Basin, historically 23 irrigated areas were scattered across the Navajo Nation plus a small amount of land near Lees Ferry irrigated by the National Park Service. Currently, only 16 irrigated areas are in production. An accurate assessment of consumptive use on the irrigated land is difficult due to poor quality of information, such as the exact number of acres under irrigation, the cropping pattern for each irrigated area, site climatological conditions, and the amount s of water actually diverted. In many cases, during the latter part of the irrigation season, farmers have to rely on dry land farming since there is little water available in the streams. This means that the crops do not receive their full water requirement.

For this report, the U.S. Department of Agriculture, Soil Conservation Service's (SCS) Modified Blaney-Criddle evapotranspiration, without an elevation adjustment, estimation formula was used for computing irrigated crop consumptive use. This model, along with appropriate crop-growth stage coefficients and the method for computing effective precipitation, is described in SCS's *Irrigation Water Requirements Technical Release No. 21* (TR 21). Information required for applying this model includes mean monthly temperature and precipitation values, growing season data for each crop type, and the total number of acres planted by crop at each site. With the exception of Teec Nos Pos, Canyon de Chelly, Lukachukai, and Lees Ferry, no climatological data exist for the irrigation sites, and site values must be generated from data collected at surrounding established weather stations. Growing season dates depend largely on the judgment of the local inhabitants and are, therefore, not known. Although several reports are available with published values for irrigated acres, it is unclear if these values are meant to represent potential irrigated acres, acres irrigated in the past, acres for which farming permits have been issued, or actual acres currently under irrigation.

The crop acreage used to estimate consumptive use by irrigated crops for the year 2013 is shown in table 1. These values were estimated from previous direct field examination by a party composed of representatives from the State of Arizona and the Navajo Nation.

Table 1.—Total irrigated acreage, 2013

PROJECT	CORN (ACRES)	ALFALFA (ACRES)	GRASS PASTURE (ACRES)	SPRING GRAINS (ACRES)	SMALL VEGETABLES (ACRES)	ORCHARD (ACRES)	TOTAL (ACRES)
CHINLE AGENCY							
Canyon de Chelly	0.36	0.00	0.00	3.03	2.26	0.00	5.65
Lukachukai	39.09	7.69	0.00	7.50	5.98	2.07	62.33
Many Farms	155.02	25.86	95.73	2.52	25.86	0.00	305.00
Nazlini	0.00	0.00	0.00	0.00	1.79	0.74	2.53
Rough Rock	30.00	0.00	11.87	0.00	12.43	0.00	54.30
Tsaile	23.72	5.27	15.67	5.73	5.42	0.00	55.81
Wheatfields	0.00	60.80	0.00	0.00	0.00	0.00	60.80
TOTAL	248.19	99.62	123.27	18.78	53.74	2.81	546.42
SHIPROCK AGENCY							
Red Rock Valley	26.22	0.00	10.19	5.12	10.22	0.00	51.75
Teec Nos Pos	20.00	0.00	0.00	0.00	3.67	0.00	23.67
Toh Chin Lini	0.00	0.00	0.00	0.00	3.90	13.67	17.57
Totacon	0.00	0.00	0.00	0.00	1.00	0.00	1.00
TOTAL	46.22	0.00	10.19	5.12	18.79	13.67	93.99
WESTERN NAVAJO AGENCY							
Dennehotso	1.82	0.00	38.70	0.00	0.00	0.00	40.52
Lees Ferry	0.00	0.00	1.00	0.00	0.00	2.00	3.00
Marsh Pass	7.02	3.31	0.00	0.00	1.99	0.00	12.32
Navajo Canyon	0.00	0.00	0.00	0.00	0.00	3.50	3.50
Paiute Canyon	2.64	0.00	0.00	0.00	3.86	0.00	6.50
TOTAL	11.48	3.31	39.70	0.00	5.85	5.50	65.84
GRAND TOTAL	305.89	102.93	173.16	23.90	78.38	21.98	706.25

Several factors complicated the modeling of irrigation consumptive use. For example, the computer program used to model consumptive use assumes a full water supply; if shortages exist, as they often do in this semiarid study area, adjustments must be made. These adjustments are complicated because some of the projects have no storage water and may only have a reliable irrigation water supply during spring runoff. After spring runoff, farming becomes essentially dry land until rains in July and August provide intermittent flows for irrigation. Finally, no ditch diversion records are available to help estimate irrigation water supplies and shortages.

A full irrigation supply seldom exists at many of the projects. Generally, a full supply is available for Lees Ferry, Navajo Canyon, Tsaile, and Wheatfields projects because of adequate stream flows or because of available storage water. In years with average precipitation, it is estimated that Chinle Wash provides approximately 75 percent of the irrigation requirement. Precipitation in the area averages approximately 9.5 inches per year. Based on this information, it would require approximately 12.67 inches of precipitation to provide 100 percent of the irrigation requirement. The percent of crop water requirement met was computed as a ratio of annual precipitation to 12.67 inches. These values are found in table 2.

The percentage of crop water requirement met was multiplied by the total net crop water requirement to come up with the amount of crop consumptive use. Incidental irrigation losses, evaporation, and phreatophyte consumptive use along supply canals are estimated to be 5 percent of the consumptive use of the irrigated area and are added to the crop consumptive use value to develop a total consumptive use value.

A portion of the water used for irrigation at these sites may not be contributing to the Colorado River System since evaporation rates in the area are high and the nature of most of the drainage enhances evapotranspiration. A good example of such a drainage is Chinle Wash, which after it leaves Canyon de Chelly, becomes wide and sandy and is lined with willows, cottonwoods, and other phreatophytes.

The uncertainties in the irrigation consumptive use values displayed in table 2 are very large and are estimated as 40 percent of the total consumptive use. This estimate of possible error only reflects the uncertainty of consumptive use and does not account for any possible errors in the acreage estimates. The effective consumptive use for irrigation for 2013 was estimated to equal 1,005 acre-feet. Including the 5 percent for incidental losses, the irrigation related consumptive use is 1,056 (±422) acre-feet.

Table 2.—Net consumptive use values, 2013

PROJECT	CROP WATER REQUIREMENT (INCHES)	TOTAL IRRIGATED (ACRES)	TOTAL WATER REQUIRED (ACRE-FEET)	CROP WATER REQUIREMENT MET (%)	CROP WATER REQUIREMENT MET (ACRE-FEET)	TOTAL CONSUMPTIVE USE (ACRE-FEET)[1]
CHINLE AGENCY						
Canyon de Chelly	25.05	5.65	12	69%	8	8.5
Lukachukai	25.35	62.33	132	69%	91	95.2
Many Farms	25.25	306.00	642	69%	442	464.0
Nazlini	22.59	2.53	5	69%	3	3.4
Rough Rock	20.81	54.30	94	78%	74	77.2
Tsaile	25.81	55.81	120	69%	83	86.8
Wheatfields	32.79	60.80	166	69%	114	120.1
TOTAL	177.64	546.42	1170		814	855.2
SHIPROCK AGENCY						
Red Rock Valley	25.66	51.75	111	62%	69	72.6
Teec Nos Pos	25.92	23.67	51	56%	29	30.1
Toh Chin Lini	35.66	17.57	52	28%	15	15.4
Totacon	23.16	1.00	2	28%	1	0.6
TOTAL	110.41	93.99	216		113	118.6
WESTERN NAVAJO AGENCY						
Dennehotso	35.23	40.52	119	34%	41	43.0
Lees Ferry	41.62	3.00	10	100%	10	10.7
Marsh Pass	19.89	12.32	20	65%	13	14.0
Navajo Canyon	36.54	3.50	11	70%	8	7.9
Paiute Canyon	23.72	6.50	13	44%	6	5.9
TOTAL	157.00	65.84	173		78	81.7
GRAND TOTAL	445.05	706.25	1559		1005	1055.6

[1] Total includes 5% addition for incidental losses.

STOCK POND EVAPORATION

Stock pond consumptive use is assumed to be the evaporation from the stock pond. It is also assumed that any consumptive use by natural vegetation prior to the construction of the stock ponds is limited to precipitation which is subtracted from the evaporation losses.

A compilation of the stock ponds in the study area, including their locations and the water surface areas when ponds are full, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 3. For an average year conditions, the stock pond evaporative surface area was estimated as one-third the water surface area that occurs when the ponds are full. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average water surface area. These values are found in table 3.

Table 3.—Stock pond evaporation, 2013

COUNTY	SURFACE AREA FULL (ACRES)	SURFACE AREA USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Coconino	80	26	97%	57	6.54	50.46	108.9
Navajo	40	12	90%	55	8.72	46.28	46.0
Apache	646	194	90%	53	7.91	45.09	727.1
TOTAL	766	231					882

This method of evaporation estimation was used because continuous useful water level records for all stock ponds from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual stock ponds. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation. It was assumed that any consumptive use by natural vegetation prior to construction of the stock ponds is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for stock pond evaporation for calendar year 2013 are shown in table 3. The total evaporative losses in 2013 are 882 (±265) acre-feet with the stock pond evaporation uncertainty being estimated as 30 percent.

LIVESTOCK WATER

The source of most livestock water in the study area is from wells, with windmill-operated pumps developed and maintained by Navajo Water Operations and Maintenance, and water collected in small surface ponds. The estimated number of

livestock in the area was estimated based on previous livestock tallies. It was estimated that horses and cattle consume 12 gallons per day; sheep and goats consume 2 gallons per day.

The number of animals for the Upper Colorado portion of each district is shown in table 4. The computed value for livestock consumptive use is 426 acre-feet. The uncertainty in this number is estimated as 30 percent of the total or ±128 acre-feet.

Table 4.—Number of livestock, 2013

AGENCY	CATTLE	HORSES	SHEEP	GOATS
Western Navajo District No. 1	0	6	1,542	596
Western Navajo District No. 2	1,383	116	1,348	1,696
Western Navajo District No. 8	6,282	1,269	10,058	6,438
Shiprock District No. 9	1,366	55	3,317	3,346
Chinle District No. 10	3,074	828	5,199	2,668
Chinle District No. 11	1,801	307	2,150	1,895
Shiprock District No. 12	4,759	890	7,512	3,945
Fort Defiance District No. 17	0	155	1,430	882
Fort Defiance District No. 18	0	199	971	0
TOTAL	18,665	3,825	33,527	21,466

TOTAL AGRICULTURAL CONSUMPTIVE USE

The total agricultural consumptive use, displayed in table 5, is the sum of the individual components discussed in the previous sections. Agricultural water consumption represents approximately 7 percent of the total use in the study area. Total degree of uncertainty was computed by taking the square root of the sum of the individual uncertainties squared; known as the quadratic sum. This method and nomenclature is used throughout this report. This method was used because a simple sum does not account for the partial cancellation of errors occurring when calculating the total uncertainty derived from individual values that are random and independent of each other. As previously discussed, the individual uncertainties were set as a percent of the consumptive use value.

Table 5.—Total agricultural consumptive use, 2013

CATEGORY	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Irrigation	1,056	422
Stock Ponds	882	265
Livestock	426	128
TOTAL	2,363	514

MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

Municipal and industrial consumptive use is divided into three categories: mineral resources, thermal electric power, and other. Mineral resources consumptive use includes water used for mineral production. No mineral resources consumptive use is reported in the study area. Thermal electric power consumptive use includes the water used at the power plants, and that used to transport material to the power plant (such as a coal slurry pipeline). Other consumptive use includes urban, rural, and industrial uses.

THERMAL ELECTRIC POWER

Thermal electric power consumptive use includes the water used in the power plant and the water used to transport material to the plant.

Navajo Generating Station

The water used by the NGS is pumped directly from Lake Powell and comprises over half of the total consumption in the study area. Since all NGS water use is metered, this quantity is among those most precisely known, with the maximum uncertainty in the metered quantities believed to be less than 3 percent. The actual quantity consumed, along with the estimated uncertainty for the calendar year 2013, was 24,963 (±749) acre-feet.

OTHER

The other consumptive use category includes the remaining use by urban, rural, and industries.

Page, AZ and Vicinity

City of Page, AZ. – The city of Page pumps its domestic water directly from Lake Powell. The water pumped is metered, and the uncertainty of the pumped quantities was assumed to be less than 3 percent. A portion of the water pumped and treated by the City

of Page, is supplied to the community of Le Chee on the Navajo Nation and is accounted for separately. The quantity supplied to the City of Page and its associated uncertainty for the calendar year 2013 was 2,240 (±67) acre-feet. Water returning to the waste water treatment plant is metered as well. The waste water for the City of Page is treated and is either evaporated from lined ponds or applied to the golf course, with a portion being returned to the Colorado River. The return flow is estimated to be 1,922 acre-feet. The net consumptive use is estimated to be 318 acre-feet (±89).

Le Chee – The community of Le Chee is supplied and metered by the City of Page. Total water supplied for 2013 was 94 (±3) acre-feet. The uncertainty was estimated to be 3 percent.

Greenhaven Water Company – The Greenhaven Water Company derives its domestic water supply from wells. Well pumping records are available. According to these records, the total water pumped for 2013 was 121 (±8) acre-feet. The uncertainty was estimated to be 7 percent.

Arizona Department of Transportation Housing – The Arizona Department of Transportation operates a housing, maintenance, and administrative facility located on US Hwy 89, north of Page, AZ. This facility is supplied from wells that have no meters installed. It is estimated that the total water pumped for 2013 was 7 acre-feet with an uncertainty of 30 percent of this value or ±2 acre-feet.

Navajo Nation

Community Water Systems – 1980 statistics from the Division of Community Development of the Navajo Nation reveal that various community water systems served 26,086, or about 83 percent of the 31,429 people residing within the study area at that time. Since additional estimates have not been repeated, this same percentage was used for 2013 resulting in 32,631 out of 39,314 people being served. These systems include those operated by the Navajo Tribal Utility Authority (NTUA), the BIA, and the Water Operations and Maintenance Department of the Navajo Nation, and some privately developed community water systems.

Table 6 shows the source of water and estimated population served by each source of water for people living on the Navajo Nation during 2013. All of the communities obtain their water supply from ground water.

Table 6.—Domestic water sources, 2013

SOURCE	PERCENTAGE OF POPULATION SERVED	NUMBER OF POPULATION SERVED[1]
Community Water Systems	83	32,631
NTUA	[2](60)	19,578
BIA	[2](25)	8,158
Navajo WOM	[2](13)	4,242
Private	[2](2)	653
Individual Wells	17	6,683
TOTAL	100	39,314

[1] Total population within the Upper Colorado River Basin portion of the Navajo Nation, estimated from 2010 US Census.
[2] These numbers are a percentage of the Community Water Systems.

NTUA Water Systems – The cities and surrounding communities of Oak Springs, Red Valley, Sweetwater, Chinle , Rough Rock, Round Rock, Rock Point, Wheatfields, Lukachukai, Kayenta, Chilchinbeto, Dennehotso, and Kaibeto derive most of their domestic water supply from wells operated by NTUA. Well pumping records are available. According to these records, the total water pumped for 2013 was 1,619 acre-feet with an uncertainty estimated to be 7 percent of this value or ±113 acre-feet.

The NTUA manages the raw waste water; portions of which flow to individual septic tanks, some to evaporation ponds, and some, such as for the cities of Chinle and Kayenta, flow to waste water treatment plants. Very little water, if any, is returned to the ground water system through leakage from the evaporation ponds, but there are losses from the main collection system. Effluent from the Chinle and Kayenta waste water treatment plants is metered. Under normal conditions, the effluent returns to the Colorado River System and is subtracted from the pumping totals to determine a net consumptive use. For 2013, Chinle's treatment plant effluent was 13.6 (±1.0) acre-feet, and Kayenta's effluent was 9.7 (±0.7) acre-feet. An estimated uncertainty of 7 percent was used for the effluent of these two plants. The total effluent of 23 acre-feet is subtracted from the NTUA pumping total of 1,619 acre-feet to arrive at a net consumptive use of 1,596 (±113) acre-feet.

BIA Water Systems – Wells developed and operated by the BIA serve numerous Navajo communities. These systems also serve BIA schools, hospitals, agency offices, and some housing on the Navajo Nation. Metered records for total amounts of water pumped from BIA wells were available for a portion of the Shiprock Agency, the Western Navajo Agency, and the Chinle Agency. Drawing 1246-406-2 shows the agency boundaries within the Upper Colorado River Basin. The uncertainty was estimated to be about 7 percent for all three agencies.

The BIA systems include sewage disposal units terminating in lined evaporation ponds with very little or no return water returning to the ground water system. Undoubtedly, some losses occur in distribution, but insufficient data currently exist to estimate these losses. The losses are probably less than the uncertainties for each of the reported values.

The BIA well data available for the Shiprock Agency include: Cove, Red Rock, and Teec Nos Pos. Total consumptive use values are 11 (±1) acre-feet.

Pumping records for the Western Navajo Agency include data for the following schools: Chilchinbeto Day School, Dennehotso Boarding School, Kaibeto Boarding School, and Kayenta Boarding School. Total consumptive use for the Western Navajo Agency was 172 (±12) acre-feet.

Well pumping records for the Chinle Agency include data for the following schools: Cottonwood Day School, Lukachukai School, and Rock Point School. Rough Rock School maintains its own records, but the data was included with the Chinle Agency data. Total consumptive use for the Chinle Agency was 69 (±5) acre-feet.

Navajo WOM Water Systems – Water use in 2013 by the Navajo WOM service areas was based on an assumed consumption rate of 110 gallons per capita per day (gpcd). For a 2013 estimated service area population of 4,242, the estimated annual water use was 523 (±157) acre-feet. The uncertainty is estimated as 30 percent of the total.

Private Water Systems – The estimated 2013 population served by private water systems on the Navajo Nation was 653. Assuming a consumptive use rate of 110 gcpd, the annual water use for 2013 was 80 (±24) acre-feet. The uncertainty is estimated as 30 percent of the total.

Individual Wells – According to census data from the Division of Community Development of the Navajo Nation, approximately 17 percent of the study area's population on the reservation (about 6,683 persons in 2013) receives a domestic water supply from individual wells. A consumptive use of 110 gpcd was derived as being a reasonable water use rate. Based on these figures, the annual consumptive use was 823 (±247) acre-feet for 2013.

TOTAL MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

The total municipal and industrial consumptive use, displayed in table 7, is the sum of the individual components discussed in the previous sections. Municipal and industrial water consumption represents approximately 82 percent of the total use in the study area.

Table 7.—Total municipal and industrial consumptive use, 2013

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
THERMAL ELECTRIC POWER		
Navajo Generating Station	24,963	749
OTHER		
Page, AZ and Vicinity		
City of Page	318	89
Le Chee	94	3
Greenhaven Water Company	121	8
Arizona Department of Transportation	7	2
Navajo Indian Reservation		
Community Water Systems		
NTUA Water Systems	1,596	113
BIA Water Systems	252	13
Navajo WOM	523	157
Private Water Systems	80	24
Individual Wells	823	247
TOTAL	28,778	817

It is questionable whether all the water pumped from wells should be considered a depletion to the Colorado River System; however, it is assumed that 100 percent of the water pumped is considered lost to the system. It is proposed that a future joint study be completed by Reclamation, the State of Arizona, and the Navajo Nation to estimate what percentage of water pumped could actually be attributed to the Colorado River System and would have affected the river flows for a particular year.

RECREATION, FISH AND WILDLIFE

The recreation, fish and wildlife consumptive uses include evaporation from reservoirs used exclusively for fish & wildlife purposes as well as acreages irrigated for wildlife feeding. Consumptive use related to recreation at National parks is also addressed.

GLEN CANYON NATIONAL RECREATION AREA

Colorado River water is used by the Glen Canyon National Recreation Area (GCNRA) at Wahweap and Lees Ferry. The recreational area at Wahweap gets its water supply from a series of wells on the shore of Lake Powell. Pumping records for both Wahweap Marina, and Lees Ferry show 296 (±9) acre-feet of water withdrawn during 2013. The uncertainty is estimated at 3 percent. This water was used for domestic purposes at the

campgrounds, picnic areas, and trailer parks. It was also used to irrigate approximately 60 acres of Bermuda grass and cottonwood trees. The domestic waste water is treated and the effluent is allowed to evaporate from two lined evaporation ponds with a total surface area of 16.7 acres.

Based on estimates of evaporation and consumptive use by the plants, there is some water which is unaccounted for and is assumed to be leakage from the delivery system, the evaporation pond, or deep percolation from irrigation application. However, since these water losses are difficult to quantify and verify, the losses were charged as consumptive uses. Therefore, net consumptive use of water is estimated to be equal to the quantity of water pumped.

RESERVOIR EVAPORATION

A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 8.

Table 8. —Recreation, fish and wildlife reservoir evaporation, 2013

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE AREA USED (ACRES)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Tsaile	260	260	35	8.72	26.3	569.4
Wheatfields	272	272	32	8.72	23.3	527.6
TOTAL	532	532				1,097

Efforts are made to maintain a nearly full condition and to minimize water surface fluctuations in reservoirs managed for a fishery. Under average operating conditions, the water surface area of a reservoir used primarily for fishing is assumed to be equal to a normal water surface area. It is assumed that, in 2013, these reservoirs filled in the spring and were maintained at the normal pool level.

This method of evaporation estimation was used because continuous useful water level records for all reservoirs from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs.

For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for reservoir evaporation for calendar year 2013 are shown in table 8. The total evaporative losses in 2013 are 1,097 (±329) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent.

TOTAL RECREATION, FISH AND WILDLIFE

The total recreation, fish and wildlife consumptive use, displayed in table 9, is the sum of the individual components discussed in the previous sections. Recreation, fish and wildlife water consumption represents approximately 4 percent of the total use in the study area.

Table 9.—Total recreation, fish and wildlife consumptive use, 2013

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Glen Canyon National Recreation Area	296	9
Reservoir Evaporation	1,097	329
TOTAL	1,393	329

RESERVOIR EVAPORATION

Reservoir evaporation losses make up about 7 percent of the total water uses and losses in the study area. A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 10. These reservoirs are used primarily for irrigation.

Table 10.—Reservoir evaporation, 2013

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE ACRES USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Many Farms	1,800	554	92%	56	8.72	47.28	2,185
Marsh Pass	40	18	88%	40	9.89	30.11	44
Round Rock	83	37	90%	57	7.91	49.09	153
Walker Creek	30	13	88%	59	7.10	51.90	57
Others	38	17	88%	55	8.96	46.04	64
TOTAL	1,991	639					2,503

Reservoirs used primarily for irrigation experience large fluctuations in water levels and, correspondingly, large variations in surface area. Reservoir level records and elevation – area curves were available at Many Farms, but not for the remaining reservoirs in table 10. For the reservoirs with no records from which surface area could be accurately computed, the average evaporative surface area was estimated as one-half the water

surface area of a full reservoir. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average evaporative surface area.

Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses. The computed values for reservoir evaporation for 2013 are shown in table 10. The total evaporative losses in 2013 are 2,503 (±751) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent of the total evaporation.

CONCLUSIONS

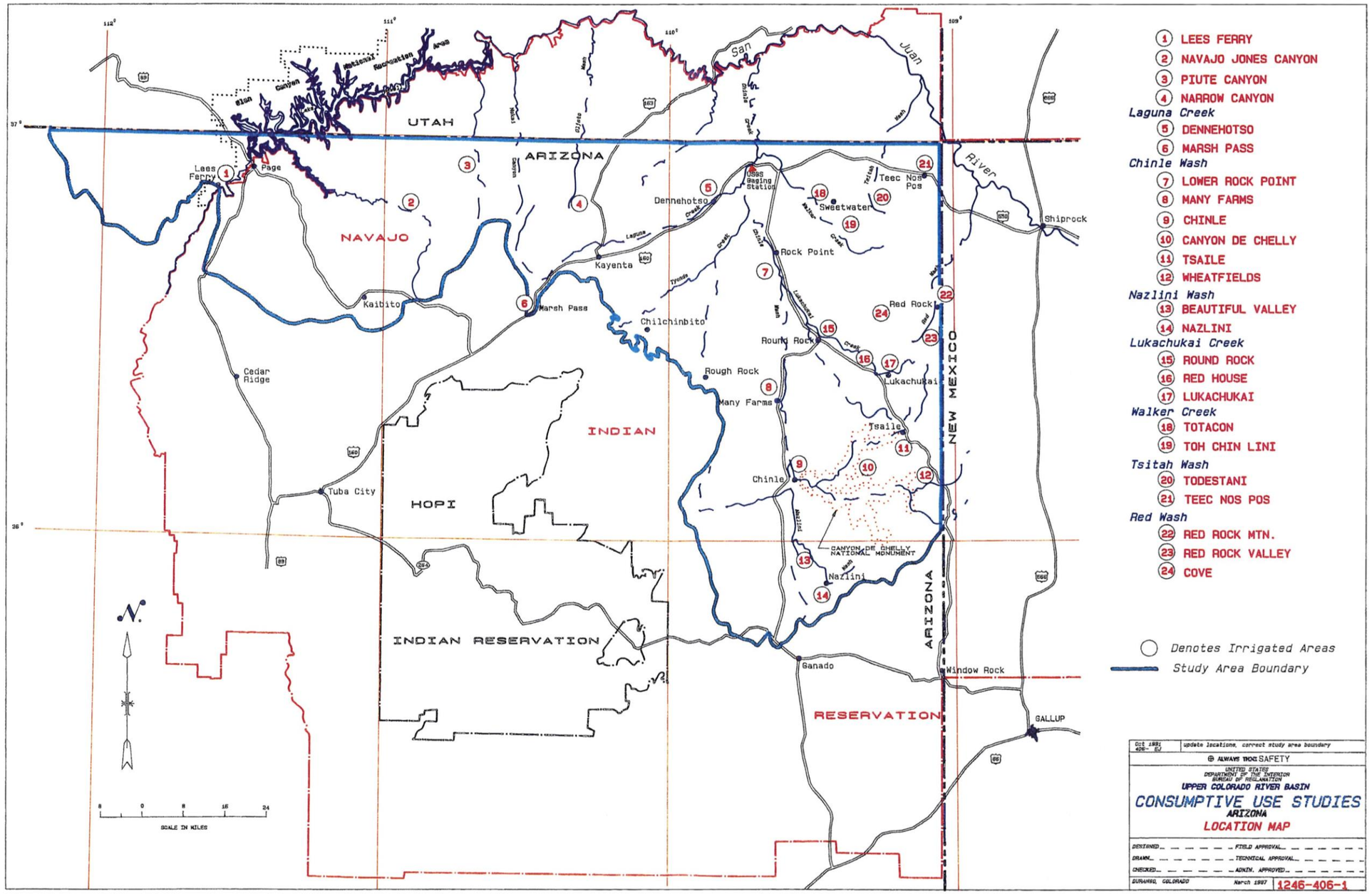
This report assesses the total consumptive use of the Arizona portion of the Upper Colorado River surface water systems, depletion of ground water, and evaporative losses. Clearly, the amounts of water used by the Navajo Generating Station, City of Page, and Wahweap and Lees Ferry recreation areas are direct depletions of water from the Upper Colorado River System, but the situation is not as clear for other consumptive uses and losses occurring in other sections of the study area. For example, the source of water used by the Navajo Nation for domestic and municipal purposes is from wells, some exceeding 1,000 feet in depth. For our purposes here, it is considered to be consumed and a depletion to the Colorado River System. But this may not actually result in a reduction of Colorado River stream flows in the same year that the withdrawal occurs, or at all. Little knowledge and information exists of ground water movement and subsurface flow rates in the study area that are accurate descriptions of the effects on river flows.

Although the water diverted for agricultural purposes is considered as consumptive use in this report, a portion of the remaining surface water on the Navajo Nation, excess to needs, does evaporate before reaching the Colorado River. No attempt has been made for this report to quantify these losses.

Uncertainties in estimating uses and losses exist, and the degree of variation in the figures is presented. Fortunately, the areas with the highest degree of uncertainty account for only a small percentage of the total consumptive use. The largest component, use by the Navajo Generating Station, is also the most accurately monitored. The total annual value for estimated consumptive use of water within the Arizona portion of the Upper Colorado River Basin for 2013 was 35,037 acre-feet, as shown in table 11.

Table 11.—Consumptive use for Arizona portion of Upper Colorado River Basin for 2013

USE CATEGORY	TOTAL CONSUMPTIVE USE (ACRE-FEET)	UNCERTAINTY	PERCENT OF TOTAL
Agriculture	2,363	514	6.74%
Municipal & Industrial	28,778	817	82.14%
Recreation, Fish & Wildlife	1,393	329	3.98%
Reservoir Evaporation	2,503	751	7.14%
TOTAL	35,037	1,267	100


1 LEES FERRY
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3 PIUTE CANYON
4 NARROW CANYON
Laguna Creek
5 DENNEHOTSO
6 MARSH PASS
Chinle Wash
7 LOWER ROCK POINT
8 MANY FARMS
9 CHINLE
10 CANYON DE CHELLY
11 TSAILE
12 WHEATFIELDS
Nazlini Wash
13 BEAUTIFUL VALLEY
14 NAZLINI
Lukachukai Creek
15 ROUND ROCK
16 RED HOUSE
17 LUKACHUKAI
Walker Creek
18 TOTACON
19 TOH CHIN LINI
Tsitah Wash
20 TODESTANI
21 TEEC NOS POS
Red Wash
22 RED ROCK MTN.
23 RED ROCK VALLEY
24 COVE
Denotes Irrigated Areas
Study Area Boundary
UTAH
ARIZONA
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INDIAN
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INDIAN RESERVATION
RESERVATION
NEW MEXICO
ARIZONA
Lees Ferry
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Kaibito
Cedar Ridge
Tuba City
Marsh Pass
Kayenta
Dennehotso
Chilchinbito
Rough Rock
Many Farms
Chinle
Rock Point
Round Rock
Sweetwater
Tsaile
Lukachukai
Red Rock
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Nazlini
Ganado
Window Rock
GALLUP
Shiprock
CANYON DE CHELLY NATIONAL MONUMENT
San Juan River
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BUREAU OF RECLAMATION
UPPER COLORADO RIVER BASIN
CONSUMPTIVE USE STUDIES
ARIZONA
LOCATION MAP
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FIELD APPROVAL
TECHNICAL APPROVAL
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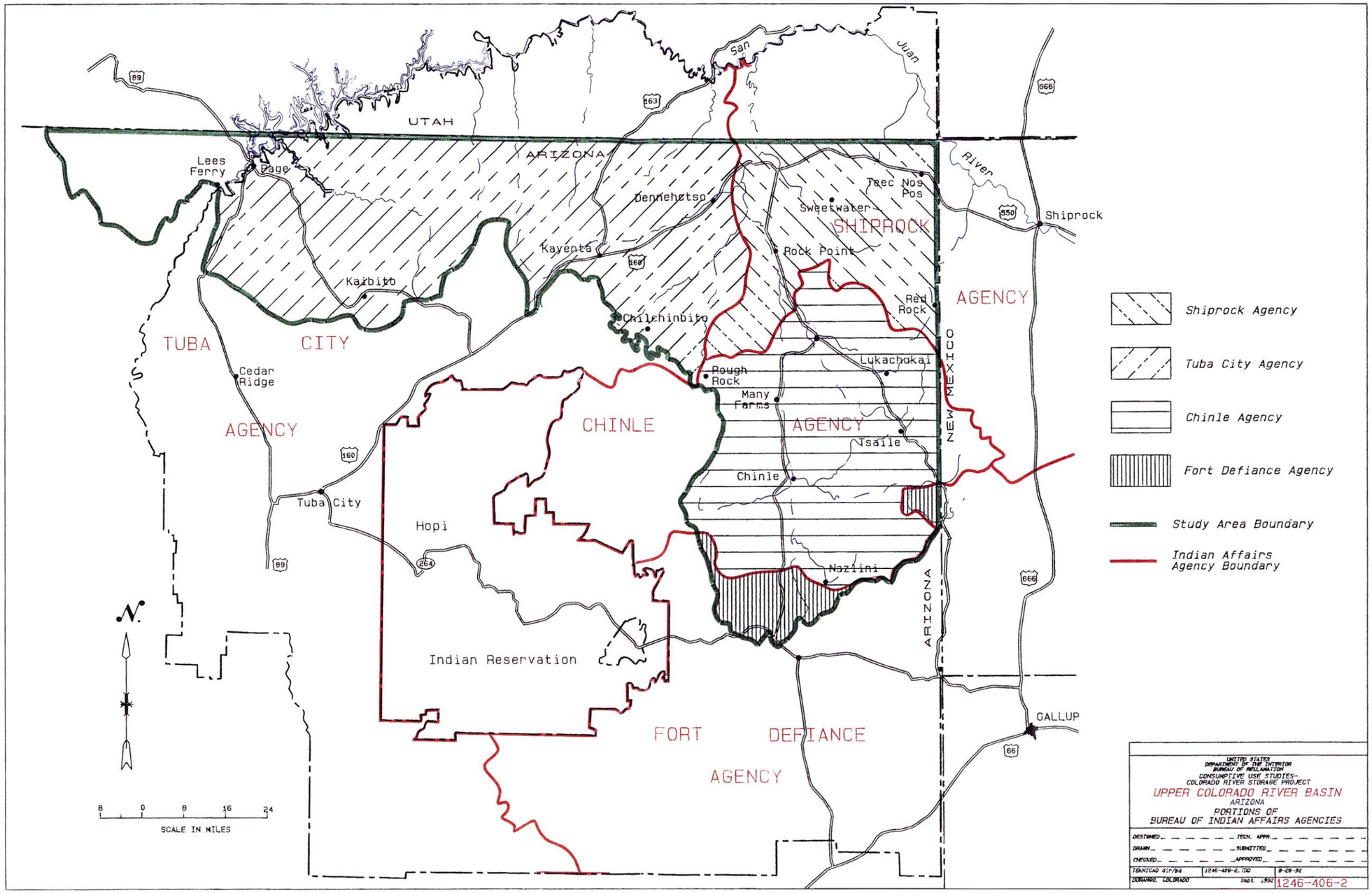
DURANGO, COLORADO
March 1987
1246-406-1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NEW MEXICO
San Juan River
Lees Ferry
Page
Dennehotso
Kayenta
Kaibito
Chilchinbito
Tsec Nos Pos
Sweetwater
Rock Point
Red Rock
Shiprock
SHIPROCK
AGENCY
TUBA
CITY
AGENCY
Cedar Ridge
Tuba City
Rough Rock
Many Farms
Lukachukai
Tsaile
Chinle
Nazlini
CHINLE
AGENCY
Hopi
Indian Reservation
FORT DEFIANCE
AGENCY
GALLUP
Shiprock Agency
Tuba City Agency
Chinle Agency
Fort Defiance Agency
Study Area Boundary
Indian Affairs Agency Boundary
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SCALE IN MILES
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CONSUMPTIVE USE STUDIES-
COLORADO RIVER STORAGE PROJECT
UPPER COLORADO RIVER BASIN
ARIZONA
PORTIONS OF
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DURANGO, COLORADO
Sept. 1992
1246-406-2

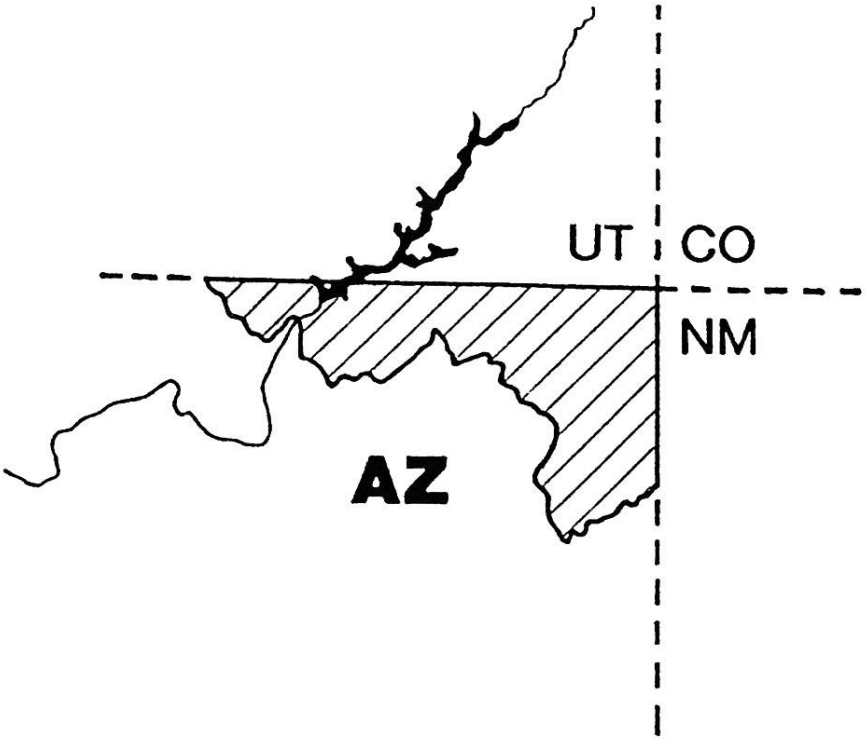
RECLAMATION

Managing Water in the West

Consumptive Uses and Losses: Provisional Estimate

Arizona Portion of the Upper Colorado River Basin Calendar Year 2014

Provisional Version dated: February 18, 2016



U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

February 2016

RECLAMATION

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Consumptive Uses and Losses: Provisional

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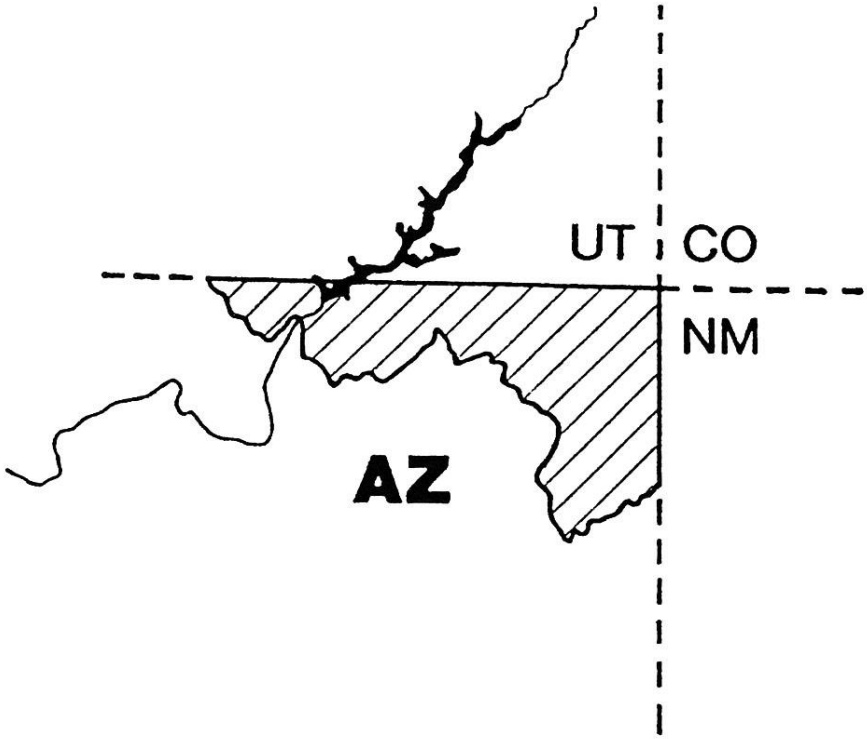

Prepared by: Alan Harrison – February 18, 2016

U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

February 2016

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UPPER COLORADO RIVER BASIN

CALENDAR YEAR
2014

AUTHORITY

This report was prepared in compliance with Public Law 90-537, Section 601 (b)(1), dated September 30, 1968, which directs the Secretary of the Interior to "make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis." Additionally, this report is in compliance with Section 49 of the Navajo Project Participation Agreement dated September 30, 1969, which states in part: "The Secretary of the Interior further agrees to make the reports required by Section 601 (b)(1) of Public Law 90-537 as they pertain to Arizona's Upper Basin uses annually rather than every five years. Within fifteen days following the completion of said reports, the Secretary of the Interior shall furnish copies of such reports to the Co-Tenants, the Navajo Tribe, each of the Upper Basin States, and the Upper Colorado River Commission."

SUMMARY

Based upon data made available for preparation of this document. the total consumptive use and loss value for the Arizona portion of the Upper Colorado River Basin for calendar year 2014 was 35,630 (±1,261) acre-feet. Reclamation prepares this estimate annually, final annual values for consumptive uses and losses for the northern Arizona portion of the Colorado River basin are published in the 5-year summary documents for the Upper Colorado River Basin

STUDY AREA DESCRIPTION

The Arizona portion of the Upper Colorado River Basin covers approximately 6,900 square miles in the north-east corner of Arizona, as shown on the location maps shown on pages 19 and 20 (Drawings 1246-406-1, 1246-406-2). The climate of the 5,900 square mile area to the west of the Chuska and Carrizo Mountains is largely arid to semiarid, with mean annual precipitation ranging from 6 to 12 inches and with summertime temperatures often reaching 100 degrees Fahrenheit (^{o}F). The potential

evaporation rate is high and exceeds mean annual precipitation, with gross lake evaporation values of up to 55 inches per year or more. Elevations in the western portion range from 3200 feet on the Colorado River at Lee Ferry to over 8000 feet on the northern edge of the Black Mesa and across the Zilnez and Skeleton Mesas, back down to 5280 feet in the Chinle Valley, and back up to about 6500 feet on the western edge of the Chuska Mountains. Much of the western part of the study area is starkly beautiful southwestern desert country with mesas and canyons intertwined across a pastoral landscape. By contrast, the eastern 1,000 square miles is largely mountainous, with elevations rising to nearly 10,000 feet and mean annual precipitation reaching 30 inches. The mountainous land responds with grass meadows interspersed with conifer forest of mostly ponderosa pine.

Except for Page, Arizona; a small area around Lee Ferry; and a portion of the Paria Plateau administered by the Bureau of Land Management; the study area lies entirely within the Navajo Nation. According to census data, 47,265 persons were living within the area in 2010, and of these 39,763 resided on the Navajo Nation.

The largest cities are Page and Kayenta, with 2010 populations of 7,247 and 5,189, respectively. Other major communities and their populations include Dennehotso (746), Kaibeto (1,522), Chinle (4,518), LeChee (1,443), Lukachukai (1,701), Many Farms (1,348), Rock Point (642), Teec Nos Pos (730), and Tsaile (1,205). Subsistence in the region is derived principally from livestock grazing, farming, tourist-related industries, employment at the Navajo Generating Station (NGS), which consumes approximately 72 percent of the water used or lost in the study area every year. Agriculture accounted for about 6 percent of the total water use; municipal and industrial (including the Navajo Generating Station) about 83 percent; recreation, fish and wildlife, about 4 percent; and reservoir evaporation, about 7 percent.

AGRICULTURAL CONSUMPTIVE USE

Agricultural consumptive use is divided into three categories: irrigation, stock pond, and livestock. Irrigation use includes all use related to irrigating crops including the incidental losses. Stock pond use is the evaporation that occurs from stock ponds and livestock use is the water consumed by livestock.

IRRIGATION USES

Within the Arizona portion of the Upper Colorado River Basin, historically 23 irrigated areas were scattered across the Navajo Nation plus a small amount of land near Lee Ferry irrigated by the National Park Service. Currently, only 16 irrigated areas are in production. An accurate assessment of consumptive use on the irrigated land is difficult due to poor quality of information, such as the exact number of acres under irrigation, the cropping pattern for each irrigated area, site climatological conditions, and the amount of water actually diverted. In many cases, during the latter part of the irrigation season, farmers have to rely on dry land farming since there is little water available in the streams. This means that the crops do not receive their full water requirement.

For this report, the U.S. Department of Agriculture, Soil Conservation Service's (SCS) Modified Blaney-Criddle evapotranspiration, without an elevation adjustment, estimation formula was used for computing irrigated crop consumptive use. This model, along with appropriate crop-growth stage coefficients and the method for computing effective precipitation, is described in SCS's *Irrigation Water Requirements Technical Release No. 21* (TR 21). Information required for applying this model includes mean monthly temperature and precipitation values, growing season data for each crop type, and the total number of acres planted by crop at each site. With the exception of Teec Nos Pos, Canyon de Chelly, Lukachukai, and Lee Ferry, no climatological data exist for the irrigation sites, and site values must be generated from data collected at surrounding established weather stations. Growing season dates depend largely on the judgment of the local inhabitants and are, therefore, not known. Although several reports are available with published values for irrigated acres, it is unclear if these values are meant to represent potential irrigated acres, acres irrigated in the past, acres for which farming permits have been issued, or actual acres currently under irrigation.

The crop acreage used to estimate consumptive use by irrigated crops for the year 2014 is shown in table 1. These values were estimated from previous direct field examination by a party composed of representatives from the State of Arizona and the Navajo Nation.

Table 1.—Total irrigated acreage, 2014

PROJECT	CORN (ACRES)	ALFALFA (ACRES)	GRASS PASTURE (ACRES)	SPRING GRAINS (ACRES)	SMALL VEGETABLES (ACRES)	ORCHARD (ACRES)	TOTAL (ACRES)
CHINLE AGENCY							
Canyon de Chelly	0.36	0.00	0.00	3.03	2.26	0.00	5.65
Lukachukai	39.09	7.69	0.00	7.50	5.98	2.07	62.33
Many Farms	160.92	26.85	99.37	2.62	26.85	0.00	316.60
Nazlini	0.00	0.00	0.00	0.00	1.79	0.74	2.53
Rough Rock	30.00	0.00	11.87	0.00	12.43	0.00	54.30
Tsaile	23.72	5.27	15.67	5.73	5.42	0.00	55.81
Wheatfields	0.00	60.80	0.00	0.00	0.00	0.00	60.80
TOTAL	254.09	100.61	126.91	18.88	54.73	2.81	558.02
SHIPROCK AGENCY							
Red Rock Valley	26.22	0.00	10.19	5.12	10.22	0.00	51.75
Teec Nos Pos	20.00	0.00	0.00	0.00	3.67	0.00	23.67
Toh Chin Lini	0.00	0.00	0.00	0.00	3.90	13.67	17.57
Totacon	0.00	0.00	0.00	0.00	1.00	0.00	1.00
TOTAL	46.22	0.00	10.19	5.12	18.79	13.67	93.99
WESTERN NAVAJO AGENCY							
Dennehotso	1.82	0.00	38.70	0.00	0.00	0.00	40.52
Lees Ferry	0.00	0.00	1.00	0.00	0.00	2.00	3.00
Marsh Pass	7.02	3.31	0.00	0.00	1.99	0.00	12.32
Navajo Canyon	0.00	0.00	0.00	0.00	0.00	3.50	3.50
Paiute Canyon	2.64	0.00	0.00	0.00	3.86	0.00	6.50
TOTAL	11.48	3.31	39.70	0.00	5.85	5.50	65.84
GRAND TOTAL	311.79	103.92	176.80	24.00	79.37	21.98	717.85

Several factors complicate the modeling of irrigation consumptive use. For example, the computer program used to model consumptive use assumes a full water supply; if shortages exist, as they often do in this semiarid study area, adjustments must be made. These adjustments are complicated because some of the projects have no storage water and may only have a reliable irrigation water supply during spring runoff. After spring runoff, farming becomes essentially dry land until rains in July and August provide intermittent flows for irrigation. Finally, no ditch diversion records are available to help estimate irrigation water supplies and shortages.

A full irrigation supply seldom exists at many of the projects. Generally, a full supply is available for Lee Ferry, Navajo Canyon, Tsaile, and Wheatfields projects because of adequate stream flows or because of available storage water. In years with average precipitation, it is estimated that Chinle Wash provides approximately 75 percent of the irrigation requirement. Precipitation in the area averages approximately 9.5 inches per year. Based on this information, it would require approximately 12.67 inches of precipitation to provide 100 percent of the irrigation requirement. The percent of crop water requirement met was computed as a ratio of annual precipitation to 12.67 inches. These values are found in table 2.

The percentage of crop water requirement met was multiplied by the total net crop water requirement to determine the amount of crop consumptive use. Incidental irrigation losses, evaporation, and phreatophyte consumptive use along supply canals are estimated to be 5 percent of the consumptive use of the irrigated area and are added to the crop consumptive use value to develop a total consumptive use value.

A portion of the water used for irrigation at these sites may not be contributing to the Colorado River System since evaporation rates in the area are high and the nature of most of the drainage enhances evapotranspiration. A good example of such a drainage is Chinle Wash, which after leaving Canyon de Chelly, becomes wide and sandy and is lined with willows, cottonwoods, and other phreatophytes.

The uncertainties in the irrigation consumptive use values displayed in table 2 are very large and are estimated as 40 percent of the total consumptive use. This estimate of possible error only reflects the uncertainty of consumptive use and does not account for any possible errors in the acreage estimates. The effective consumptive use for irrigation for 2014 was estimated to equal 922 acre-feet. Including 5 percent for incidental losses, the irrigation related consumptive use is 968 (±387) acre-feet.

Table 2.—Net consumptive use values, 2014

PROJECT	CROP WATER REQUIREMENT (INCHES)	TOTAL IRRIGATED (ACRES)	TOTAL WATER REQUIRED (ACRE-FEET)	CROP WATER REQUIREMENT MET (%)	CROP WATER REQUIREMENT MET (ACRE-FEET)	TOTAL CONSUMPTIVE USE (ACRE-FEET)[1]
CHINLE AGENCY						
Canyon de Chelly	27.45	5.65	13	59%	8	8.0
Lukachukai	27.82	62.33	145	59%	85	89.4
Many Farms	27.73	316.60	732	59%	431	452.4
Nazlini	25.31	2.53	5	59%	3	3.3
Rough Rock	23.32	54.30	106	51%	54	56.9
Tsaile	28.33	55.81	132	59%	78	81.5
Wheatfields	36.22	60.80	183	59%	108	113.5
TOTAL	196.18	558.02	1315		766	804.8
SHIPROCK AGENCY						
Red Rock Valley	28.91	51.75	125	47%	59	61.5
Teec Nos Pos	30.20	23.67	60	35%	21	21.9
Toh Chin Lini	39.84	17.57	58	18%	10	10.7
Totacon	26.93	1.00	2	18%	0	0.4
TOTAL	125.88	93.99	245		90	94.6
WESTERN NAVAJO AGENCY						
Dennehotso	38.97	40.52	132	29%	39	40.7
Lee Ferry	41.81	3.00	10	100%	10	11.0
Marsh Pass	22.92	12.32	24	33%	8	8.1
Navajo Canyon	38.73	3.50	11	49%	5	5.8
Paiute Canyon	25.49	6.50	14	22%	3	3.2
TOTAL	167.91	65.84	191		65	68.7
GRAND TOTAL	489.97	717.85	1751		922	968.1

[1] Total includes 5% addition for incidental losses.

STOCK POND EVAPORATION

Stock pond consumptive use is assumed to be the evaporation from area stock ponds. It is also assumed that any consumptive use by natural vegetation prior to the construction of the stock ponds is limited to precipitation which is subtracted from the evaporation losses.

A compilation of the stock ponds in the study area, including their locations and the water surface areas when ponds are full, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 3. For average year conditions, the stock pond evaporative surface area was estimated as one-third the water surface area that occurs when the ponds are full. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average water surface area. These values are found in table 3.

Table 3.—Stock pond evaporation, 2014

COUNTY	SURFACE AREA FULL (ACRES)	SURFACE AREA USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Coconino	80	26	99%	57	6.64	50.36	110.3
Navajo	40	7	49%	55	4.81	50.19	27.5
Apache	646	146	68%	53	5.95	47.05	570.5
TOTAL	766	178					708

This method of evaporation estimation was used because continuous useful water level records for all stock ponds from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual stock ponds. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation. It was assumed that any consumptive use by natural vegetation prior to construction of the stock ponds is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for stock pond evaporation for calendar year 2014 are shown in table 3. The total evaporative losses in 2014 are 708 (±212) acre-feet with the stock pond evaporation uncertainty being estimated as 30 percent.

LIVESTOCK WATER

The source of most livestock water in the study area is from wells, with windmill-operated pumps developed and maintained by Navajo Water Operations and Maintenance, and water collected in small surface ponds. The estimated number of

livestock in the area was estimated based on previous livestock tallies. It was estimated that horses and cattle consume 12 gallons per day; sheep and goats consume 2 gallons per day.

The number of animals for the Upper Colorado portion of each district is shown in table 4. The computed value for livestock consumptive use is 457 acre-feet. The uncertainty in this number is estimated as 30 percent of the total or ±137 acre-feet.

Table 4.—Number of livestock, 2014

AGENCY	CATTLE	HORSES	SHEEP	GOATS
Western Navajo District No. 1	0	0	1,440	497
Western Navajo District No. 2	1,458	109	1,359	1,799
Western Navajo District No. 8	6,842	1,393	10,923	7,007
Shiprock District No. 9	1,345	3	3,491	3,493
Chinle District No. 10	3,281	880	5,574	2,860
Chinle District No. 11	1,960	325	2,354	2,088
Shiprock District No. 12	5,260	983	8,311	4,365
Fort Defiance District No. 17	0	154	1,406	937
Fort Defiance District No. 18	0	203	964	0
TOTAL	20,146	4,050	35,822	23,046

TOTAL AGRICULTURAL CONSUMPTIVE USE

The total agricultural consumptive use, displayed in table 5, is the sum of the individual components discussed in the previous sections. Agricultural water consumption represents approximately 6 percent of the total use in the study area. Total degree of uncertainty was computed by taking the square root of the sum of the individual uncertainties squared; known as the quadratic sum. This method and nomenclature is used throughout this report. This method was used because a simple sum does not account for the partial cancellation of errors occurring when calculating the total uncertainty derived from individual values that are random and independent of each other. As previously discussed, the individual uncertainties were set as a percent of the consumptive use value.

Table 5.—Total agricultural consumptive use, 2014

CATEGORY	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Irrigation	968	387
Stock Ponds	708	212
Livestock	457	137
TOTAL	2,134	463

MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

Municipal and industrial consumptive use is divided into three categories: mineral resources, thermal electric power, and other. Mineral resources consumptive use includes water used for mineral production. No mineral resources consumptive use is reported in the study area. Thermal electric power consumptive use includes the water used at the power plants, and that used to transport material to the power plant (such as a coal slurry pipeline). Other consumptive use includes urban, rural, and industrial uses.

THERMAL ELECTRIC POWER

Thermal electric power consumptive use includes the water used in the power plant and the water used to transport material to the plant.

Navajo Generating Station

The water used by the NGS is pumped directly from Lake Powell and comprises approximately 72% of the total consumption in the study area. Since all NGS water use is metered, this quantity is among those most precisely known, with the maximum uncertainty in the metered quantities believed to be less than 3 percent. The actual quantity consumed, along with the estimated uncertainty for the calendar year 2014, was 25,810 (±774) acre-feet.

OTHER

The other consumptive use category includes the remaining use by urban, rural, and industries.

Page, AZ and Vicinity

City of Page, AZ. – The city of Page pumps its domestic water directly from Lake Powell. The water pumped is metered, and the uncertainty of the pumped quantities was assumed to be less than 3 percent. A portion of the water pumped and treated by the City

of Page, is supplied to the community of Le Chee on the Navajo Nation and is accounted for separately. The quantity supplied to the City of Page and its associated uncertainty for the calendar year 2014 was 2,240 (±67) acre-feet. Water returning to the waste water treatment plant is metered as well. The waste water for the City of Page is treated and is either evaporated from lined ponds or applied to the golf course, with a portion being returned to the Colorado River. The return flow is estimated to be 1,922 acre-feet. The net consumptive use is estimated to be 318 acre-feet (±89).

Le Chee – The community of Le Chee is supplied and metered by the City of Page. Total water supplied for 2014 was 94 (±3) acre-feet. The uncertainty was estimated to be 3 percent.

Greenhaven Water Company – The Greenhaven Water Company derives its domestic water supply from wells. Well pumping records are available. According to these records, the total water pumped for 2014 was 121 (±8) acre-feet. The uncertainty was estimated to be 7 percent.

Arizona Department of Transportation Housing – The Arizona Department of Transportation operates a housing, maintenance, and administrative facility located on US Hwy 89, north of Page, AZ. This facility is supplied from wells that have no meters installed. It is estimated that the total water pumped for 2014 was 7 acre-feet with an uncertainty of 30 percent of this value or ±2 acre-feet.

Navajo Nation

Community Water Systems – 1980 statistics from the Division of Community Development of the Navajo Nation reveal that various community water systems served 26,086, or about 83 percent of the 31,429 people residing within the study area at that time. Since additional estimates have not been repeated, this same percentage was used for 2014 resulting in 32,484 out of 39,137 people being served. These systems include those operated by the Navajo Tribal Utility Authority (NTUA), the BIA, and the Water Operations and Maintenance Department of the Navajo Nation, and some privately developed community water systems.

Table 6 shows the source of water and estimated population served by each source of water for people living on the Navajo Nation during 2014. All of the communities obtain their water supply from ground water.

Table 6.—Domestic water sources, 2014

SOURCE	PERCENTAGE OF POPULATION SERVED	NUMBER OF POPULATION SERVED[1]
Community Water Systems	83	32,484
NTUA	[2](60)	19,490
BIA	[2](25)	8,121
Navajo WOM	[2](13)	4,223
Private	[2](2)	650
Individual Wells	17	6,653
TOTAL	100	39,137

[1] Total population within the Upper Colorado River Basin portion of the Navajo Nation, estimated from 2010 US Census.
[2] These numbers are a percentage of the Community Water Systems.

NTUA Water Systems – The cities and surrounding communities of Oak Springs, Red Valley, Sweetwater, Chinle , Rough Rock, Round Rock, Rock Point, Wheatfields, Lukachukai, Kayenta, Chilchinbeto, Dennehotso, and Kaibeto derive most of their domestic water supply from wells operated by NTUA. Well pumping records are available. According to these records, the total water pumped for 2014 was 1,596 acre-feet with an uncertainty estimated to be 7 percent of this value or ±113 acre-feet.

The NTUA manages the raw waste water; portions of which flow to individual septic tanks, some to evaporation ponds, and some, such as for the cities of Chinle and Kayenta, flow to waste water treatment plants. Very little water, if any, is returned to the ground water system through leakage from the evaporation ponds, but there are losses from the main collection system. Effluent from the Chinle and Kayenta waste water treatment plants is metered. Under normal conditions, the effluent returns to the Colorado River System and is subtracted from the pumping totals to determine a net consumptive use. For 2014, Chinle's treatment plant effluent was 13.6 (±1.0) acre-feet, and Kayenta's effluent was 9.7 (±0.7) acre-feet. An estimated uncertainty of 7 percent was used for the effluent of these two plants. The total effluent of 23.3 acre-feet is subtracted from the NTUA pumping total of 1,619 acre-feet to arrive at a net consumptive use of 1,596 (±113) acre-feet.

BIA Water Systems – Wells developed and operated by the BIA serve numerous Navajo communities. These systems also serve BIA schools, hospitals, agency offices, and some housing on the Navajo Nation. Metered records for total amounts of water pumped from BIA wells were available for a portion of the Shiprock Agency, the Western Navajo Agency, and the Chinle Agency. Drawing 1246-406-2 shows the agency boundaries within the Upper Colorado River Basin. The uncertainty was estimated to be about 7 percent for all three agencies.

The BIA systems include sewage disposal units terminating in lined evaporation ponds with very little or no return water returning to the ground water system. Undoubtedly, some losses occur in distribution, but insufficient data currently exist to estimate these losses. The losses are probably less than the uncertainties for each of the reported values.

The BIA well data available for the Shiprock Agency include: Cove, Red Rock, and Teec Nos Pos. Total consumptive use values are 11 (±1) acre-feet.

Pumping records for the Western Navajo Agency include data for the following schools: Chilchinbeto Day School, Dennehotso Boarding School, Kaibeto Boarding School, and Kayenta Boarding School. Total consumptive use for the Western Navajo Agency was 172 (±12) acre-feet.

Well pumping records for the Chinle Agency include data for the following schools: Cottonwood Day School, Lukachukai School, and Rock Point School. Rough Rock School maintains its own records, but the data was included with the Chinle Agency data. Total consumptive use for the Chinle Agency was 69 (±5) acre-feet.

Navajo WOM Water Systems – Water use in 2014 by the Navajo WOM service areas was based on an assumed consumption rate of 110 gallons per capita per day (gpcd). For a 2014 estimated service area population of 4,223, the estimated annual water use was 520 (±156) acre-feet. The uncertainty is estimated as 30 percent of the total.

Private Water Systems – The estimated 2014 population served by private water systems on the Navajo Nation was 650. Assuming a consumptive use rate of 110 gcpd, the annual water use for 2014 was 80 (±24) acre-feet. The uncertainty is estimated as 30 percent of the total.

Individual Wells – According to census data from the Division of Community Development of the Navajo Nation, approximately 17 percent of the study area's population on the reservation (about 6,653 persons in 2014) receives a domestic water supply from individual wells. A consumptive use of 110 gpcd was derived as being a reasonable water use rate. Based on these figures, the annual consumptive use was 820 (±246) acre-feet for 2014.

TOTAL MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

The total municipal and industrial consumptive use, displayed in table 7, is the sum of the individual components discussed in the previous sections. Municipal and industrial water consumption, including the Navajo Generating Station, represents approximately 83 percent of the total use in the study area.

Table 7.—Total municipal and industrial consumptive use, 2014

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
THERMAL ELECTRIC POWER		
Navajo Generating Station	25,810	774
OTHER		
Page, AZ and Vicinity		
City of Page	318	89
Le Chee	94	3
Greenhaven Water Company	121	8
Arizona Department of Transportation	7	2
Navajo Indian Reservation		
Community Water Systems		
NTUA Water Systems	1,596	113
BIA Water Systems	252	13
Navajo WOM	520	156
Private Water Systems	80	24
Individual Wells	820	246
TOTAL	29,618	840

It is questionable whether all the water pumped from wells should be considered a depletion to the Colorado River System; however, it is assumed that 100 percent of the water pumped is considered lost to the system. It is proposed that a future joint study be completed by Reclamation, the State of Arizona, and the Navajo Nation to estimate what percentage of water pumped could actually be attributed to the Colorado River System and would have affected the river flows for a particular year.

RECREATION, FISH AND WILDLIFE

The recreation, fish and wildlife consumptive uses include evaporation from reservoirs used exclusively for fish & wildlife purposes as well as acreages irrigated for wildlife feeding. Consumptive use related to recreation at National parks is also addressed.

GLEN CANYON NATIONAL RECREATION AREA

Colorado River water is used by the Glen Canyon National Recreation Area (GCNRA) at Wahweap and Lee Ferry. The recreational area at Wahweap gets its water supply from a series of wells on the shore of Lake Powell. Pumping records for both Wahweap Marina, and Lee Ferry show 254 (±8) acre-feet of water withdrawn during 2014. The uncertainty

is estimated at 3 percent. This water was used for domestic purposes at the campgrounds, picnic areas, and trailer parks. It was also used to irrigate approximately 60 acres of Bermuda grass and cottonwood trees. The domestic waste water is treated and the effluent is allowed to evaporate from two lined evaporation ponds with a total surface area of 16.7 acres.

Based on estimates of evaporation and consumptive use by the plants, there is some water which is unaccounted for and is assumed to be leakage from the delivery system, the evaporation pond, or deep percolation from irrigation application. However, since these water losses are difficult to quantify and verify, the losses were charged as consumptive uses. Therefore, net consumptive use of water is estimated to be equal to the quantity of water pumped.

RESERVOIR EVAPORATION

A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 8.

Table 8. —Recreation, fish and wildlife reservoir evaporation, 2014

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE AREA USED (ACRES)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Tsaile	260	260	35	7.46	27.54	596.7
Wheatfields	272	272	32	7.46	24.54	556.2
TOTAL	532	532				1,153

Efforts are made to maintain a nearly full condition and to minimize water surface fluctuations in reservoirs managed for a fishery. Under average operating conditions, the water surface area of a reservoir used primarily for fishing is assumed to be equal to a normal water surface area. It is assumed that, in 2014, these reservoirs filled in the spring and were maintained at the normal pool level.

This method of evaporation estimation was used because continuous useful water level records for all reservoirs from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs.

For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for reservoir evaporation for calendar year 2014 are shown in table 8. The total evaporative losses in 2014 are 1,153 (±346) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent.

TOTAL RECREATION, FISH AND WILDLIFE

The total recreation, fish and wildlife consumptive use, displayed in table 9, is the sum of the individual components discussed in the previous sections. Recreation, fish and wildlife water consumption represents approximately 4 percent of the total use in the study area.

Table 9.—Total recreation, fish and wildlife consumptive use, 2014

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Glen Canyon National Recreation Area	254	8
Reservoir Evaporation	1,153	346
TOTAL	1,407	346

RESERVOIR EVAPORATION

Reservoir evaporation losses make up about 7 percent of the total water uses and losses in the study area. A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 10. These reservoirs are used primarily for irrigation.

Table 10.—Reservoir evaporation, 2013

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE ACRES USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Many Farms	1,800	554	78%	56	7.46	48.54	2,242.9
Marsh Pass	40	9	46%	40	5.18	34.83	26.6
Round Rock	83	28	68%	57	5.95	51.05	119.3
Walker Creek	30	8	55%	59	4.44	54.56	37.5
Others	38	17	58%	55	5.83	49.17	44.8
TOTAL	1,991	611					2,471.1

Reservoirs used primarily for irrigation experience large fluctuations in water levels and, correspondingly, large variations in surface area. Reservoir level records and elevation – area curves were available at Many Farms, but not for the remaining reservoirs in table 10. For the reservoirs with no records from which surface area could be accurately

computed, the average evaporative surface area was estimated as one-half the water surface area of a full reservoir. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average evaporative surface area.

Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses. The computed values for reservoir evaporation for 2014 are shown in table 10. The total evaporative losses in 2014 are 2,471 (±741) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent of the total evaporation.

CONCLUSIONS

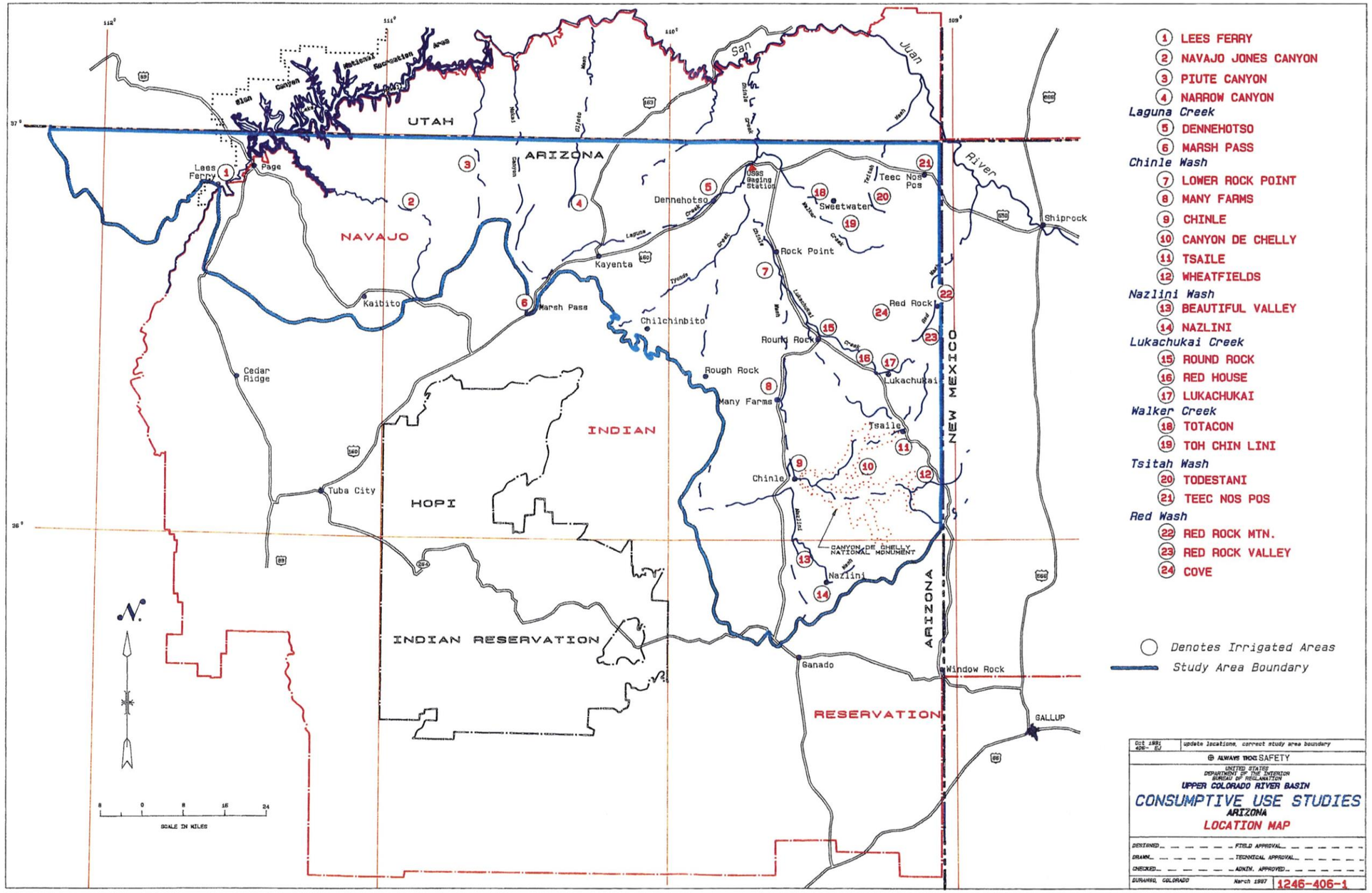
This report assesses the total consumptive use of the Arizona portion of the Upper Colorado River surface water systems, depletion of ground water, and evaporative losses. Clearly, the amounts of water used by the Navajo Generating Station, City of Page, and Wahweap and Lee Ferry recreation areas are direct depletions of water from the Upper Colorado River System, but the situation is not as clear for other consumptive uses and losses occurring in other sections of the study area. For example, the source of water used by the Navajo Nation for domestic and municipal purposes is from wells, some exceeding 1,000 feet in depth. For our purposes here, it is considered to be consumed and a depletion to the Colorado River System. But this may not actually result in a reduction of Colorado River stream flows in the same year that the withdrawal occurs, or at all. Little knowledge and information exists of ground water movement and subsurface flow rates in the study area that are accurate descriptions of the effects on river flows.

Although the water diverted for agricultural purposes is considered as consumptive use in this report, a portion of the remaining surface water on the Navajo Nation, excess to needs, does evaporate before reaching the Colorado River. No attempt has been made for this report to quantify these losses.

Uncertainties in estimating uses and losses exist, and the degree of variation in the figures is presented. Fortunately, the areas with the highest degree of uncertainty account for only a small percentage of the total consumptive use. The largest component, use by the Navajo Generating Station, is also the most accurately monitored. The total annual value for estimated consumptive use of water within the Arizona portion of the Upper Colorado River Basin for 2014 was 35,630 acre-feet, as shown in table 11.

Table 11.—Consumptive use for Arizona portion of Upper Colorado River Basin for 2014

USE CATEGORY	TOTAL CONSUMPTIVE USE (ACRE-FEET)	UNCERTAINTY	PERCENT OF TOTAL
Agriculture	2,134	463	5.98%
Municipal & Industrial	29,618	840	83.13%
Recreation, Fish & Wildlife	1,407	346	3.95%
Reservoir Evaporation	2,471	741	6.94%
TOTAL	35,630	1,261	100%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3 PIUTE CANYON
4 NARROW CANYON
Laguna Creek
5 DENNEHOTSO
6 MARSH PASS
Chinle Wash
7 LOWER ROCK POINT
8 MANY FARMS
9 CHINLE
10 CANYON DE CHELLY
11 TSAILE
12 WHEATFIELDS
Nazlini Wash
13 BEAUTIFUL VALLEY
14 NAZLINI
Lukachukai Creek
15 ROUND ROCK
16 RED HOUSE
17 LUKACHUKAI
Walker Creek
18 TOTACON
19 TOH CHIN LINI
Tsitah Wash
20 TODESTANI
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Red Wash
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23 RED ROCK VALLEY
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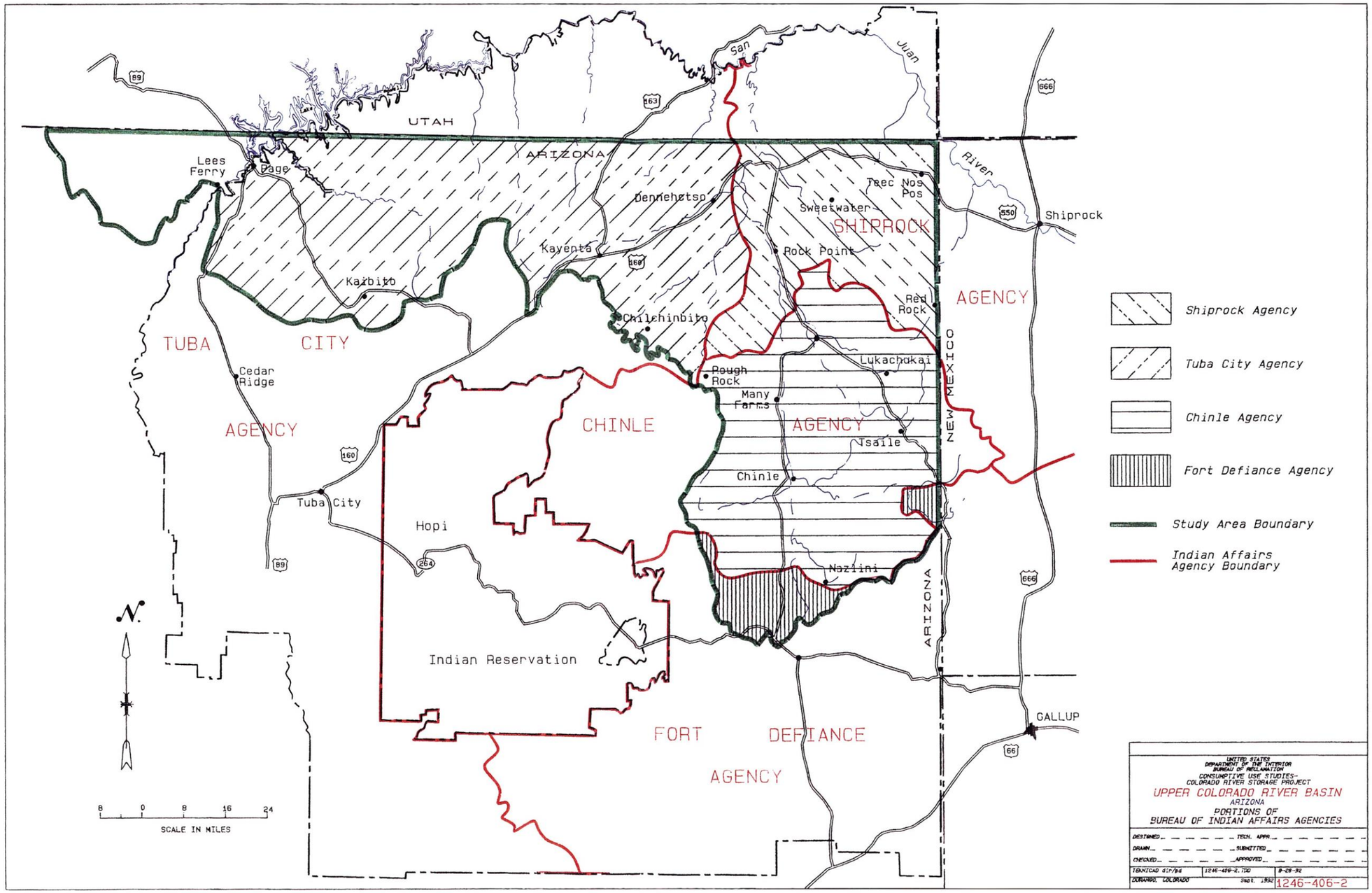
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Red Rock
Shiprock
Lukachukai
Rough Rock
Many Farms
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Nazlini
Cedar Ridge
Tuba City
Hopi
Indian Reservation
GALLUP
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CHINLE AGENCY
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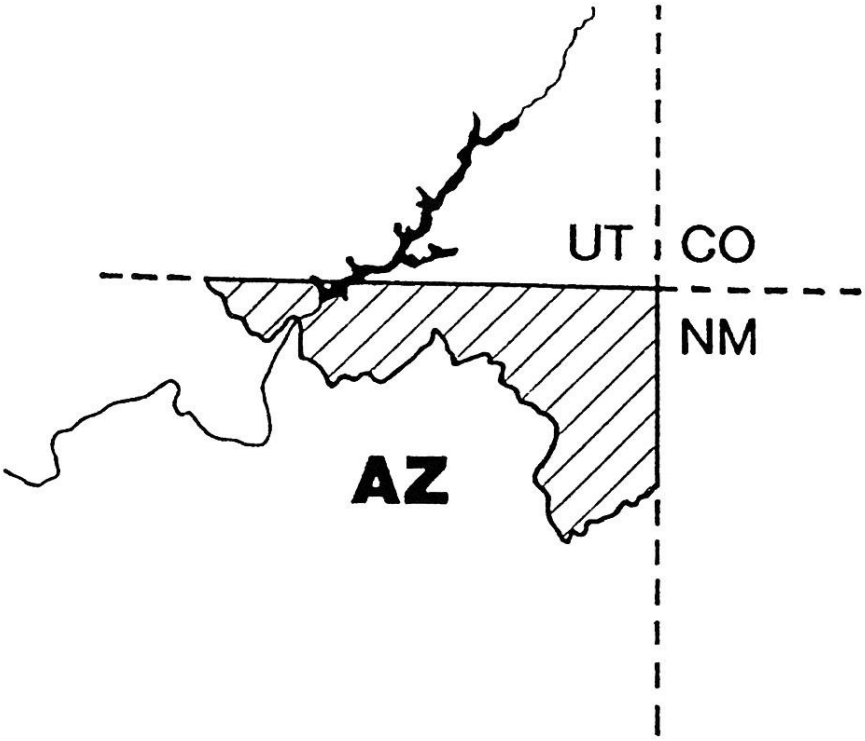
RECLAMATION

Managing Water in the West

Consumptive Uses and Losses: Provisional Estimate

Arizona Portion of the Upper Colorado River Basin Calendar Year 2015

Provisional Version dated: February 15, 2017



U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

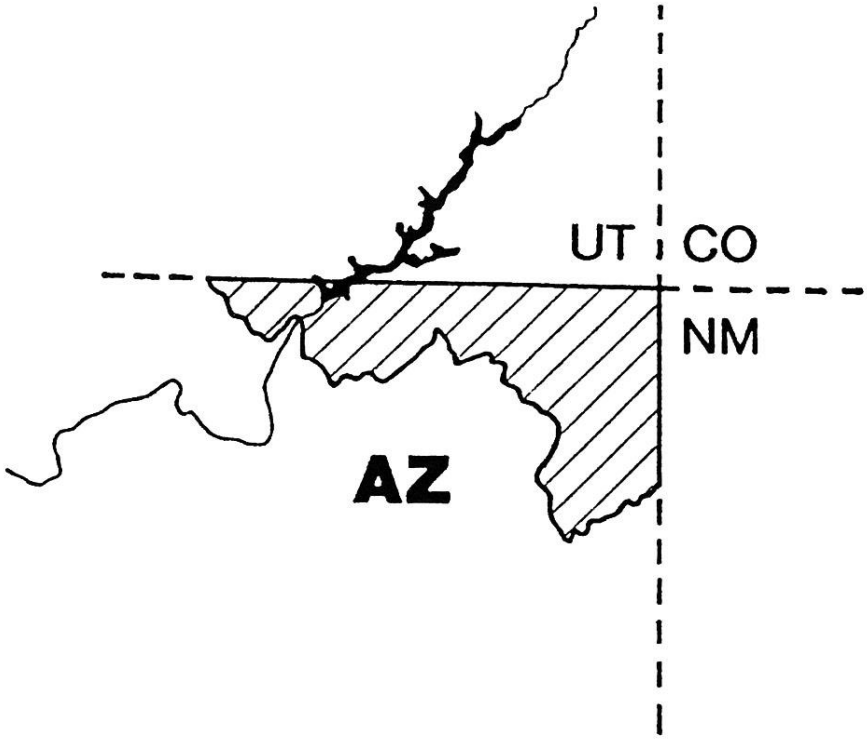
February 2017

RECLAMATION

Managing Water in the West

Consumptive Uses and Losses: Provisional

Arizona Portion of the Upper Colorado River Basin Calendar Year 2015



Prepared by: Alan Harrison – February 15, 2017

U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

February 2017

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CALENDAR YEAR
2015

AUTHORITY

This report was prepared in compliance with Public Law 90-537, Section 601 (b)(1), dated September 30, 1968, which directs the Secretary of the Interior to "make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis." Additionally, this report is in compliance with Section 49 of the Navajo Project Participation Agreement dated September 30, 1969, which states in part: "The Secretary of the Interior further agrees to make the reports required by Section 601 (b)(1) of Public Law 90-537 as they pertain to Arizona's Upper Basin uses annually rather than every five years. Within fifteen days following the completion of said reports, the Secretary of the Interior shall furnish copies of such reports to the Co-Tenants, the Navajo Tribe, each of the Upper Basin States, and the Upper Colorado River Commission."

SUMMARY

Based upon data made available for preparation of this document, the total consumptive use and loss value for the Arizona portion of the Upper Colorado River Basin for calendar year 2015 was 28,916 (±1,093) acre-feet. Reclamation prepares this estimate annually, final annual values for consumptive uses and losses for the northern Arizona portion of the Colorado River basin are published in the 5-year summary documents for the Upper Colorado River Basin

STUDY AREA DESCRIPTION

The Arizona portion of the Upper Colorado River Basin covers approximately 6,900 square miles in the north-east corner of Arizona, as shown on the location maps shown on pages 19 and 20 (Drawings 1246-406-1, 1246-406-2). The climate of the 5,900 square mile area to the west of the Chuska and Carrizo Mountains is largely arid to semiarid, with mean annual precipitation ranging from 6 to 12 inches and with

summertime temperatures often reaching 100 degrees Fahrenheit (°F). The potential evaporation rate is high and exceeds mean annual precipitation, with gross lake evaporation values of up to 55 inches per year or more. Elevations in the western portion range from 3200 feet on the Colorado River at Lee Ferry to over 8000 feet on the northern edge of the Black Mesa and across the Zilnez and Skeleton Mesas, back down to 5280 feet in the Chinle Valley, and back up to about 6500 feet on the western edge of the Chuska Mountains. Much of the western part of the study area is starkly beautiful southwestern desert country with mesas and canyons intertwined across a pastoral landscape. By contrast, the eastern 1,000 square miles is largely mountainous, with elevations rising to nearly 10,000 feet and mean annual precipitation reaching 30 inches. The mountainous land responds with grass meadows interspersed with conifer forest of mostly ponderosa pine.

Except for Page, Arizona; a small area around Lee Ferry; and a portion of the Paria Plateau administered by the Bureau of Land Management; the study area lies entirely within the Navajo Nation. According to census data, 47,265 persons were living within the area in 2010, and of these 39,763 resided on the Navajo Nation.

The largest cities are Page and Kayenta, with 2010 populations of 7,247 and 5,189, respectively. Other major communities and their populations include Dennehotso (746), Kaibeto (1,522), Chinle (4,518), LeChee (1,443), Lukachukai (1,701), Many Farms (1,348), Rock Point (642), Teec Nos Pos (730), and Tsaile (1,205). Subsistence in the region is derived principally from livestock grazing, farming, tourist-related industries, employment at the Navajo Generating Station (NGS), which consumed approximately 66 percent of the water used or lost in the study area. Agriculture accounts for about 9 percent of the total water use; municipal and industrial (including the Navajo Generating Station) about 81 percent; recreation, fish and wildlife, about 3 percent; and reservoir evaporation, about 7 percent.

AGRICULTURAL CONSUMPTIVE USE

Agricultural consumptive use is divided into three categories: irrigation, stock pond, and livestock. Irrigation use includes all use related to irrigating crops including the incidental losses. Stock pond use is the evaporation that occurs from stock ponds and livestock use is the water consumed by livestock.

IRRIGATION USES

Within the Arizona portion of the Upper Colorado River Basin, historically 23 irrigated areas were scattered across the Navajo Nation plus a small amount of land near Lee Ferry irrigated by the National Park Service. Currently, only 16 irrigated areas are in production. An accurate assessment of consumptive use on the irrigated land is difficult due to poor quality of information, such as the exact number of acres under irrigation, the cropping pattern for each irrigated area, site climatological conditions, and the amount of water actually diverted. In many cases, during the latter part of the irrigation season, farmers have to rely on dry land farming since there is little water available in the streams. This means that the crops do not receive their full water requirement.

For this report, the U.S. Department of Agriculture, Soil Conservation Service's (SCS) Modified Blaney-Criddle evapotranspiration, without an elevation adjustment, estimation formula was used for computing irrigated crop consumptive use. This model, along with appropriate crop-growth stage coefficients and the method for computing effective precipitation, is described in SCS's *Irrigation Water Requirements Technical Release No. 21* (TR 21). Information required for applying this model includes mean monthly temperature and precipitation values, growing season data for each crop type, and the total number of acres planted by crop at each site. With the exception of Teec Nos Pos, Canyon de Chelly, Lukachukai, and Lee Ferry, no climatological data exist for the irrigation sites, and site values must be generated from data collected at surrounding established weather stations. Growing season dates depend largely on the judgment of the local inhabitants and are, therefore, not known. Although several reports are available with published values for irrigated acres, it is unclear if these values are meant to represent potential irrigated acres, acres irrigated in the past, acres for which farming permits have been issued, or actual acres currently under irrigation.

The crop acreage used to estimate consumptive use by irrigated crops for the year 2015 is shown in table 1. These values were estimated from previous direct field examination by a party composed of representatives from the State of Arizona and the Navajo Nation.

Table 1.—Total irrigated acreage, 2015

PROJECT	CORN (ACRES)	ALFALFA (ACRES)	GRASS PASTURE (ACRES)	SPRING GRAINS (ACRES)	SMALL VEGETABLES (ACRES)	ORCHARD (ACRES)	TOTAL (ACRES)
CHINLE AGENCY							
Canyon de Chelly	0.36	0.00	0.00	3.03	2.26	0.00	5.65
Lukachukai	39.09	7.69	0.00	7.50	5.98	2.07	62.33
Many Farms	167.73	27.98	103.57	2.73	27.98	0.00	330.00
Nazlini	0.00	0.00	0.00	0.00	1.79	0.74	2.53
Rough Rock	30.00	0.00	11.87	0.00	12.43	0.00	54.30
Tsaile	23.72	5.27	15.67	5.73	5.42	0.00	55.81
Wheatfields	0.00	60.80	0.00	0.00	0.00	0.00	60.80
TOTAL	260.90	101.74	131.11	18.99	55.86	2.81	571.42
SHIPROCK AGENCY							
Red Rock Valley	26.22	0.00	10.19	5.12	10.22	0.00	51.75
Teec Nos Pos	20.00	0.00	0.00	0.00	3.67	0.00	23.67
Toh Chin Lini	0.00	0.00	0.00	0.00	3.90	13.67	17.57
Totacon	0.00	0.00	0.00	0.00	1.00	0.00	1.00
TOTAL	46.22	0.00	10.19	5.12	18.79	13.67	93.99
WESTERN NAVAJO AGENCY							
Dennehotso	1.82	0.00	38.70	0.00	0.00	0.00	40.52
Lees Ferry	0.00	0.00	1.00	0.00	0.00	2.00	3.00
Marsh Pass	7.02	3.31	0.00	0.00	1.99	0.00	12.32
Navajo Canyon	0.00	0.00	0.00	0.00	0.00	3.50	3.50
Paiute Canyon	2.64	0.00	0.00	0.00	3.86	0.00	6.50
TOTAL	11.48	3.31	39.70	0.00	5.85	5.50	65.84
GRAND TOTAL	218.60	105.05	181.00	24.11	80.50	21.98	731.25

Several factors complicate the modeling of irrigation consumptive use. For example, the computer program used to model consumptive use assumes a full water supply; if shortages exist, as they often do in this semiarid study area, adjustments must be made. These adjustments are complicated because some of the projects have no storage water and may only have a reliable irrigation water supply during spring runoff. After spring runoff, farming becomes essentially dry land until rains in July and August provide intermittent flows for irrigation. Finally, no ditch diversion records are available to help estimate irrigation water supplies and shortages.

A full irrigation supply seldom exists at many of the projects. Generally, a full supply is available for Lee Ferry, Navajo Canyon, Tsaile, and Wheatfields projects because of adequate stream flows or because of available storage water. In years with average precipitation, it is estimated that Chinle Wash provides approximately 75 percent of the irrigation requirement. Precipitation in the area averages approximately 9.5 inches per year. Based on this information, it would require approximately 12.67 inches of precipitation to provide 100 percent of the irrigation requirement. The percent of crop water requirement met was computed as a ratio of annual precipitation to 12.67 inches. These values are found in table 2.

The percentage of crop water requirement met was multiplied by the total net crop water requirement to determine the amount of crop consumptive use. Incidental irrigation losses, evaporation, and phreatophyte consumptive use along supply canals are estimated to be 5 percent of the consumptive use of the irrigated area and are added to the crop consumptive use value to develop a total consumptive use value.

A portion of the water used for irrigation at these sites may not be contributing to the Colorado River System since evaporation rates in the area are high and the nature of most of the drainage enhances evapotranspiration. A good example of such a drainage is Chinle Wash, which after leaving Canyon de Chelly, becomes wide and sandy and is lined with willows, cottonwoods, and other phreatophytes.

The uncertainties in the irrigation consumptive use values displayed in table 2 are very large and are estimated as 40 percent of the total consumptive use. This estimate of possible error only reflects the uncertainty of consumptive use and does not account for any possible errors in the acreage estimates. The effective consumptive use for irrigation for 2015 was estimated to equal 1,122 acre-feet. Including 5 percent for incidental losses, the irrigation related consumptive use is 1,179 (±471) acre-feet.

Table 2.—Net consumptive use values, 2015

PROJECT	CROP WATER REQUIREMENT (INCHES)	TOTAL IRRIGATED (ACRES)	TOTAL WATER REQUIRED (ACRE-FEET)	CROP WATER REQUIREMENT MET (%)	CROP WATER REQUIREMENT MET (ACRE-FEET)	TOTAL CONSUMPTIVE USE (ACRE-FEET)[1]
CHINLE AGENCY						
Canyon de Chelly	17.21	5.65	13	100	8	8.5
Lukachukai	17.06	62.33	89	100	89	93.0
Many Farms	17.26	330.00	475	100	475	498.5
Nazlini	14.83	2.53	3	100	3	3.3
Rough Rock	15.62	54.30	71	100	71	74.2
Tsaile	17.77	55.81	83	100	83	86.8
Wheatfields	22.91	60.80	116	100	116	121.9
TOTAL	122.67	571.42	844		844	886.2
SHIPROCK AGENCY						
Red Rock Valley	20.55	51.75	89	100	89	93.1
Teec Nos Pos	24.68	23.67	49	91	44	46.5
Toh Chin Lini	34.46	17.57	50	46	23	24.1
Totacon	22.06	1.00	2	46	1	0.9
TOTAL	101.75	93.99	190		157	164.6
WESTERN NAVAJO AGENCY						
Dennehotso	33.99	40.52	115	66	76	79.9
Lee Ferry	42.19	3.00	11	100	11	11.1
Marsh Pass	16.99	12.32	17	100	17	18.3
Navajo Canyon	35.06	3.50	10	94	10	10.1
Paiute Canyon	22.09	6.50	12	67	8	8.4
TOTAL	150.32	65.84	165		122	127.8
GRAND TOTAL	374.74	731.25	1199		1122	1178.6

[1] Total includes 5% addition for incidental losses.

STOCK POND EVAPORATION

Stock pond consumptive use is assumed to be the evaporation from area stock ponds. It is also assumed that any consumptive use by natural vegetation prior to the construction of the stock ponds is limited to precipitation which is subtracted from the evaporation losses.

A compilation of the stock ponds in the study area, including their locations and the water surface areas when ponds are full, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 3. For average year conditions, the stock pond evaporative surface area was estimated as one-third the water surface area that occurs when the ponds are full. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average water surface area. These values are found in table 3.

Table 3.—Stock pond evaporation, 2015

COUNTY	SURFACE AREA FULL (ACRES)	SURFACE AREA USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Coconino	80	26	99%	57	6.65	50.35	110.4
Navajo	40	13	100%	55	15.42	39.59	44.0
Apache	646	215	100%	53	14.17	38.84	696.9
TOTAL	766	255					851

This method of evaporation estimation was used because continuous useful water level records for all stock ponds from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual stock ponds. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation. It was assumed that any consumptive use by natural vegetation prior to construction of the stock ponds is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for stock pond evaporation for calendar year 2015 are shown in table 3. The total evaporative losses in 2015 are 851 (±255) acre-feet with the stock pond evaporation uncertainty being estimated as 30 percent.

LIVESTOCK WATER

The source of most livestock water in the study area is from wells, with windmill-operated pumps developed and maintained by Navajo Water Operations and Maintenance, and water collected in small surface ponds. The estimated number of

livestock in the area was estimated based on previous livestock tallies. It was estimated that horses and cattle consume 12 gallons per day; sheep and goats consume 2 gallons per day.

The number of animals for the Upper Colorado portion of each district is shown in table 4. The computed value for livestock consumptive use is 489 acre-feet. The uncertainty in this number is estimated as 30 percent of the total or ±147 acre-feet.

Table 4.—Number of livestock, 2015

AGENCY	CATTLE	HORSES	SHEEP	GOATS
Western Navajo District No. 1	0	0	1,338	398
Western Navajo District No. 2	1,533	102	1,370	1,902
Western Navajo District No. 8	7,402	1,517	11,788	7,576
Shiprock District No. 9	1,324	0	3,665	3,640
Chinle District No. 10	3,488	932	5,949	3,052
Chinle District No. 11	2,119	343	2,558	2,281
Shiprock District No. 12	5,761	1,076	9,110	4,785
Fort Defiance District No. 17	0	153	1,382	992
Fort Defiance District No. 18	0	207	957	0
TOTAL	21,627	4,330	38,117	24,626

TOTAL AGRICULTURAL CONSUMPTIVE USE

The total agricultural consumptive use, displayed in table 5, is the sum of the individual components discussed in the previous sections. Agricultural water consumption represents approximately 9 percent of the total use in the study area. Total degree of uncertainty was computed by taking the square root of the sum of the individual uncertainties squared; known as the quadratic sum. This method and nomenclature is used throughout this report. This method was used because a simple sum does not account for the partial cancellation of errors occurring when calculating the total uncertainty derived from individual values that are random and independent of each other. As previously discussed, the individual uncertainties were set as a percent of the consumptive use value.

Table 5.—Total agricultural consumptive use, 2015

CATEGORY	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Irrigation	1,179	471
Stock Ponds	851	255
Livestock	489	147
TOTAL	2,519	556

MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

Municipal and industrial consumptive use is divided into three categories: mineral resources, thermal electric power, and other. Mineral resources consumptive use includes water used for mineral production. No mineral resources consumptive use is reported in the study area. Thermal electric power consumptive use includes the water used at the power plants, and that used to transport material to the power plant (such as a coal slurry pipeline). Other consumptive use includes urban, rural, and industrial uses.

THERMAL ELECTRIC POWER

Thermal electric power consumptive use includes the water used in the power plant and the water used to transport material to the plant.

Navajo Generating Station

The water used by the NGS is pumped directly from Lake Powell and comprises approximately 66% of the total consumption in the study area. Since all NGS water use is metered, this quantity is among those most precisely known, with the maximum uncertainty in the metered quantities believed to be less than 3 percent. The actual quantity consumed, along with the estimated uncertainty for the calendar year 2015, was 19,077 (±572) acre-feet.

OTHER

The other consumptive use category includes the remaining use by urban, rural, and industries.

Page, AZ and Vicinity

City of Page, AZ. – The city of Page pumps its domestic water directly from Lake Powell. The water pumped is metered, and the uncertainty of the pumped quantities was assumed to be less than 3 percent. A portion of the water pumped and treated by the City

of Page, is supplied to the community of Le Chee on the Navajo Nation and is accounted for separately. The quantity supplied to the City of Page and its associated uncertainty for the calendar year 2015 was 2,219 (±67) acre-feet. Water returning to the waste water treatment plant is metered as well. The waste water for the City of Page is treated and is either evaporated from lined ponds or applied to the golf course, with a portion being returned to the Colorado River. The return flow is estimated to be 1,446 acre-feet. The net consumptive use is estimated to be 773 acre-feet (±79).

Le Chee – The community of Le Chee is supplied and metered by the City of Page. Total water supplied for 2015 was 94 (±3) acre-feet. The uncertainty was estimated to be 3 percent.

Greenhaven Water Company – The Greenhaven Water Company derives its domestic water supply from wells. Well pumping records are available. According to these records, the total water pumped for 2015 was 121 (±8) acre-feet. The uncertainty was estimated to be 7 percent.

Arizona Department of Transportation Housing – The Arizona Department of Transportation operates a housing, maintenance, and administrative facility located on US Hwy 89, north of Page, AZ. This facility is supplied from wells that have no meters installed. It is estimated that the total water pumped for 2015 was 7 acre-feet with an uncertainty of 30 percent of this value or ±2 acre-feet.

Navajo Nation

Community Water Systems – 1980 statistics from the Division of Community Development of the Navajo Nation reveal that various community water systems served 26,086, or about 83 percent of the 31,429 people residing within the study area at that time. Since additional estimates have not been repeated, this same percentage was used for 2015 resulting in 32,337 out of 38,960 people being served. These systems include those operated by the Navajo Tribal Utility Authority (NTUA), the BIA, and the Water Operations and Maintenance Department of the Navajo Nation, and some privately developed community water systems.

Table 6 shows the source of water and estimated population served by each source of water for people living on the Navajo Nation during 2015. All of the communities obtain their water supply from ground water.

Table 6.—Domestic water sources, 2015

SOURCE	PERCENTAGE OF POPULATION SERVED	NUMBER OF POPULATION SERVED[1]
Community Water Systems	83	32,337
NTUA	[2](60)	19,402
BIA	[2](25)	8,084
Navajo WOM	[2](13)	4,204
Private	[2](2)	647
Individual Wells	17	6,623
TOTAL	100	38,960

[1] Total population within the Upper Colorado River Basin portion of the Navajo Nation, estimated from 2010 US Census.
[2] These numbers are a percentage of the Community Water Systems.

NTUA Water Systems – The cities and surrounding communities of Oak Springs, Red Valley, Sweetwater, Chinle , Rough Rock, Round Rock, Rock Point, Wheatfields, Lukachukai, Kayenta, Chilchinbeto, Dennehotso, and Kaibeto derive most of their domestic water supply from wells operated by NTUA. Well pumping records are available. According to these records, the total water pumped for 2015 was 1,619 acre-feet with an uncertainty estimated to be 7 percent of this value or ±113 acre-feet.

The NTUA manages the raw waste water; portions of which flow to individual septic tanks, some to evaporation ponds, and some, such as for the cities of Chinle and Kayenta, flow to waste water treatment plants. Very little water, if any, is returned to the ground water system through leakage from the evaporation ponds, but there are losses from the main collection system. Effluent from the Chinle and Kayenta waste water treatment plants is metered. Under normal conditions, the effluent returns to the Colorado River System and is subtracted from the pumping totals to determine a net consumptive use. For 2015, Chinle's treatment plant effluent was 13.6 (±1.0) acre-feet, and Kayenta's effluent was 9.7 (±0.7) acre-feet. An estimated uncertainty of 7 percent was used for the effluent of these two plants. The total effluent of 23.3 acre-feet is subtracted from the NTUA pumping total of 1,619 acre-feet to arrive at a net consumptive use of 1,596 (±113) acre-feet.

BIA Water Systems – Wells developed and operated by the BIA serve numerous Navajo communities. These systems also serve BIA schools, hospitals, agency offices, and some housing on the Navajo Nation. Metered records for total amounts of water pumped from BIA wells were available for a portion of the Shiprock Agency, the Western Navajo Agency, and the Chinle Agency. Drawing 1246-406-2 shows the agency boundaries within the Upper Colorado River Basin. The uncertainty was estimated to be about 7 percent for all three agencies.

The BIA systems include sewage disposal units terminating in lined evaporation ponds with very little or no return water returning to the ground water system. Undoubtedly, some losses occur in distribution, but insufficient data currently exist to estimate these losses. The losses are probably less than the uncertainties for each of the reported values.

The BIA well data available for the Shiprock Agency include: Cove, Red Rock, and Teec Nos Pos. Total consumptive use values are 11 (±1) acre-feet.

Pumping records for the Western Navajo Agency include data for the following schools: Chilchinbeto Day School, Dennehotso Boarding School, Kaibeto Boarding School, and Kayenta Boarding School. Total consumptive use for the Western Navajo Agency was 172 (±12) acre-feet.

Well pumping records for the Chinle Agency include data for the following schools: Cottonwood Day School, Lukachukai School, and Rock Point School. Rough Rock School maintains its own records, but the data was included with the Chinle Agency data. Total consumptive use for the Chinle Agency was 69 (±5) acre-feet.

Navajo WOM Water Systems – Water use in 2015 by the Navajo WOM service areas was based on an assumed consumption rate of 110 gallons per capita per day (gpcd). For a 2015 estimated service area population of 4,204, the estimated annual water use was 518 (±155) acre-feet. The uncertainty is estimated as 30 percent of the total.

Private Water Systems – The estimated 2015 population served by private water systems on the Navajo Nation was 647. Assuming a consumptive use rate of 110 gcpd, the annual water use for 2015 was 80 (±24) acre-feet. The uncertainty is estimated as 30 percent of the total.

Individual Wells – According to census data from the Division of Community Development of the Navajo Nation, approximately 17 percent of the study area's population on the reservation (about 6,623 persons in 2015) receives a domestic water supply from individual wells. A consumptive use of 110 gpcd was derived as being a reasonable water use rate. Based on these figures, the annual consumptive use was 816 (±245) acre-feet for 2015.

TOTAL MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

The total municipal and industrial consumptive use, displayed in table 7, is the sum of the individual components discussed in the previous sections. Municipal and industrial water consumption, including the Navajo Generating Station, represents approximately 81 percent of the total use in the study area.

Table 7.—Total municipal and industrial consumptive use, 2015

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
THERMAL ELECTRIC POWER		
Navajo Generating Station	19,077	572
OTHER		
Page, AZ and Vicinity		
City of Page	773	79
Le Chee	94	3
Greenhaven Water Company	121	8
Arizona Department of Transportation	7	2
Navajo Indian Reservation		
Community Water Systems		
NTUA Water Systems	1,596	113
BIA Water Systems	252	13
Navajo WOM	518	155
Private Water Systems	80	24
Individual Wells	816	245
TOTAL	23,333	657

It is questionable whether all the water pumped from wells should be considered a depletion to the Colorado River System; however, it is assumed that 100 percent of the water pumped is considered lost to the system. It is proposed that a future joint study be completed by Reclamation, the State of Arizona, and the Navajo Nation to estimate what percentage of water pumped could actually be attributed to the Colorado River System and would have affected the river flows for a particular year.

RECREATION, FISH AND WILDLIFE

The recreation, fish and wildlife consumptive uses include evaporation from reservoirs used exclusively for fish & wildlife purposes as well as acreages irrigated for wildlife feeding. Consumptive use related to recreation at National parks is also addressed.

GLEN CANYON NATIONAL RECREATION AREA

Colorado River water is used by the Glen Canyon National Recreation Area (GCNRA) at Wahweap and Lee Ferry. The recreational area at Wahweap gets its water supply from a series of wells on the shore of Lake Powell. Pumping records for both Wahweap Marina, and Lee Ferry show 202 (±6) acre-feet of water withdrawn during 2015. The uncertainty

is estimated at 3 percent. This water was used for domestic purposes at the campgrounds, picnic areas, and trailer parks. It was also used to irrigate approximately 60 acres of Bermuda grass and cottonwood trees. The domestic waste water is treated and the effluent is allowed to evaporate from two lined evaporation ponds with a total surface area of 16.7 acres.

Based on estimates of evaporation and consumptive use by the plants, there is some water which is unaccounted for and is assumed to be leakage from the delivery system, the evaporation pond, or deep percolation from irrigation application. However, since these water losses are difficult to quantify and verify, the losses were charged as consumptive uses. Therefore, net consumptive use of water is estimated to be equal to the quantity of water pumped.

RESERVOIR EVAPORATION

A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 8.

Table 8. —Recreation, fish and wildlife reservoir evaporation, 2015

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE AREA USED (ACRES)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Tsaile	260	260	35	16.8	18.2	394.3
Wheatfields	272	272	32	16.8	15.2	344.5
TOTAL	532	532				739

Efforts are made to maintain a nearly full condition and to minimize water surface fluctuations in reservoirs managed for a fishery. Under average operating conditions, the water surface area of a reservoir used primarily for fishing is assumed to be equal to a normal water surface area. It is assumed that, in 2015, these reservoirs filled in the spring and were maintained at the normal pool level.

This method of evaporation estimation was used because continuous useful water level records for all reservoirs from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs.

For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for reservoir evaporation for calendar year 2015 are shown in table 8. The total evaporative losses in 2015 are 739 (±222) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent.

TOTAL RECREATION, FISH AND WILDLIFE

The total recreation, fish and wildlife consumptive use, displayed in table 9, is the sum of the individual components discussed in the previous sections. Recreation, fish and wildlife water consumption represents approximately 4 percent of the total use in the study area.

Table 9.—Total recreation, fish and wildlife consumptive use, 2015

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Glen Canyon National Recreation Area	202	6
Reservoir Evaporation	739	222
TOTAL	941	222

RESERVOIR EVAPORATION

Reservoir evaporation losses make up about 7 percent of the total water uses and losses in the study area. A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 10. These reservoirs are used primarily for irrigation.

Table 10.—Reservoir evaporation, 2015

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE ACRES USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Many Farms	1,800	554	100%	56	16.8	39.20	1,811.3
Marsh Pass	40	20	100%	40	16.2	23.81	39.7
Round Rock	83	42	100%	57	14.2	42.84	148.1
Walker Creek	30	15	100%	59	11.5	47.47	59.3
Others	38	19	100%	55	15.1	39.88	63.1
TOTAL	1,991	650					2,121.6

Reservoirs used primarily for irrigation experience large fluctuations in water levels and, correspondingly, large variations in surface area. Reservoir level records and elevation – area curves were available at Many Farms, but not for the remaining reservoirs in table 10. For the reservoirs with no records from which surface area could be accurately

computed, the average evaporative surface area was estimated as one-half the water surface area of a full reservoir. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average evaporative surface area.

Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses. The computed values for reservoir evaporation for 2014 are shown in table 10. The total evaporative losses in 2015 are 2,122 (±636) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent of the total evaporation.

CONCLUSIONS

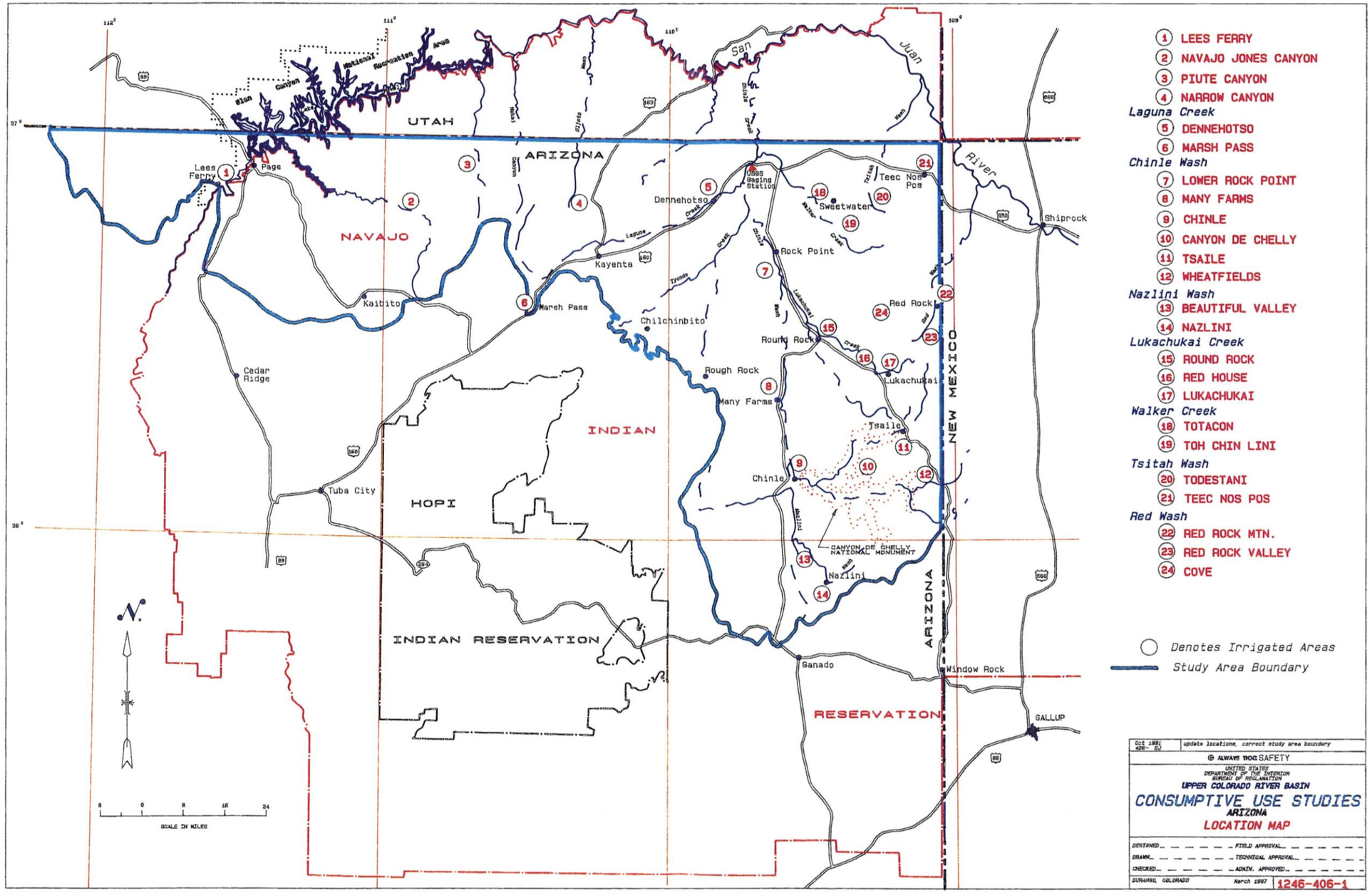
This report assesses the total consumptive use of the Arizona portion of the Upper Colorado River surface water systems, depletion of ground water, and evaporative losses. Clearly, the amounts of water used by the Navajo Generating Station, City of Page, and Wahweap and Lee Ferry recreation areas are direct depletions of water from the Upper Colorado River System, but the situation is not as clear for other consumptive uses and losses occurring in other sections of the study area. For example, the source of water used by the Navajo Nation for domestic and municipal purposes is from wells, some exceeding 1,000 feet in depth. For our purposes here, it is considered to be consumed and a depletion to the Colorado River System. But this may not actually result in a reduction of Colorado River stream flows in the same year that the withdrawal occurs, or at all. Little knowledge and information exists of ground water movement and subsurface flow rates in the study area that are accurate descriptions of the effects on river flows.

Although the water diverted for agricultural purposes is considered as consumptive use in this report, a portion of the remaining surface water on the Navajo Nation, excess to needs, does evaporate before reaching the Colorado River. No attempt has been made for this report to quantify these losses.

Uncertainties in estimating uses and losses exist, and the degree of variation in the figures is presented. Fortunately, the areas with the highest degree of uncertainty account for only a small percentage of the total consumptive use. The largest component, use by the Navajo Generating Station, is also the most accurately monitored. The total annual value for estimated consumptive use of water within the Arizona portion of the Upper Colorado River Basin for 2015 was 28,916 acre-feet, as shown in table 11.

Table 11.—Consumptive use for Arizona portion of Upper Colorado River Basin for 2015

USE CATEGORY	TOTAL CONSUMPTIVE USE (ACRE-FEET)	UNCERTAINTY	PERCENT OF TOTAL
Agriculture	2,519	556	8.71
Municipal & Industrial	23,333	657	80.70
Recreation, Fish & Wildlife	941	222	3.26
Reservoir Evaporation	2,122	636	7.33
TOTAL	28,916	1,093	100%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3 PIUTE CANYON
4 NARROW CANYON
Laguna Creek
5 DENNEHOTSO
6 MARSH PASS
Chinle Wash
7 LOWER ROCK POINT
8 MANY FARMS
9 CHINLE
10 CANYON DE CHELLY
11 TSAILE
12 WHEATFIELDS
Nazlini Wash
13 BEAUTIFUL VALLEY
14 NAZLINI
Lukachukai Creek
15 ROUND ROCK
16 RED HOUSE
17 LUKACHUKAI
Walker Creek
18 TOTACON
19 TOH CHIN LINI
Tsitah Wash
20 TODESTANI
21 TEEC NOS POS
Red Wash
22 RED ROCK MTN.
23 RED ROCK VALLEY
24 COVE
Denotes Irrigated Areas
Study Area Boundary
UTAH
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NAVAJO
INDIAN
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INDIAN RESERVATION
RESERVATION
NEW MEXICO
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Lees Ferry
Page
Kaibito
Cedar Ridge
Tuba City
Marsh Pass
Kayenta
Dennehotso
Chilchinbito
Rough Rock
Many Farms
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Round Rock
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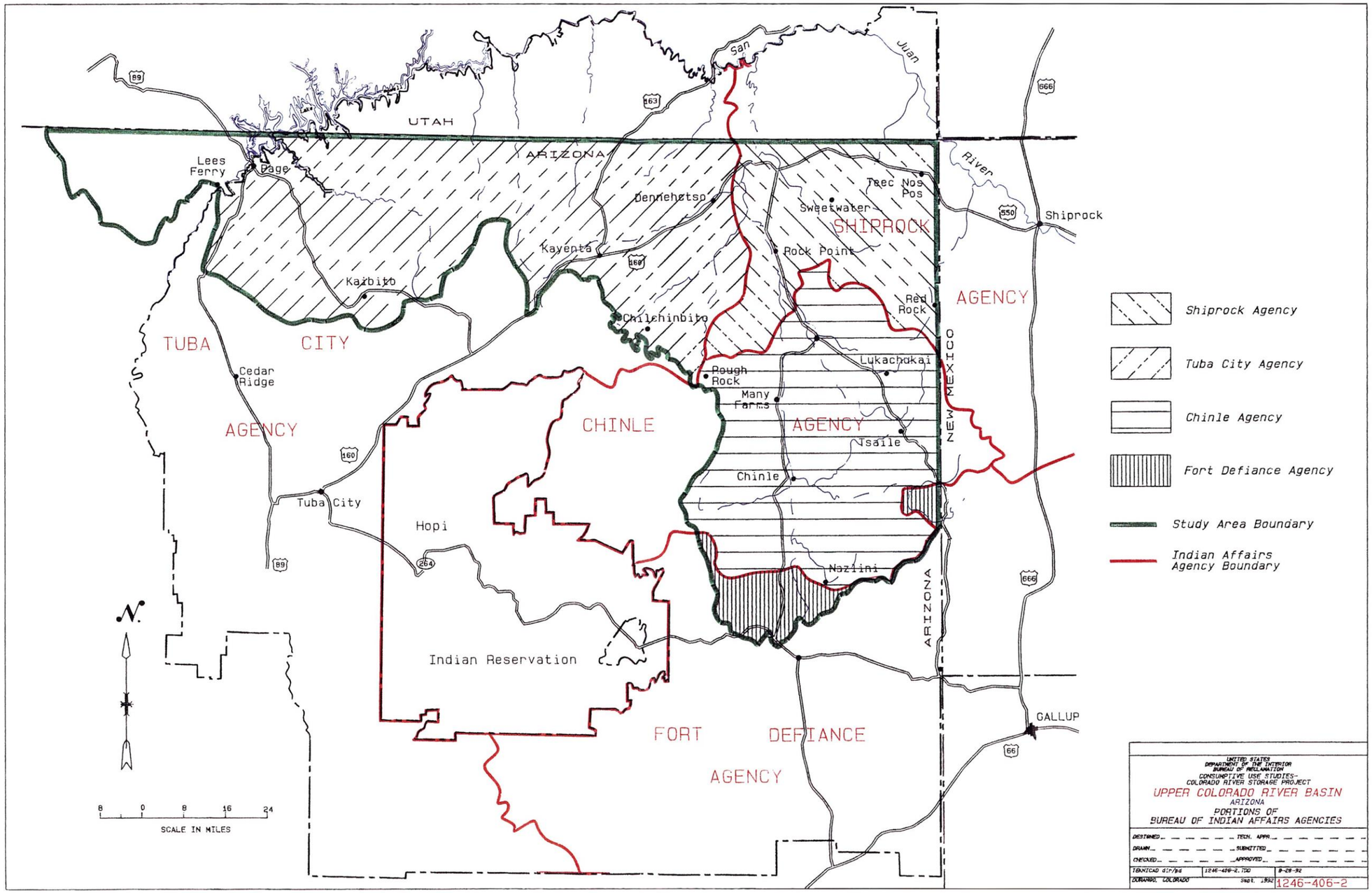
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Rock Point
Red Rock
Shiprock
SHIPROCK AGENCY
TUBA CITY AGENCY
Cedar Ridge
Tuba City
Rough Rock
Many Farms
Lukachukai
Tsaile
Chinle
CHINLE AGENCY
Hopi
Nazlini
Indian Reservation
FORT DEFIANCE AGENCY
GALLUP
Shiprock Agency
Tuba City Agency
Chinle Agency
Fort Defiance Agency
Study Area Boundary
Indian Affairs Agency Boundary
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BUREAU OF RECLAMATION
CONSUMPTIVE USE STUDIES-
COLORADO RIVER STORAGE PROJECT
UPPER COLORADO RIVER BASIN
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Sept. 1992
1246-406-2

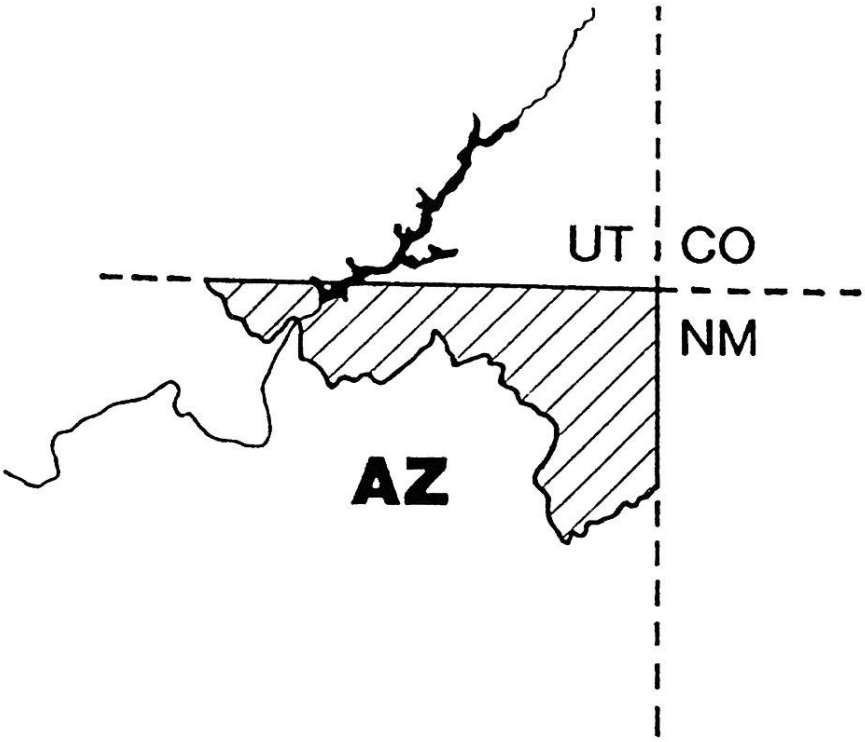
RECLAMATION

Managing Water in the West

Consumptive Uses and Losses: Provisional Estimate

Arizona Portion of the Upper Colorado River Basin Calendar Year 2016

Provisional Version dated: March 13, 2018



U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

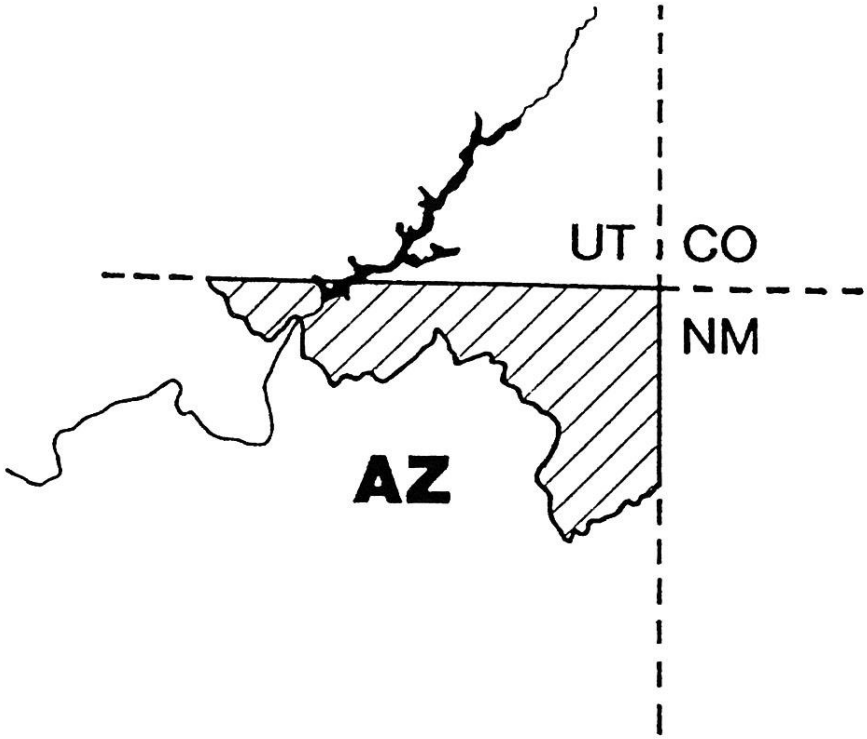
March 2018

RECLAMATION

Managing Water in the West

Consumptive Uses and Losses: Provisional

Arizona Portion of the Upper Colorado River Basin Calendar Year 2016



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Provisional Estimates (03/18)

ARIZONA PORTION
OF THE
UPPER COLORADO RIVER BASIN

CALENDAR YEAR
2016

AUTHORITY

This report was prepared in compliance with Public Law 90-537, Section 601 (b)(1), dated September 30, 1968, which directs the Secretary of the Interior to "make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis." Additionally, this report is in compliance with Section 49 of the Navajo Project Participation Agreement dated September 30, 1969, which states in part: "The Secretary of the Interior further agrees to make the reports required by Section 601 (b)(1) of Public Law 90-537 as they pertain to Arizona's Upper Basin uses annually rather than every five years. Within fifteen days following the completion of said reports, the Secretary of the Interior shall furnish copies of such reports to the Co-Tenants, the Navajo Tribe, each of the Upper Basin States, and the Upper Colorado River Commission."

SUMMARY

Based upon data made available for preparation of this document, the total consumptive use and loss value for the Arizona portion of the Upper Colorado River Basin for calendar year 2016 was 29,458 (±1,160) acre-feet. Reclamation prepares this estimate annually, final annual values for consumptive uses and losses for the northern Arizona portion of the Colorado River basin are published in the 5-year summary documents for the Upper Colorado River Basin

STUDY AREA DESCRIPTION

The Arizona portion of the Upper Colorado River Basin covers approximately 6,900 square miles in the north-east corner of Arizona, as shown on the location maps shown on pages 19 and 20 (Drawings 1246-406-1, 1246-406-2). The climate of the 5,900 square mile area to the west of the Chuska and Carrizo Mountains is largely arid to semiarid, with mean annual precipitation ranging from 6 to 12 inches and with summertime temperatures often reaching 100 degrees Fahrenheit (^{o}F). The potential

evaporation rate is high and exceeds mean annual precipitation, with gross lake evaporation values of up to 55 inches per year or more. Elevations in the western portion range from 3200 feet on the Colorado River at Lee Ferry to over 8000 feet on the northern edge of the Black Mesa and across the Zilnez and Skeleton Mesas, back down to 5280 feet in the Chinle Valley, and back up to about 6500 feet on the western edge of the Chuska Mountains. Much of the western part of the study area is starkly beautiful southwestern desert country with mesas and canyons intertwined across a pastoral landscape. By contrast, the eastern 1,000 square miles is largely mountainous, with elevations rising to nearly 10,000 feet and mean annual precipitation reaching 30 inches. The mountainous land responds with grass meadows interspersed with conifer forest of mostly ponderosa pine.

Except for Page, Arizona; a small area around Lee Ferry; and a portion of the Paria Plateau administered by the Bureau of Land Management; the study area lies entirely within the Navajo Nation. According to census data, 47,791 persons were living within the area in 2010, and of these 40,018 resided on the Navajo Nation.

The largest cities are Page and Kayenta, with 2010 populations of 7,247 and 5,189, respectively. Other major communities and their populations include Dennehotso (746), Kaibeto (1,522), Chinle (4,518), LeChee (1,443), Lukachukai (1,701), Many Farms (1,348), Rock Point (642), Teec Nos Pos (730), and Tsaile (1,205). Subsistence in the region is derived principally from livestock grazing, farming, tourist-related industries, employment at the Navajo Generating Station (NGS), which consumes approximately 61 percent of the water used or lost in the study area in an average every year. Agriculture accounts for about 9 percent of the total water use; municipal and industrial (including the Navajo Generating Station) about 78 percent; recreation, fish and wildlife, about 4 percent; and reservoir evaporation, about 8 percent in an average year.

AGRICULTURAL CONSUMPTIVE USE

Agricultural consumptive use is divided into three categories: irrigation, stock pond, and livestock. Irrigation use includes all use related to irrigating crops including the incidental losses. Stock pond use is the evaporation that occurs from stock ponds and livestock use is the water consumed by livestock.

IRRIGATION USES

Within the Arizona portion of the Upper Colorado River Basin, historically 23 irrigated areas were scattered across the Navajo Nation plus a small amount of land near Lee Ferry irrigated by the National Park Service. Currently, only 16 irrigated areas are in production. An accurate assessment of consumptive use on the irrigated land is difficult due to poor quality of information, such as the exact number of acres under irrigation, the cropping pattern for each irrigated area, site climatological conditions, and the amount of water actually diverted. In many cases, during the latter part of the irrigation season, farmers have to rely on dry land farming since there is little water available in the streams. This means that the crops do not receive their full water requirement.

For this report, the U.S. Department of Agriculture, Soil Conservation Service's (SCS) Modified Blaney-Criddle evapotranspiration, without an elevation adjustment, estimation formula was used for computing irrigated crop consumptive use. This model, along with appropriate crop-growth stage coefficients and the method for computing effective precipitation, is described in SCS's *Irrigation Water Requirements Technical Release No. 21* (TR 21). Information required for applying this model includes mean monthly temperature and precipitation values, growing season data for each crop type, and the total number of acres planted by crop at each site. With the exception of Teec Nos Pos, Canyon de Chelly, Lukachukai, and Lee Ferry, no climatological data exist for the irrigation sites, and site values must be generated from data collected at surrounding established weather stations. Growing season dates depend largely on the judgment of the local inhabitants and are, therefore, not known. Although several reports are available with published values for irrigated acres, it is unclear if these values are meant to represent potential irrigated acres, acres irrigated in the past, acres for which farming permits have been issued, or actual acres currently under irrigation.

The crop acreage used to estimate consumptive use by irrigated crops for the year 2016 is shown in table 1. These values were estimated from previous direct field examination by a party composed of representatives from the State of Arizona and the Navajo Nation.

Table 1.—Total irrigated acreage, 2016

PROJECT	CORN (ACRES)	ALFALFA (ACRES)	GRASS PASTURE (ACRES)	SPRING GRAINS (ACRES)	SMALL VEGETABLES (ACRES)	ORCHARD (ACRES)	TOTAL (ACRES)
CHINLE AGENCY							
Canyon de Chelly	0.36	0.00	0.00	3.03	2.26	0.00	5.65
Lukachukai	39.09	7.69	0.00	7.50	5.98	2.07	62.33
Many Farms	176.12	29.38	108.75	2.87	29.38	0.00	346.50
Nazlini	0.00	0.00	0.00	0.00	1.79	0.74	2.53
Rough Rock	30.00	0.00	11.87	0.00	12.43	0.00	54.30
Tsaile	23.72	5.27	15.67	5.73	5.42	0.00	55.81
Wheatfields	0.00	60.80	0.00	0.00	0.00	0.00	60.80
TOTAL	269.29	103.14	136.29	19.13	57.26	2.81	587.92
SHIPROCK AGENCY							
Red Rock Valley	26.22	0.00	10.19	5.12	10.22	0.00	51.75
Teec Nos Pos	20.00	0.00	0.00	0.00	3.67	0.00	23.67
Toh Chin Lini	0.00	0.00	0.00	0.00	3.90	13.67	17.57
Totacon	0.00	0.00	0.00	0.00	1.00	0.00	1.00
TOTAL	46.22	0.00	10.19	5.12	18.79	13.67	93.99
WESTERN NAVAJO AGENCY							
Dennehotso	1.82	0.00	38.70	0.00	0.00	0.00	40.52
Lees Ferry	0.00	0.00	1.00	0.00	0.00	2.00	3.00
Marsh Pass	7.02	3.31	0.00	0.00	1.99	0.00	12.32
Navajo Canyon	0.00	0.00	0.00	0.00	0.00	3.50	3.50
Paiute Canyon	2.64	0.00	0.00	0.00	3.86	0.00	6.50
TOTAL	11.48	3.31	39.70	0.00	5.85	5.50	65.84
GRAND TOTAL	326.99	106.45	186.18	24.25	81.90	21.98	747.75

Several factors complicate the modeling of irrigation consumptive use. For example, the computer program used to model consumptive use assumes a full water supply; if shortages exist, as they often do in this semiarid study area, adjustments must be made. These adjustments are complicated because some of the projects have no storage water and may only have a reliable irrigation water supply during spring runoff. After spring runoff, farming becomes essentially dry land until rains in July and August provide intermittent flows for irrigation. Finally, no ditch diversion records are available to help estimate irrigation water supplies and shortages.

A full irrigation supply seldom exists at many of the projects. Generally, a full supply is available for Lee Ferry, Navajo Canyon, Tsaile, and Wheatfields projects because of adequate stream flows or because of available storage water. In years with average precipitation, it is estimated that Chinle Wash provides approximately 75 percent of the irrigation requirement. Precipitation in the area averages approximately 9.5 inches per year. Based on this information, it would require approximately 12.67 inches of precipitation to provide 100 percent of the irrigation requirement. The percent of crop water requirement met was computed as a ratio of annual precipitation to 12.67 inches. These values are found in table 2.

The percentage of crop water requirement met was multiplied by the total net crop water requirement to determine the amount of crop consumptive use. Incidental irrigation losses, evaporation, and phreatophyte consumptive use along supply canals are estimated to be 5 percent of the consumptive use of the irrigated area and are added to the crop consumptive use value to develop a total consumptive use value.

A portion of the water used for irrigation at these sites may not be contributing to the Colorado River System since evaporation rates in the area are high and the nature of most of the drainage enhances evapotranspiration. A good example of such a drainage is Chinle Wash, which after leaving Canyon de Chelly, becomes wide and sandy and is lined with willows, cottonwoods, and other phreatophytes.

The uncertainties in the irrigation consumptive use values displayed in table 2 are very large and are estimated as 40 percent of the total consumptive use. This estimate of possible error only reflects the uncertainty of consumptive use and does not account for any possible errors in the acreage estimates. The effective consumptive use for irrigation for 2016 was estimated to equal 1,062 acre-feet. Including 5 percent for incidental losses, the irrigation related consumptive use is 1,115 (±446) acre-feet.

Table 2.—Net consumptive use values, 2016

PROJECT	CROP WATER REQUIREMENT (INCHES)	TOTAL IRRIGATED (ACRES)	TOTAL WATER REQUIRED (ACRE-FEET)	CROP WATER REQUIREMENT MET (%)	CROP WATER REQUIREMENT MET (ACRE-FEET)	TOTAL CONSUMPTIVE USE (ACRE-FEET)[1]
CHINLE AGENCY						
Canyon de Chelly	21.63	5.65	10	80%	8	8.5
Lukachukai	20.99	62.33	109	80%	87	91.2
Many Farms	21.07	346.50	608	80%	485	508.9
Nazlini	19.34	2.53	4	80%	3	3.4
Rough Rock	18.28	54.30	83	87%	81	84.8
Tsaile	21.80	55.81	101	80%	81	84.8
Wheatfields	28.32	60.80	143	80%	114	120.0
TOTAL	151.42	587.92	1,059		850	892.7
SHIPROCK AGENCY						
Red Rock Valley	23.71	51.75	102	71%	72	76.1
Teec Nos Pos	26.20	23.67	52	62%	32	33.7
Toh Chin Lini	37.43	17.57	55	31%	17	17.9
Totacon	24.55	1.00	2	31%	1	0.7
TOTAL	111.89	93.99	211		122	128.3
WESTERN NAVAJO AGENCY						
Dennehotso	37.93	40.52	128	40%	51	53.6
Lee Ferry	42.19	3.00	11	100%	11	11.1
Marsh Pass	18.85	12.32	19	71%	14	14.5
Navajo Canyon	36.49	3.50	11	74%	8	8.3
Paiute Canyon	23.34	6.50	13	48%	6	6.3
TOTAL	158.81	65.84	181		89	93.7
GRAND TOTAL	422.12	747.75	1,451		1,062	1,114.7

[1] Total includes 5% addition for incidental losses.

STOCK POND EVAPORATION

Stock pond consumptive use is assumed to be the evaporation from area stock ponds. It is also assumed that any consumptive use by natural vegetation prior to the construction of the stock ponds is limited to precipitation which is subtracted from the evaporation losses.

A compilation of the stock ponds in the study area, including their locations and the water surface areas when ponds are full, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 3. For average year conditions, the stock pond evaporative surface area was estimated as one-third the water surface area that occurs when the ponds are full. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average water surface area. These values are found in table 3.

Table 3.—Stock pond evaporation, 2016

COUNTY	SURFACE AREA FULL (ACRES)	SURFACE AREA USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Coconino	80	26	99%	57	6.65	50.35	110.4
Navajo	40	13	98%	55	9.60	45.41	49.7
Apache	646	215	100%	53	8.98	44.03	790.0
TOTAL	766	255					950.0

This method of evaporation estimation was used because continuous useful water level records for all stock ponds from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual stock ponds. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation. It was assumed that any consumptive use by natural vegetation prior to construction of the stock ponds is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for stock pond evaporation for calendar year 2016 are shown in table 3. The total evaporative losses in 2016 are 950 (±285) acre-feet with the stock pond evaporation uncertainty being estimated as 30 percent.

LIVESTOCK WATER

The source of most livestock water in the study area is from wells, with windmill-operated pumps developed and maintained by Navajo Water Operations and Maintenance, and water collected in small surface ponds. The estimated number of

livestock in the area was estimated based on previous livestock tallies and current-year estimates from the USDA Agriculture Statistics Service. It was estimated that horses and cattle consume 12 gallons per day; sheep and goats consume 2 gallons per day.

The number of animals for the Upper Colorado portion of each district is shown in table 4. The computed value for livestock consumptive use is 522 acre-feet. The uncertainty in this number is estimated as 30 percent of the total or ±157 acre-feet.

Table 4.—Number of livestock, 2016

AGENCY	CATTLE	HORSES	SHEEP	GOATS
Western Navajo District No. 1	0	0	1,236	299
Western Navajo District No. 2	1,608	95	1,381	2,005
Western Navajo District No. 8	7,962	1,641	12,653	8,145
Shiprock District No. 9	1,303	0	3,839	3,787
Chinle District No. 10	3,695	984	6,324	3,244
Chinle District No. 11	2,278	361	2,762	2,474
Shiprock District No. 12	6,262	1,169	9,909	5,205
Fort Defiance District No. 17	0	152	1,358	1,047
Fort Defiance District No. 18	0	211	950	0
TOTAL	23,108	4,613	40,412	26,206

TOTAL AGRICULTURAL CONSUMPTIVE USE

The total agricultural consumptive use, displayed in table 5, is the sum of the individual components discussed in the previous sections. Agricultural water consumption represents approximately 9 percent of the total use in the study area. Total degree of uncertainty was computed by taking the square root of the sum of the individual uncertainties squared; known as the quadratic sum. This method and nomenclature is used throughout this report. This method was used because a simple sum does not account for the partial cancellation of errors occurring when calculating the total uncertainty derived from individual values that are random and independent of each other. As previously discussed, the individual uncertainties were set as a percent of the consumptive use value.

Table 5.—Total agricultural consumptive use, 2016

CATEGORY	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Irrigation	1,115	446
Stock Ponds	950	285
Livestock	522	157
TOTAL	2,587	552

MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

Municipal and industrial consumptive use is divided into three categories: mineral resources, thermal electric power, and other. Mineral resources consumptive use includes water used for mineral production. No mineral resources consumptive use is reported in the study area. Thermal electric power consumptive use includes the water used at the power plants, and that used to transport material to the power plant (such as a coal slurry pipeline). Other consumptive use includes urban, rural, and industrial uses.

THERMAL ELECTRIC POWER

Thermal electric power consumptive use includes the water used in the power plant and the water used to transport material to the plant.

Navajo Generating Station

The water used by the NGS is pumped directly from Lake Powell and comprises approximately 61 percent of the total consumption in the study area. Since all NGS water use is metered, this quantity is among those most precisely known, with the maximum uncertainty in the metered quantities believed to be less than 3 percent. The actual quantity consumed, along with the estimated uncertainty for the calendar year 2016, was 18,116 (±543) acre-feet.

OTHER

The other consumptive use category includes the remaining use by urban, rural, and industries.

Page, AZ and Vicinity

City of Page, AZ. – The city of Page pumps its domestic water directly from Lake Powell. The water pumped is metered, and the uncertainty of the pumped quantities was assumed to be less than 3 percent. A portion of the water pumped and treated by the City

of Page, is supplied to the community of Le Chee on the Navajo Nation and is accounted for separately. The quantity supplied to the City of Page and its associated uncertainty for the calendar year 2016 was 2,241 (±67) acre-feet. Water returning to the waste water treatment plant is metered as well. The waste water for the City of Page is treated and is either evaporated from lined ponds or applied to the golf course, with a portion being returned to the Colorado River. The return flow is estimated to be 706 acre-feet. The net consumptive use is estimated to be 1,535 acre-feet (±70).

Le Chee – The community of Le Chee is supplied and metered by the City of Page. Total water supplied for 2016 was 79 (±2) acre-feet. The uncertainty was estimated to be 3 percent.

Greenhaven Water Company – The Greenhaven Water Company derives its domestic water supply from wells. Well pumping records are available. According to these records, the total water pumped for 2016 was 121 (±8) acre-feet. The uncertainty was estimated to be 7 percent.

Arizona Department of Transportation Housing – The Arizona Department of Transportation operates a housing, maintenance, and administrative facility located on US Hwy 89, north of Page, AZ. This facility is supplied from wells that have no meters installed. It is estimated that the total water pumped for 2016 was 7 acre-feet with an uncertainty of 30 percent of this value or ±2 acre-feet.

Navajo Nation

Community Water Systems – 1980 statistics from the Division of Community Development of the Navajo Nation reveal that various community water systems served 26,086, or about 83 percent of the 31,429 people residing within the study area at that time. Since additional estimates have not been repeated, this same percentage was used for 2015 resulting in 32,337 out of 38,960 people being served. These systems include those operated by the Navajo Tribal Utility Authority (NTUA), the BIA, and the Water Operations and Maintenance Department of the Navajo Nation, and some privately developed community water systems.

Table 6 shows the source of water and estimated population served by each source of water for people living on the Navajo Nation during 2016. All of the communities obtain their water supply from ground water.

Table 6.—Domestic water sources, 2016

SOURCE	PERCENTAGE OF POPULATION SERVED	NUMBER OF POPULATION SERVED[1]
Community Water Systems	83	32,190
NTUA	[2](60)	19,314
BIA	[2](25)	8,047
Navajo WOM	[2](13)	4,185
Private	[2](2)	644
Individual Wells	17	6,593
TOTAL	100	38,783

[1] Total population within the Upper Colorado River Basin portion of the Navajo Nation, estimated from 2010 US Census.
[2] These numbers are a percentage of the Community Water Systems.

NTUA Water Systems – The cities and surrounding communities of Oak Springs, Red Valley, Sweetwater, Chinle , Rough Rock, Round Rock, Rock Point, Wheatfields, Lukachukai, Kayenta, Chilchinbeto, Dennehotso, and Kaibeto derive most of their domestic water supply from wells operated by NTUA. Well pumping records are available. According to these records, the total water pumped for 2016 was 1,619 acre-feet with an uncertainty estimated to be 7 percent of this value or ±113 acre-feet.

The NTUA manages the raw waste water; portions of which flow to individual septic tanks, some to evaporation ponds, and some, such as for the cities of Chinle and Kayenta, flow to waste water treatment plants. Very little water, if any, is returned to the ground water system through leakage from the evaporation ponds, but there are losses from the main collection system. Effluent from the Chinle and Kayenta waste water treatment plants is metered. Under normal conditions, the effluent returns to the Colorado River System and is subtracted from the pumping totals to determine a net consumptive use. For 2016, Chinle's treatment plant effluent was 13.6 (±1.0) acre-feet, and Kayenta's effluent was 9.7 (±0.7) acre-feet. An estimated uncertainty of 7 percent was used for the effluent of these two plants. The total effluent of 23.3 acre-feet is subtracted from the NTUA pumping total of 1,619 acre-feet to arrive at a net consumptive use of 1,596 (±112) acre-feet.

BIA Water Systems – Wells developed and operated by the BIA serve numerous Navajo communities. These systems also serve BIA schools, hospitals, agency offices, and some housing on the Navajo Nation. Metered records for total amounts of water pumped from BIA wells were available for a portion of the Shiprock Agency, the Western Navajo Agency, and the Chinle Agency. Drawing 1246-406-2 shows the agency boundaries within the Upper Colorado River Basin. The uncertainty was estimated to be about 7 percent for all three agencies.

The BIA systems include sewage disposal units terminating in lined evaporation ponds with very little or no return water returning to the ground water system. Undoubtedly, some losses occur in distribution, but insufficient data currently exist to estimate these losses. The losses are probably less than the uncertainties for each of the reported values.

The BIA well data available for the Shiprock Agency include: Cove, Red Rock, and Teec Nos Pos. Total consumptive use values are 11 (±1) acre-feet.

Pumping records for the Western Navajo Agency include data for the following schools: Chilchinbeto Day School, Dennehotso Boarding School, Kaibeto Boarding School, and Kayenta Boarding School. Total consumptive use for the Western Navajo Agency was 172 (±12) acre-feet.

Well pumping records for the Chinle Agency include data for the following schools: Cottonwood Day School, Lukachukai School, and Rock Point School. Rough Rock School maintains its own records, but the data was included with the Chinle Agency data. Total consumptive use for the Chinle Agency was 69 (±5) acre-feet.

Navajo WOM Water Systems – Water use in 2016 by the Navajo WOM service areas was based on an assumed consumption rate of 110 gallons per capita per day (gpcd). For a 2016 estimated service area population of 4,185, the estimated annual water use was 516 (±155) acre-feet. The uncertainty is estimated as 30 percent of the total.

Private Water Systems – The estimated 2016 population served by private water systems on the Navajo Nation was 644. Assuming a consumptive use rate of 110 gcpd, the annual water use for 2016 was 79 (±24) acre-feet. The uncertainty is estimated as 30 percent of the total.

Individual Wells – According to census data from the Division of Community Development of the Navajo Nation, approximately 17 percent of the study area's population on the reservation (about 6,593 persons in 2016) receives a domestic water supply from individual wells. A consumptive use of 110 gpcd was derived as being a reasonable water use rate. Based on these figures, the annual consumptive use was 812 (±244) acre-feet for 2016.

TOTAL MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

The total municipal and industrial consumptive use, displayed in table 7, is the sum of the individual components discussed in the previous sections. Municipal and industrial water consumption, including the Navajo Generating Station, represents approximately 78 percent of the total use in the study area.

Table 7.—Total municipal and industrial consumptive use, 2016

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
THERMAL ELECTRIC POWER		
Navajo Generating Station	18,116	543
OTHER		
Page, AZ and Vicinity		
City of Page	1,535	70
Le Chee	79	2
Greenhaven Water Company	121	8
Arizona Department of Transportation	7	2
Navajo Indian Reservation		
Community Water Systems		
NTUA Water Systems	1,596	113
BIA Water Systems	252	13
Navajo WOM	516	155
Private Water Systems	79	24
Individual Wells	812	244
TOTAL	23,114	630

It is questionable whether all the water pumped from wells should be considered a depletion to the Colorado River System; however, it is assumed that 100 percent of the water pumped is considered lost to the system. It is proposed that a future joint study be completed by Reclamation, the State of Arizona, and the Navajo Nation to estimate what percentage of water pumped could actually be attributed to the Colorado River System and would have affected the river flows for a particular year.

RECREATION, FISH AND WILDLIFE

The recreation, fish and wildlife consumptive uses include evaporation from reservoirs used exclusively for fish & wildlife purposes as well as acreages irrigated for wildlife feeding. Consumptive use related to recreation at National parks is also addressed.

GLEN CANYON NATIONAL RECREATION AREA

Colorado River water is used by the Glen Canyon National Recreation Area (GCNRA) at Wahweap and Lee Ferry. The recreational area at Wahweap gets its water supply from a series of wells on the shore of Lake Powell. Pumping records for both Wahweap Marina, and Lee Ferry show 255 (±8) acre-feet of water withdrawn during 2016. The uncertainty

is estimated at 3 percent. This water was used for domestic purposes at the campgrounds, picnic areas, and trailer parks. It was also used to irrigate approximately 60 acres of Bermuda grass and cottonwood trees. The domestic waste water is treated and the effluent is allowed to evaporate from two lined evaporation ponds with a total surface area of 16.7 acres.

Based on estimates of evaporation and consumptive use by the plants, there is some water which is unaccounted for and is assumed to be leakage from the delivery system, the evaporation pond, or deep percolation from irrigation application. However, since these water losses are difficult to quantify and verify, the losses were charged as consumptive uses. Therefore, net consumptive use of water is estimated to be equal to the quantity of water pumped.

RESERVOIR EVAPORATION

A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 8.

Table 8. —Recreation, fish and wildlife reservoir evaporation, 2016

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE AREA USED (ACRES)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Tsaile	260	260	35	10.1	24.9	539.7
Wheatfields	272	272	32	10.1	21.91	496.6
TOTAL	532	532				1,036

Efforts are made to maintain a nearly full condition and to minimize water surface fluctuations in reservoirs managed for a fishery. Under average operating conditions, the water surface area of a reservoir used primarily for fishing is assumed to be equal to a normal water surface area. It is assumed that, in 2016, these reservoirs filled in the spring and were maintained at the normal pool level.

This method of evaporation estimation was used because continuous useful water level records for all reservoirs from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs.

For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for reservoir evaporation for calendar year 2016 are shown in table 8. The total evaporative losses in 2016 are 1,036 (±311) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent.

TOTAL RECREATION, FISH AND WILDLIFE

The total recreation, fish and wildlife consumptive use, displayed in table 9, is the sum of the individual components discussed in the previous sections. Recreation, fish and wildlife water consumption represents approximately 4 percent of the total use in the study area.

Table 9.—Total recreation, fish and wildlife consumptive use, 2016

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Glen Canyon National Recreation Area	255	8
Reservoir Evaporation	1,036	311
TOTAL	1,291	311

RESERVOIR EVAPORATION

Reservoir evaporation losses make up about 8 percent of the total water uses and losses in the study area. A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 10. These reservoirs are used primarily for irrigation.

Table 10.—Reservoir evaporation, 2016

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE ACRES USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Many Farms	1,800	554	100%	56	10.1	45.9	2,121.3
Marsh Pass	40	19	96%	40	10.8	29.2	46.7
Round Rock	83	42	100%	57	9.0	48.0	166.1
Walker Creek	30	15	97%	59	7.9	51.1	62.2
Others	38	19	99%	55	10.0	45.0	70.3
TOTAL	1,991	648					2,466.6

Reservoirs used primarily for irrigation experience large fluctuations in water levels and, correspondingly, large variations in surface area. Reservoir level records and elevation – area curves were available at Many Farms, but not for the remaining reservoirs in table 10. For the reservoirs with no records from which surface area could be accurately computed, the average evaporative surface area was estimated as one-half the water

surface area of a full reservoir. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average evaporative surface area.

Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses. The computed values for reservoir evaporation for 2016 are shown in table 10. The total evaporative losses in 2016 are 2,467 (±740) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent of the total evaporation.

CONCLUSIONS

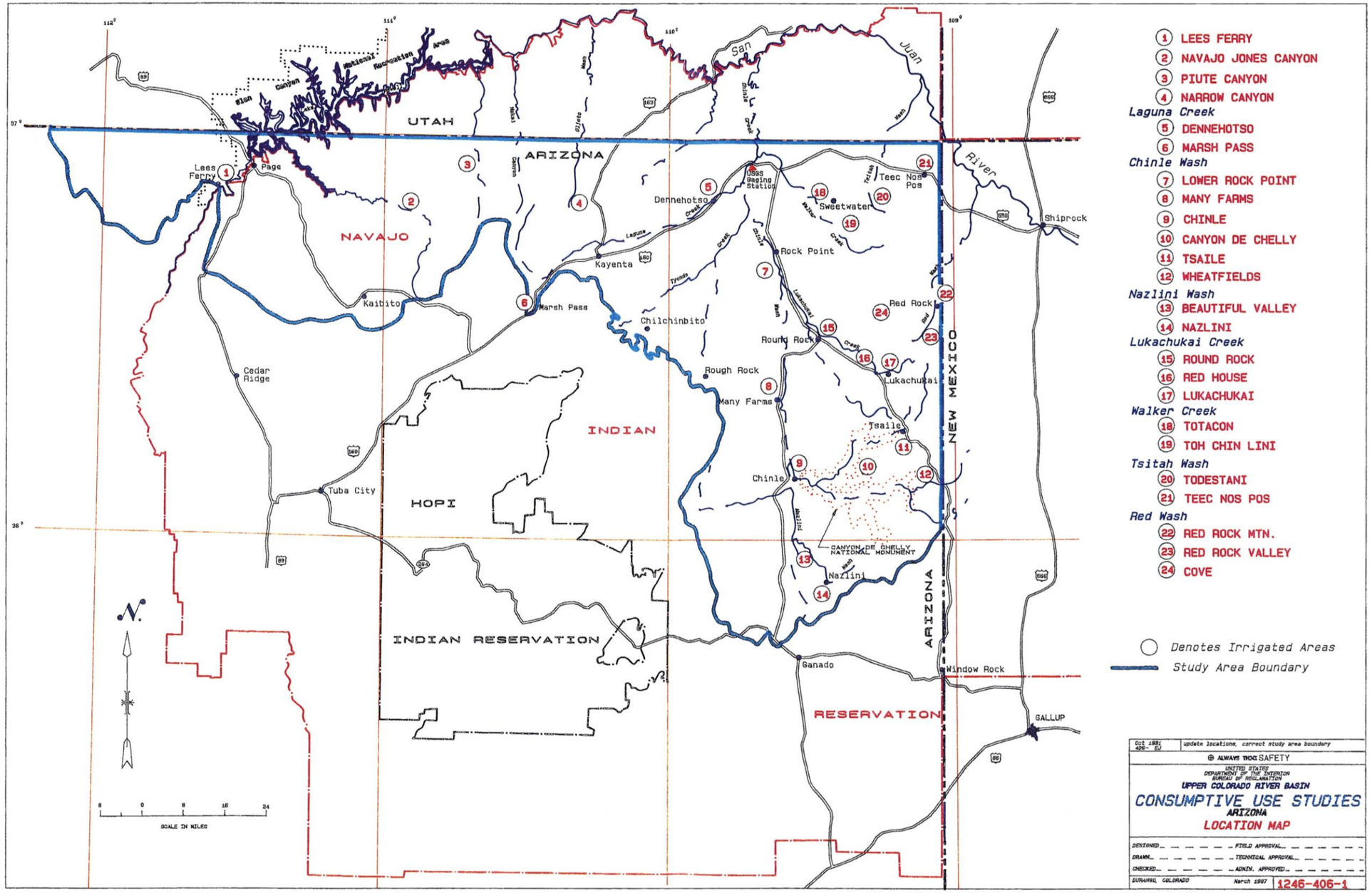
This report assesses the total consumptive use of the Arizona portion of the Upper Colorado River surface water systems, depletion of ground water, and evaporative losses. Clearly, the amounts of water used by the Navajo Generating Station, City of Page, and Wahweap and Lee Ferry recreation areas are direct depletions of water from the Upper Colorado River System, but the situation is not as clear for other consumptive uses and losses occurring in other sections of the study area. For example, the source of water used by the Navajo Nation for domestic and municipal purposes is from wells, some exceeding 1,000 feet in depth. For our purposes here, it is considered to be consumed and a depletion to the Colorado River System. But this may not actually result in a reduction of Colorado River stream flows in the same year that the withdrawal occurs, or at all. Little knowledge and information exists of ground water movement and subsurface flow rates in the study area that are accurate descriptions of the effects on river flows.

Although the water diverted for agricultural purposes is considered as consumptive use in this report, a portion of the remaining surface water on the Navajo Nation, excess to needs, does evaporate before reaching the Colorado River. No attempt has been made for this report to quantify these losses.

Uncertainties in estimating uses and losses exist, and the degree of variation in the figures is presented. Fortunately, the areas with the highest degree of uncertainty account for only a small percentage of the total consumptive use. The largest component, use by the Navajo Generating Station, is also the most accurately monitored. The total annual value for estimated consumptive use of water within the Arizona portion of the Upper Colorado River Basin for 2016 was 29,458 acre-feet, as shown in table 11.

Table 11.—Consumptive use for Arizona portion of Upper Colorado River Basin for 2016

USE CATEGORY	TOTAL CONSUMPTIVE USE (ACRE-FEET)	UNCERTAINTY	PERCENT OF TOTAL
Agriculture	2,587	552	8.78%
Municipal & Industrial	23,114	630	78.46%
Recreation, Fish & Wildlife	1,291	311	4.38%
Reservoir Evaporation	2,467	740	8.38%
TOTAL	29,458	1,160	100%


1 LEES FERRY
2 NAVAJO JONES CANYON
3 PIUTE CANYON
4 NARROW CANYON
Laguna Creek
5 DENNEHOTSO
6 MARSH PASS
Chinle Wash
7 LOWER ROCK POINT
8 MANY FARMS
9 CHINLE
10 CANYON DE CHELLY
11 TSAILE
12 WHEATFIELDS
Nazlini Wash
13 BEAUTIFUL VALLEY
14 NAZLINI
Lukachukai Creek
15 ROUND ROCK
16 RED HOUSE
17 LUKACHUKAI
Walker Creek
18 TOTACON
19 TOH CHIN LINI
Tsitah Wash
20 TODESTANI
21 TEEC NOS POS
Red Wash
22 RED ROCK MTN.
23 RED ROCK VALLEY
24 COVE
Denotes Irrigated Areas
Study Area Boundary
UTAH
ARIZONA
NAVAJO
INDIAN
HOPI
INDIAN RESERVATION
RESERVATION
NEW MEXICO
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San Juan River
Lees Ferry
Page
Kaibito
Cedar Ridge
Tuba City
Marsh Pass
Kayenta
Dennehotso
USGS Gaging Station
Chilchinbito
Rough Rock
Many Farms
Chinle
Rock Point
Sweetwater
Teec Nos Pos
Round Rock
Red Rock
Lukachukai
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CANYON DE CHELLY NATIONAL MONUMENT
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Ganado
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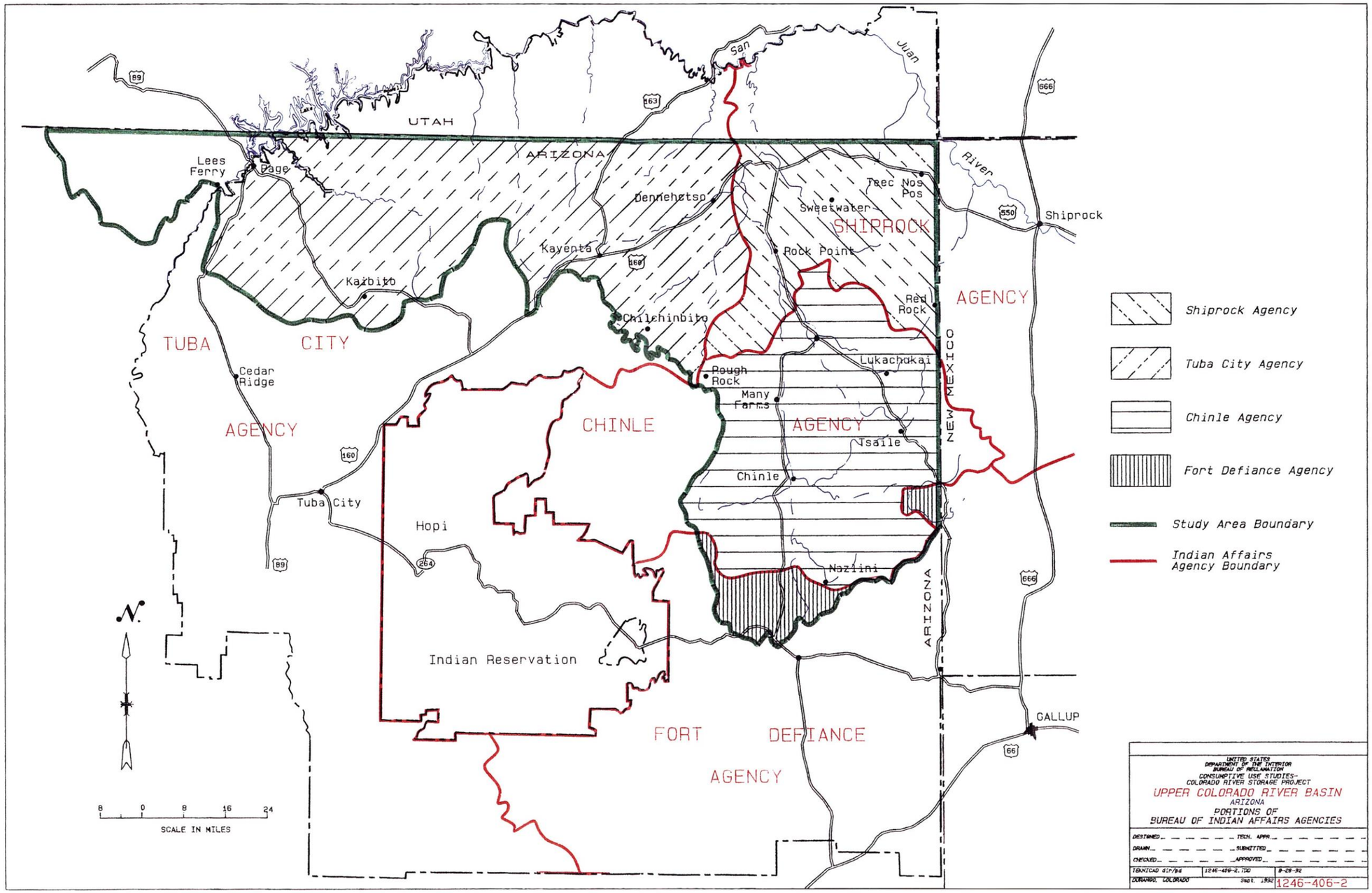
CONSUMPTIVE USE STUDIES
ARIZONA
LOCATION MAP
DENVER, COLORADO
March 1987
1246-406-1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Kayenta
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Chilchinbito
Tsec Nos Pos
Sweetwater
Rock Point
Red Rock
Shiprock
Lukachukai
Rough Rock
Many Farms
Tsaile
Chinle
Nazlini
Cedar Ridge
Tuba City
Hopi
Indian Reservation
GALLUP
TUBA CITY AGENCY
CHINLE AGENCY
SHIPROCK AGENCY
FORT DEFIANCE AGENCY
Shiprock Agency
Tuba City Agency
Chinle Agency
Fort Defiance Agency
Study Area Boundary
Indian Affairs Agency Boundary
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DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CONSUMPTIVE USE STUDIES-
COLORADO RIVER STORAGE PROJECT
UPPER COLORADO RIVER BASIN
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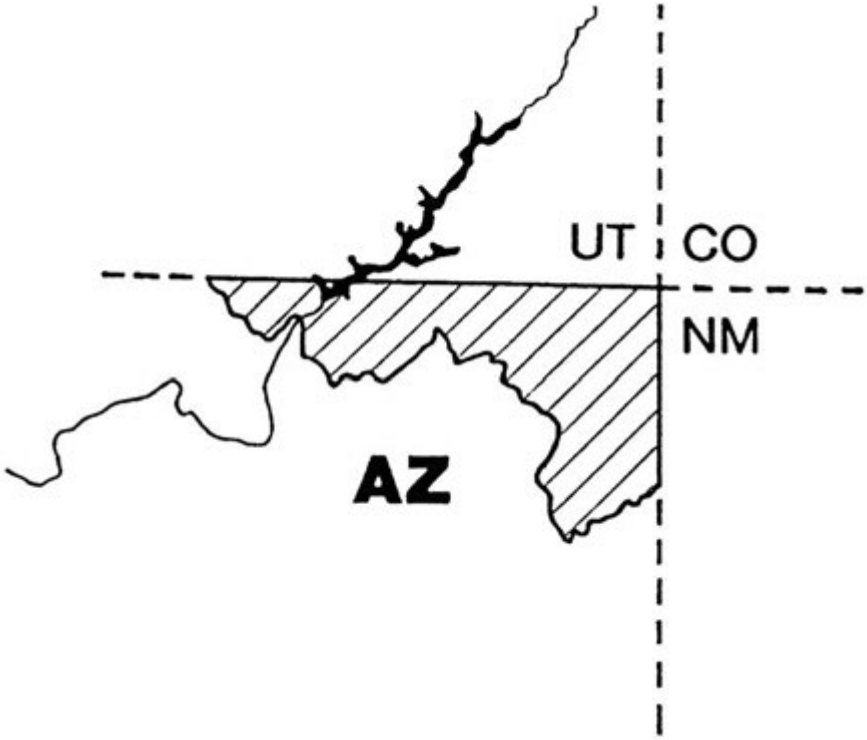
RECLAMATION

Managing Water in the West

Consumptive Uses and Losses: Provisional Estimate

Arizona Portion of the Upper Colorado River Basin Calendar Year 2017

Provisional Version dated: September 28, 2018



U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

September 2018

RECLAMATION

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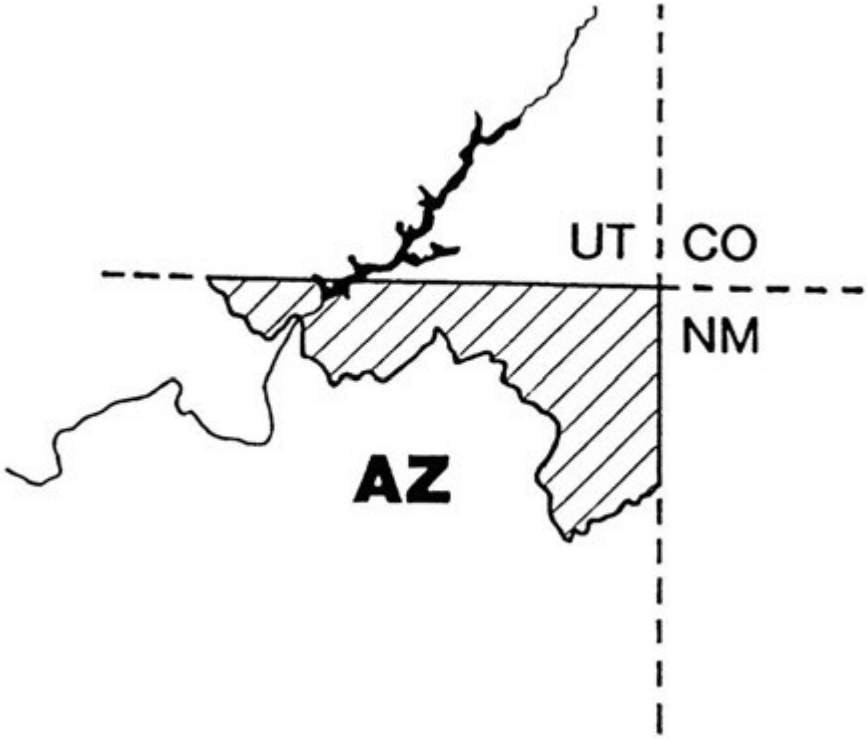

Prepared by: Alan Harrison – September 28, 2018

U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

September 2018

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CONSUMPTIVE USES AND LOSSES
Provisional Estimates (09/18)

ARIZONA PORTION
OF THE
UPPER COLORADO RIVER BASIN

CALENDAR YEAR
2017

AUTHORITY

This report was prepared in compliance with Public Law 90-537, Section 601 (b)(1), dated September 30, 1968, which directs the Secretary of the Interior to "make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis." Additionally, this report is in compliance with Section 49 of the Navajo Project Participation Agreement dated September 30, 1969, which states in part: "The Secretary of the Interior further agrees to make the reports required by Section 601 (b)(1) of Public Law 90-537 as they pertain to Arizona's Upper Basin uses annually rather than every five years. Within fifteen days following the completion of said reports, the Secretary of the Interior shall furnish copies of such reports to the Co-Tenants, the Navajo Tribe, each of the Upper Basin States, and the Upper Colorado River Commission."

SUMMARY

Based upon data made available for preparation of this document, the total consumptive use and loss value for the Arizona portion of the Upper Colorado River Basin for calendar year 2017 was 29,254 (±1,188) acre-feet. Reclamation prepares this estimate annually, final annual values for consumptive uses and losses for the northern Arizona portion of the Colorado River basin are published in the 5-year summary documents for the Upper Colorado River Basin

STUDY AREA DESCRIPTION

The Arizona portion of the Upper Colorado River Basin covers approximately 6,900 square miles in the north-east corner of Arizona, as shown on the location maps shown on pages 19 and 20 (Drawings 1246-406-1, 1246-406-2). The climate of the 5,900 square mile area to the west of the Chuska and Carrizo Mountains is largely arid to semiarid, with mean annual precipitation ranging from 6 to 12 inches and with

summertime temperatures often reaching 100 degrees Fahrenheit (°F). The potential evaporation rate is high and exceeds mean annual precipitation, with gross lake evaporation values of up to 55 inches per year or more. Elevations in the western portion range from 3,200 feet on the Colorado River at Lee Ferry to over 8,000 feet on the northern edge of the Black Mesa and across the Zilnez and Skeleton Mesas, back down to 5,280 feet in the Chinle Valley, and back up to about 6,500 feet on the western edge of the Chuska Mountains. Much of the western part of the study area is starkly beautiful southwestern desert country with mesas and canyons intertwined across a pastoral landscape. By contrast, the eastern 1,000 square miles is largely mountainous, with elevations rising to nearly 10,000 feet and mean annual precipitation reaching 30 inches. The mountainous land responds with grass meadows interspersed with conifer forest of mostly ponderosa pine.

Except for Page, Arizona; a small area around Lee Ferry; and a portion of the Paria Plateau administered by the Bureau of Land Management; the study area lies entirely within the Navajo Nation. According to census data, 47,791 persons were living within the area in 2010, and of these 40,018 resided on the Navajo Nation.

The largest cities are Page and Kayenta, with 2010 populations of 7,247 and 5,189, respectively. Other major communities and their populations include Dennehotso (746), Kaibeto (1,522), Chinle (4,518), LeChee (1,443), Lukachukai (1,701), Many Farms (1,348), Rock Point (642), Teec Nos Pos (730), and Tsaile (1,205). Subsistence in the region is derived principally from livestock grazing, farming, tourist-related industries, employment at the Navajo Generating Station (NGS), which consumes approximately 60 percent of the water used or lost in the study area in an average every year. Agriculture accounts for about 9 percent of the total water use; municipal and industrial (including the Navajo Generating Station) about 77 percent; recreation, fish and wildlife, about 5 percent; and reservoir evaporation, about 9 percent in an average year.

AGRICULTURAL CONSUMPTIVE USE

Agricultural consumptive use is divided into three categories: irrigation, stock pond, and livestock. Irrigation use includes all use related to irrigating crops including the incidental losses. Stock pond use is the evaporation that occurs from stock ponds and livestock use is the water consumed by livestock.

IRRIGATION USES

Within the Arizona portion of the Upper Colorado River Basin, historically 23 irrigated areas were scattered across the Navajo Nation plus a small amount of land near Lee Ferry irrigated by the National Park Service. Currently, only 16 irrigated areas are in production. An accurate assessment of consumptive use on the irrigated land is difficult due to poor quality of information, such as the exact number of acres under irrigation, the cropping pattern for each irrigated area, site climatological conditions, and the amount of water actually diverted. In many cases, during the latter part of the irrigation season, farmers have to rely on dry land farming since there is little water available in the streams. This means that the crops do not receive their full water requirement.

For this report, the U.S. Department of Agriculture, Soil Conservation Service's (SCS) Modified Blaney-Criddle evapotranspiration, without an elevation adjustment, estimation formula was used for computing irrigated crop consumptive use. This model, along with appropriate crop-growth stage coefficients and the method for computing effective precipitation, is described in SCS's *Irrigation Water Requirements Technical Release No. 21* (TR 21). Information required for applying this model includes mean monthly temperature and precipitation values, growing season data for each crop type, and the total number of acres planted by crop at each site. With the exception of Teec Nos Pos, Canyon de Chelly, Lukachukai, and Lee Ferry, no climatological data exist for the irrigation sites, and site values must be generated from data collected at surrounding established weather stations. Growing season dates depend largely on the judgment of the local inhabitants and are, therefore, not known. Although several reports are available with published values for irrigated acres, it is unclear if these values are meant to represent potential irrigated acres, acres irrigated in the past, acres for which farming permits have been issued, or actual acres currently under irrigation.

The crop acreage used to estimate consumptive use by irrigated crops for the year 2017 is shown in table 1. These values were estimated from previous direct field examination by a party composed of representatives from the State of Arizona and the Navajo Nation.

Table 1.—Total irrigated acreage, 2017

PROJECT	CORN (ACRES)	ALFALFA (ACRES)	GRASS PASTURE (ACRES)	SPRING GRAINS (ACRES)	SMALL VEGETABLES (ACRES)	ORCHARD (ACRES)	TOTAL (ACRES)
CHINLE AGENCY							
Canyon de Chelly	0.36	0.00	0.00	3.03	2.26	0.00	5.65
Lukachukai	39.09	7.69	0.00	7.50	5.98	2.07	62.33
Many Farms	184.91	30.85	114.18	3.01	30.85	0.00	363.80
Nazlini	0.00	0.00	0.00	0.00	1.79	0.74	2.53
Rough Rock	30.00	0.00	11.87	0.00	12.43	0.00	54.30
Tsaile	23.72	5.27	15.67	5.73	5.42	0.00	55.81
Wheatfields	0.00	60.80	0.00	0.00	0.00	0.00	60.80
TOTAL	278.08	104.61	141.72	19.27	58.73	2.81	605.22
SHIPROCK AGENCY							
Red Rock Valley	26.22	0.00	10.19	5.12	10.22	0.00	51.75
Teec Nos Pos	20.00	0.00	0.00	0.00	3.67	0.00	23.67
Toh Chin Lini	0.00	0.00	0.00	0.00	3.90	13.67	17.57
Totacon	0.00	0.00	0.00	0.00	1.00	0.00	1.00
TOTAL	46.22	0.00	10.19	5.12	18.79	13.67	93.99
WESTERN NAVAJO AGENCY							
Dennehotso	1.82	0.00	38.70	0.00	0.00	0.00	40.52
Lees Ferry	0.00	0.00	1.00	0.00	0.00	2.00	3.00
Marsh Pass	7.02	3.31	0.00	0.00	1.99	0.00	12.32
Navajo Canyon	0.00	0.00	0.00	0.00	0.00	3.50	3.50
Paiute Canyon	2.64	0.00	0.00	0.00	3.86	0.00	6.50
TOTAL	11.48	3.31	39.70	0.00	5.85	5.50	65.84
GRAND TOTAL	335.78	107.92	191.61	24.39	83.37	21.98	765.05

Several factors complicate the modeling of irrigation consumptive use. For example, the computer program used to model consumptive use assumes a full water supply; if shortages exist, as they often do in this semiarid study area, adjustments must be made. These adjustments are complicated because some of the projects have no storage water and may only have a reliable irrigation water supply during spring runoff. After spring runoff, farming becomes essentially dry land until rains in July and August provide intermittent flows for irrigation. Finally, no ditch diversion records are available to help estimate irrigation water supplies and shortages.

A full irrigation supply seldom exists at many of the projects. Generally, a full supply is available for Lee Ferry, Navajo Canyon, Tsaile, and Wheatfields projects because of adequate stream flows or because of available storage water. In years with average precipitation, it is estimated that Chinle Wash provides approximately 75 percent of the irrigation requirement. Precipitation in the area averages approximately 9.5 inches per year. Based on this information, it would require approximately 12.67 inches of precipitation to provide 100 percent of the irrigation requirement. The percent of crop water requirement met was computed as a ratio of annual precipitation to 12.67 inches. These values are found in table 2.

The percentage of crop water requirement met was multiplied by the total net crop water requirement to determine the amount of crop consumptive use. Incidental irrigation losses, evaporation, and phreatophyte consumptive use along supply canals are estimated to be 5 percent of the consumptive use of the irrigated area and are added to the crop consumptive use value to develop a total consumptive use value.

A portion of the water used for irrigation at these sites may not be contributing to the Colorado River System since evaporation rates in the area are high and the nature of most of the drainage enhances evapotranspiration. A good example of such a drainage is Chinle Wash, which after leaving Canyon de Chelly, becomes wide and sandy and is lined with willows, cottonwoods, and other phreatophytes.

The uncertainties in the irrigation consumptive use values displayed in table 2 are very large and are estimated as 40 percent of the total consumptive use. This estimate of possible error only reflects the uncertainty of consumptive use and does not account for any possible errors in the acreage estimates. The effective consumptive use for irrigation for 2017 was estimated to equal 1,054 acre-feet. Including 5 percent for incidental losses, the irrigation related consumptive use is 1,107 (±443) acre-feet.

Table 2.—Net consumptive use values, 2017

PROJECT	CROP WATER REQUIREMENT (INCHES)	TOTAL IRRIGATED (ACRES)	TOTAL WATER REQUIRED (ACRE-FEET)	CROP WATER REQUIREMENT MET (%)	CROP WATER REQUIREMENT MET (ACRE-FEET)	TOTAL CONSUMPTIVE USE (ACRE-FEET)[1]
CHINLE AGENCY						
Canyon de Chelly	28.43	5.65	13	57%	8	8.0
Lukachukai	27.54	62.33	143	57%	82	85.8
Many Farms	27.46	363.80	832	57%	476	499.6
Nazlini	25.41	2.53	5	57%	3	3.2
Rough Rock	22.98	54.30	104	75%	78	81.6
Tsaile	28.41	55.81	132	57%	76	79.3
Wheatfields	36.29	60.80	184	57%	105	110.4
TOTAL	196.51	605.22	1,414		827	867.9
SHIPROCK AGENCY						
Red Rock Valley	27.43	51.75	118	69%	81	85.6
Teec Nos Pos	27.06	23.67	53	81%	43	45.2
Toh Chin Lini	39.07	17.57	57	40%	23	24.2
Totacon	25.47	1.00	2	40%	1	0.9
TOTAL	119.03	93.99	231		148	155.8
WESTERN NAVAJO AGENCY						
Dennehotso	39.49	40.52	133	29%	38	40.0
Lee Ferry	42.20	3.00	11	100%	11	11.1
Marsh Pass	22.21	12.32	23	69%	16	16.6
Navajo Canyon	39.16	3.50	11	73%	8	8.7
Paiute Canyon	25.14	6.50	14	46%	6	6.6
TOTAL	168.21	65.84	192		79	83.0
GRAND TOTAL	483.75	765.05	1,837		1,054	1,106.8

[1] Total includes 5% addition for incidental losses.

STOCK POND EVAPORATION

Stock pond consumptive use is assumed to be the evaporation from area stock ponds. It is also assumed that any consumptive use by natural vegetation prior to the construction of the stock ponds is limited to precipitation which is subtracted from the evaporation losses.

A compilation of the stock ponds in the study area, including their locations and the water surface areas when ponds are full, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 3. For average year conditions, the stock pond evaporative surface area was estimated as one-third the water surface area that occurs when the ponds are full. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average water surface area. These values are found in table 3.

Table 3.—Stock pond evaporation, 2017

COUNTY	SURFACE AREA FULL (ACRES)	SURFACE AREA USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Coconino	80	26	99%	57	6.65	50.35	110.4
Navajo	40	11	79%	55	7.71	47.29	41.6
Apache	646	213	99%	53	8.73	44.28	787.3
TOTAL	766	250					939

This method of evaporation estimation was used because continuous useful water level records for all stock ponds from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual stock ponds. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation. It was assumed that any consumptive use by natural vegetation prior to construction of the stock ponds is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for stock pond evaporation for calendar year 2017 are shown in table 3. The total evaporative losses in 2017 are 939 (±282) acre-feet with the stock pond evaporation uncertainty being estimated as 30 percent.

LIVESTOCK WATER

The source of most livestock water in the study area is from wells, with windmill-operated pumps developed and maintained by Navajo Water Operations and Maintenance, and water collected in small surface ponds. The estimated number of

livestock in the area was estimated based on previous livestock tallies and current-year estimates from the USDA Agriculture Statistics Service. It was estimated that horses and cattle consume 12 gallons per day; sheep and goats consume 2 gallons per day.

The number of animals for the Upper Colorado portion of each district is shown in table 4. The computed value for livestock consumptive use is 554 acre-feet. The uncertainty in this number is estimated as 30 percent of the total or ±166 acre-feet.

Table 4.—Number of livestock, 2017

AGENCY	CATTLE	HORSES	SHEEP	GOATS
Western Navajo District No. 1	0	0	1,134	200
Western Navajo District No. 2	1,683	88	1,392	2,108
Western Navajo District No. 8	8,522	1,765	13,518	8,714
Shiprock District No. 9	1,282	0	4,013	3,934
Chinle District No. 10	3,902	1,036	6,699	3,436
Chinle District No. 11	2,437	379	2,966	2,667
Shiprock District No. 12	6,763	1,262	10,708	5,625
Fort Defiance District No. 17	0	151	1,334	1,102
Fort Defiance District No. 18	0	215	943	0
TOTAL	24,589	4,896	42,707	27,786

TOTAL AGRICULTURAL CONSUMPTIVE USE

The total agricultural consumptive use, displayed in table 5, is the sum of the individual components discussed in the previous sections. Agricultural water consumption represents approximately 9 percent of the total use in the study area. Total degree of uncertainty was computed by taking the square root of the sum of the individual uncertainties squared; known as the quadratic sum. This method and nomenclature is used throughout this report. This method was used because a simple sum does not account for the partial cancellation of errors occurring when calculating the total uncertainty derived from individual values that are random and independent of each other. As previously discussed, the individual uncertainties were set as a percent of the consumptive use value.

Table 5.—Total agricultural consumptive use, 2017

CATEGORY	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Irrigation	1,107	443
Stock Ponds	939	282
Livestock	554	166
TOTAL	2,600	550

MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

Municipal and industrial consumptive use is divided into three categories: mineral resources, thermal electric power, and other. Mineral resources consumptive use includes water used for mineral production. No mineral resources consumptive use is reported in the study area. Thermal electric power consumptive use includes the water used at the power plants, and that used to transport material to the power plant (such as a coal slurry pipeline). Other consumptive use includes urban, rural, and industrial uses.

THERMAL ELECTRIC POWER

Thermal electric power consumptive use includes the water used in the power plant and the water used to transport material to the plant.

Navajo Generating Station

The water used by the NGS is pumped directly from Lake Powell and comprises approximately 60 percent of the total consumption in the study area. Since all NGS water use is metered, this quantity is among those most precisely known, with the maximum uncertainty in the metered quantities believed to be less than 3 percent. The actual quantity consumed, along with the estimated uncertainty for the calendar year 2017, was 17,631 (±529) acre-feet.

OTHER

The other consumptive use category includes the remaining use by urban, rural, and industries.

Page, AZ and Vicinity

City of Page, AZ. – The city of Page pumps its domestic water directly from Lake Powell. The water pumped is metered, and the uncertainty of the pumped quantities was assumed to be less than 3 percent. A portion of the water pumped and treated by the City

of Page, is supplied to the community of Le Chee on the Navajo Nation and is accounted for separately. The quantity supplied to the City of Page and its associated uncertainty for the calendar year 2017 was 2,241 (±67) acre-feet. Water returning to the waste water treatment plant is metered as well. The waste water for the City of Page is treated and is either evaporated from lined ponds or applied to the golf course, with a portion being returned to the Colorado River. The return flow is estimated to be 706 acre-feet. The net consumptive use is estimated to be 1,535 acre-feet (±70).

Le Chee – The community of Le Chee is supplied and metered by the City of Page. Total water supplied for 2017 was 79 (±2) acre-feet. The uncertainty was estimated to be 3 percent.

Greenhaven Water Company – The Greenhaven Water Company derives its domestic water supply from wells. Well pumping records are available. According to these records, the total water pumped for 2017 was 121 (±8) acre-feet. The uncertainty was estimated to be 7 percent.

Arizona Department of Transportation Housing – The Arizona Department of Transportation operates a housing, maintenance, and administrative facility located on US Hwy 89, north of Page, AZ. This facility is supplied from wells that have no meters installed. It is estimated that the total water pumped for 2017 was 7 acre-feet with an uncertainty of 30 percent of this value or ±2 acre-feet.

Navajo Nation

Community Water Systems – 1980 statistics from the Division of Community Development of the Navajo Nation reveal that various community water systems served 26,086, or about 83 percent of the 31,429 people residing within the study area at that time. Since additional estimates have not been repeated, this same percentage was used for 2015 resulting in 32,337 out of 38,960 people being served. These systems include those operated by the Navajo Tribal Utility Authority (NTUA), the BIA, and the Water Operations and Maintenance Department of the Navajo Nation, and some privately developed community water systems.

Table 6 shows the source of water and estimated population served by each source of water for people living on the Navajo Nation during 2017. All of the communities obtain their water supply from ground water.

Table 6.—Domestic water sources, 2017

SOURCE	PERCENTAGE OF POPULATION SERVED	NUMBER OF POPULATION SERVED[1]
Community Water Systems	83	32,043
NTUA	[2](60)	19,226
BIA	[2](25)	8,011
Navajo WOM	[2](13)	4,166
Private	[2](2)	641
Individual Wells	17	6,563
TOTAL	100	38,606

[1] Total population within the Upper Colorado River Basin portion of the Navajo Nation, estimated from 2010 US Census.
[2] These numbers are a percentage of the Community Water Systems.

NTUA Water Systems – The cities and surrounding communities of Oak Springs, Red Valley, Sweetwater, Chinle , Rough Rock, Round Rock, Rock Point, Wheatfields, Lukachukai, Kayenta, Chilchinbeto, Dennehotso, and Kaibeto derive most of their domestic water supply from wells operated by NTUA. Well pumping records are available. According to these records, the total water pumped for 2017 was 1,619 acre-feet with an uncertainty estimated to be 7 percent of this value or ±113 acre-feet.

The NTUA manages the raw waste water; portions of which flow to individual septic tanks, some to evaporation ponds, and some, such as for the cities of Chinle and Kayenta, flow to waste water treatment plants. Very little water, if any, is returned to the ground water system through leakage from the evaporation ponds, but there are losses from the main collection system. Effluent from the Chinle and Kayenta waste water treatment plants is metered. Under normal conditions, the effluent returns to the Colorado River System and is subtracted from the pumping totals to determine a net consumptive use. For 2017, Chinle's treatment plant effluent was 13.6 (±1.0) acre-feet, and Kayenta's effluent was 9.7 (±0.7) acre-feet. An estimated uncertainty of 7 percent was used for the effluent of these two plants. The total effluent of 23.3 acre-feet is subtracted from the NTUA pumping total of 1,619 acre-feet to arrive at a net consumptive use of 1,596 (±112) acre-feet.

BIA Water Systems – Wells developed and operated by the BIA serve numerous Navajo communities. These systems also serve BIA schools, hospitals, agency offices, and some housing on the Navajo Nation. Metered records for total amounts of water pumped from BIA wells were available for a portion of the Shiprock Agency, the Western Navajo Agency, and the Chinle Agency. Drawing 1246-406-2 shows the agency boundaries within the Upper Colorado River Basin. The uncertainty was estimated to be about 7 percent for all three agencies.

The BIA systems include sewage disposal units terminating in lined evaporation ponds with very little or no return water returning to the ground water system. Undoubtedly, some losses occur in distribution, but insufficient data currently exist to estimate these losses. The losses are probably less than the uncertainties for each of the reported values.

The BIA well data available for the Shiprock Agency include: Cove, Red Rock, and Teec Nos Pos. Total consumptive use values are 11 (±1) acre-feet.

Pumping records for the Western Navajo Agency include data for the following schools: Chilchinbeto Day School, Dennehotso Boarding School, Kaibeto Boarding School, and Kayenta Boarding School. Total consumptive use for the Western Navajo Agency was 172 (±12) acre-feet.

Well pumping records for the Chinle Agency include data for the following schools: Cottonwood Day School, Lukachukai School, and Rock Point School. Rough Rock School maintains its own records, but the data was included with the Chinle Agency data. Total consumptive use for the Chinle Agency was 69 (±5) acre-feet.

Navajo WOM Water Systems – Water use in 2017 by the Navajo WOM service areas was based on an assumed consumption rate of 110 gallons per capita per day (gpcd). For a 2017 estimated service area population of 4,166, the estimated annual water use was 513 (±154) acre-feet. The uncertainty is estimated as 30 percent of the total.

Private Water Systems – The estimated 2017 population served by private water systems on the Navajo Nation was 641. Assuming a consumptive use rate of 110 gcpd, the annual water use for 2017 was 79 (±24) acre-feet. The uncertainty is estimated as 30 percent of the total.

Individual Wells – According to census data from the Division of Community Development of the Navajo Nation, approximately 17 percent of the study area's population on the reservation (about 6,563 persons in 2017) receives a domestic water supply from individual wells. A consumptive use of 110 gpcd was derived as being a reasonable water use rate. Based on these figures, the annual consumptive use was 809 (±243) acre-feet for 2017.

TOTAL MUNICIPAL AND INDUSTRIAL CONSUMPTIVE USE

The total municipal and industrial consumptive use, displayed in table 7, is the sum of the individual components discussed in the previous sections. Municipal and industrial water consumption, including the Navajo Generating Station, represents approximately 77 percent of the total use in the study area.

Table 7.—Total municipal and industrial consumptive use, 2017

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
THERMAL ELECTRIC POWER		
Navajo Generating Station	17,631	529
OTHER		
Page, AZ and Vicinity		
City of Page	1,535	70
Le Chee	79	2
Greenhaven Water Company	121	8
Arizona Department of Transportation	7	2
Navajo Indian Reservation		
Community Water Systems		
NTUA Water Systems	1,596	113
BIA Water Systems	252	13
Navajo WOM	513	154
Private Water Systems	79	24
Individual Wells	809	243
TOTAL	22,622	617

It is questionable whether all the water pumped from wells should be considered a depletion to the Colorado River System; however, it is assumed that 100 percent of the water pumped is considered lost to the system. It is proposed that a future joint study be completed by Reclamation, the State of Arizona, and the Navajo Nation to estimate what percentage of water pumped could actually be attributed to the Colorado River System and would have affected the river flows for a particular year.

RECREATION, FISH AND WILDLIFE

The recreation, fish and wildlife consumptive uses include evaporation from reservoirs used exclusively for fish & wildlife purposes as well as acreages irrigated for wildlife feeding. Consumptive use related to recreation at National parks is also addressed.

GLEN CANYON NATIONAL RECREATION AREA

Colorado River water is used by the Glen Canyon National Recreation Area (GCNRA) at Wahweap and Lee Ferry. The recreational area at Wahweap gets its water supply from a series of wells on the shore of Lake Powell. Pumping records for both Wahweap Marina, and Lee Ferry show 277 (±8) acre-feet of water withdrawn during 2017. The uncertainty

is estimated at 3 percent. This water was used for domestic purposes at the campgrounds, picnic areas, and trailer parks. It was also used to irrigate approximately 60 acres of Bermuda grass and cottonwood trees. The domestic waste water is treated and the effluent is allowed to evaporate from two lined evaporation ponds with a total surface area of 16.7 acres.

Based on estimates of evaporation and consumptive use by the plants, there is some water which is unaccounted for and is assumed to be leakage from the delivery system, the evaporation pond, or deep percolation from irrigation application. However, since these water losses are difficult to quantify and verify, the losses were charged as consumptive uses. Therefore, net consumptive use of water is estimated to be equal to the quantity of water pumped.

RESERVOIR EVAPORATION

A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 8.

Table 8. —Recreation, fish and wildlife reservoir evaporation, 2017

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE AREA USED (ACRES)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Tsaile	260	260	35	7.24	27.76	601.5
Wheatfields	272	272	32	7.24	24.76	561.2
TOTAL	532	532				1,163

Efforts are made to maintain a nearly full condition and to minimize water surface fluctuations in reservoirs managed for a fishery. Under average operating conditions, the water surface area of a reservoir used primarily for fishing is assumed to be equal to a normal water surface area. It is assumed that, in 2017, these reservoirs filled in the spring and were maintained at the normal pool level.

This method of evaporation estimation was used because continuous useful water level records for all reservoirs from which surface area could be accurately computed were not available. Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs.

For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses.

The computed values for reservoir evaporation for calendar year 2017 are shown in table 8. The total evaporative losses in 2017 are 1,163 (±349) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent.

TOTAL RECREATION, FISH AND WILDLIFE

The total recreation, fish and wildlife consumptive use, displayed in table 9, is the sum of the individual components discussed in the previous sections. Recreation, fish and wildlife water consumption represents approximately 5 percent of the total use in the study area.

Table 9.—Total recreation, fish and wildlife consumptive use, 2017

USER	CONSUMPTIVE USE (ACRE-FEET)	ESTIMATED UNCERTAINTY (ACRE-FEET)
Glen Canyon National Recreation Area	277	8
Reservoir Evaporation	1,163	349
TOTAL	1,440	349

RESERVOIR EVAPORATION

Reservoir evaporation losses make up about 9 percent of the total water uses and losses in the study area. A listing of the reservoirs in the study area, including their locations and normal water surface areas, was obtained from a previous BIA report entitled "1985 Survey of Irrigated Land in the Arizona Portion of the Upper Colorado River" and are shown in table 10. These reservoirs are used primarily for irrigation.

Table 10.—Reservoir evaporation, 2017

RESERVOIR	SURFACE ACRES FULL (ACRES)	SURFACE ACRES USED (ACRES)	WATER SUPPLY AVAILABLE (%)	LAKE EVAPORATION (INCHES)	NET PRECIPITATION (INCHES)	NET EVAPORATION (INCHES)	NET EVAPORATION (ACRE-FEET)
Many Farms	1,800	554	76%	56	7.24	48.76	2,253.0
Marsh Pass	40	17	86%	40	9.70	30.30	43.4
Round Rock	83	41	99%	57	8.73	48.28	165.4
Walker Creek	30	15	100%	59	10.21	48.79	61.0
Others	38	18	96%	55	9.69	45.31	68.6
TOTAL	1,991	646					2,591

Reservoirs used primarily for irrigation experience large fluctuations in water levels and, correspondingly, large variations in surface area. Reservoir level records and elevation – area curves were available at Many Farms, but not for the remaining reservoirs in table 10. For the reservoirs with no records from which surface area could be accurately computed, the average evaporative surface area was estimated as one-half the water

surface area of a full reservoir. The surface area used was computed by multiplying the percentage of water supply available (the ratio of the current year precipitation to the average annual precipitation) by the average evaporative surface area.

Another factor complicating the estimating procedure is that evaporation rates are not known at the individual reservoirs. For this report, the NOAA Technical Report NWS 33 "Evaporation Atlas for the Contiguous 48 United States," June 1982, was used to determine the amount of lake evaporation at each reservoir location. It was assumed that any consumptive use by natural vegetation prior to construction of the reservoirs is limited to precipitation which is subtracted from reservoir evaporation losses. The computed values for reservoir evaporation for 2017 are shown in table 10. The total evaporative losses in 2017 are 2,591 (±777) acre-feet with the reservoir evaporation uncertainty being estimated as 30 percent of the total evaporation.

CONCLUSIONS

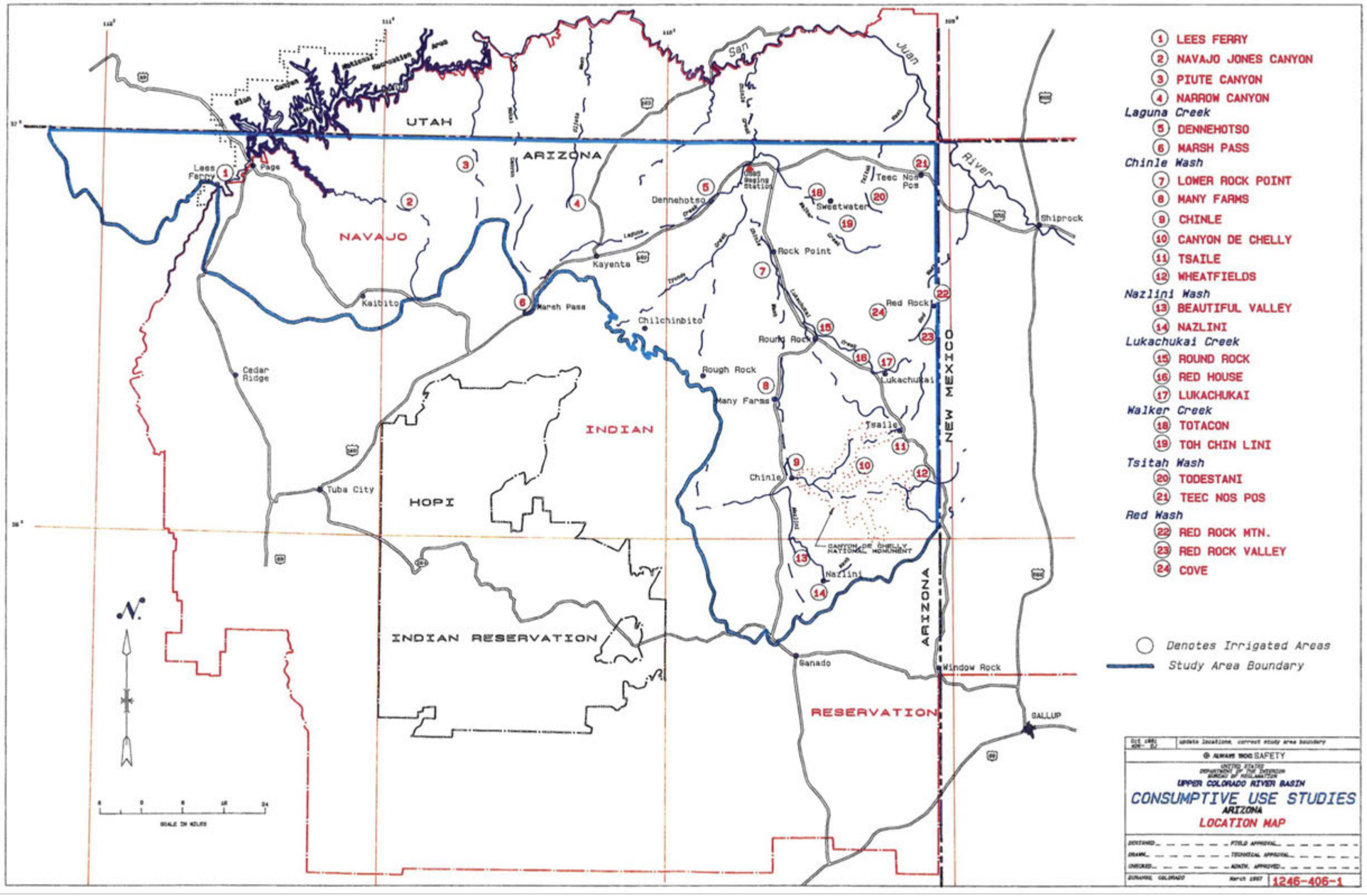
This report assesses the total consumptive use of the Arizona portion of the Upper Colorado River surface water systems, depletion of ground water, and evaporative losses. Clearly, the amounts of water used by the Navajo Generating Station, City of Page, and Wahweap and Lee Ferry recreation areas are direct depletions of water from the Upper Colorado River System, but the situation is not as clear for other consumptive uses and losses occurring in other sections of the study area. For example, the source of water used by the Navajo Nation for domestic and municipal purposes is from wells, some exceeding 1,000 feet in depth. For our purposes here, it is considered to be consumed and a depletion to the Colorado River System. But this may not actually result in a reduction of Colorado River stream flows in the same year that the withdrawal occurs, or at all. Little knowledge and information exists of ground water movement and subsurface flow rates in the study area that are accurate descriptions of the effects on river flows.

Although the water diverted for agricultural purposes is considered as consumptive use in this report, a portion of the remaining surface water on the Navajo Nation, excess to needs, does evaporate before reaching the Colorado River. No attempt has been made for this report to quantify these losses.

Uncertainties in estimating uses and losses exist, and the degree of variation in the figures is presented. Fortunately, the areas with the highest degree of uncertainty account for only a small percentage of the total consumptive use. The largest component, use by the Navajo Generating Station, is also the most accurately monitored. The total annual value for estimated consumptive use of water within the Arizona portion of the Upper Colorado River Basin for 2017 was 29,254 acre-feet, as shown in table 11.

Table 11.—Consumptive use for Arizona portion of Upper Colorado River Basin for 2017

USE CATEGORY	TOTAL CONSUMPTIVE USE (ACRE-FEET)	UNCERTAINTY	PERCENT OF TOTAL
Agriculture	2,600	550	8.89%
Municipal & Industrial	22,622	617	77.33%
Recreation, Fish & Wildlife	1,440	349	4.92%
Reservoir Evaporation	2,591	777	8.86%
TOTAL	29,254	1,188	100%


UTAH
ARIZONA
NAVAJO
INDIAN
HOPI
INDIAN RESERVATION
RESERVATION
NEW MEXICO
ARIZONA
San Juan River
Lees Ferry
Page
Kaibito
Cedar Ridge
Tuba City
Marsh Pass
Kayenta
Dennehotso
Chilchinbito
Rough Rock
Many Farms
Chinle
Rock Point
Sweetwater
Teec Nos Pos
Red Rock
Round Rock
Lukachukai
Tsaile
Nazlini
Ganado
Window Rock
GALLUP
Shiprock
CANYON DE CHELLY NATIONAL MONUMENT
N.
SCALE IN MILES
1 LEES FERRY
2 NAVAJO JONES CANYON
3 PIUTE CANYON
4 NARROW CANYON
Laguna Creek
5 DENNEHOTSO
6 MARSH PASS
Chinle Wash
7 LOWER ROCK POINT
8 MANY FARMS
9 CHINLE
10 CANYON DE CHELLY
11 TSAILE
12 WHEATFIELDS
Nazlini Wash
13 BEAUTIFUL VALLEY
14 NAZLINI
Lukachukai Creek
15 ROUND ROCK
16 RED HOUSE
17 LUKACHUKAI
Walker Creek
18 TOTACON
19 TOH CHIN LINI
Tsitah Wash
20 TODESTANI
21 TEEC NOS POS
Red Wash
22 RED ROCK MTN.
23 RED ROCK VALLEY
24 COVE
Denotes Irrigated Areas
Study Area Boundary
update locations, correct study area boundary
ALWAYS THOUGHT SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
UPPER COLORADO RIVER BASIN
CONSUMPTIVE USE STUDIES
ARIZONA
LOCATION MAP
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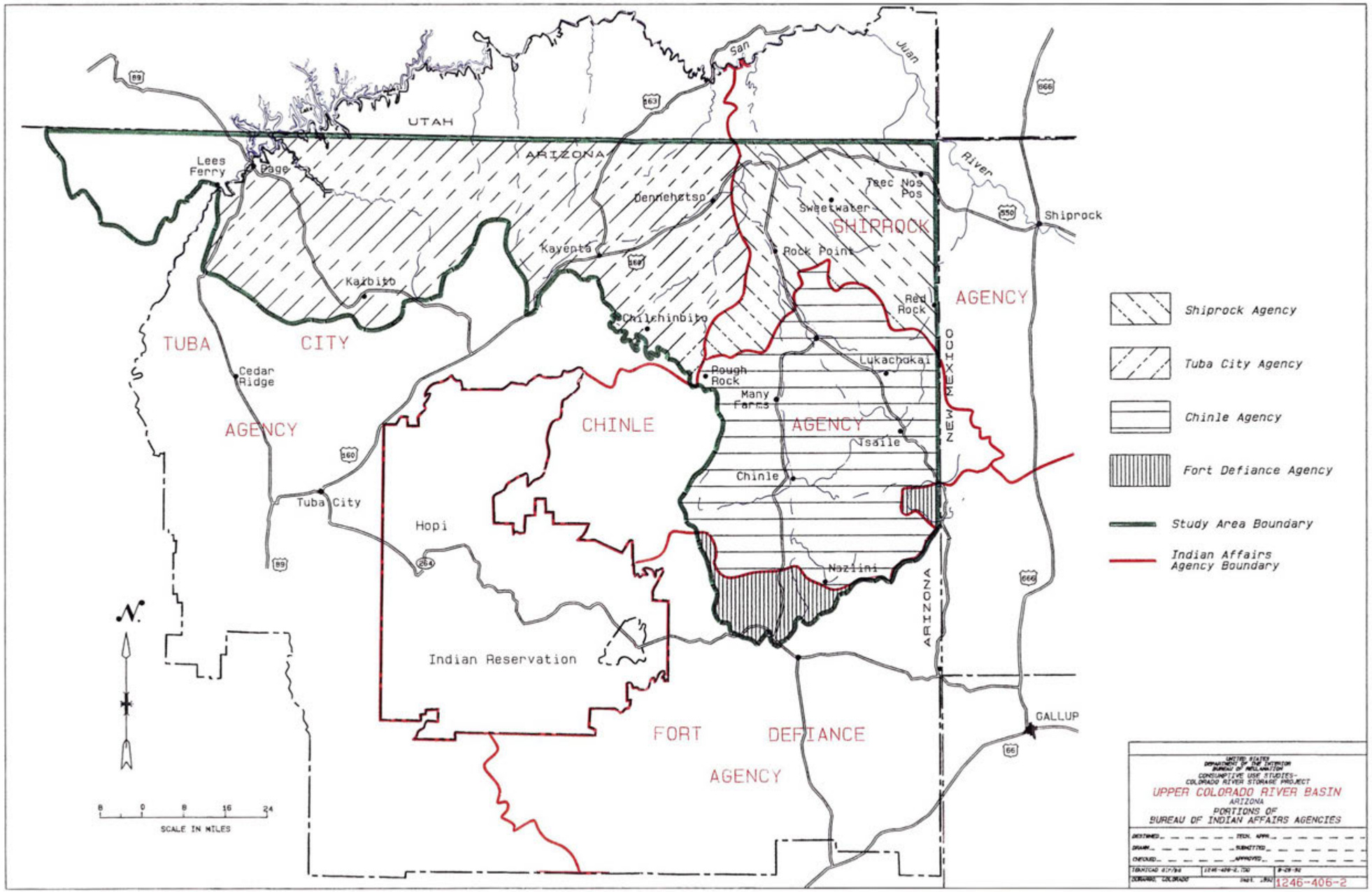
March 1997
1246-406-1


UTAH
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Kayenta
Chilchinbito
Tsec Nos Pos
Sweetwater
SHIPROCK
Rock Point
Red Rock
AGENCY
Shiprock
San Juan River
Lukachukai
Rough Rock
Many Farms
Tsaile
Chinle
Nazlini
TUBA CITY
AGENCY
Cedar Ridge
Tuba City
CHINLE
AGENCY
Hopi
Indian Reservation
FORT DEFIANCE
AGENCY
GALLUP
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SCALE IN MILES
Shiprock Agency
Tuba City Agency
Chinle Agency
Fort Defiance Agency
Study Area Boundary
Indian Affairs Agency Boundary
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CONSUMPTIVE USE STUDIES-
COLORADO RIVER STORAGE PROJECT
UPPER COLORADO RIVER BASIN
ARIZONA
PORTIONS OF
BUREAU OF INDIAN AFFAIRS AGENCIES
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