NRCE

ZUNI INDIAN RESERVATION
IDENTIFICATION OF LANDS AND ESTIMATION OF WATER REQUIREMENTS
FOR
PAST AND PRESENT IRRIGATED LANDS
SERVED BY
PERMANENT IRRIGATION WORKS

In the matter of
United States vs. A&R Productions, et. al.
Case # 01cv00072-BB/ACE

Prepared for:
Bureau of Indian Affairs
And
United States Department of Justice

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

This report was completed for purposes of Sub proceeding 1, Zuni Indian Tribe Claims in the *United States vs. A&R Productions, et. al.* Zuni River Basin Water Rights Adjudication. It describes the past and present irrigated lands that have been served by permanent irrigation works. Irrigated lands were delineated from aerial photography taken between 1934 and 2005. Maps from the BIA showing irrigation works and irrigated lands, field visits, and BIA crop reports also provided supplemental information on the extent of irrigated lands. The irrigation water requirements associated with the identified lands were determined using climate-based estimates of crop evapotranspiration and estimated irrigation efficiencies. Separate reports will be submitted that discuss past and present irrigation by the Zuni Pueblo from non-permanent works, otherwise known as runoff irrigated lands.

1.1 Description of the Study Area

The Zuni Indian Reservation consists of about 640 square miles in west-central New Mexico, along the Arizona border. The Reservation covers approximately 446,600 acres, of which approximately 322,550 acres are located in McKinley County, and 124,050 acres are located in Cibola County, New Mexico.

The study area for this report includes all lands within the Reservation that are or have been served from permanent irrigation works. To identify these lands, aerial photography and irrigation maps were analyzed as described in Section 2. The analysis indicates that the Zuni Indian Tribe have cultivated over 13,000 acres of crops, of which approximately 7,000 acres have been served from permanent water conveyance systems. There are five areas or agricultural units within the Zuni Reservation that are irrigated through permanent works; these units are Nutria, Pescado, Zuni, Tekapo, and Ojo Caliente as shown of Figure 1-1.

1.2 History of Permanent Irrigation Works

Agriculture has long been an essential part of life for the Zuni people. In the 16th century Spaniards reported extensive farming of corn and other crops in the area. Zuni agricultural methods in the past have mainly consisted of three types: floodwater irrigation, canal systems, and waffle gardens. Zuni floodwater irrigation involved planting crops in channels that received occasional water flows. Diversions were utilized to control water levels and velocities. Zuni canal systems were largely used to grow wheat and corn. The canals and ditches were used to convey water from natural springs to the fields. Waffle gardens have traditionally been used to grow specialty crops. These small plots had short mud walls to retain water and were hand watered by the Zuni women. When the Zuni Indian Reservation was established in 1877, these methods for agriculture were still being used. In addition to the lands irrigated from canals, the use of flooding/runoff irrigation and hand watering of gardens and small fields were practiced. These methods were described by early explorers from 1600-1880, as discussed by Hart (2006).

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

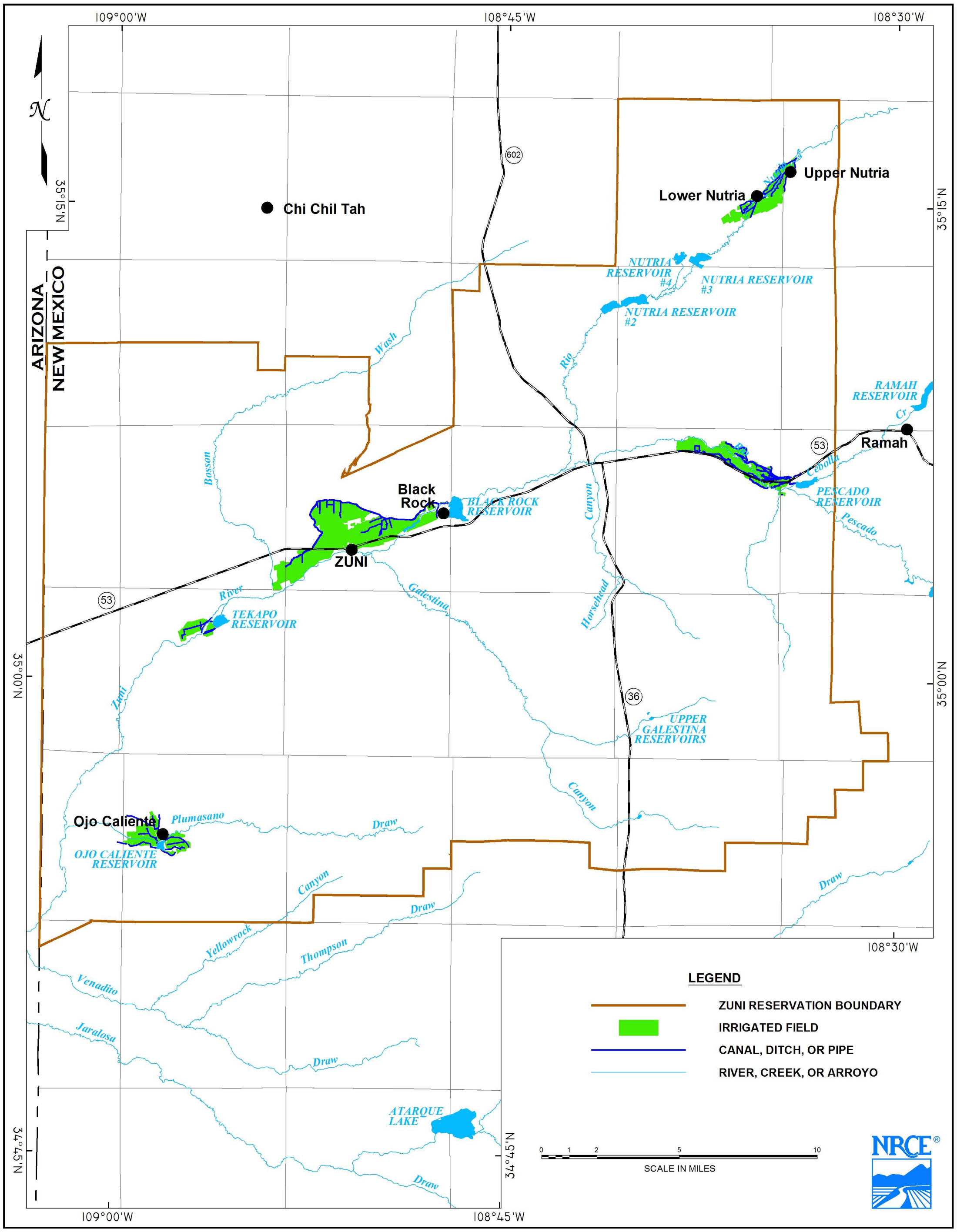

Figure 1-1: Zuni Reservation Agriculture Units.

2 LANDS IRRIGATED BY PERMANENT IRRIGATION WORKS

An evaluation of past and present lands irrigated from permanent irrigation works was completed. The evaluation utilized existing historical irrigation maps, aerial photography, and recent field assessments. Permanent irrigation works were defined to include diversion structures, canals and ditches, pipelines, reservoirs, and wells. The water sources serving the irrigated lands include springs, washes, rivers, creeks, reservoirs, and groundwater. Table 2-1 summarizes the past and presently irrigated acreage in each project area, and individual tracts of land are listed in Appendix A. The past and present lands irrigated from permanent irrigation works have been mapped to a scale of 1"=300' with aerial photography from 2005 as a background image. These maps are part of the hydrographic survey maps that were submitted to the Court and are viewable or can be downloaded at *www.zunibasin.com*. After submittal of claim and upon review of data, a 17.14 acre parcel was added to the Nutria Project Area.

Table 2-1: Summary of Acreage Served from Permanent Works by Project Area.

Project Area	Acreage	Primary Water Source(s)
Nutria	976.61	Rio Nutria, Springs, and three Reservoirs
Pescado	1317.86	Springs, Zuni River, Rio Pescado, Cebolla Creek, Pescado Reservoir
Zuni	3629.78	Zuni River and Black Rock Reservoir
Tekapo	320.57	Zuni River and Tekapo Reservoir
Ojo Caliente	773.73	Springs and Ojo Caliente Reservoir
Total	**7018.55**	

2.1 BIA Historical Maps

Maps were obtained from the Bureau of Indian Affairs (BIA) for each of the five project areas (Nutria, Pescado, Zuni, Tekapo, and Ojo Caliente). Two map sets were used in evaluating irrigated lands and project works: (1) Indian Irrigated and Irrigable Lands maps showing irrigated and irrigable land tracts, and (2) Engineering Maps showing permanent irrigation works.

2.1.1 Indian Irrigated and Irrigable Lands (April / June 1956)

These maps show the areas of irrigated and irrigable lands based upon land classification plane table sheets prepared by Bureau of Reclamation in 1939. The irrigated and irrigable lands map for each unit are provided in Appendix B.

2.1.2 Engineering Maps (1966)

The engineering maps provide a drawing of the project works for each irrigation area. These maps provide a record of canals, dams, diversions, and irrigated lands. The maps also provide rehabilitation recommendations for the project works of each area. The engineering maps for each area are provided in Appendix B.

2.2 Aerial Photography

In addition to the historical BIA maps, aerial photographs taken between 1934 and 2005 were utilized to map lands irrigated by permanent irrigation works. Aerial photography coverage of the study area exists for the years of 1934-36, 1953-54, 1981, 1996-97, 2001, and 2005. The BIA office in Albuquerque provided black and white aerial photographs of the project areas for the years 1934-1936, 1953-1954 and 1981 and color images for 2001. NRCE obtained the black and white Digital Orthophoto Quarter-Quadrangles (DOQQs) aerial photo maps for 1996-97 and DOQQ color aerial photo maps for 2005 from the United State Geological Survey (USGS). Table 2-2 summarizes the aerial photographs used in the evaluation.

Table 2-2: Aerial Photographs Used in Evaluating Irrigated Lands and Irrigation Works.

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

The cropped fields and evidence of their corresponding irrigation works can be seen in the aerial photographs, and this irrigated acreage and their associated works were seen to change over time in the aerial photography. A composite delineation of irrigated lands was created based on all of the aerial photography data, summarized in Table 2-1. The composite delineation is overlaid on each of the aerial photography datasets in Appendix C.

2.3 Zuni Pueblo Information

The Zuni Pueblo provided a Geographic Information System (GIS) digital coverage of the past and present irrigated lands served by permanent irrigation works. This coverage was used along with the other maps and aerial photos to assist in determining past and presently irrigated lands. The coverage was prepared in part by the Zuni Pueblo using a Global Positioning System (GPS) to map fields and irrigation conveyance systems.

2.4 Field Assessments

Field assessments were performed in 2004-2006 by the author and other employees of Natural Resources Consulting Engineers, Inc. to verify the mapping and obtain additional GPS data. The field visits were to confirm the presence of the irrigation facilities and fields and observe irrigation methods.

2.5 BIA Crop Reports

Irrigated acreage data are available from the annual BIA crop reports for each area. Available crop reports range in date from 1934 – 2004. Crop reports were not available for the years of 1935-51, 1953-80, 1992-96, and 2002. The acreages in the BIA crop reports are less in any given year than the total acreages developed from aerial photography, shown in Table 2-1, because the aerial photography acreage data represents a composite total of all acreages determined to have been irrigated, as opposed to the total acreage in any one year.

2.6 Irrigation Wells

For the most part, all of the irrigated lands identified in the agricultural units are served from reservoirs and springs, as shown in Appendix A. A total of 12 irrigation wells were identified that represent an additional water supply source; four in the Nutria unit and eight in the Zuni unit. These irrigation wells are identified in Table 2- and shown on the maps in Appendix C.

Table 2-3: Wells Used for Irrigation on the Irrigation Project Lands.

Map Label	Township	Range	Section	Unit	X (ft)	Y (ft)
1C-3-W007	10N	19W	13	Zuni	2434282.25	1489664.52
1C-4-W004	10N	19W	24	Zuni	2435464.44	1489101.17
1C-4-W005	10N	19W	24	Zuni	2435457.69	1489149.5
1C-4-W007	10N	19W	23	Zuni	2432491.13	1487340.29
1C-4-W012	10N	19W	23	Zuni	2427887.77	1486911.21
1C-4-W026	10N	19W	27	Zuni	2423723.47	1481932.77
1C-4-W027	10N	19W	27	Zuni	2422631.39	1483533.12
1C-4-W058	10N	19W	24	Zuni	2433878.15	1489220.77
2C-2-W005	12N	16W	6	Nutria	2506102.42	1564902.8
2C-3-W001	12N	17W	24	Nutria	2501327.21	1547361.87
2C-3-W010	12N	16W	19	Nutria	2503721.41	1547534.52
2C-3-W015	12N	17W	25	Nutria	2497322.86	1546088.23

2.7 Impoundments Used for Irrigation

Small impoundments also serve some of the irrigated lands identified in the agricultural units. The identified impoundments serve municipal and livestock uses in addition to being used for irrigation. A total of 16 impoundments were identified that represent an additional water supply source; six in the Nutria unit, one in the Pescado unit, three in the Ojo Caliente unit, and six in the Zuni unit. The six impoundments in the Zuni unit are used primarily as municipal wastewater ponds with overflow used for irrigation. These impoundments are identified in Table 2-4 and shown on the maps in Appendix C.

Table 2-4: Impoundments Used for Irrigation on Project Lands

Map Label	T	R	S	Unit	X (ft)	Y (ft)	Volume (ac-ft)
1B-4-SP005	10N	20W	36	Zuni	2405837.07	1475174.18	16.62
1B-4-SP006	10N	19W	31	Zuni	2406472.54	1475438.59	11.90
1B-4-SP007	10N	19W	31	Zuni	2406998.34	1475663.28	11.72
1B-4-SP008	10N	20W	36	Zuni	2405991.57	1474805.26	17.03
1B-4-SP009	10N	19W	31	Zuni	2406625.38	1475069.94	11.98
1B-4-SP010	10N	19W	31	Zuni	2407156.78	1475290.29	12.28
2C-2-SP010	12N	16W	6	Nutria	2504713.17	1567605.84	0.03
2C-2-SP011	12N	16W	7	Nutria	2505679.56	1560435.93	0.45
2C-3-SP006	12N	17W	24	Nutria	2501255.45	1547295.8	0.05
2C-3-SP007	12N	17W	24	Nutria	2500858.93	1547268.54	0.15
2C-3-SP009	12N	16W	18	Nutria	2504871.3	1553254.09	3.36
2C-3-SP011	12N	17W	24	Nutria	2498567.68	1549481.75	6.15
2C-5-SP001	10N	17W	12	Pescado	2497640.78	1494988.12	0.52
5A-3-SP001	08N	20W	17	Ojo Caliente	2382272.45	1431138.72	0.68
5B-3-SP002	08N	20W	21	Ojo Caliente	2386480.44	1424574.87	0.04
5B-3-SP009	08N	20W	16	Ojo Caliente	2386350.09	1426928.74	0.14

3 CROPPING AND IRRIGATION PRACTICES

The Zuni cropping and irrigation practices factor into the estimation of irrigation water requirements for the identified lands. The crop mix was determined based on BIA crop reports and county agricultural statistics. Growing seasons were estimated based on typical growing seasons for each crop.

3.1 Cropping Pattern / Crop Mix

The Zuni Pueblo have grown a wide variety of crops on their lands. Using data recorded by the BIA from 1934 to 2004, along with additional data obtained for the counties of Cibola and McKinley (NASS, 2007), the cropping patterns were determined as a percentage of the total irrigated land. The cropping pattern and the irrigated acreage have changed significantly during the last century. These changes are due to numerous factors such as development of irrigation projects, condition of irrigation systems and water storage facilities, water supply, demand for crops, livestock and wildlife encroachment, and demographics. The selected cropping pattern is based on the weighted-average percent of each crop in the BIA crop mix, adjusted to include pasture.

3.1.1 BIA Crop History Reports

BIA annual crop reports provide data specific to each of the irrigation project areas. The BIA inventoried the crops for each project area of Nutria, Ojo Caliente, Pescado, Tekapo, and Zuni. The results of these annual inventories are summarized in Table 3-1 and Table 3-2. The table values are an average percentage of irrigated area that is based on data collected from the following periods: 1934, 1952, 1981-1993, 1997-2001, and 2003-2004. The crops were grouped to include corn, small grains, hay, alfalfa, and garden crops. Small grains include oats, rye, and wheat crops. Hay includes general hay, oat hay, and rye hay. Garden crops include general gardens, beans, chili, melons, orchards, pumpkins, squash, and other similar types of vegetables. The trend in cropping pattern from the BIA records and recent field visits has been a reduction in the percentage of grains (particularly wheat) and an increase in alfalfa. .

Table 3-1: Crops Grown in each Project Area. Information from BIA Crop Reports.

Crop	Nutria	Ojo Caliente	Pescado	Tekapo	Zuni
Corn	26.3%	33.0%	18.9%	77.5%	45.9%
Hay	10.3%	8.8%	6.3%	0.5%	3.5%
Small Grains	15.6%	11.5%	11.1%	0.5%	10.0%
Alfalfa	37.1%	38.0%	61.3%	8.4%	33.6%
Garden Crops	4.1%	5.4%	1.5%	10.9%	1.5%
Non-Crops	6.6%	3.4%	1.0%	2.2%	5.5%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

Table 3-2: Crops Grown in Various Time Periods. Information from BIA Crop Reports.

Crop	1934	1952	1981-1993	1997-2001	2003-2004
Corn	4.1%	1.3%	42.2%	10.2%	9.1%
Hay	0.0%	0.8%	9.5%	0.0%	0.0%
Small Grains	46.7%	47.0%	7.1%	11.6%	17.3%
Alfalfa	33.9%	0.6%	29.7%	78.2%	73.6%
Garden Crops(1)	2.9%	50.4%	3.5%	0.0%	0.0%
Non-Crops(2)	12.4%	0.0%	8.1%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

(1) In 1997-2001 and 2003-2004 the crops reports listed a yield for garden crops but no acreage.

(2) Non-Crops - Listed as irrigated non-cropped and defined as winter wheat in 1934 crop reports. In 1982 only listed as irrigated non-cropped.

3.1.2 New Mexico Agricultural Statistics Service

Data from the New Mexico Agricultural Statistics Service for the years 1999 and 2000 were obtained to evaluate crop mixes for Cibola and McKinley counties. The data show that alfalfa and pasture make up the majority of the cropping patterns for these two counties. The high percentage of pasture found in these two counties helps support the use of a higher percentage in the overall cropping mix for Zuni relative to what has historically been reported by the BIA. Table 3-3 shows the county crop mix data.

Table 3-3: Crop Mix Data for Cibola and McKinley Counties (NASS).

Crop	1999		2000	
	Cibola	McKinley	Cibola	McKinley
Corn	4.7%	7.3%	5.9%	7.5%
Hay	0.0%	0.0%	0.7%	0.0%
Small Grains	0.0%	9.0%	1.6%	7.6%
Alfalfa	47.2%	12.2%	44.6%	12.5%
Garden Crops	2.4%	4.4%	3.9%	3.7%
Irrigated Pasture	45.7%	67.1%	43.1%	68.7%
Total	100.0%	100.0%	100.0%	100.0%

3.1.3 Overall Crop Mix

There is some concern that the BIA data collection procedures have not been consistent and the records are not complete. The acreage of irrigated pasture was not always reported; therefore, the percent irrigated of pasture is based on information from 1934, 1952, 1981, and 1982 BIA crop reports. Overall, pasture is estimated to comprise approximately 20% of the total irrigated area for each project. The acre percentages for the other crops have been adjusted to include the 20% pasture and are shown in Table 3-4.

Table 3-4: Crops Grown in each Project Area, Adjusted for Pasture.

Crop	Nutria	Ojo Caliente	Pescado	Tekapo	Zuni
Corn	21.0%	26.4%	15.1%	62.1%	36.7%
Hay	8.2%	7.0%	5.0%	0.4%	2.8%
Small Grains	12.5%	9.2%	8.9%	0.4%	8.0%
Alfalfa	29.7%	30.4%	49.0%	6.7%	26.9%
Garden Crops	3.3%	4.3%	1.2%	8.7%	1.2%
Non-Crops	5.3%	2.7%	0.8%	1.8%	4.4%
Irrigated Pasture*	20%	20%	20%	20%	20%
Total	100.00%	100.00%	100.00%	100.00%	100.00%

* Irrigated Pasture is estimated as 20% for each area

The cropping patterns in the irrigated areas have not been consistent over the period of record. The figures in Appendix D show that the percentage of any given crop fluctuates over time. Realizing that cropping patterns have changed and will likely continue to change over time and location, a single cropping pattern was used for all areas. The percentages shown in Table 3-5 are acreage-weighted averages based upon the combined irrigated area for all five agricultural units in this project.

Table 3-5: Cropping Pattern for all Units.

Crop	Percentage by Area
Corn	30%
Small Grains, Hay	4%
Small Grains, Grain	9%
Alfalfa	31%
Garden Crops	2%
Irrigated Pasture*	24%

* Irrigated pasture includes the pasture (20%) plus non-crops (4%) percentage.

3.2 Growing Seasons

Growing seasons were determined for the agricultural areas using a number of methods, and climate data analysis. The main portion of the growing season for corn and garden crops was determined by finding the median dates of last 28˚F spring frost and the number of days required for the crop to mature. Alfalfa growth can be estimated to occur between the last -4 ˚C (24.8˚F) occurrence in spring to the first -4˚C (24.8˚F) occurrence in fall, in climates having frosts. Grass and pasture growth can be estimated to occur 7 days before and after the first and last -4˚C (24.8˚F) occurrence (FAO, 1998). The beginning of the small grains growing season was determined as the average date of the first continuous average temperature of 40˚ F (NMSU, 1968). The growing seasons for each irrigation area are provided in Table 3-6.

The temperature data from National Weather Service stations were used to determine the growing seasons for crops in the cropping pattern. A discussion on which climate stations were applied to the irrigation areas is provided in Section 4.1.

Table 3-6: Growing Seasons by Unit and Crop.

Irrigation Area/Unit	Crop	Growing Season Start	End	Days
Tekapo, Ojo Caliente, Zuni	Small Grains, Grain	13-Mar	10-Jul	120
	Small Grains, Hay	13-Mar	16-Jun	96
	Irrigated Pasture	17-Apr	3-Nov	201
	Alfalfa	24-Apr	28-Oct	187
	Corn	9-May	10-Sep	125
	Garden	9-May	26-Aug	110
Nutria	Small Grains, Grain	4-Apr	1-Aug	120
	Small Grains, Hay	4-Apr	8-Jul	96
	Irrigated Pasture	22-Apr	26-Oct	188
	Alfalfa	29-Apr	19-Oct	174
	Corn	15-May	16-Sep	125
	Garden	15-May	1-Sep	110
Pescado	Small Grains, Grain	19-Mar	16-Jul	120
	Small Grains, Hay	19-Mar	22-Jun	96
	Irrigated Pasture	30-Apr	30-Oct	184
	Alfalfa	6-May	23-Oct	171
	Corn	13-May	14-Sep	125
	Garden	13-May	30-Aug	110

3.3 Irrigation Methods

The lands irrigated by permanent irrigation works are irrigated primarily by surface irrigation methods including border, furrow, basin, and wild flooding methods. The water conveyance systems include canals, ditches, and gravity pipelines.

4 CROP IRRIGATION REQUIREMENTS

The irrigation requirements for any crop are based on the contribution of a number of factors. One of the more important factors that affect the irrigation requirements are climatic conditions. This includes average daily temperatures, annual precipitation, average wind speeds, humidity, and the amount of cloud cover. These variables influence the amount of water loss to the atmosphere through evaporation and the amount of water that is used by plant life though transpiration. These elements are commonly combined into a single parameter known as evapotranspiration (ET) and used to evaluate the total amount of water required by a crop for growth and maintenance in order to produce maximum annual yields. Irrigation requirements represent the portion of the crop ET that is not satisfied by natural rainfall. The water necessary to fulfill the crop irrigation requirements, sometimes referred to as the diversion requirement, must take into account water losses that occur in conveying water from the source to the fields and in applying water to the crops.

4.1 Climate Data

The climate of the Zuni River Basin where the Zuni Indian Reservation is located is considered to be mostly arid with elevations ranging from approximately 6,000 to 8,000 feet above sea level. The average high temperature during the summer months is approximately 90^{o}F with an average low of 50^{o}F. In the winter months, the average high is approximately 50^{o}F with an average low dropping below 20°F. Like most areas located in the southwestern United States, precipitation is received in relatively low amounts. The Zuni River Basin receives approximately 12 inches of precipitation annually, over 2 inches of which falls in the month of August. For most crops, the growing season falls between the spring and fall months, starting as early as March for some crops and extending through the month of November for later crops.

For the purposes of collecting climatic data, historical records obtained from the National Climatic Data Center (NCDC) generated from Nation Weather Service (NWS) stations near the project areas were used. A detailed discussion on the climate data used in this analysis is provided in Appendix E. Climate data from each station were adjusted by elevation to match the mean elevation of each irrigation area. Data for the Nutria agricultural area were obtained from weather station #5560 at an elevation band of 6,800 feet. Data for the Pescado area were obtained from weather station #9897 at an elevation band of 6,600 feet. Tekapo, Ojo Caliente, and Zuni all reside within the same elevation band at 6,200 feet; therefore data from weather station #9897 were used for all three of these agricultural areas. Climatic data necessary for the calculation of ET include temperature, precipitation, dew point, sky cover, and wind speed.

4.2 Crop Evapotranspiration

For each climate zone, a single reference ET is calculated. The reference ET represents the ET rate of a specific crop, usually clipped grass or alfalfa. To account for the fact that crops behave differently within their environment due to differences in size, water requirements, surface area, and growing season, the reference ET (ET_o) needs to be adjusted for each type of crop. These differences between individual crops are taken into account with crop coefficients. Calculation of the reference ET is based on climate data. Crop coefficients have been calculated previously and are found in the literature.

4.2.1 Reference ET

A reference ET was calculated through the use of the American Society of Civil Engineers (ASCE) Penman-Monteith method (ASCE, 2005). It is based on the climatic conditions at the geographic region of interest, taking into consideration variations in the local climates in each agricultural area of the Zuni Indian Reservation. ASCE defines the reference crop as a clipped, cool-season grass with adequate irrigation to facilitate unstinted growth under the specified climatic conditions. The equations and methods used to calculate ET_o are provided in Appendix F.

The reference ET values calculated using the ASCE Penman-Monteith method were compared to other methods of calculating reference ET that require fewer data inputs. Some of the climate inputs into the ASCE Penman-Montieth equation are not recorded at nearby climate stations #5566 and #9897, and must be obtained from climate stations located farther away or estimated based on climate and location conditions. As a check on utilizing these non-local climate inputs, alternative ET_o calculation methods were explored that do not require these non-local climate inputs. The results, provided in Appendix F, support the ASCE Penman-Monteith results.

4.2.2 Crop Coefficients

The crop coefficients were determined by methods given in USDA Natural Resources Conservation Service National Engineering Handbook (NRCS-NEH) (1993). Three factors are considered in calculating crop coefficients: basal crop coefficients, water stress on the crop, and wet soil evaporation. Basal crop coefficients represent the water demand of a healthy crop that does not suffer water stress. Basal crop coefficients are divided by the various stages of crop growth such as germination, canopy development, full development, and harvest. Separate coefficients are provided for each growth stage in NRCS-NEH (1993).

The water stress factor was not included in the crop coefficient calculations. The water stress factor is typically included to account for reduced rates of crop ET that occur when there is a shortage of water in the crop root zone. For this water rights claim, water shortages or water stress are not considered because the water right quantification is to provide a full water supply to the past and presently irrigated lands.

During the initial, development, and late season stages of crop growth, the water evaporation from a wet soil surface is considered. The amount of evaporation depends on the amount of canopy development, hydraulic properties of the soil, and the amount of available energy to drive evaporation. A wet soil evaporation factor is provided in NRCS-NEH (1993) based on soil properties and irrigation methods.

A more detailed discussion of crop coefficient calculations is provided in Appendix F.

4.3 Effective Precipitation

Effective precipitation is that portion of precipitation that contributes to the water needs of the crop, which is dependant upon the field soils, rainfall amounts, and crop rooting depth. Monthly effective precipitation was calculated using the method presented by NRCS-NEH (1993). Effective precipitation was calculated using the 80% exceedence rainfall during the irrigation season, instead of the average rainfall, in order to provide a more conservative estimate of irrigation water requirements. The effective precipitation for each crop and agricultural area can be seen in Appendix G.

4.4 Net Irrigation Requirements

The net irrigation requirement (NIR) of a crop is the difference in the amount of water that is required by the crop (ET_c) and the effective precipitation that the crop receives from rainfall. By taking the cropping patterns and growing seasons into account, the weighted average monthly NIR for each project area can be determined, as provided in Table 4-1. Complete results are tabulated in Appendix G.

Table 4-1: Weighted Average Monthly Net Irrigation Requirements (inches).

Unit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Nutria				0.44	3.51	5.49	5.41	4.17	2.52	1.26			**22.79**
Pescado			0.04	0.45	3.30	5.79	5.03	4.00	2.48	1.41			**22.51**
Zuni			0.08	0.97	4.23	5.72	5.35	4.34	2.52	1.60	0.05		**24.86**
Tekapo			0.08	1.01	4.28	5.74	5.29	4.29	2.51	1.60	0.05		**24.85**
Ojo Caliente			0.08	0.97	4.23	5.72	5.35	4.34	2.52	1.60	0.05		**24.86**

4.5 Irrigation Efficiency

Water losses to irrigation occur as water is diverted from the source to the cultivated fields and as water is applied to the fields as irrigation. The greater these losses are, the less efficient the irrigation system. Sufficient water needs to be diverted such that the crop receives its full irrigation requirement after losses have reduced the water supply to the crop. Therefore, the efficiency of the application, conveyance, and distribution systems must be taken into account when calculating the total diversion requirements for crops.

4.5.1 Conveyance and Distribution Efficiency

Conveyance losses occur as water is diverted from a source, such as a stream or reservoir, and transported to the irrigation area. Distribution losses occur as water is moved from field to field throughout the irrigation area. These losses typically occur as evaporation from the surface of canals and infiltration into the soil along canals. Earthen canals are typically less efficient (greater losses), but even closed-conduit systems may develop leaks as they age or become damaged, losing water to soil infiltration. Conveyance and distribution efficiencies were estimated as follows: 70 percent for open-channel systems and 90 percent for pipeline systems.

4.5.2 On Farm Efficiency

Losses occur as water is applied to the fields for irrigation. These losses can be caused by evaporation of surface water and sprinkler droplets, surface runoff, and deep soil percolation beyond the roots of the crops. The on-farm irrigation efficiencies were estimated at 60 percent. All of the areas practice a mix of surface irrigation methods; including border, furrow, and flood irrigation. In general, reasonable irrigation efficiencies for surface irrigation range from 50 to 85 percent. Typically, 50 percent irrigation efficiencies are associated with surface diversion irrigations with little control of flow rate or application time. Fangmeier and Biggs (1986) state that a well designed surface irrigation system is expected to have a range of efficiencies averaging between 60 to 70 percent. A guide of estimated application efficiencies for various irrigation systems is included in Martin et. al. (1990). It gives an efficiency range of 50 to 85 percent for graded borders.

Different irrigation units use combinations of both canals and pipelines, so specific irrigation efficiencies are estimated for each irrigated area, as shown in Table 4-2.

Table 4-2: Estimated Efficiency of Irrigation Systems

Unit	Conveyance Efficiency	On-Farm Efficiency	Overall Efficiency
Nutria	70%	60%	42%
Pescado	80%	60%	48%
Zuni	70%	60%	42%
Tekapo	80%	60%	48%
Ojo Caliente	90%	60%	54%

4.6 Irrigation Diversion Requirements and Depletion

The total diversion requirement is based on the amount of irrigation water required by the crops taking the overall irrigation system efficiency into account. Specifically, the net irrigation requirement is divided by the overall irrigation efficiency. This is the amount of water that must be diverted in order to ensure that the required amount of water is applied to the crops. The unit diversion requirements for each agricultural unit are listed in Table 4-3.

Table 4-3: Monthly Irrigation Unit Diversion Requirements (inches)

Unit	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Annual
Nutria		1.04	8.37	13.06	12.88	9.92	6.01	2.99		**54.27**
Pescado	0.09	0.93	6.87	12.07	10.48	8.34	5.17	2.94		**46.89**
Zuni	0.18	2.31	10.07	13.62	12.73	10.33	6.01	3.80	0.13	**59.18**
Tekapo	0.17	2.11	8.93	11.95	11.01	8.93	5.24	3.33	0.11	**51.77**
Ojo Caliente	0.14	1.79	7.83	10.59	9.90	8.03	4.68	2.96	0.10	**46.03**

Some of the losses described in Section 4.5 return to surface waters and/or groundwater. These return flows do not represent a net depletion from the water source, even though the water was diverted for irrigation. The depletion represents the net reduction of water from the source caused by the diversion. The depletion for each project area was calculated as the sum of the net irrigation requirement and 20 percent of the diverted flow that is lost due to conveyance and application inefficiencies. Summary results are provided in Table 4-4. The results for each individual tract that are shown on the accompanying set of maps are listed in Appendix A.

Table 4-4: Irrigation Diversion Requirements and Depletion

Unit	Irrigated Area (acres)	Diversion (ac-ft)	Depletion (ac-ft)
Nutria	976.6	4,401.7	2,359.3
Pescado	1,317.9	5,096.9	2,976.6
Zuni	3,629.8	17,901.4	9,595.1
Tekapo	320.6	1,383.0	807.7
Ojo Caliente	773.7	2,967.9	1,875.7
Total	7,018.6	31,751.0	17,614.4

After submittal of the Zuni historical irrigation water rights claims, subsequent work identified two modifications to improve the crop ET calculations. Wind speed data used to calculate reference ET were changed from daytime data to 24-hour average data, which resulted in lower reference ET values relative to those in the claims. The crop coefficients used to calculate crop ET were modified to include soil water evaporation, which had the effect of raising the crop coefficient values. The net effect of these changes, seen by comparing the net irrigation requirements of the claims and the modified results, indicate less than one percent difference. This difference is considered to be within the accuracy of the estimation methods. Appendix H provides more information on these modifications and the comparison with the claims. Since subsequent modifications had a relatively minor effect on the original claim values for the net irrigation requirement, the original claim values for irrigation diversion and depletion should be utilized instead of those values reported in Table 4-4. The irrigation diversion and depletions in the original claim are provided in Table 4-5.

Table 4-5: Claim Irrigation Diversion Requirements and Depletion.

Unit	Irrigated Area (acres)	Diversion (ac-ft)	Depletion (ac-ft)
Nutria	959.5	4,338.7	2,325.8
Pescado	1,317.9	5,195.0	3,033.7
Zuni	3,629.8	17,934.9	9,611.8
Tekapo	320.6	1,583.9	848.9
Ojo Caliente	773.7	2,973.4	1,879.4
Total	7,001.4	32,026.0	17,699.5

Note: Nutria acreage does not include the 17.14 acre parcel (2C-3C-IRR004) that was added to the project unit after the claim had been submitted.

5 REFERENCES

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APPENDIX A

TRACTS IRRIGATED BY PERMANENT WORKS

Appendix A provides a listing of individual irrigated tracts delineated from aerial photography. The *map label* identifies each tract as according to a unique indicator. The entire Zuni River Basin has been divided into 11 sub-areas, and each sub-area is further divided into a grid. Figure A-1 describes the map indicator labels. The *coordinates* (X,Y) are located at the centroid of each irrigated tract, in UTM coordinates. The *area* of each tract represents the estimated irrigated area of each tract from the composite delineation of aerial photography (see Section 2). The *depletion* and *diversion* volumes follow the methodology discussed in Section 4. The *water source* and *means of diversion* are listeed. The *water source ID* identifies the water source using a unique indicator similar to the map label system.

The maps can be viewed on the internet at http://www.zunibasin.com/. They are located at the **Relevant Reports** tab and at the **ZUNI RIVER BASIN ADJUDICATION HYDROGRAPHIC SURVEY AND IRRIGATED TRACTS MAPS ZUNI INDIAN RESERVATION AND MAZONE RANCH TRUST LANDS** tab. The claims can also be found on the web page under **Court Documents, Decisions, Orders, Etc**. tab, **subproceeding 1, Zuni Indian Claims**. The claims were filed May 11, 2007, titled UNITED STATES' SUBPROCEEDING COMPLAINT AND STATEMENT OF CLAIMS FOR WATER RIGHTS ON BEHALF OF, AND FOR THE BENEFIT OF, THE ZUNI INDIAN TRIBE AND ZUNI ALLOTTEES**,** document number 1. Upon review of the data another 17.14 acre irrigated field (2C-3C-IRR004) was added to the claim see Figure A-2.

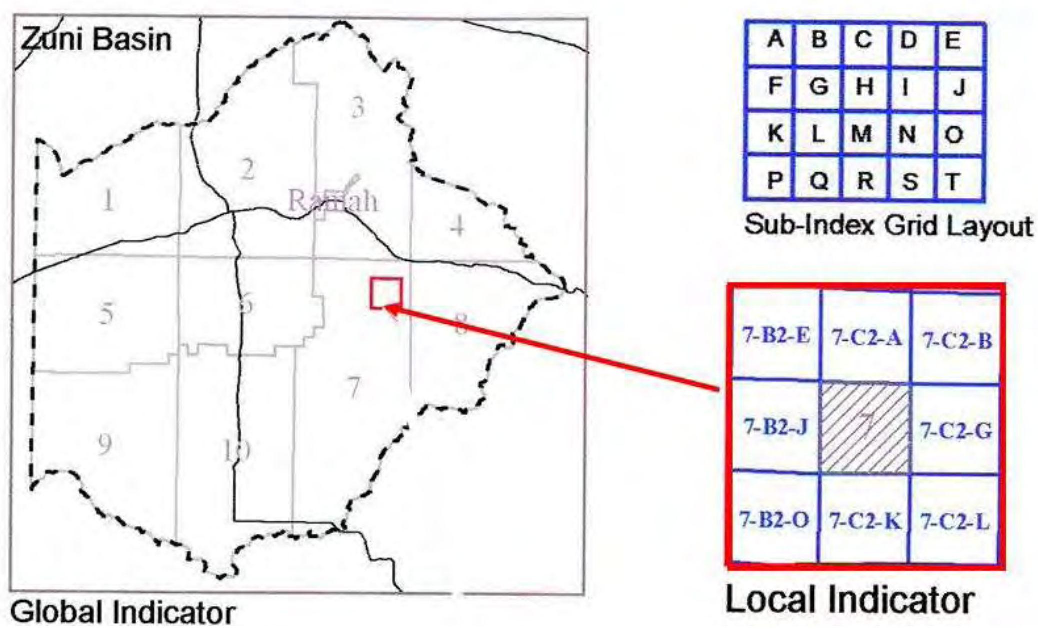


Figure A-1: Map Label System

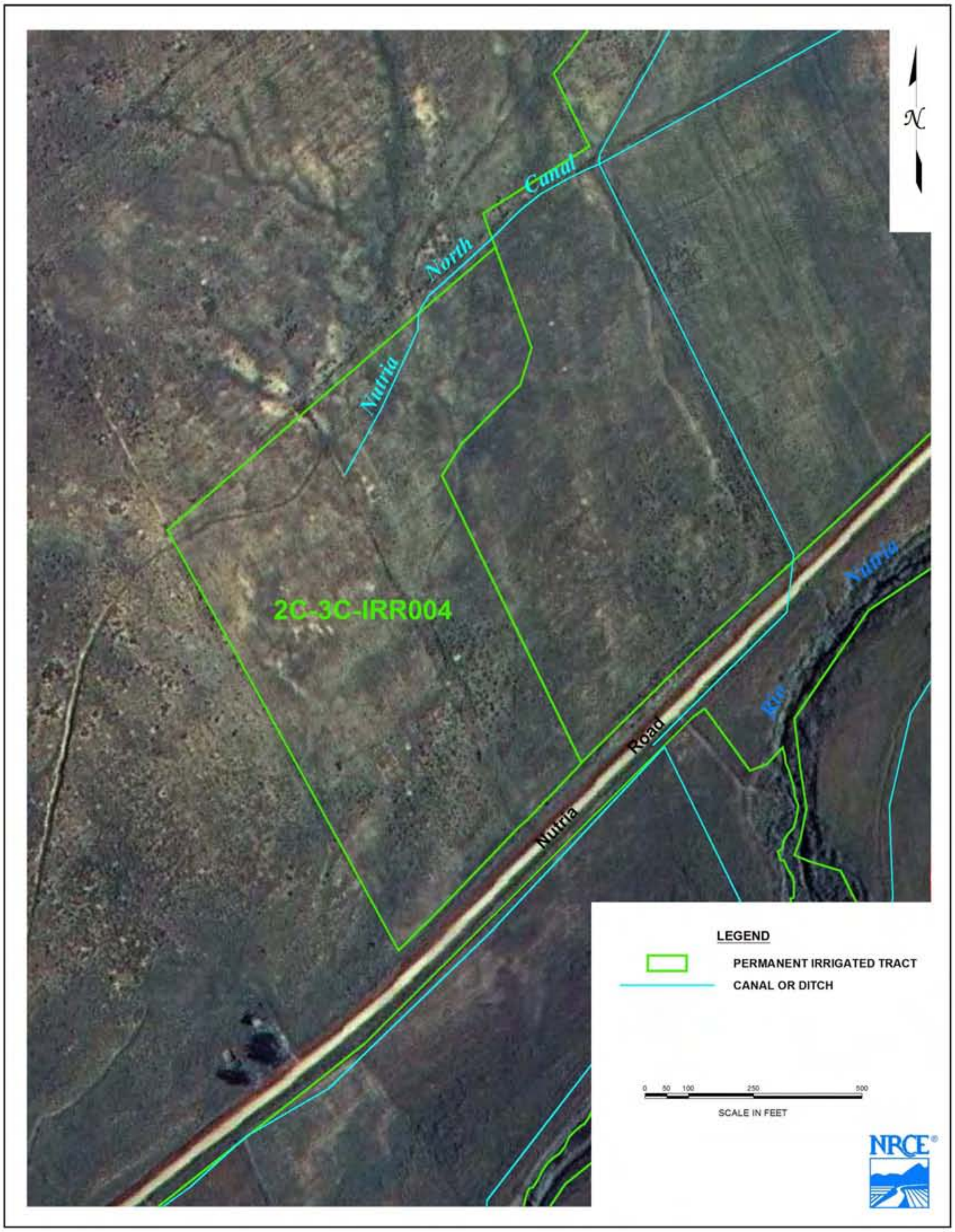


Figure A-2: Additional Irrigated Parcel added to the Zuni Indian Tribe claim for past and present irrigation from permanent irrigation works.

Map Label	X (ft)	Y (ft)	Area (acres)	Depletion (ac-ft/yr)	Diversion (ac-ft/yr)	Means of Diversion	Water Source	Water Source ID
1B-4J-IRR001	2,410,133	1,480,146	152.14	402.87	751.73	Zuni Canal	Black Rock Reservoir	2A-4-RS01
1B-4J-IRR002	2,410,556	1,481,884	0.52	1.38	2.57	Zuni Canal	Black Rock Reservoir	2A-4-RS01
1B-4J-IRR003	2,409,601	1,481,294	28.88	76.48	142.71	Zuni Canal	Black Rock Reservoir	2A-4-RS01
1B-4N-IRR001	2,405,412	1,476,721	195.12	516.68	964.08	Zuni Canal	Black Rock Reservoir	2A-4-RS01
1B-4O-IRR001	2,406,825	1,478,997	8.08	21.39	39.91	Zuni Canal	Black Rock Reservoir	2A-4-RS01
1B-4O-IRR002	2,408,555	1,477,601	309.05	818.37	1527.02	Zuni Canal	Black Rock Reservoir	2A-4-RS01
1C-3P-IRR001	2,416,388	1,490,381	41.11	108.87	203.14	Zuni Canal	Black Rock Reservoir	2A-4-RS01
1C-3P-IRR002	2,414,446	1,490,427	85.84	227.31	424.14	Zuni Canal	Black Rock Reservoir	2A-4-RS01
1C-3P-IRR003	2,412,854	1,490,368	12.81	33.93	63.32	Zuni Canal	Black Rock Reservoir	2A-4-RS01
1C-3Q-IRR001	2,419,323	1,490,073	39.85	105.53	196.91	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-3Q-IRR002	2,417,692	1,490,215	32.46	85.95	160.37	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-3T-IRR001	2,434,302	1,490,018	37.41	99.07	184.85	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4A-IRR001	2,416,353	1,485,735	77.51	205.26	383.00	Zuni Canal	Black Rock Reservoir	2A-4-RS01
1C-4A-IRR002	2,414,428	1,485,797	147.78	391.31	730.16	Zuni Canal	Black Rock Reservoir	2A-4-RS01
1C-4A-IRR003	2,412,549	1,486,677	16.93	44.83	83.65	Zuni Canal	Black Rock Reservoir	2A-4-RS01
1C-4A-IRR004	2,416,377	1,488,378	78.22	207.12	386.47	Zuni Canal	Black Rock Reservoir	2A-4-RS01
1C-4A-IRR005	2,414,390	1,488,398	156.32	413.93	772.37	Zuni Canal	Black Rock Reservoir	2A-4-RS01
1C-4A-IRR006	2,412,276	1,488,493	89.38	236.68	441.63	Zuni Canal	Black Rock Reservoir	2A-4-RS01
1C-4B-IRR001	2,421,642	1,485,248	35.95	95.21	177.65	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4B-IRR002	2,417,685	1,488,342	79.89	211.54	394.71	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4B-IRR003	2,421,603	1,488,372	48.09	127.35	237.64	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4B-IRR004	2,421,508	1,486,352	36.42	96.44	179.94	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4B-IRR005	2,419,606	1,488,597	125.74	332.97	621.30	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4B-IRR006	2,419,805	1,485,315	101.02	267.49	499.12	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4B-IRR007	2,417,617	1,485,595	69.32	183.55	342.49	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4B-IRR008	2,419,389	1,486,554	6.32	16.75	31.25	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4C-IRR001	2,424,455	1,485,623	233.55	618.43	1153.96	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4C-IRR002	2,427,449	1,484,404	4.31	11.41	21.30	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4C-IRR003	2,426,889	1,486,022	97.21	257.42	480.33	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4C-IRR004	2,423,531	1,486,907	52.63	139.35	260.02	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4C-IRR005	2,423,519	1,487,542	18.55	49.11	91.64	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4D-IRR001	2,428,177	1,486,171	76.77	203.29	379.32	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01

Map Label	X (ft)	Y (ft)	Area (acres)	Depletion (ac-ft/yr)	Diversion (ac-ft/yr)	Means of Diversion	Water Source	Water Source ID
1C-4D-IRR002	2,431,834	1,486,542	55.08	145.86	272.16	Zuni South Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4D-IRR003	2,430,377	1,486,918	92.22	244.20	455.67	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4E-IRR001	2,434,142	1,487,833	108.8	288.11	537.60	Zuni South Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4E-IRR002	2,433,059	1,489,139	5.29	14.01	26.14	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4F-IRR001	2,413,360	1,480,736	175.49	464.71	867.11	Zuni Canal	Black Rock Reservoir	2A-4-RS01
1C-4F-IRR002	2,416,332	1,483,097	76.94	203.75	380.18	Zuni Canal	Black Rock Reservoir	2A-4-RS01
1C-4F-IRR003	2,413,990	1,483,021	193.4	512.13	955.60	Zuni Canal	Black Rock Reservoir	2A-4-RS01
1C-4G-IRR001	2,420,970	1,482,302	34.13	90.37	168.63	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4G-IRR002	2,420,981	1,483,218	72.4	191.72	357.75	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4G-IRR003	2,420,547	1,483,791	20.75	54.94	102.51	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4G-IRR004	2,417,613	1,483,197	69.37	183.70	342.77	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4G-IRR005	2,419,221	1,483,758	54.2	143.53	267.82	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4H-IRR001	2,423,703	1,483,889	64.23	170.09	317.38	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4H-IRR002	2,424,689	1,483,228	104.63	277.07	516.99	Zuni Main Pipeline	Black Rock Reservoir	2A-4-RS01
1C-4K-IRR001	2,412,007	1,478,951	7.67	20.32	37.92	Zuni Canal	Black Rock Reservoir	2A-4-RS01
2B-5O-IRR001	2,483,668	1,501,803	202.32	465.73	797.53	Pescado Spring Main Pipe	Springs And Pescado Reservoir	2C-5-SPR001, 2C-5-SPR002, 2C-5-RS01
2C-3C-IRR001	2,500,476	1,552,250	32.54	78.89	147.16	Nutria North Canal	Nutria Diversion Reservoir	2C-2-RS01
2C-3C-IRR002	2,501,622	1,552,057	113.68	275.57	514.08	Nutria South Canal	Nutria Diversion Reservoir	2C-2-RS01
2C-3C-IRR003	2,501,466	1,554,487	50.76	123.04	229.54	Nutria North Canal	Nutria Diversion Reservoir	2C-2-RS01
2C-3C-IRR004	2,500,509	1,553,586	17.14	41.54	77.51	Nutria North Canal	Nutria Diversion Reservoir	2C-2-RS01
2C-3D-IRR001	2,502,955	1,553,498	2.67	6.48	12.08	Nutria South Canal	Nutria Diversion Reservoir	2C-2-RS01
2C-3D-IRR002	2,503,927	1,556,349	10.73	26.00	48.51	Nutria Pipeline	Nutria Diversion Reservoir	2C-2-RS01
2C-3D-IRR003	2,503,565	1,554,952	28.83	69.88	130.35	Nutria South Canal	Nutria Diversion Reservoir	2C-2-RS01
2C-3D-IRR004	2,502,716	1,555,411	18.83	45.64	85.13	Nutria Pipeline	Nutria Diversion Reservoir	2C-2-RS01

Map Label	X (ft)	Y (ft)	Area (acres)	Depletion (ac-ft/yr)	Diversion (ac-ft/yr)	Means of Diversion	Water Source	Water Source ID
2C-3G-IRR001	2,496,133	1,548,759	4.62	11.19	20.87	Nutria North Canal	Nutria Diversion Reservoir	2C-2-RS01
2C-3G-IRR002	2,494,559	1,547,304	75.07	181.97	339.46	Nutria North Canal	Nutria Diversion Reservoir	2C-2-RS01
2C-3G-IRR003	2,496,069	1,547,413	26.45	64.11	119.60	Rio Nutria Canal	Nutria Diversion Reservoir	2C-2-RS01
2C-3G-IRR004	2,495,543	1,548,593	4.28	10.37	19.34	Nutria North Canal	Nutria Diversion Reservoir	2C-2-RS01
2C-3H-IRR001	2,498,357	1,550,241	18.36	44.51	83.03	Nutria North Canal	Nutria Diversion Reservoir	2C-2-RS01
2C-3H-IRR002	2,499,370	1,550,723	49.74	120.58	224.94	Nutria North Canal	Nutria Diversion Reservoir	2C-2-RS01
2C-3H-IRR003	2,499,332	1,548,244	293.8	712.17	1328.56	Nutria South Canal	Nutria Diversion Reservoir	2C-2-RS01
2C-3H-IRR004	2,497,754	1,549,582	4.38	10.61	19.79	Nutria North Canal	Nutria Diversion Reservoir	2C-2-RS01
2C-3H-IRR005	2,497,401	1,549,382	1.5	3.63	6.77	Nutria North Canal	Nutria Diversion Reservoir	2C-2-RS01
2C-3H-IRR006	2,497,736	1,548,715	32	77.58	144.72	Rio Nutria Canal	Nutria Diversion Reservoir	2C-2-RS01
2C-3H-IRR007	2,497,409	1,548,042	6.1	14.80	27.60	Rio Nutria Canal	Nutria Diversion Reservoir	2C-2-RS01
2C-3L-IRR001	2,495,271	1,546,021	35.24	85.42	159.35	Rio Nutria Canal	Nutria Diversion Reservoir	2C-2-RS01
2C-3L-IRR002	2,492,388	1,545,415	149.89	363.33	677.80	Nutria North Canal	Nutria Diversion Reservoir	2C-2-RS01
2C-5K-IRR001	2,489,170	1,500,536	139.18	320.40	548.66	Pescado Spring Main Pipe	Springs And Pescado Reservoir	2C-5-SPR001, 2C-5-SPR002, 2C-5-RS01
2C-5K-IRR002	2,486,726	1,501,164	17.06	39.27	67.25	Pescado Spring Main Pipe	Springs And Pescado Reservoir	2C-5-SPR001, 2C-5-SPR002, 2C-5-RS01
2C-5K-IRR003	2,485,931	1,501,288	63.86	147.00	251.73	Pescado Spring Main Pipe	Springs And Pescado Reservoir	2C-5-SPR001, 2C-5-SPR002, 2C-5-RS01
2C-5K-IRR004	2,489,281	1,499,769	8.34	19.20	32.88	Pescado Spring Main Pipe	Springs And Pescado Reservoir	2C-5-SPR001, 2C-5-SPR002,

Map Label	X (ft)	Y (ft)	Area (acres)	Depletion (ac-ft/yr)	Diversion (ac-ft/yr)	Means of Diversion	Water Source	Water Source ID
								2C-5-RS01
2C-5K-IRR005	2,490,374	1,501,963	21.85	50.30	86.14	North Pescado Draw	Pescado Spring And Pescado Reservoir	2C-5-SPR001, 2C-5-RS01
2C-5L-IRR001	2,494,202	1,500,656	27.21	62.65	107.28	North Pescado Draw	Pescado Spring And Pescado Reservoir	2C-5-SPR001, 2C-5-RS01
2C-5L-IRR002	2,491,848	1,500,996	48.14	110.83	189.78	North Pescado Draw	Pescado Spring And Pescado Reservoir	2C-5-SPR001, 2C-5-RS01
2C-5L-IRR003	2,493,186	1,500,732	14.65	33.72	57.74	North Pescado Draw	Pescado Spring And Pescado Reservoir	2C-5-SPR001, 2C-5-RS01
2C-5L-IRR004	2,493,087	1,500,185	10.78	24.83	42.51	North Pescado Draw	Pescado Spring And Pescado Reservoir	2C-5-SPR001, 2C-5-RS01
2C-5L-IRR005	2,491,228	1,500,105	8.49	19.53	33.45	Pescado Spring Main Pipe	Springs And Pescado Reservoir	2C-5-SPR001, 2C-5-SPR002, 2C-5-RS01
2C-5L-IRR006	2,491,813	1,499,699	12.23	28.15	48.21	Pescado Spring Main Pipe	Springs And Pescado Reservoir	2C-5-SPR001, 2C-5-SPR002, 2C-5-RS01
2C-5L-IRR007	2,493,966	1,499,772	11.55	26.59	45.53	North Pescado Draw	Pescado Spring And Pescado Reservoir	2C-5-SPR001, 2C-5-RS01
2C-5L-IRR008	2,494,572	1,499,517	7.07	16.28	27.89	Pescado Spring North Pipe	Pescado Spring And Pescado Reservoir	2C-5-SPR001, 2C-5-RS01
2C-5P-IRR001	2,490,522	1,499,355	16.49	37.96	65.01	Pescado Spring Main Pipe	Springs And Pescado Reservoir	2C-5-SPR001, 2C-5-SPR002, 2C-5-RS01
2C-5Q-IRR001	2,494,212	1,499,040	21.27	48.97	83.86	North Pescado Draw Canal 'D'	Pescado Spring And Pescado Reservoir	2C-5-SPR001, 2C-5-RS01
2C-5Q-IRR002	2,491,176	1,499,369	10.86	25.00	42.80	Pescado Spring Main Pipe	Springs And Pescado Reservoir	2C-5-SPR001, 2C-5-SPR002, 2C-5-RS01
2C-5Q-IRR003	2,491,445	1,498,447	22.33	51.40	88.01	Pescado Spring Main Pipe	Springs And Pescado Reservoir	2C-5-SPR001, 2C-5-SPR002, 2C-5-RS01
2C-5Q-IRR004	2,493,868	1,497,652	172.46	397.00	679.84	Pescado Spring Main Pipe	Springs And Pescado Reservoir	2C-5-SPR001, 2C-5-SPR002, 2C-5-RS01
2C-5Q-IRR005	2,494,999	1,495,704	15.71	36.16	61.92	Upper Rio Pescado Canal	Pescado Reservoir	2C-5-RS01

Map Label	X (ft)	Y (ft)	Area (acres)	Depletion (ac-ft/yr)	Diversion (ac-ft/yr)	Means of Diversion	Water Source	Water Source ID
2C-5R-IRR001	2,496,496	1,497,754	51.88	119.42	204.50	Pescado Spring North Pipe	Pescado Spring And Pescado Reservoir	2C-5-SPR001, 2C-5-RS01
2C-5R-IRR002	2,497,277	1,496,772	11.83	27.24	46.65	North Pescado Draw Canal 'A'	Pescado Spring And Pescado Reservoir	2C-5-SPR001, 2C-5-RS01
2C-5R-IRR003	2,497,883	1,496,540	3.98	9.16	15.69	North Pescado Draw Canal 'A'	Pescado Spring And Pescado Reservoir	2C-5-SPR001, 2C-5-RS01
2C-5R-IRR004	2,498,610	1,496,586	5.94	13.66	23.40	North Pescado Draw Canal 'A'	Pescado Spring And Pescado Reservoir	2C-5-SPR001, 2C-5-RS01
2C-5R-IRR005	2,498,441	1,496,072	15.72	36.18	61.96	Ruins Canal	Pescado Spring	2C-5-SPR001
2C-5R-IRR006	2,497,666	1,495,939	19.29	44.41	76.05	Ruins Canal	Pescado Spring	2C-5-SPR001
2C-5R-IRR007	2,500,025	1,495,869	27.4	63.08	108.01	Pescado North Canal	Pescado Spring And Pescado Reservoir	2C-5-SPR001, 2C-5-RS01
2C-5R-IRR008	2,498,527	1,496,800	39.72	91.43	156.58	Pescado Spring North Pipe	Pescado Spring And Pescado Reservoir	2C-5-SPR001, 2C-5-RS01
2C-5R-IRR009	2,498,111	1,495,241	10.99	25.29	43.31	Pescado Spring South Pipe	Springs	2C-5-SPR001, 2C-5-SPR002
2C-5R-IRR010	2,500,927	1,495,323	2.73	6.29	10.77	Pescado North Canal	Pescado Spring And Pescado Reservoir	2C-5-SPR001, 2C-5-RS01
2C-5R-IRR011	2,499,526	1,495,318	20.16	46.41	79.47	Pescado Spring South Pipe	Pescado Spring And Pescado Reservoir	2C-5-SPR001, 2C-5-RS01
2C-5R-IRR012	2,498,738	1,495,082	7.04	16.20	27.75	Ruins Spring Canal	Spring	2C-5-SPR002
2C-5R-IRR013	2,500,226	1,494,959	2.27	5.23	8.95	Pescado Spring South Pipe	Pescado Spring And Pescado Reservoir	2C-5-SPR001, 2C-5-RS01
2C-5R-IRR014	2,500,507	1,494,914	0.89	2.04	3.49	Pescado Spring South Pipe	Pescado Spring And Pescado Reservoir	2C-5-SPR001, 2C-5-RS01
2C-5R-IRR015	2,496,621	1,494,835	37.95	87.37	149.61	Upper Rio Pescado Canal	Pescado Reservoir	2C-5-RS01
2C-5R-IRR016	2,497,927	1,494,662	3.86	8.88	15.21	Pescado South Canal	Spring And Pescado Reservoir	2C-5-SPR002, 2C-5-RS01
2C-5R-IRR017	2,498,603	1,494,362	10.85	24.98	42.77	Pescado South Canal	Pescado Reservoir	2C-5-RS01
2C-5R-IRR018	2,499,300	1,497,348	8.93	20.57	35.22	Pescado North Canal	Pescado Reservoir	2C-5-RS01
2C-5R-IRR019	2,496,671	1,495,860	21.53	49.56	84.86	Pescado Spring Main Pipe	Springs And Pescado Reservoir	2C-5-SPR001, 2C-5-SPR002, 2C-5-RS01

Map Label	X (ft)	Y (ft)	Area (acres)	Depletion (ac-ft/yr)	Diversion (ac-ft/yr)	Means of Diversion	Water Source	Water Source ID
2C-5S-IRR001	2,502,090	1,495,159	51.5	118.56	203.02	Pescado North Canal	Pescado Reservoir	2C-5-RS01
2C-5S-IRR002	2,501,415	1,494,272	11.3	26.02	44.56	Pescado South Canal	Pescado Reservoir	2C-5-RS01
2C-6C-IRR001	2,500,067	1,494,162	35.93	82.70	141.62	Pescado South Canal	Pescado Reservoir	2C-5-RS01
2C-6C-IRR002	2,500,984	1,493,607	21.28	48.99	83.89	Pescado South Canal	Pescado Reservoir	2C-5-RS01
2C-6C-IRR003	2,498,021	1,493,906	15.21	35.02	59.97	Upper Rio Pescado Canal	Pescado Reservoir	2C-5-RS01
2C-6D-IRR001	2,502,168	1,494,157	14.32	32.96	56.45	Pescado South Canal	Pescado Reservoir	2C-5-RS01
2C-6D-IRR002	2,501,611	1,492,432	13.51	31.09	53.24	Stockpond Canal	Springs	2C-6-SPR001, 2C-6-SPR002, 2C-6-SPR003, 2C-6-SPR004
5A-3D-IRR001	2,379,659	1,428,673	26.31	63.90	101.10	Ojo Caliente Reservoir North Pipeline	Ojo Caliente Reservoir	5A-3-RS01
5A-3D-IRR002	2,377,830	1,427,301	61.3	148.89	235.57	Ojo Caliente Reservoir North Canal	Ojo Caliente Reservoir	5A-3-RS01
5A-3D-IRR003	2,379,813	1,427,421	4.07	9.89	15.65	Ojo Caliente Reservoir North Canal	Ojo Caliente Reservoir	5A-3-RS01
5A-3D-IRR004	2,379,861	1,426,790	34.52	83.86	132.67	Ojo Caliente Reservoir North Pipeline	Ojo Caliente Reservoir	5A-3-RS01
5A-3D-IRR005	2,378,781	1,428,140	36.88	89.58	141.72	Ojo Caliente Reservoir North Pipeline	Ojo Caliente Reservoir	5A-3-RS01
5A-3E-IRR001	2,381,143	1,430,179	40.57	98.56	155.93	Ojo Caliente North Pipeline Canal	Rainbow Spring	5B-3-SPR001
5A-3E-IRR002	2,385,105	1,427,044	16.47	40.00	63.28	Rainbow Spring Pipeline	Rainbow Spring	5B-3-SPR001
5A-3E-IRR003	2,381,916	1,429,884	15.8	38.38	60.72	Rainbow Spring Pipeline	Rainbow Spring	5B-3-SPR001

Map Label	X (ft)	Y (ft)	Area (acres)	Depletion (ac-ft/yr)	Diversion (ac-ft/yr)	Means of Diversion	Water Source	Water Source ID
5A-3E-IRR004	2,382,002	1,427,793	40.45	98.24	155.43	Rainbow Spring Pipeline	Rainbow Spring	5B-3-SPR001
5A-3E-IRR005	2,380,880	1,427,589	42.91	104.24	164.92	Ojo Caliente Reservoir North Pipeline	Ojo Caliente Reservoir	5A-3-RS01
5A-3I-IRR001	2,378,816	1,425,671	167.14	405.97	642.30	Ojo Caliente Reservoir South Pipeline	Ojo Caliente Reservoir	5A-3-RS01
5A-3I-IRR002	2,377,666	1,426,618	15.05	36.57	57.85	Ojo Caliente Reservoir North Canal	Ojo Caliente Reservoir	5A-3-RS01
5A-3J-IRR001	2,381,771	1,426,337	19.29	46.85	74.12	Ojo Caliente Reservoir North Pipeline	Ojo Caliente Reservoir	5A-3-RS01
5A-3J-IRR002	2,384,518	1,426,392	28.97	70.36	111.32	Rainbow Spring Pipeline	Rainbow Spring	5B-3-SPR001
5A-3J-IRR003	2,383,267	1,423,950	5.02	12.21	19.31	Sacred Spring Pipeline	Sacred Spring	5A-3-SPR002
5A-3J-IRR004	2,384,583	1,423,571	17.71	43.02	68.06	Sacred Spring Pipeline	Sacred Spring	5A-3-SPR002
5A-3J-IRR005	2,384,533	1,425,305	53.95	131.04	207.32	Ojo Caliente North Canal	Rainbow Spring	5B-3-SPR001
5A-3J-IRR006	2,383,470	1,426,062	1.79	4.35	6.88	Rainbow Spring Pipeline	Rainbow Spring	5B-3-SPR001
5B-1F-IRR001	2,388,411	1,466,585	244.11	646.39	1206.13	Tekapo Main Canal	Tekapo Reservoir	5B-1-RS01
5B-1G-IRR001	2,391,910	1,466,310	76.46	202.46	377.78	Tekapo South Canal	Tekapo Reservoir	5B-1-RS01
5B-3A-IRR001	2,386,413	1,427,051	17.5	42.51	67.25	Rainbow Spring Pipeline	Rainbow Spring	5B-3-SPR001
5B-3A-IRR002	2,385,863	1,426,724	9.3	22.59	35.73	Rainbow Spring Pipeline	Rainbow Spring	5B-3-SPR001
5B-3F-IRR001	2,386,697	1,425,593	66.55	161.66	255.76	Ojo Caliente North Canal	Rainbow Spring	5B-3-SPR001
5B-3F-IRR002	2,386,985	1,424,682	35.34	85.85	135.83	Ojo Caliente South Canal	Springs	5B-3-SPR001, 5B-3-SPR002, 5B-3-SPR007

Map Label	X (ft)	Y (ft)	Area (acres)	Depletion (ac-ft/yr)	Diversion (ac-ft/yr)	Means of Diversion	Water Source	Water Source ID
5B-3F-IRR003	2,386,085	1,424,202	16.84	40.90	64.70	Ojo Caliente South Canal 'B'	Springs	5B-3-SPR003, 5B-3-SPR006

APPENDIX B

HISTORICAL BIA MAPS

Two BIA maps are provided for each irrigation area: Irrigated and Irrigable Lands Map, and Engineering Maps. These maps were provided by the Albuquerque BIA Office.

Figure B-1: Nutria Unit, Irrigated and Irrigable Lands Map

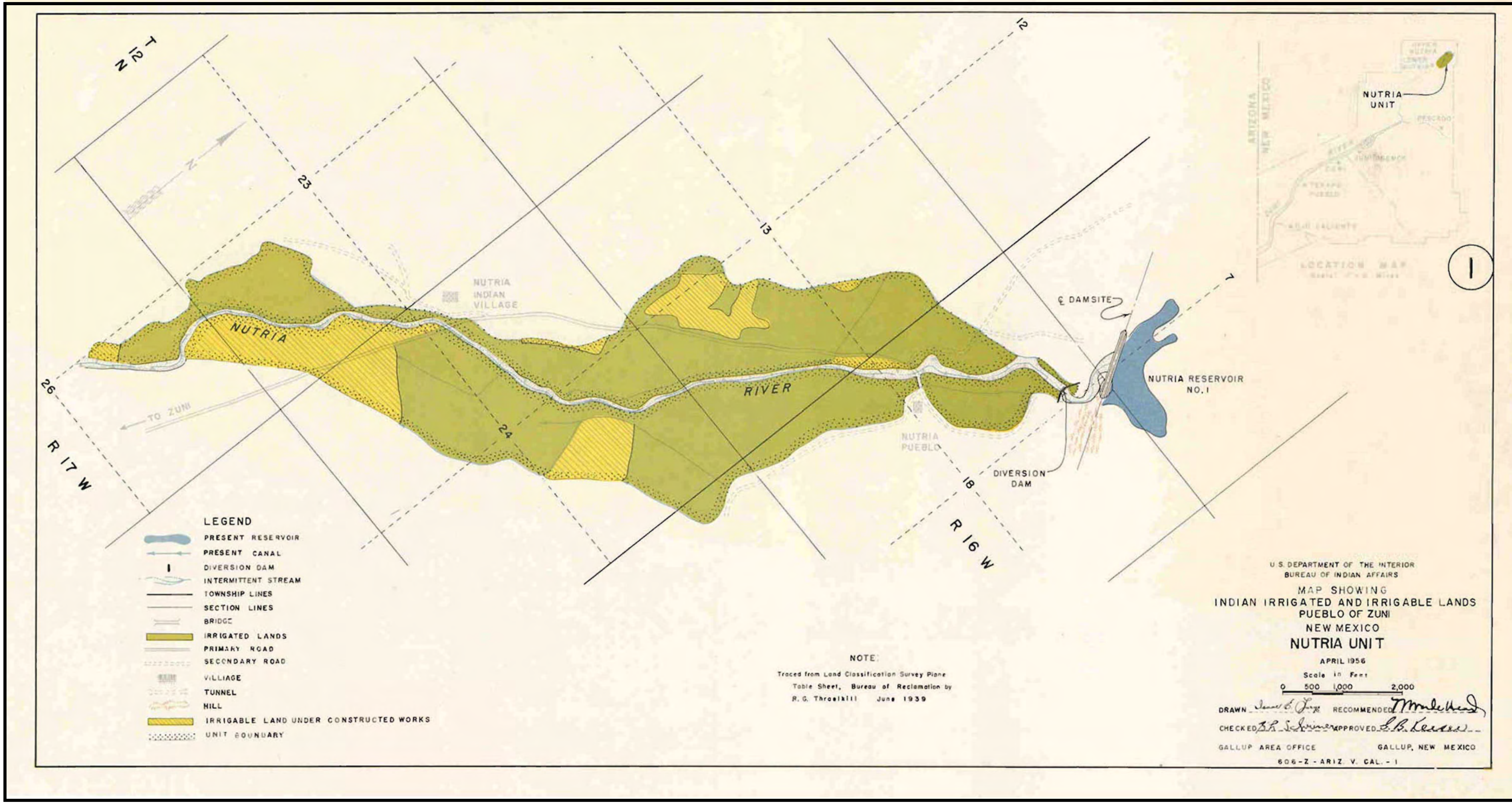


Figure B-2: Nutria Unit, Engineering Map

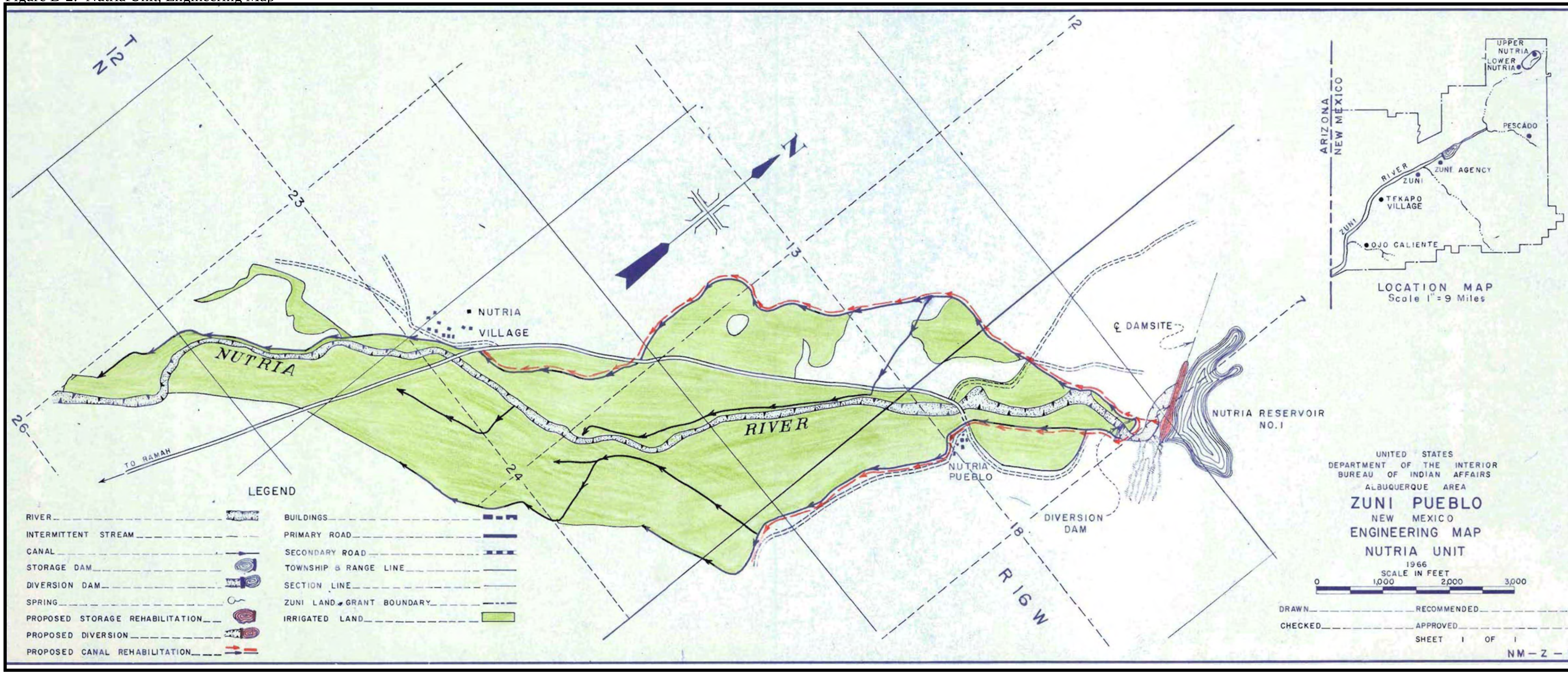


Figure B-3: Ojo Caliente Unit, Irrigated and Irrigable Lands Map

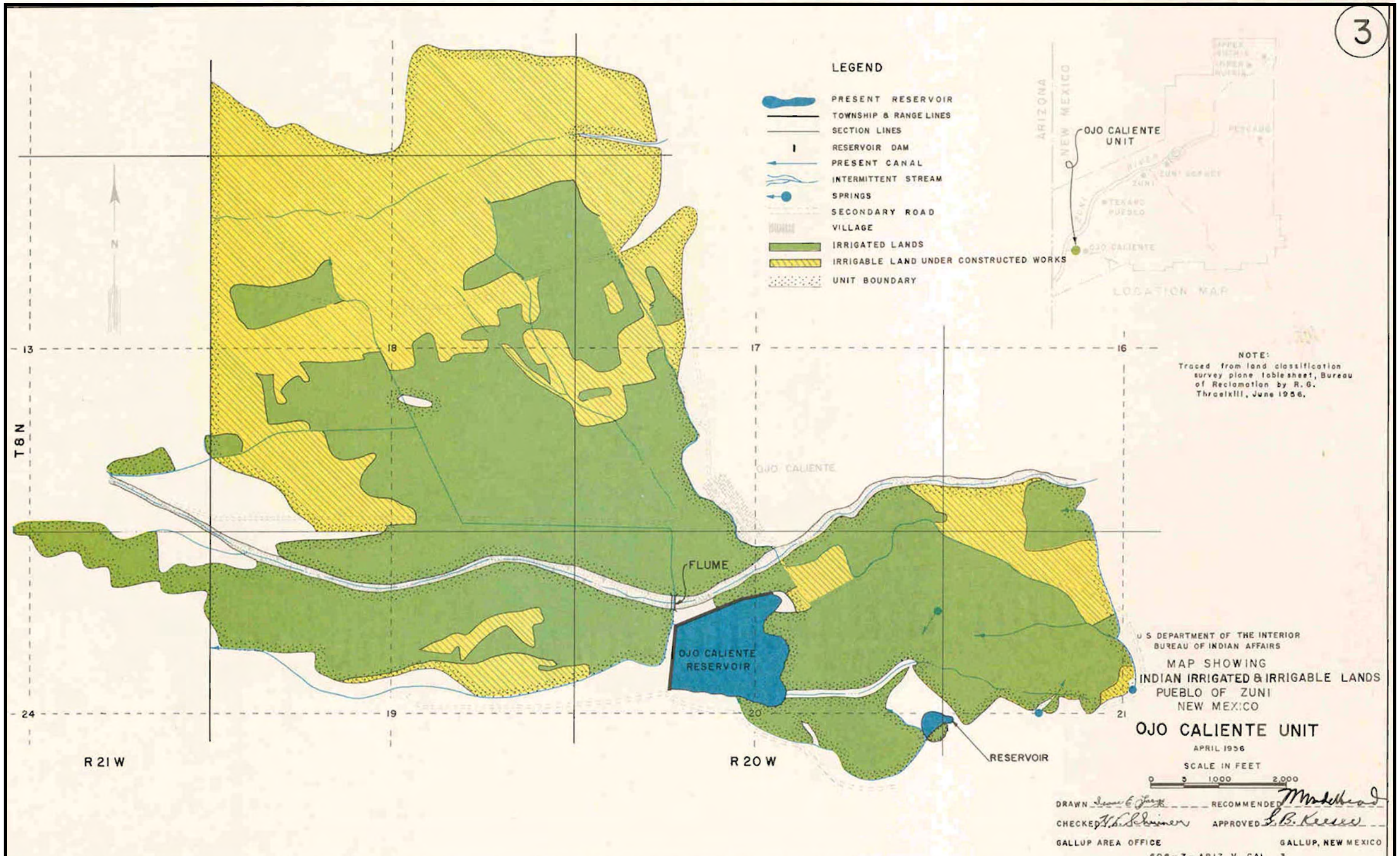


Figure B-4: Ojo Caliente Unit, Engineering Map

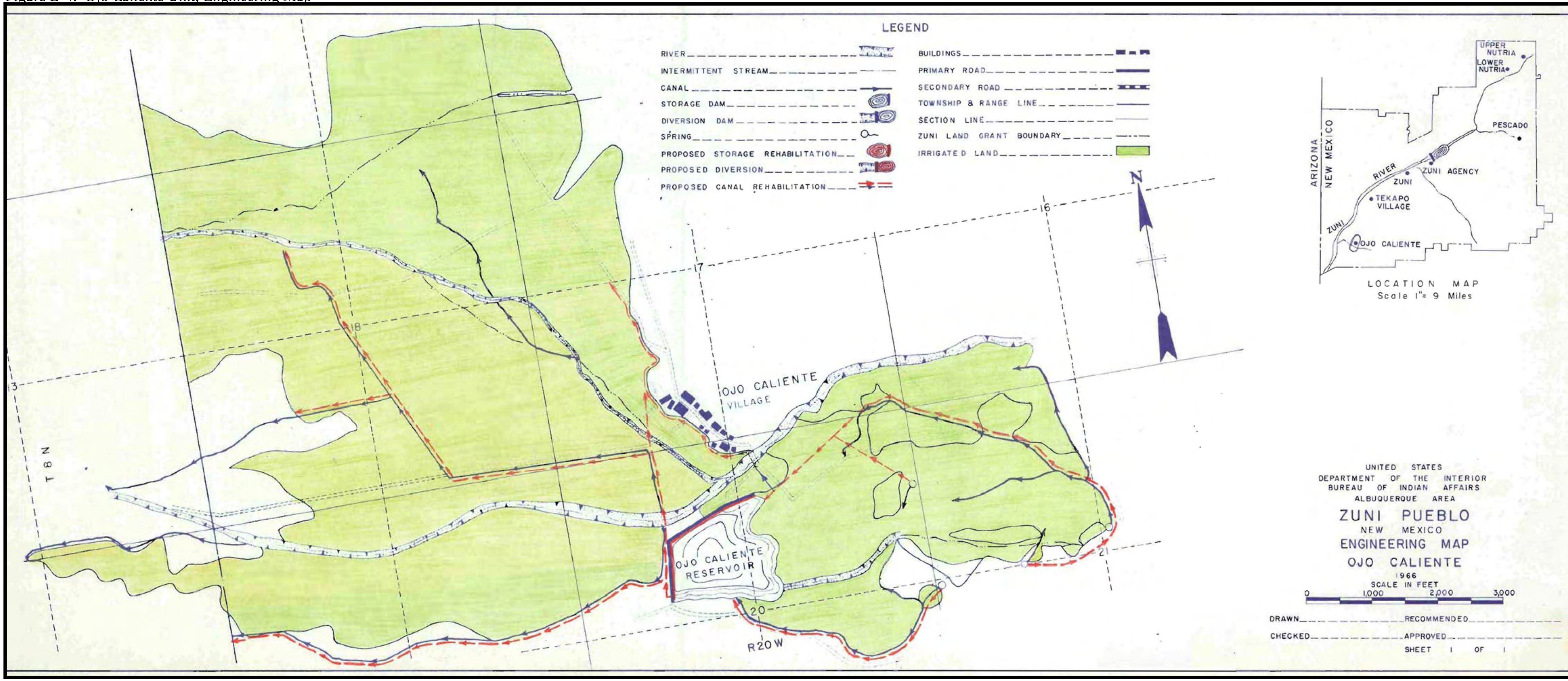


Figure B-5: Pescado Unit, Irrigated and Irrigable Lands Map

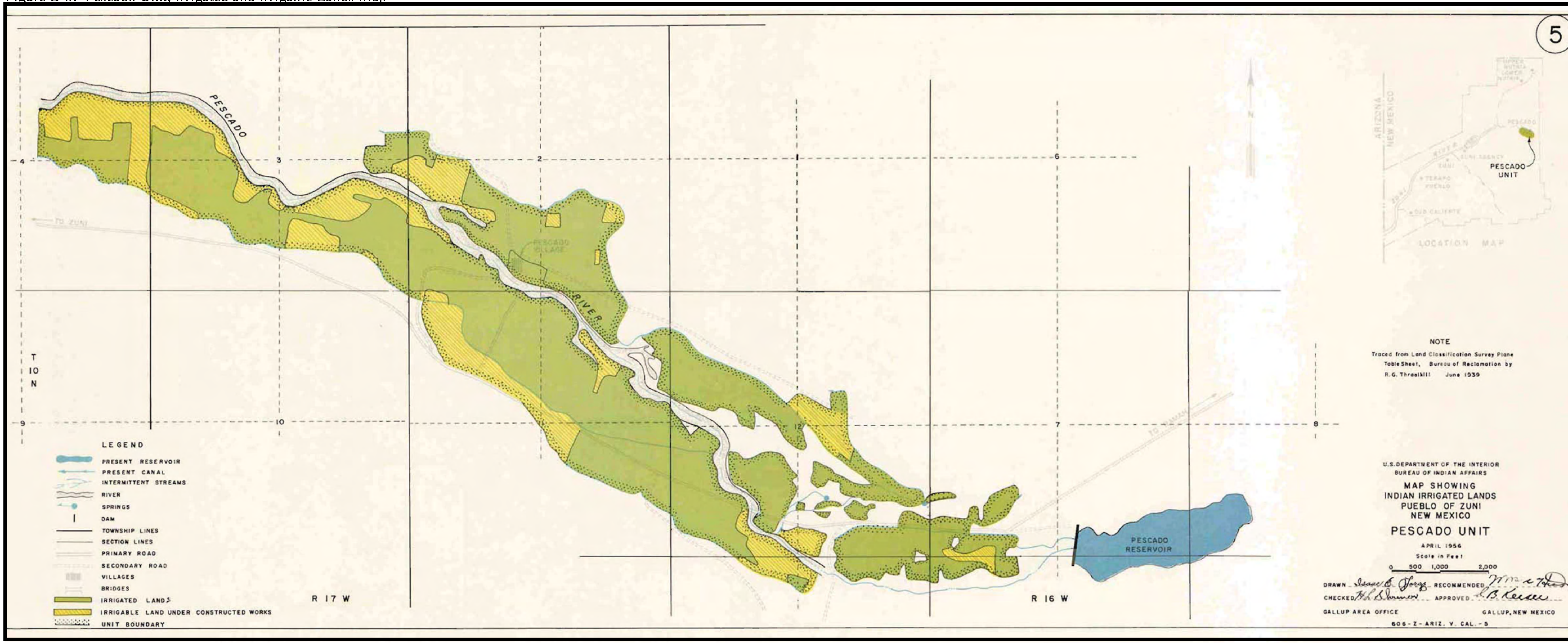


Figure B-6: Pescado Unit, Engineering Map

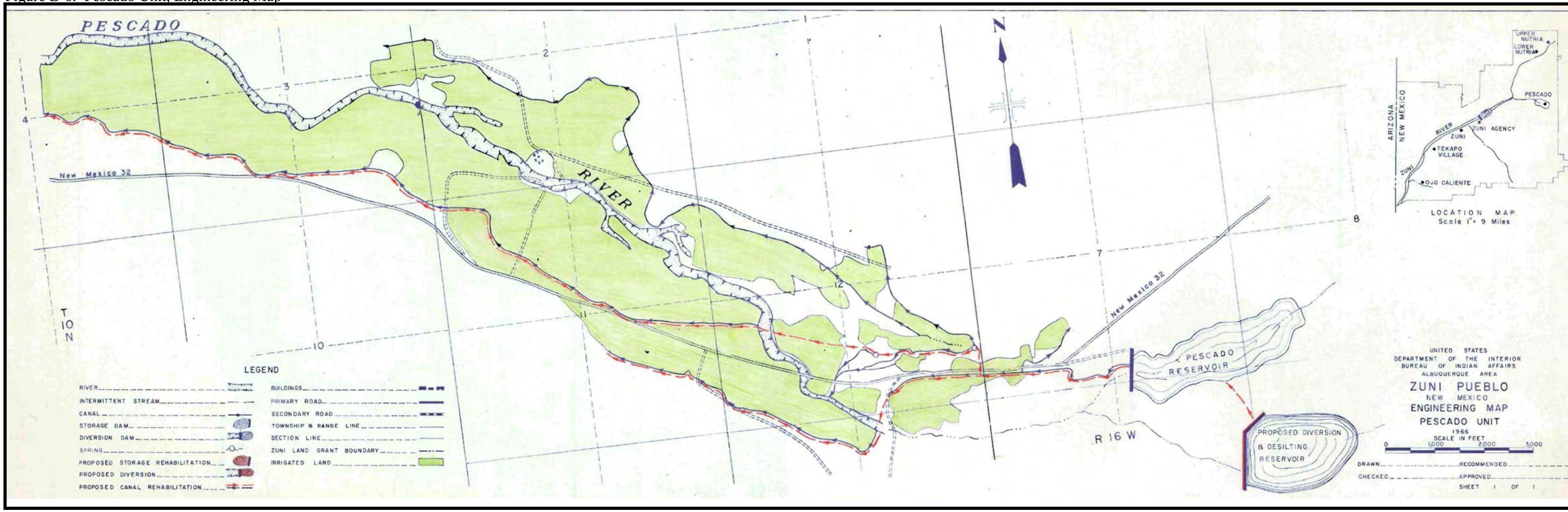


Figure B-7: Tekapo Unit, Irrigated and Irrigable Lands Map

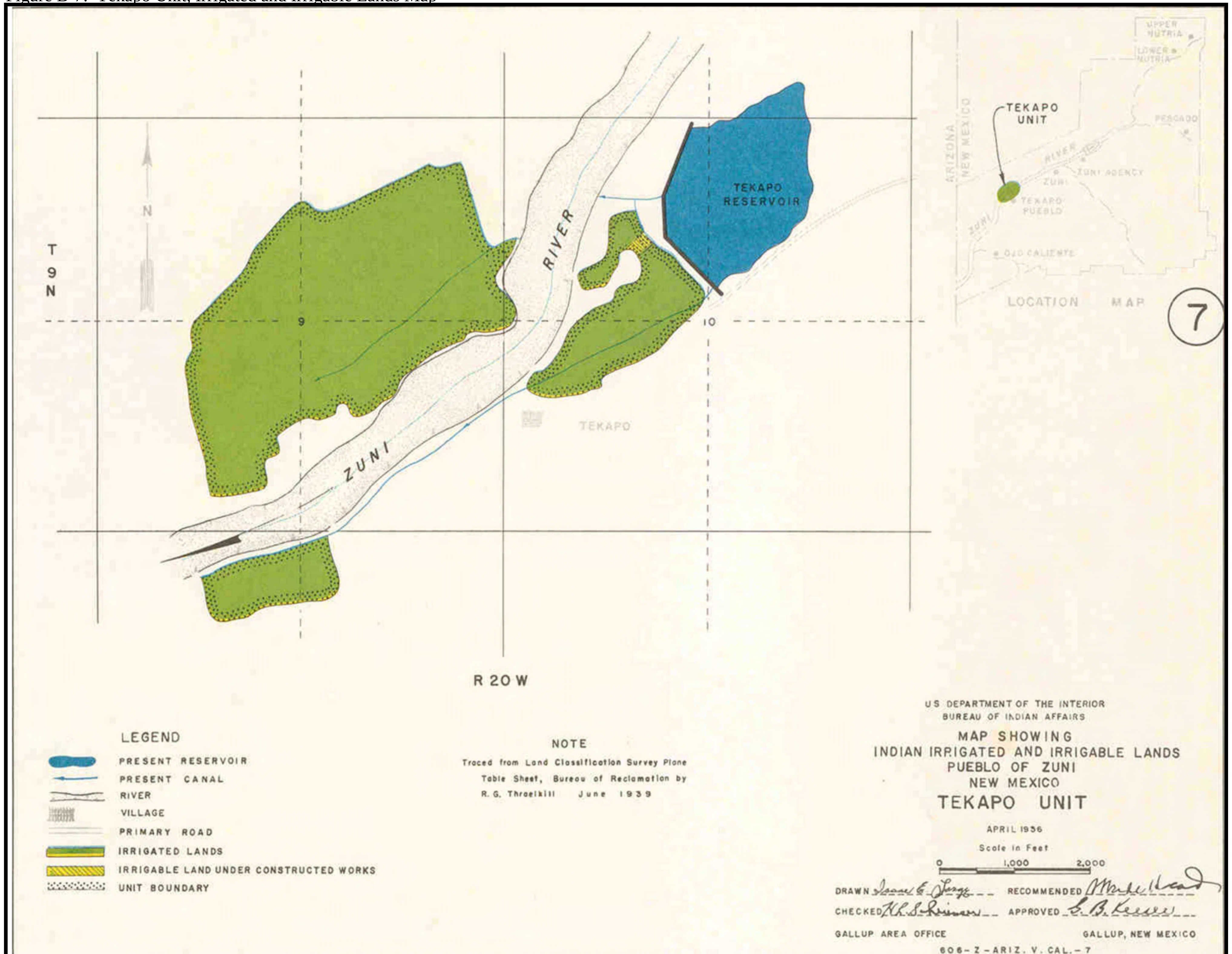


Figure B-8: Tekapo Unit, Engineering Map

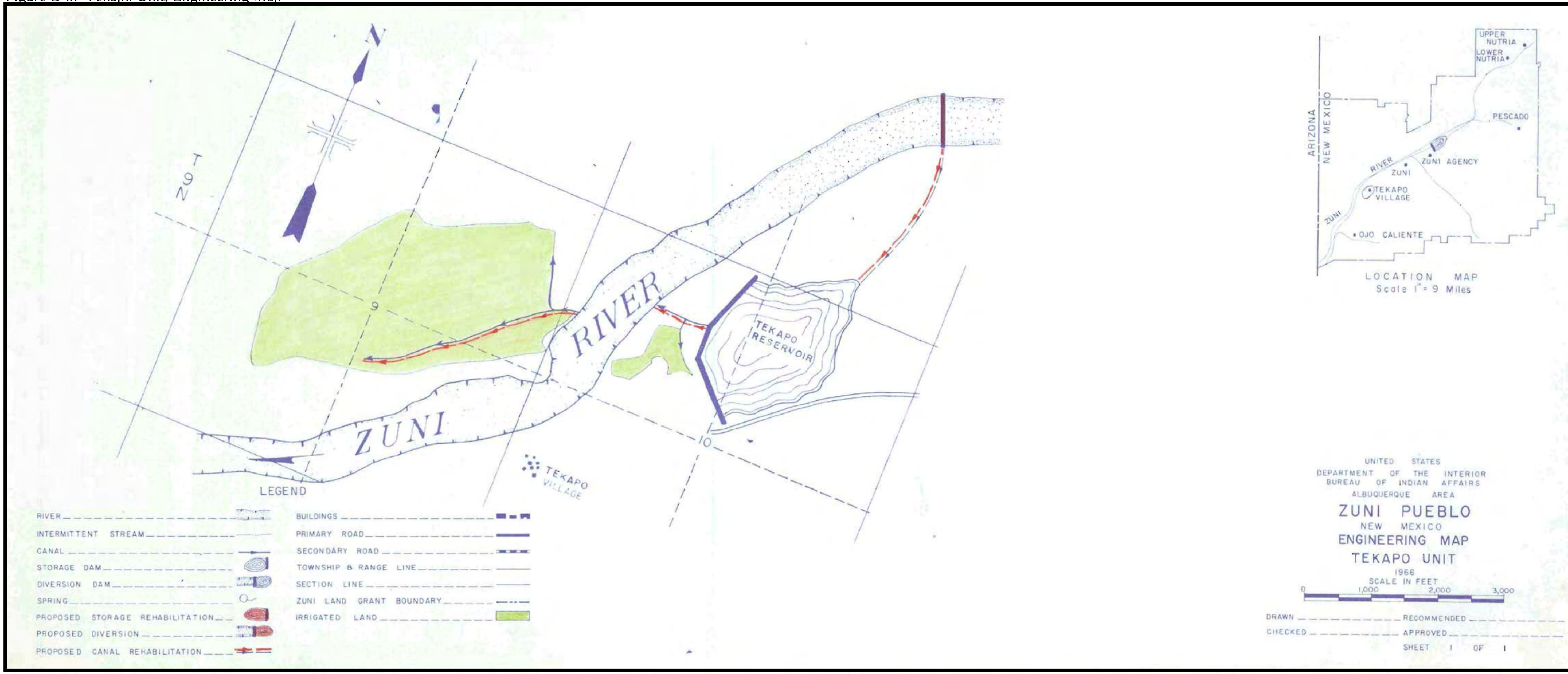


Figure B-9: Zuni Unit, Irrigated and Irrigable Lands Map

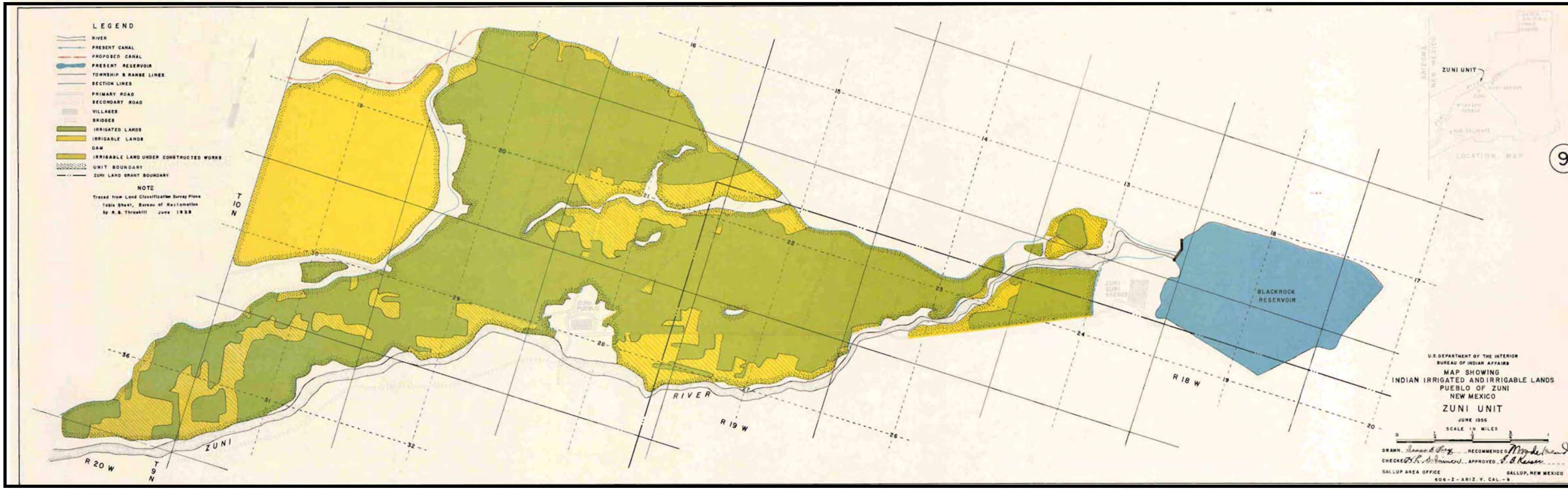
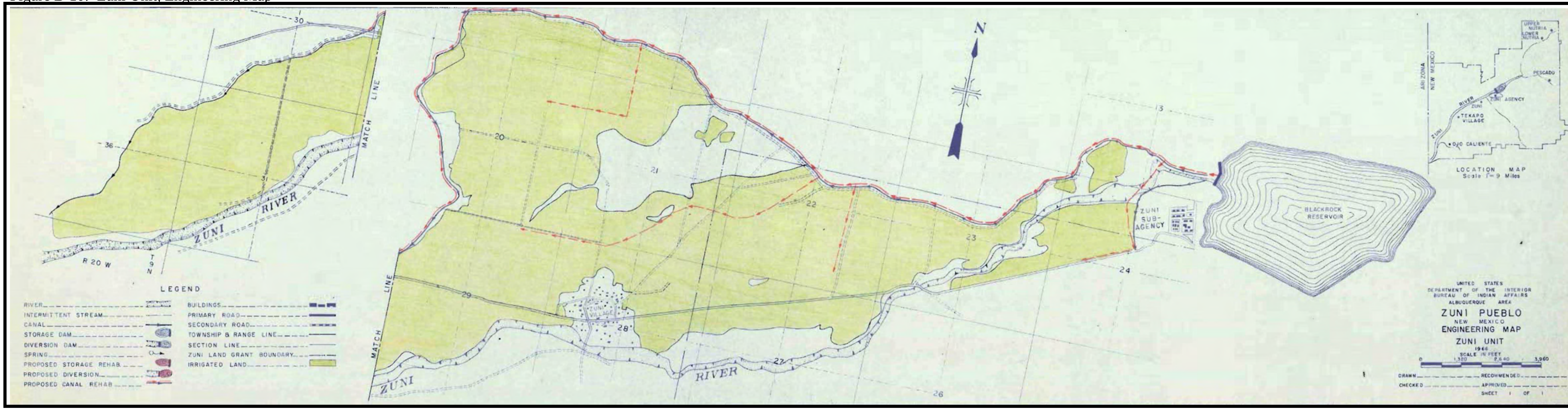


Figure B-10: Zuni Unit, Engineering Map



APPENDIX C

HISTORICAL AERIAL PHOTOS

Historical aerial photographs are provided for each irrigation unit for 1953-54 are provided for illustration. The composite irrigated land delineations, based on all years, are shown on each aerial photograph data set. The maps for the other years 1934-36, 1981, 1996-97, 2001, and 2005 are not shown in this Appendix.

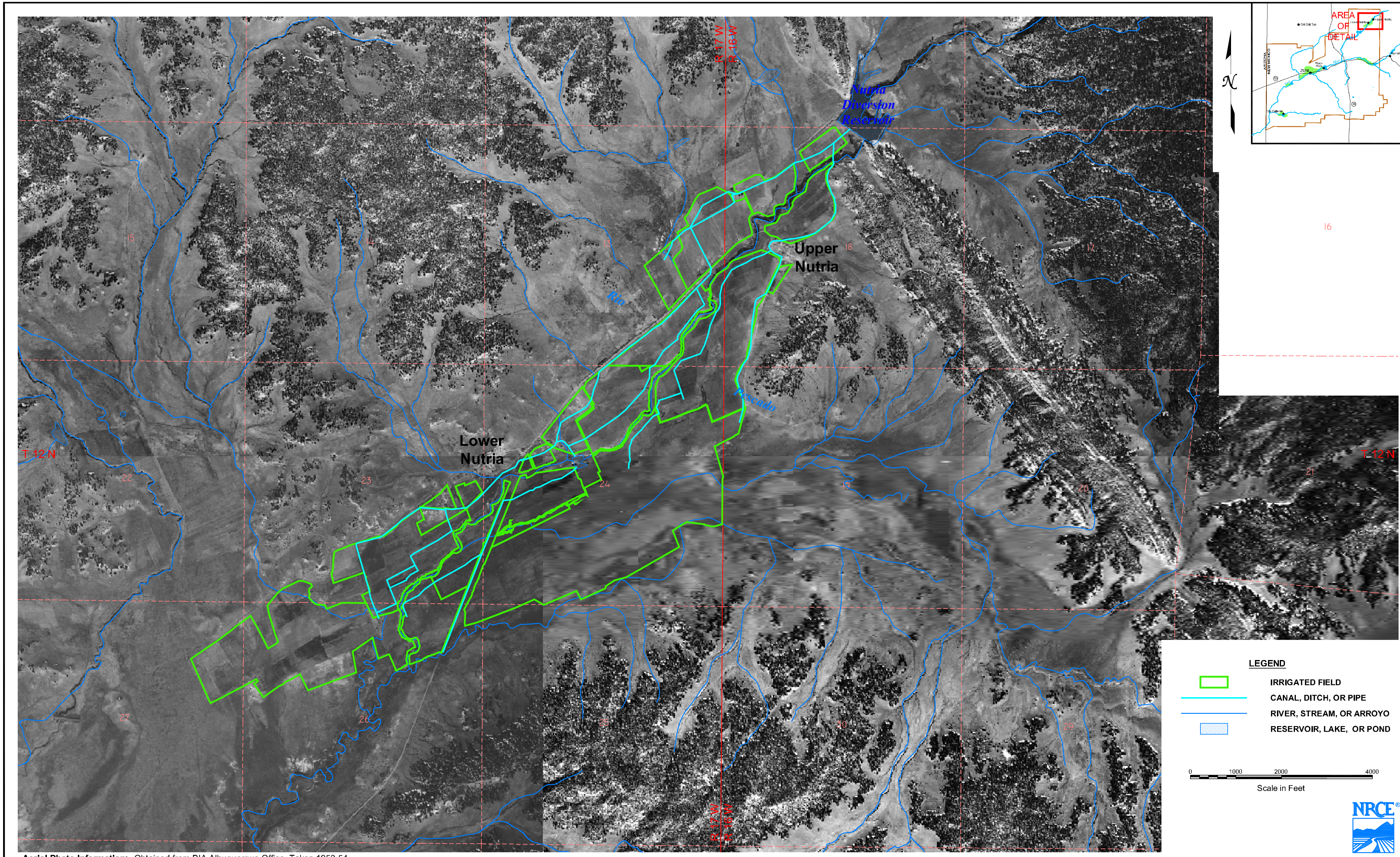
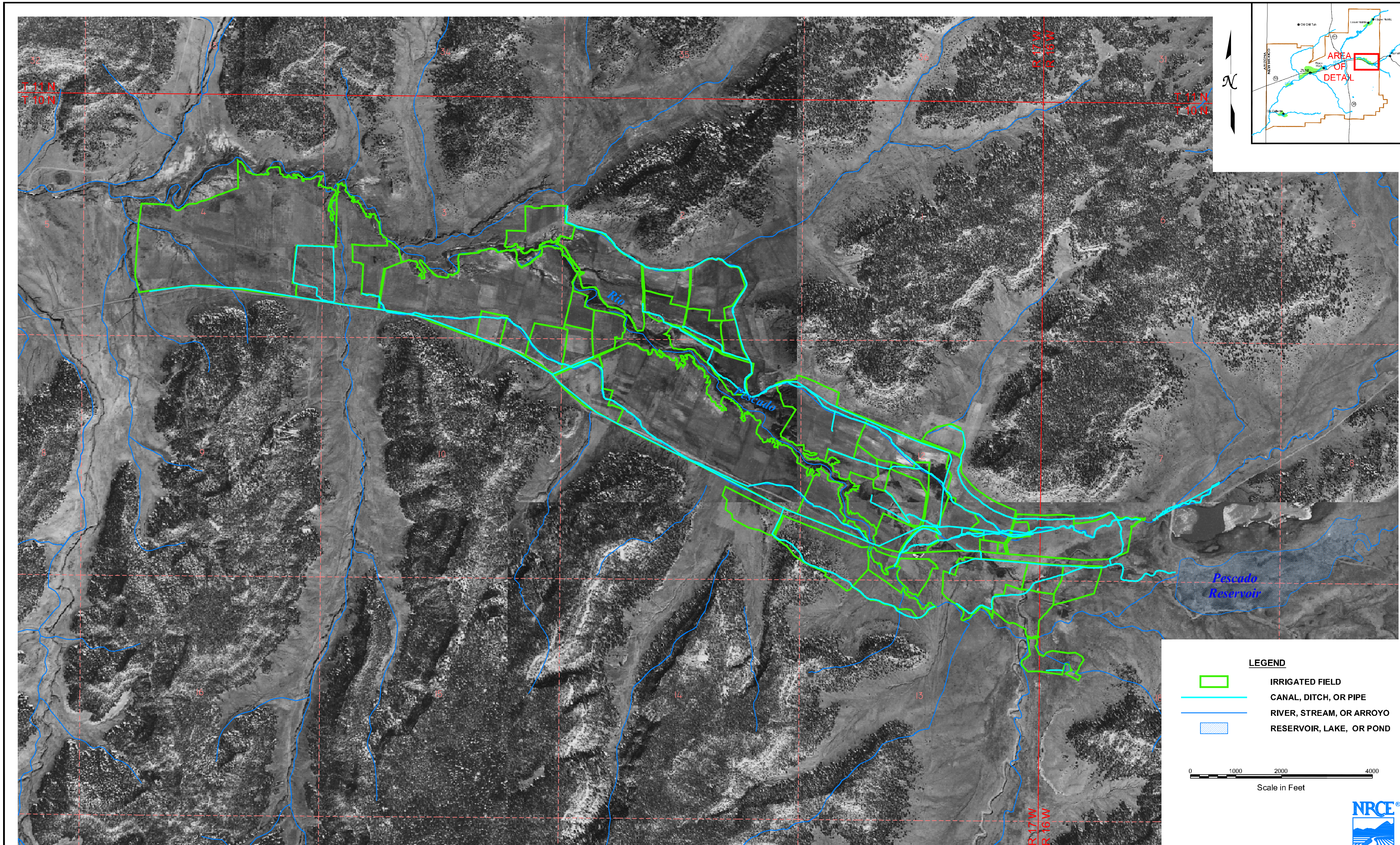


Figure C-1: Past and Present Irrigated Fields of the Nutria Agricultural Unit

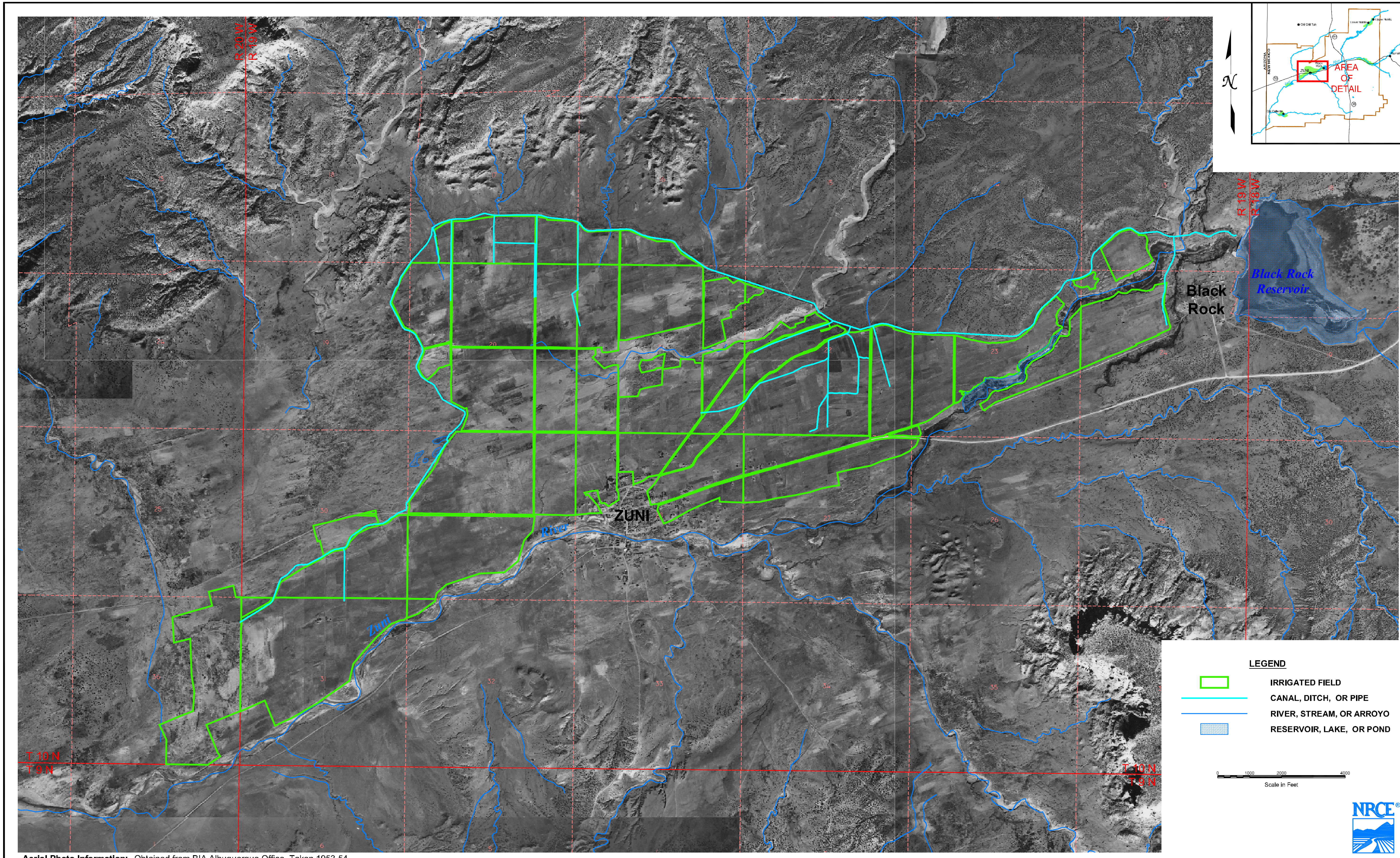
November 2008



Aerial Photo Information: Obtained from BIA Albuquerque Office, Taken 1953-54.

Figure C-2: Past and Present Irrigated Fields of the Pescado Agricultural Unit

November 2008



Aerial Photo Information: Obtained from BIA Albuquerque Office, Taken 1953-54.

Figure C-3: Past and Present Irrigated Fields of the Zuni Agricultural Unit

November 2008

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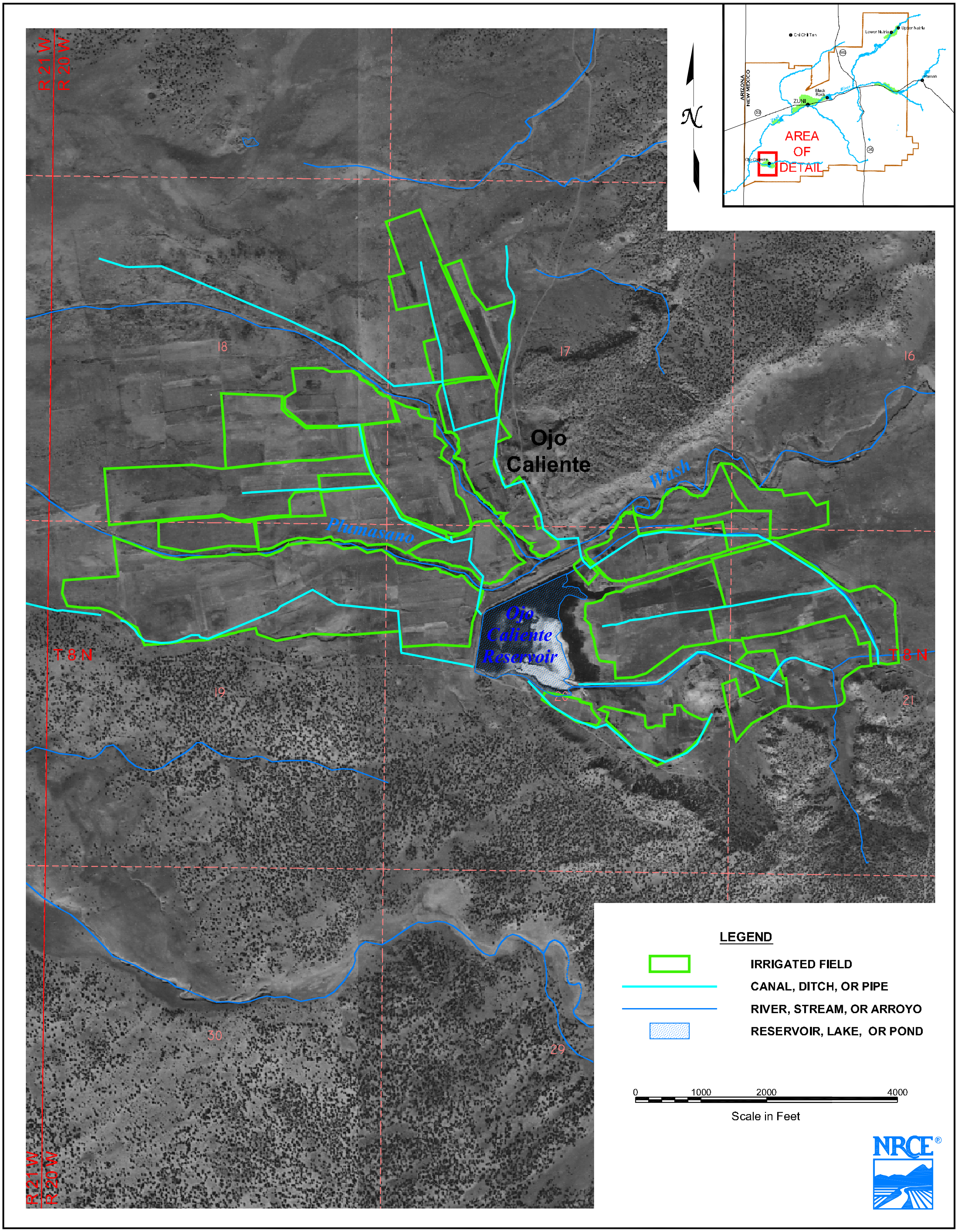


Figure C-4: Past and Present Irrigated Fields of the Ojo Caliente Agricultural Unit November 2008

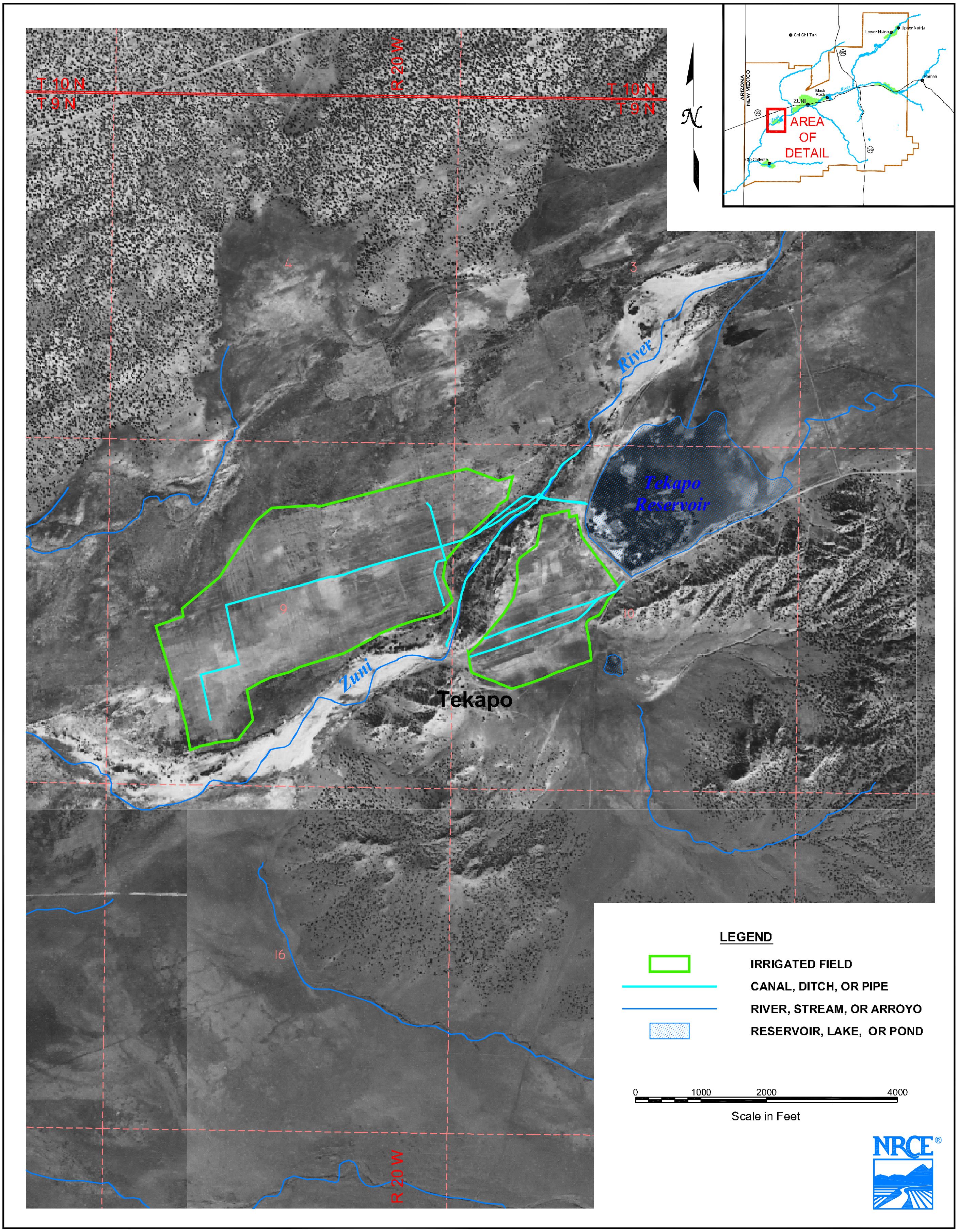


Figure C-5: Past and Present Irrigated Fields of the Tekapo Agricultural Unit November 2008

APPENDIX D

CROP MIX DATA

Appendix D provides graphs of crop mixes for each irrigation unit, from 1981 to 2004. The graphs indicate variations in the cropping pattern from year to year in each unit. The annual crop mixes were developed from the annual BIA crop reports for each unit. The "Crop % in Overall Mix, All Units" represents the weighted average crop mix used in the crop water requirement calculations. The "Average Crop %" for a particular irrigation unit represents the average percentage of that particular crop, in the specified unit only, based on all BIA crop reports from 1934-2004.

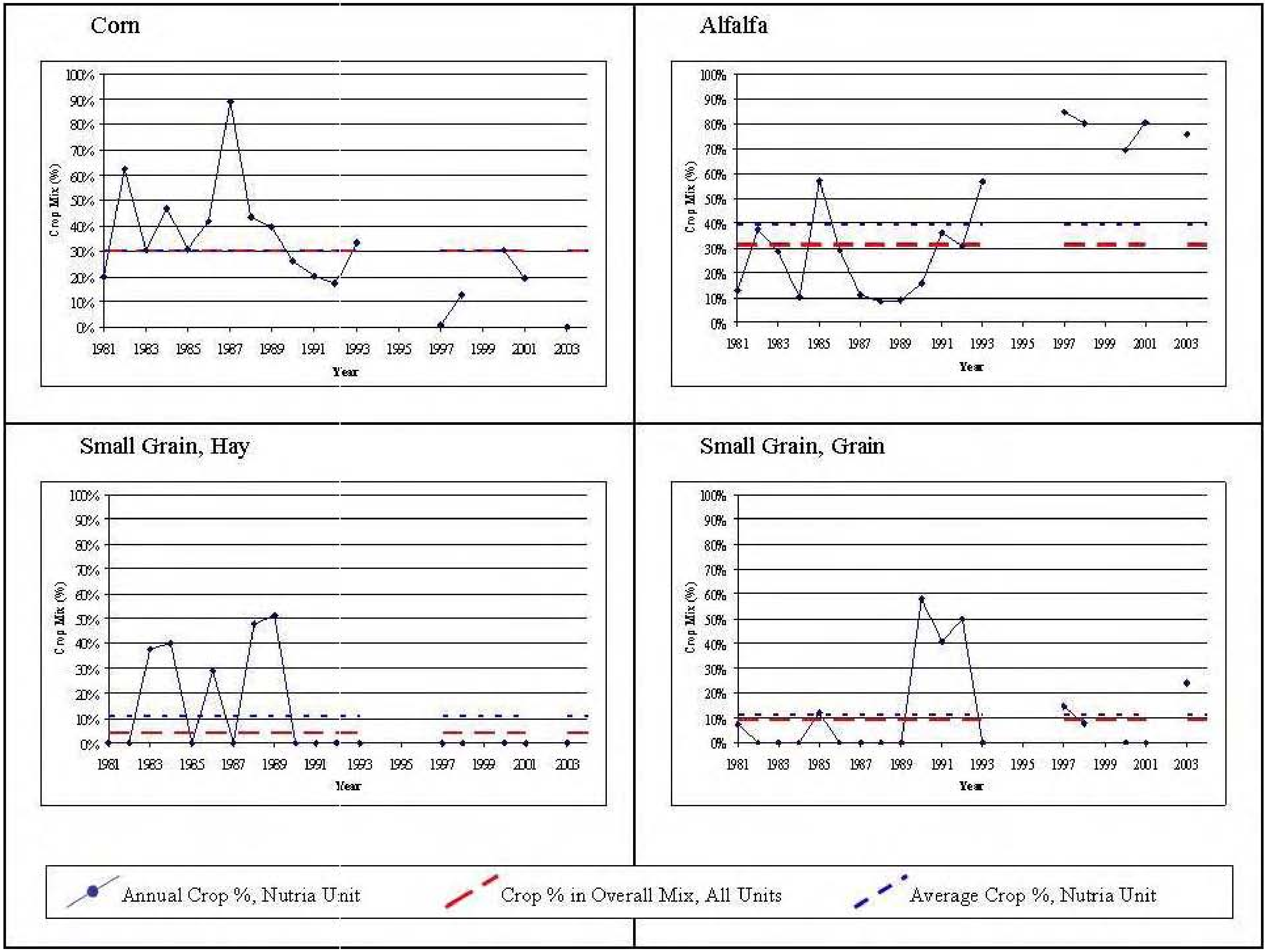


Figure D-1: Nutria Unit Crop Mix Data

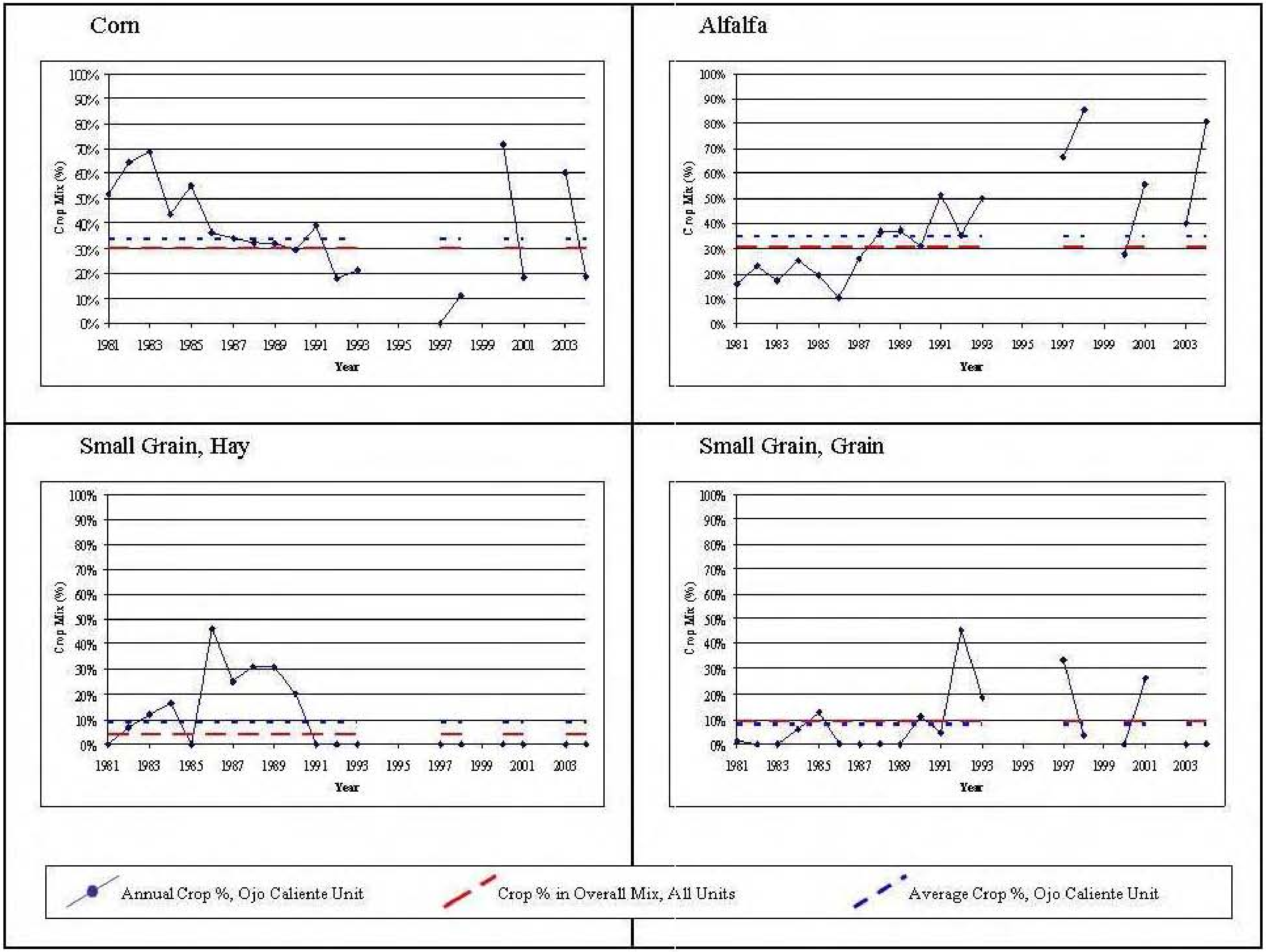


Figure D-2: Ojo Caliente Unit Crop Mix Data

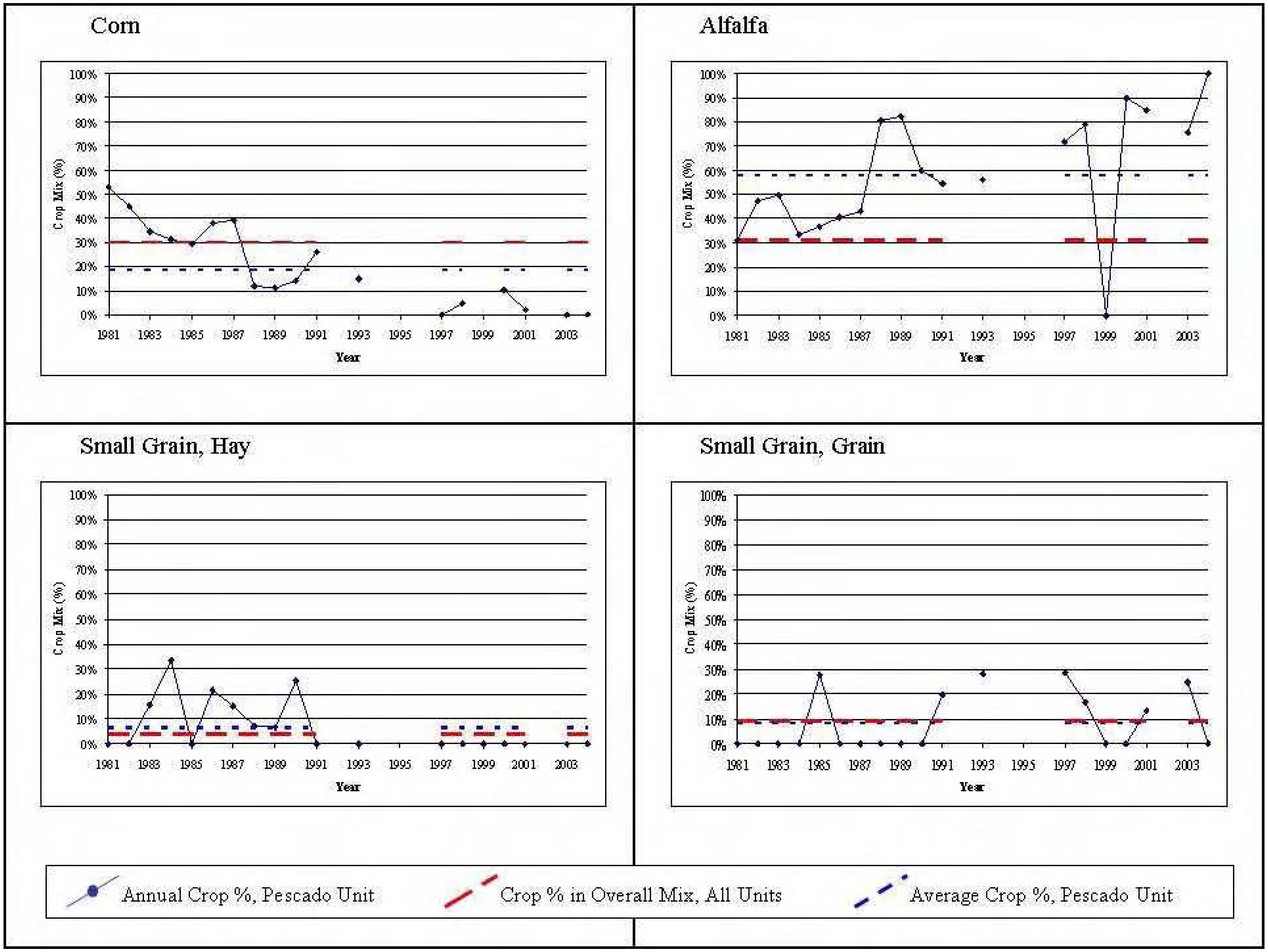


Figure D-3: Pescado Unit Crop Mix Data

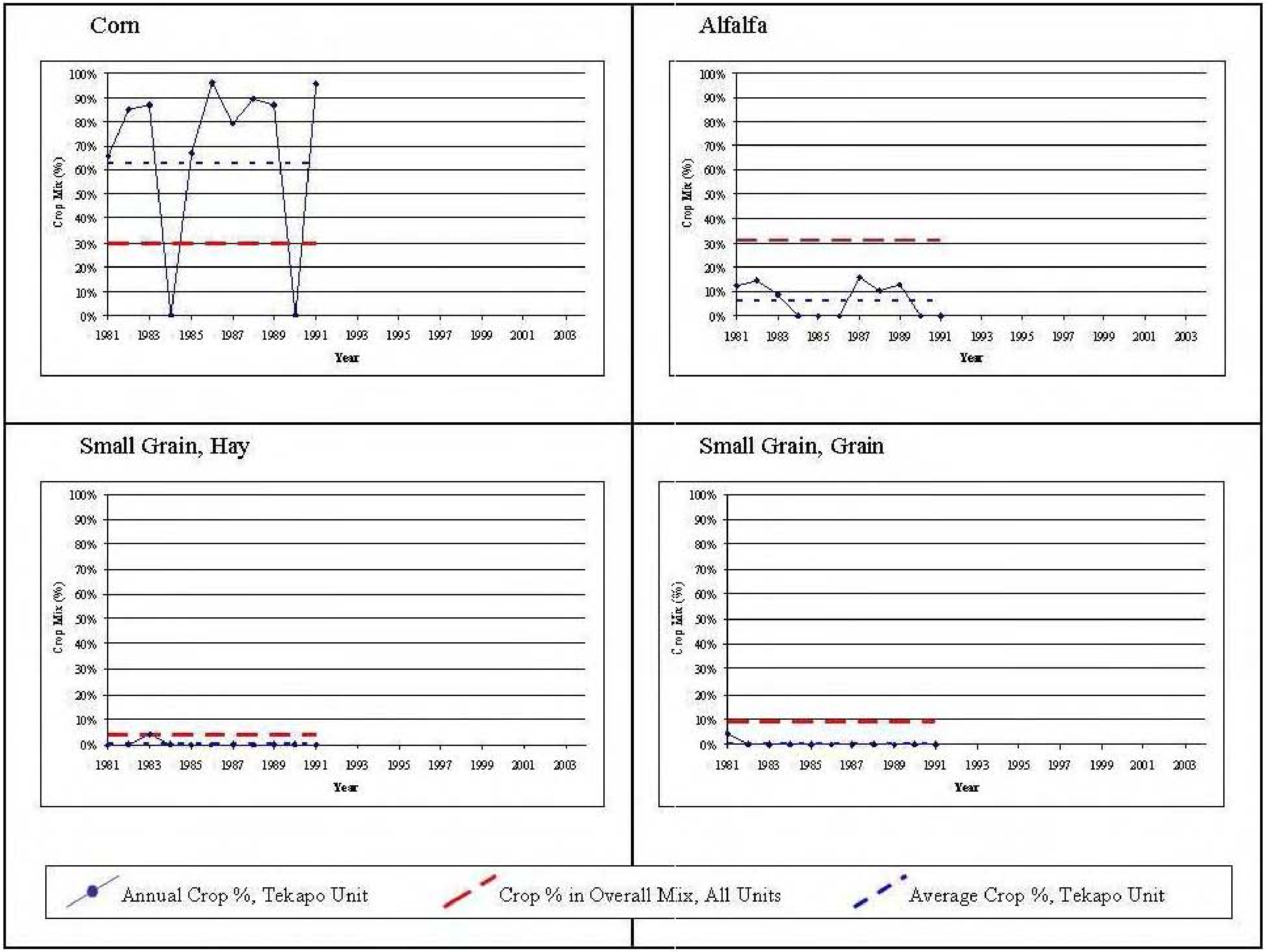


Figure D-4: Tekapo Unit Crop Mix Data

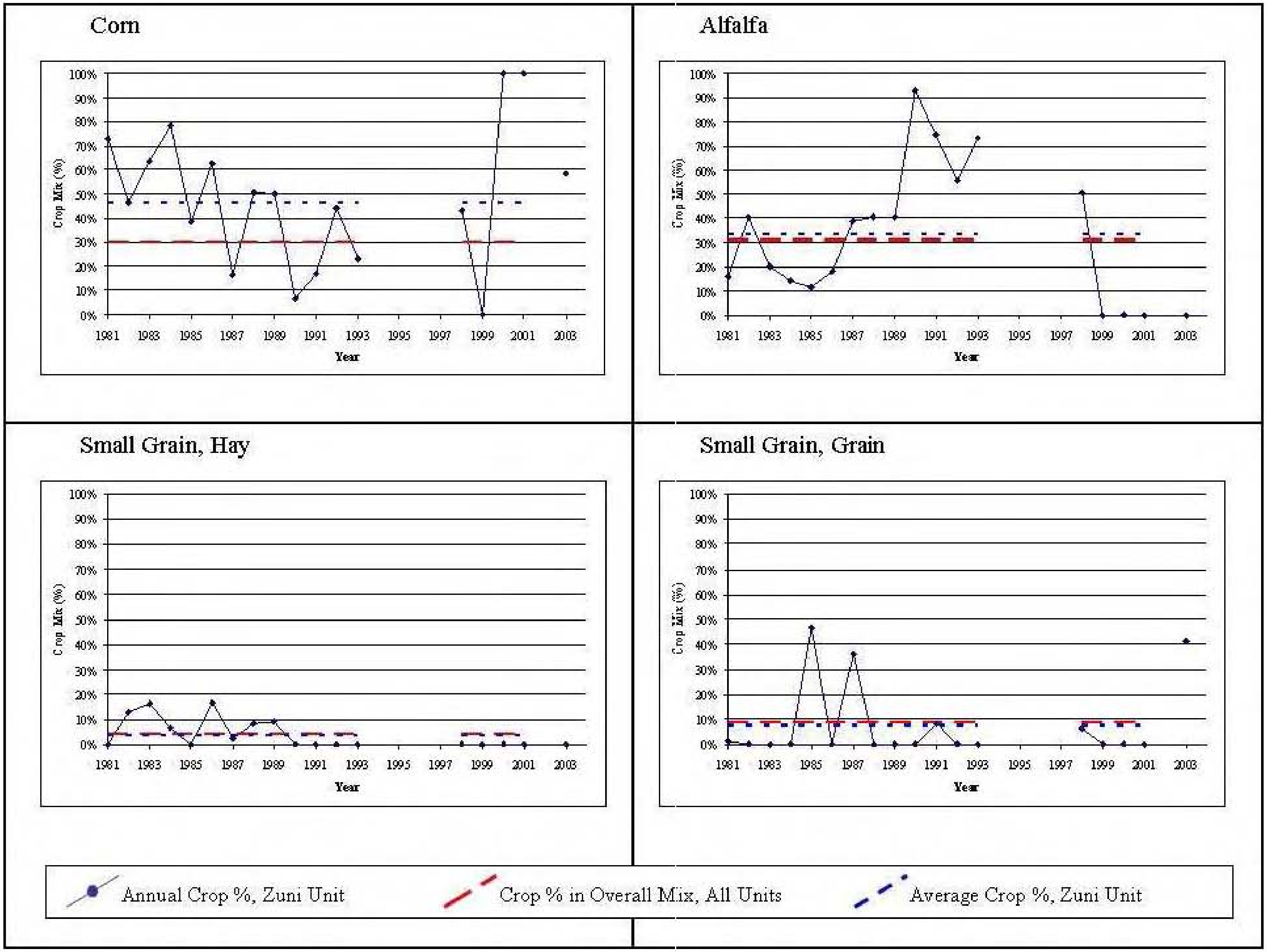


Figure D-5: Zuni Unit Crop Mix Data

APPENDIX E

CLIMATE DATA

Appendix E describes the climate data, and modifications to the climate data, used in generating estimates of crop ET. Original climate data were filled/extended to reduce missing values, and expanded to develop specific climate data for individual elevation bands.

The estimation of crop ET requires climatic inputs in the form of time series for the precipitation, reference evapotranspiration, air temperature, dew point temperature, solar radiation, and wind speed. This appendix describes the development of the climatic inputs for the Zuni Indian Reseravtion. Throughout this appendix, the following abbreviations are used: *Prcp* = precipitation, *Tmax* = maximum temperature, *Tmin* = minimum temperature, *Tavg* = average temperature, *Tdew* = dew point temperature, *Tskc* = total sky cover, *Wind* = wind speed, *Grad* = solar radiation, ET_{ref} = reference evapotranspiration, *Evap* = open water evaporation, and *Cwr* = crop water requirements.

E.1 Climatic Data

The climatic inputs for the ET calculations are constructed based on the historical climatic data. The historical climatic data used in the study were obtained from the National Climatic Data Center (NCDC) Summary of the Day (SD) and Surface Airways (SA) databases (EarthInfo 2005a, 2005b). The NCDC SD database contains daily records of *Prcp*, *Tmax*, and *Tmin*. The NCDC SA database contains hourly and daily records of *Tdew*, *Tskc*, and *Wind*. The climatic stations used are listed in Table E-1. The climatic data sets contain missing values. A summary of the missing data for each station/data type is shown in Table E-2 for years 1948 to 2004.

Table E-1: Summary of Climate Stations Used for the Development of Climatic Inputs.

Database	Station ID	Station Name	Latitude	Longitude	Elevation (feet)	Available Data			Period
NCDC SD	1018	Black Rock	N35:06:00	W108:47:00	6,453	Prcp	Tmax	Tmin	1908-1949
NCDC SD	2785	El Morro Natl Mon	N35:03:00	W108:21:00	7,227	Prcp	Tmax	Tmin	1938-2004
NCDC SD	3180	Fence Lake	N34:39:00	W108:40:00	7,055	Prcp	Tmax	Tmin	1933-2004
NCDC SD	5560	McGaffey 5 SE	N35:20:00	W108:27:00	8,000	Prcp	Tmax	Tmin	1949-2004
NCDC SD	9897	Zuni	N35:04:00	W108:50:00	6,310	Prcp	Tmax	Tmin	1949-2004
NCDC SA	23081	Gallup	N35:31:00	W108:47:00	6,466	Tdew	Tskc	Wind	1973-2004
NCDC SA	23050	Albuquerque	N35:03:00	W:106:37:00	5,310	Tdew	Tskc	Wind	1948-2004

Table E-2: Summary of Missing Climatic Data for Years 1948 to 2004.

Year	Number of Days with Missing Data																				
	Prcp					Tmax					Tmin					Tdew		Tskc		Wind	
	1018	2785	3180	5560	9897	1018	2785	3180	5560	9897	1018	2785	3180	5560	9897	23050	23081	23050	23081	23050	23081
1948	1	21	---	---	---	50	51	---	---	---	38	51	---	---	---	182	---	182	---	182	---
1949	184	7	---	17	47	189	17	---	26	47	189	27	---	22	47	0	---	0	---	0	---
1950	---	0	---	0	0	---	0	---	0	0	---	4	---	0	0	0	---	0	---	0	---
1951	---	0	---	1	0	---	0	---	1	1	---	0	---	1	0	0	---	0	---	0	---
1952	---	0	---	1	0	---	0	---	2	0	---	16	---	2	0	0	---	0	---	0	---
1953	---	0	---	0	0	---	0	---	1	0	---	0	---	1	0	0	---	0	---	0	---
1954	---	0	---	0	0	---	24	---	1	0	---	24	---	1	0	0	---	0	---	0	---
1955	---	0	---	62	0	---	3	---	62	0	---	10	---	62	0	0	---	0	---	0	---
1956	---	0	---	152	0	---	2	---	178	0	---	1	---	175	0	0	---	0	---	0	---
1957	---	0	---	0	0	---	1	---	0	1	---	1	---	0	0	0	---	0	---	0	---
1958	---	0	---	0	0	---	0	---	0	0	---	0	---	0	0	0	---	0	---	0	---
1959	---	0	---	0	0	---	0	---	0	0	---	0	---	0	0	0	---	0	---	0	---
1960	---	0	---	0	0	---	0	---	17	0	---	0	---	16	0	0	---	0	---	0	---
1961	---	0	---	0	0	---	0	---	9	0	---	0	---	8	0	0	---	0	---	0	---
1962	---	0	---	0	0	---	0	---	10	0	---	0	---	10	0	0	---	0	---	0	---
1963	---	0	---	0	2	---	0	---	7	2	---	0	---	7	2	0	---	0	---	0	---
1964	---	0	121	0	0	---	0	126	2	0	---	0	127	12	0	0	---	0	---	0	---
1965	---	13	0	0	0	---	12	19	1	0	---	12	19	1	0	0	---	0	---	0	---
1966	---	0	61	10	0	---	0	100	11	0	---	0	100	11	0	0	---	0	---	0	---
1967	---	0	0	0	0	---	0	33	16	0	---	0	37	16	0	0	---	0	---	0	---
1968	---	0	61	0	0	---	0	99	25	0	---	2	114	25	0	0	---	0	---	0	---
1969	---	0	170	0	0	---	2	143	47	0	---	1	145	47	0	0	---	0	---	0	---
1970	---	0	0	0	0	---	2	0	39	0	---	2	0	39	0	0	---	0	---	0	---
1971	---	0	11	33	0	---	0	0	45	0	---	0	0	45	0	0	---	0	---	0	---
1972	---	0	0	0	0	---	0	13	32	0	---	0	14	32	0	0	---	0	---	0	---
1973	---	0	0	0	284	---	0	23	17	255	---	0	23	17	314	0	7	0	7	0	7
1974	---	0	0	0	334	---	0	5	38	348	---	0	5	38	349	0	0	0	0	0	0
1975	---	0	0	0	31	---	0	1	27	105	---	0	1	27	164	0	0	0	0	0	0
1976	---	31	0	0	62	---	0	0	23	148	---	0	0	25	189	0	0	0	0	0	0
1977	---	0	2	0	0	---	1	2	19	6	---	0	2	18	7	0	0	0	0	0	0
1978	---	1	1	0	32	---	0	3	17	56	---	0	2	15	55	0	0	0	0	0	0
1979	---	2	0	0	0	---	0	1	15	37	---	0	1	15	36	0	0	0	0	0	0
1980	---	5	0	0	0	---	0	0	13	14	---	0	1	14	12	0	0	0	0	0	0
1981	---	0	0	0	0	---	1	0	18	19	---	2	0	18	82	0	0	0	0	0	0
1982	---	0	0	1	3	---	0	0	0	0	---	0	0	0	0	0	0	0	0	0	0
1983	---	1	0	0	3	---	0	0	0	0	---	0	0	0	0	0	0	0	0	0	0
1984	---	1	0	1	6	---	0	0	0	1	---	0	0	0	0	0	0	0	0	0	0
1985	---	4	0	0	4	---	0	0	0	0	---	0	0	0	0	0	0	0	0	0	0
1986	---	1	0	33	3	---	0	0	31	0	---	0	0	61	0	0	0	0	0	0	0
1987	---	0	0	6	3	---	0	0	0	0	---	0	0	0	0	0	0	0	0	0	0
1988	---	0	0	1	7	---	0	0	0	0	---	0	0	0	0	0	0	0	0	0	0
1989	---	0	0	0	1	---	0	0	0	16	---	0	0	0	20	0	0	0	0	0	0
1990	---	0	0	4	6	---	0	0	0	0	---	0	0	0	0	0	0	0	0	0	0
1991	---	1	1	13	1	---	0	0	0	0	---	0	0	0	0	0	0	0	0	0	0
1992	---	0	0	2	4	---	0	0	0	0	---	0	0	0	0	0	0	0	0	0	0
1993	---	2	0	3	2	---	0	0	0	0	---	0	0	1	0	0	0	0	0	0	0
1994	---	1	0	7	5	---	0	0	0	0	---	0	0	0	1	0	0	0	0	0	0
1995	---	1	0	0	0	---	0	0	0	0	---	1	0	1	0	0	0	0	0	0	0
1996	---	7	0	3	1	---	0	0	0	0	---	0	0	0	0	0	19	305	60	0	0
1997	---	4	2	8	15	---	0	0	0	0	---	0	0	1	0	0	0	---	59	0	0
1998	---	1	0	2	0	---	0	0	0	0	---	0	0	0	0	0	0	---	305	0	0
1999	---	61	0	0	0	---	61	0	2	0	---	62	0	18	1	0	80	---	121	0	31
2000	---	2	0	9	2	---	0	0	0	0	---	0	0	23	0	0	96	---	91	0	0
2001	---	1	1	24	1	---	20	0	0	0	---	25	0	37	0	0	0	---	---	0	0
2002	---	0	0	57	0	---	0	0	39	0	---	0	0	39	0	0	0	---	---	0	0
2003	---	3	0	15	1	---	0	0	14	0	---	0	0	14	0	0	0	---	---	0	0
2004	---	0	5	19	3	---	0	5	20	0	---	0	5	21	0	0	0	---	---	0	0
Total	1210	326	2231	484	863	1423	435	1828	825	1056	1424	472	1864	936	1279	182	202	487	643	182	38
% Miss	7.89	1.33	11.75	2.37	4.22	9.28	1.78	10.01	4.03	5.16	9.28	1.93	10.21	4.58	6.25	0.87	1.73	2.72	6.29	0.87	0.33

Notes: Percentage of missing data calculated with respect to the number of years on record for the particular station/variable.
"---" indicates years with no data which are not included in the calculation of the percentage of missing data.

E.2 Filling of Missing Data/Record Extension

The first step in the development of the climatic inputs is to fill all missing data and to extend the period of record for the shorter-term stations. This process will be referred to as “filling/extension”. The general method used for the filling/extension at the station where data is missing on a given day is to utilize the data from one or more nearby stations at which the data are available on that day.

Based on the review of Table E-2, the following conclusions can be made:

- The complete data sets for *Prcp*, *Tmax*, and *Tmin* for the El Morro, Fence Lake, McGaffey, and Zuni stations can be developed for calendar years 1948-2004.

- The complete data sets for *Tdew* and *Wind* for the Gallup station can be developed for the period from July 1, 1948 through December 31, 2004, using data from the 23050 Albuquerque station (the 182 missing days in 1948 at the Albuquerque station are from January 1 through June 30).

- A nearly complete record for *Tskc* for the Gallup station can be developed for the period from July 1, 1948 through 1995, using data from the 23050 Albuquerque station. Filling/extension to obtain a complete *Tskc* record through 2004 was accomplished using a method from the literature (Thornton and Running, 1999).

Since *Prcp*, *Tmax*, *Tmin*, *Tdew*, *Tskc* and *Wind* are all needed for the development of the climatic inputs, the complete set of the climatic inputs can be developed for the period from July 1, 1948 through December 31, 2004.

The Black Rock and Zuni stations are located near to each other, separated by a distance of less than four miles and an elevation difference of less than 150 feet. However, the common period of record between them is insufficient to determine the statistical relationship between these records. Therefore, Black Rock *Prcp*, *Tmax*, and *Tmin* records were appended on to the Zuni records of these variables to form a single long station record.

The procedures used for the filling/extension are described in the following sections.

E.2.1 Air Temperature

Filling/extension of the maximum and minimum temperature data was performed using the linear regression method. In this method, the missing data at station Y ("filled station") is filled/extended using the data from station X ("filling station") using the equation $y = a + bx$, where x is the data at the station X; y is the estimate for the missing data at station Y; $b = S_{xy} / S_{xx}$; $a = \bar{y} - b\bar{x}$; $\bar{x}$ and $\bar{y}$ are the means of x and y, respectively, during the common period of record of stations X and Y; $S_{xx} = \sum_{i=1}^{n} (x_i - \bar{x})^2$; $S_{xy} = \sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})$; and n is the number of days on the common period of record of stations X and Y.

The missing data was first filled/extended using the data from the climatic station that exhibited the highest degree of correlation of the average temperature with the climatic station being filled. Any remaining missing data was filled using the data from the climatic station that exhibited the next-highest degree of correlation of the average temperature with the climatic station being filled, and so forth until all stations have been considered. Any remaining missing data was filled by linear interpolation. The average daily temperatures were calculated as the arithmetic averages of the maximum and minimum daily temperatures.

Table E-3 and Table E-4 present the filling/extension summaries for the maximum and minimum temperature data. It can be seen from this table that the majority of the missing data was filled/extended as follows:

- Station 2785 El Morro was filled mostly by the station 9897 Zuni,
- Station 3180 Fence Lake was filled mostly by the station 2785 El Morro,
- Station 5560 McGaffey was filled mostly by the station 2785 El Morro,
- Station 9897 Zuni was filled mostly by the station 2785 El Morro.

Several missing days were also filled by linear interpolation, all of which occur in calendar years 1948 and 1949, (October 1, 1949).

Table E-3: Summary of Filling/Extension of the Maximum Temperature Data.

Filled Station	Filling Station	Intercept *a*	Slope *b*	R^2	Days Filled	Total Days Filled by Regression	Total Days Filled by Interpolation	Total Days Filled
2785	9897	-0.7956	0.9673	0.951	193	193	4	197
3180	2785	3.1235	0.9779	0.955	6,318	6,413	4	6,417
	9897	0.9412	0.9608	0.938	95			
5560	2785	-1.0725	0.9487	0.911	1,134	1,187	4	1,191
	9897	-3.2122	0.9351	0.903	53			
9897	2785	4.1057	0.9829	0.951	1,055	1,055	4	1,059

Table E-4: Summary of Filling/Extension of the Minimum Temperature Data.

Filled Station	Filling Station	Intercept *a*	Slope *b*	R^2	Days Filled	Total Days Filled by Regression	Total Days Filled by Interpolation	Total Days Filled
2785	9897	-1.5538	0.9635	0.916	236	238	3	241
	3180	1.3567	0.9489	0.896	2			
3180	2785	2.0107	0.9445	0.896	6,305	6,437	3	6,440
	9897	-0.0760	0.9399	0.885	132			
5560	2785	-2.5120	0.9351	0.872	1,240	1,299	3	1,302
	9897	-5.4015	0.9394	0.874	59			
9897	2785	4.3504	0.9505	0.916	1,265	1,267	3	1,270
	3180	4.0415	0.9413	0.885	2			

E.2.2 Dew Point Temperature

The NCDC SA database contains hourly and daily dew point temperature data for the Gallup and Albuquerque stations. The calculations of solar radiation and reference evapotranspiration require daily dew point temperature data. Therefore, the daily dew point temperature record for the Gallup station was filled/extended using data from the Albuquerque station.

Filling/extension of the Gallup dew point temperature data was performed using the linear regression method described in Section E.2.1. Table E-5 presents the filling/extension summary for the dew point temperature data.

Table E-5: Summary of Filling/Extension of the Gallup Dew Point Temperature Data

Filled Station	Filling Station	Intercept *a*	Slope *b*	R^2	Days Filled by Regression	Days Filled Other Methods	Total Days Filled
23081	23050	1.4124	0.8545	0.8273	9152	0	9152

E.2.3 Total Sky Cover

The NCDC SA database contains hourly and daily total sky cover data for the Gallup and Albuquerque stations. The calculations of solar radiation and reference evapotranspiration require daytime sky cover data. Therefore, the daytime total sky cover record for the Gallup station was filled/extended using data from the Albuquerque station. The daytime total sky cover was calculated from the hourly sky cover observations between sunrise and sunset.

Extension of the daytime Gallup total sky cover record for the period July 1, 1948 through January 7, 1973 was performed using the linear regression method described in Section E.2.1. Filling of missing data in years 1996 to 2000 and extension of the record for years 2001 to 2004 was performed as follows. The Thornton and Running (1999) method was used to calculate for the attenuation to solar radiation due to cloud cover, called f_{cloud}, at the Gallup station, as described in Appendix E. The total sky cover was then calculated as a function of f_{cloud}. Subsequently, several remaining missing values were filled by linear interpolation. Table E-6 presents the filling/extension summary for the total sky cover data.

Table E-6: Summary of Filling/Extension of the Gallup Daytime Total Sky Cover Data.

Filled Station	Filling Station	a	b	R^2	Days Filled by Regression	Days Filled by Thornton & Running method	Days Filled by Linear Interpolation	Total Days Filled
23081	23050	10.661	0.7858	0.6251	8956	2100	4	11060

E.2.4 Wind Speed

The NCDC SA database contains hourly and daily wind speed data for the Gallup and Albuquerque stations. The ASCE Penman-Monteith equation also requires daily wind speed data as an input. Therefore, the daily wind speed records for the Gallup station were filled/extended using data from the Albuquerque station.

The filling/extension of the wind speed data was performed using the method of ratio of monthly means (RMM). In this method, the missing data at station Y ("filled station") in month m is filled using the data from station X ("filling station") using the equation $y = b_m x$; where x is the data at the station X; y is the estimate for the missing data at station Y; $b_m = \bar{y}_m / \bar{x}_m$; and $\bar{x}_m$ and $\bar{y}_m$ are the monthly means of x and y, respectively, during the common period of record of stations X and Y in month m. Subsequently, several missing days in the daytime record were filled by linear interpolation. Table E-7 presents the filling/extension summary for the wind speed data.

Table E-7: Summary of Filling/Extension of the Gallup Wind Speed Data Using the Albuquerque Wind Speed Data.

Ratios of Monthly Means												Days Filled by RMM	Total Days Filled by Linear Interpolation	Total Days Filled
Jan b_1	Feb b_2	Mar b_3	Apr b_4	May b_5	Jun b_6	Jul b_7	Aug b_8	Sep b_9	Oct b_{10}	Nov b_{11}	Dec b_{12}			
0.658	0.734	0.839	0.853	0.848	0.807	0.767	0.741	0.757	0.714	0.728	0.671	8988	0	8988

E.2.5 Precipitation

Filling/extension of the precipitation data was performed using a modified version of the method of inverse-distance squared interpolation (Maidment, 1993) that accounts for the ratios of the monthly means using the RMM method presented in Section E.2.1. The method used also incorporates the feature of the Thornton et al. (1997) approach by which the probability of precipitation (POP_P) on the missing day at station Y ("filled station") is calculated from in the observed precipitation at n surrounding stations X_1, X_2, …, X_n ("filling stations") using the equation:

$$POP_P = \frac{\sum_{i=1}^{n} d_i^{-2} PO_i}{\sum_{i=1}^{n} d_i^{-2}}, \qquad PO_i = \begin{Bmatrix} 0; & x_i = 0 \\ 1; & x_i > 0 \end{Bmatrix},$$

where d_i is the distance from station X_i to station Y in miles, x_i is the daily precipitation observed at station X_i in inches, and PO_i is a binomial variable related to precipitation occurrence at station X_i. Precipitation is estimated to occur at station Y when POP_P is greater than or equal to a critical threshold, POP_{crit}, which Thornton et al. (1997) estimated to be 0.52 for their analyses. For the present study, POP_{crit} was set equal to 0.5. For missing days with $POP_P < 0.5$, the missing precipitation value was set equal to zero. For missing days with $POP_P \geq 0.5$, the missing precipitation value at station Y in month m was filled using the observed precipitation data at the n surrounding stations X_1, X_2, …, X_n using the equation:

$$y = \left\{ \frac{\sum_{i=1}^{n} d_i^{-2} PO_i x_i}{\sum_{i=1}^{n} d_i^{-2} PO_i} \right\} b_m^i,$$

where d_i, x_i, and PO_i are the same as defined above and b_m^i is the ratio of the monthly means as between stations X_i and Y as defined in Section E.2.1.

For this study, the minimum allowable number of stations to be used to fill a missing value, n, was set equal to two. Stations were selected for use in filling a missing value if they have at least four years common period of record with the filled station, have a daily cross-correlation coefficient of at least 0.3, and fall within a 50-mile radius about the filled station. Although Thornton et al. (1997) report finding good results for a larger radius (87 miles) and for a large number of stations (average on the order of 20 to 30), in the present study of the Zuni River System, better results were found using the smaller radius (50 miles) and generally fewer stations (5 to 7 on average). This difference may be due to the smaller area of the present study and to the relative sparseness of stations in the Zuni region.

One additional criterion was applied: A minimum difference of 45 degrees in the azimuths between stations used in a spatial group about a station being filled was used. The purpose of this is to ensure that spatial interpolation is performed using stations that *surround* the filled station rather than using several nearby stations that are all lined up in the same direction from the filled station.

The climatic stations used in the filling/extension of the precipitation records are listed in Table E-8.

Table E-8: Stations Used to Fill/Extend Precipitation Records.

Station ID	Latitude (d:m:s)	Longitude (d:m:s)	Elevation (feet)	Begin Date	End Date	Coverage (%)	Record Years	Station Name
74	N35:03:00	W107:43:00	6,585	1/1/1941	4/28/1953	98.8	13	ACOMITA CAA AP
1080	N35:15:00	W108:02:00	6,804	7/ 1/1896	11/30/1959	75.9	55	BLUEWATER 3 WSW
2219	N35:41:00	W108:09:00	6,965	7/1/1914	11/12/1969	92.1	56	CROWNPOINT
2780	N35:01:00	W108:24:00	7,123	3/1/1940	2/14/1949	93.0	10	EL MORRO CAA AIRPORT
2785	N35:02:17	W108:20:57	7,223	3/1/1938	12/31/2004	98.9	67	EL MORRO NATL MON
3180	N34:39:10	W108:40:35	7,065	11/1/1933	12/31/2004	64.5	52	FENCE LAKE
3305	N35:28:00	W108:32:00	7,005	3/ 1/1897	7/22/1966	56.1	43	FORT WINGATE
3420	N35:32:00	W108:39:00	6,604	8/1/1918	12/31/1979	54.9	39	GALLUP 5 E
3422	N35:30:40	W108:47:22	6,472	7/1/1973	12/31/2004	100.0	32	GALLUP FAA AP
3431	N35:36:00	W108:46:00	6,745	7/1/1922	5/31/1951	98.1	30	GAMERCO
3626	N35:20:00	W108:45:00	7,306	4/26/1919	12/24/1948	63.9	23	GOWER
3678	N35:10:00	W107:52:00	6,506	6/1/1945	10/31/1956	94.3	12	GRANTS
5560	N35:20:11	W108:26:41	8,000	1/1/1949	12/1/2004	98.0	56	MCGAFFEY 5 SE
7180	N34:20:41	W108:29:32	6,878	7/1/1915	12/31/2004	76.5	81	QUEMADO
7435	N34:31:02	W109:24:10	5,790	8/26/1901	12/31/2004	92.4	101	SAINT JOHNS
7488	N35:13:26	W109:19:20	5,853	11/1/1942	12/31/2004	74.6	53	SANDERS
7827	N35:06:00	W107:36:00	6,165	5/1/1920	9/30/1976	91.5	57	SAN FIDEL 2 E
8261	N35:27:00	W108:34:00	7,106	8/1/1943	7/31/1966	86.6	23	GALLUP RANGER STN
8919	N35:51:00	W108:44:00	6,424	7/14/1914	4/30/1979	82.5	64	TOHATCHI 1 ESE
9410	N35:37:01	W109:07:28	6,920	3/1/1937	9/1/1999	95.0	62	WINDOW ROCK 4 SW
1018-9897	N35:04:14	W108:50:20	6,311	6/1/1908	12/1/2004	95.2	97	ZUNI / BLACK ROCK
3969-6812	N34:29:35	W107:53:18	7,961	9/1/1943	12/1/2004	91.6	60	PIETOWN 19 NE / HICKMAN

As may be seen from Table E-8, for the purpose of filling/extension, the records for NCDC SD stations 3969 Pietown 19 NE and 6812 Hickman were also combined to for a single precipitation record. These stations share no common period of record, yet are located within about three miles of each other, and their elevations are different by only 156 feet.

E.3 Precipitation Data Filling/Extension Data

This section presents tables that summarize the filling/extension of the daily precipitation records according to the methodology presented in Section E.2.5.

Table E-9: Stations Used in Filling/ Extending Station 5560 McGaffey

Station Rank	Station ID	Distance to station (miles)	Cross-correlation coefficient	Common period of record (days)	Azimuth to station (degrees)	Ratios of the means
1	8261	10.43	0.574	6,156	318.8	1.324
2	3305	10.29	0.449	6,145	331.0	1.475
3	1018-9897	25.16	0.443	19,157	229.5	1.574
4	2785	21.31	0.427	19,821	165.3	1.373
5	3420	17.84	0.400	10,389	319.7	1.818
6	3180	49.03	0.381	14,290	195.6	1.442
7	9410	42.82	0.377	17,240	296.9	1.618
8	2219	29.12	0.338	6,964	34.6	1.728
9	74	45.69	0.336	1,557	115.7	1.939
10	8919	38.99	0.319	10,116	335.5	1.842
11	3678	34.69	0.314	2,591	109.8	1.722
12	3422	22.84	0.311	11,270	301.9	1.774

Table E-10: Sations Used in Filling/ Extending Station 1018-9897 Blackrock-

Station Rank	Station ID	Distance to station (miles)	Cross-correlation coefficient	Common period of record (days)	Azimuth to station (degrees)	Ratios of the means
1	3180	31.49	0.494	15,949	168.9	0.904
2	2785	24.93	0.473	23,095	99.9	0.875
3	3626	16.23	0.450	6,703	6.6	0.930
4	5560	25.12	0.443	19,157	49.4	0.635
5	7488	31.60	0.425	16,102	285.7	1.024
6	8261	27.08	0.414	7,254	26.8	0.846
7	3420	30.86	0.406	11,521	14.1	1.182
8	3422	28.41	0.404	10,795	359.3	1.072
9	2780	22.44	0.400	2,809	104.9	1.070
10	3305	28.98	0.389	10,296	29.0	0.900
11	9410	40.53	0.368	20,641	331.8	1.037
12	7440	45.61	0.349	5,822	329.1	0.910
13	3431	34.56	0.332	10,197	1.6	0.970
14	1080	43.57	0.304	14,582	76.2	1.214

Table E-11: Periods Filled/ Extended for Station 5560 McGaffey

Days filled	First date filled	Last date filled	Number of stations used	IDs of Stations Used:
8	1/1/1948	1/9/1948	8	3305, 10189897, 2785, 9410, 2219, 74, 8919, & 3678
1	1/8/1948	1/8/1948	7	3305, 2785, 9410, 2219, 74, 8919, & 3678
79	1/10/1948	4/23/1948	9	8261, 3305, 10189897, 2785, 9410, 2219, 74, 8919, & 3678
18	1/31/1948	4/19/1948	8	8261, 3305, 10189897, 2785, 9410, 2219, 74, & 8919
1	3/11/1948	3/11/1948	8	8261, 10189897, 2785, 9410, 2219, 74, 8919, & 3678
7	4/3/1948	4/9/1948	7	8261, 3305, 10189897, 9410, 2219, 74, & 8919
49	4/24/1948	2/24/1952	10	8261, 3305, 10189897, 2785, 3420, 9410, 2219, 74, 8919, & 3678
7	5/8/1948	5/14/1948	8	8261, 3305, 10189897, 2785, 9410, 2219, 74, & 3678
7	5/15/1948	5/21/1948	9	8261, 3305, 10189897, 2785, 3420, 9410, 2219, 74, & 3678
7	6/12/1948	6/18/1948	9	3305, 10189897, 2785, 3420, 9410, 2219, 74, 8919, & 3678
154	7/1/1948	1/17/1949	9	8261, 3305, 10189897, 2785, 3420, 2219, 74, 8919, & 3678
13	7/10/1948	10/29/1948	8	8261, 3305, 10189897, 3420, 2219, 74, 8919, & 3678
29	9/1/1948	9/30/1948	8	8261, 3305, 10189897, 2785, 3420, 74, 8919, & 3678
1	9/14/1948	9/14/1948	7	8261, 3305, 10189897, 2785, 3420, 74, & 8919
1	10/21/1948	10/21/1948	8	8261, 3305, 10189897, 2785, 3420, 2219, 74, & 8919
1	10/28/1948	10/28/1948	7	8261, 3305, 10189897, 3420, 2219, 74, & 8919
1	10/30/1948	10/30/1948	8	8261, 3305, 10189897, 2785, 2219, 74, 8919, & 3678
1	12/28/1948	12/28/1948	8	3305, 10189897, 2785, 3420, 2219, 74, 8919, & 3678
34	8/7/1955	2/24/1956	8	8261, 3305, 10189897, 2785, 3420, 9410, 8919, & 3678
1	11/9/1955	11/9/1955	7	8261, 10189897, 2785, 3420, 9410, 8919, & 3678
117	12/1/1955	8/31/1956	9	8261, 3305, 10189897, 2785, 3420, 9410, 2219, 8919, & 3678
1	1/14/1956	1/14/1956	8	8261, 10189897, 2785, 3420, 9410, 2219, 8919, & 3678
15	3/1/1956	4/19/1956	7	8261, 3305, 10189897, 2785, 9410, 8919, & 3678
46	3/14/1956	4/30/1956	8	8261, 3305, 10189897, 2785, 9410, 2219, 8919, & 3678
10	9/21/1966	9/30/1966	7	10189897, 2785, 3420, 3180, 9410, 2219, & 8919
31	11/1/1971	12/3/1971	6	10189897, 2785, 3420, 3180, 9410, & 8919
2	11/15/1971	11/16/1971	5	10189897, 2785, 3420, 3180, & 9410
76	3/18/1982	7/16/1998	5	10189897, 2785, 3180, 9410, & 3422
3	8/21/1986	11/27/1997	4	2785, 3180, 9410, & 3422
127	2/9/1993	12/31/2004	4	10189897, 2785, 3180, & 3422
1	10/15/1994	10/15/1994	4	10189897, 3180, 9410, & 3422
1	1/7/1997	1/7/1997	3	10189897, 2785, & 3422

Note: The period from first to last date filled may not be continuous.

Table E-12: Periods Filled/ Extended for Station 1018-9897 Blackrock-Zuni

Days filled	First date filled	Last date filled	Number of stations used	IDs of Stations Used:
1	1/8/1948	1/8/1948	7	2785, 3626, 2780, 3305, 9410, 3431, & 1080
2	7/26/1963	9/21/1963	6	2785, 5560, 8261, 3420, 3305, & 9410
120	1/1/1973	6/30/1973	6	3180, 2785, 5560, 7488, 3420, & 9410
11	3/1/1973	3/30/1973	5	3180, 2785, 5560, 3420, & 9410
579	8/1/1973	11/12/1978	7	3180, 2785, 5560, 7488, 3420, 3422, & 9410
31	8/1/1974	8/31/1974	6	3180, 2785, 5560, 7488, 3420, & 3422
1	10/29/1974	10/29/1974	6	3180, 2785, 5560, 3420, 3422, & 9410
1	1/25/1978	1/25/1978	6	3180, 5560, 7488, 3420, 3422, & 9410
56	9/18/1982	12/26/1997	6	3180, 2785, 5560, 7488, 3422, & 9410
2	8/21/1986	8/22/1986	4	3180, 2785, 3422, & 9410
3	1/17/1987	12/10/1997	5	3180, 2785, 5560, 3422, & 9410
8	8/29/1993	9/18/2004	5	3180, 2785, 5560, 7488, & 3422
1	11/27/1997	11/27/1997	5	3180, 2785, 7488, 3422, & 9410
1	12/29/2004	12/29/2004	4	3180, 2785, 5560, & 3422

Note: The period from first to last date filled may not be continuous.

E.4 Summary of Climatic Data

This section summarizes the filled/extended climatic data used for the development of the climatic inputs. Figure E-1: Annual Preciepitation shows the annual precipitation at the El Morro, Fence Lake, McGaffey, and Zuni stations for water years 1950 through 2004. The average annual precipitation at these stations ranges from 12.10 in/year at the Zuni station to 18.97 in/year at the McGaffey station. The average annual precipitation increases with elevation.

Figure E-2 shows the average monthly precipitation at the El Morro, Fence Lake, McGaffey, and Zuni stations for water years 1950 through 2004. It can be seen that, on the average, the largest amount of precipitation occurs in July and August.

Figure E-3 shows the average monthly maximum temperature, minimum temperature, and average temperature at the El Morro, Fence Lake, McGaffey, and Zuni stations for water years 1950 through 2004. The maximum, minimum, and average temperatures decrease with elevation. Figure E-4 shows the average monthly dew point temperature, daytime total sky cover, and daily wind speeds at the Gallup station for water years 1950 through 2004.

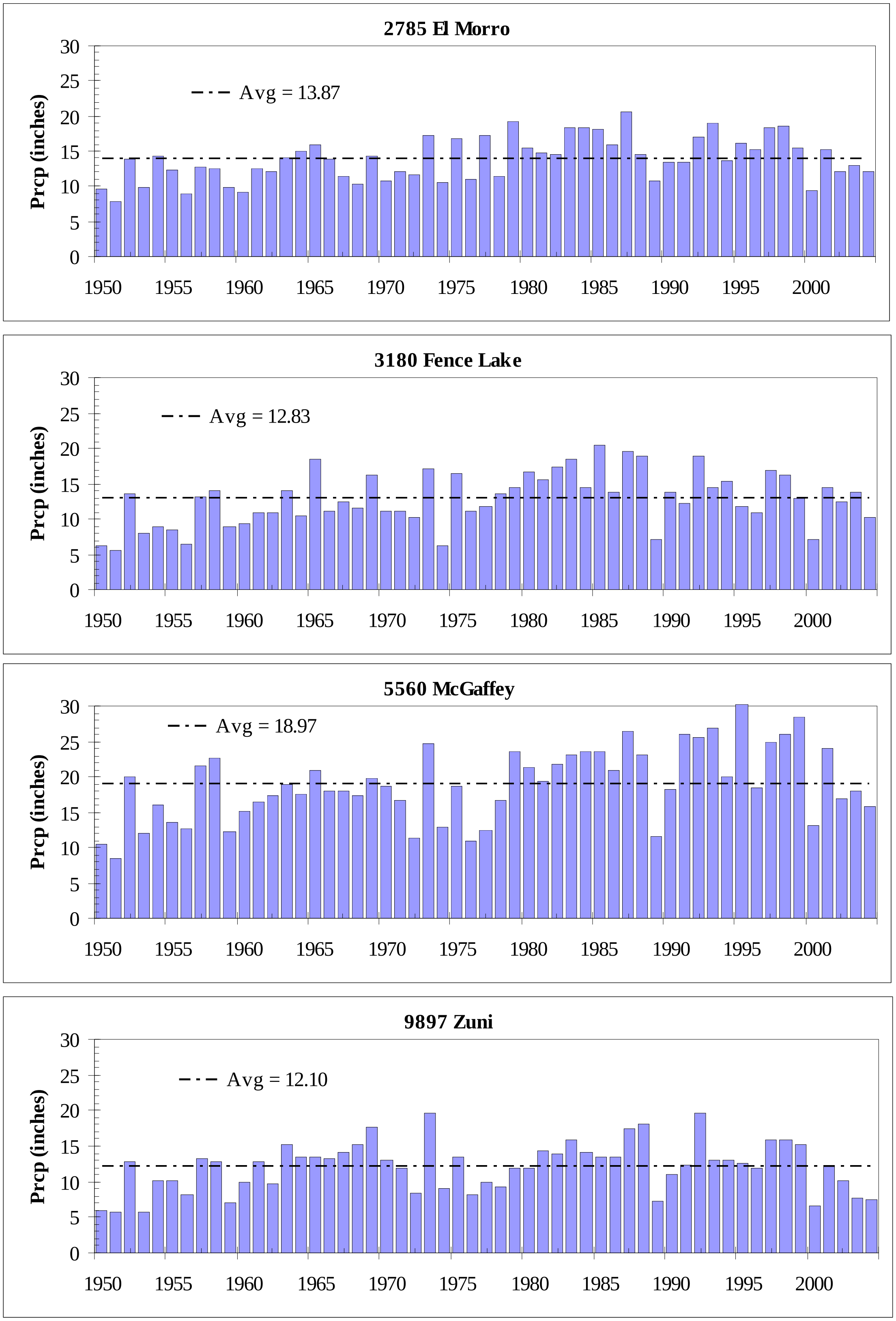


Figure E-1: Annual Precipitation.

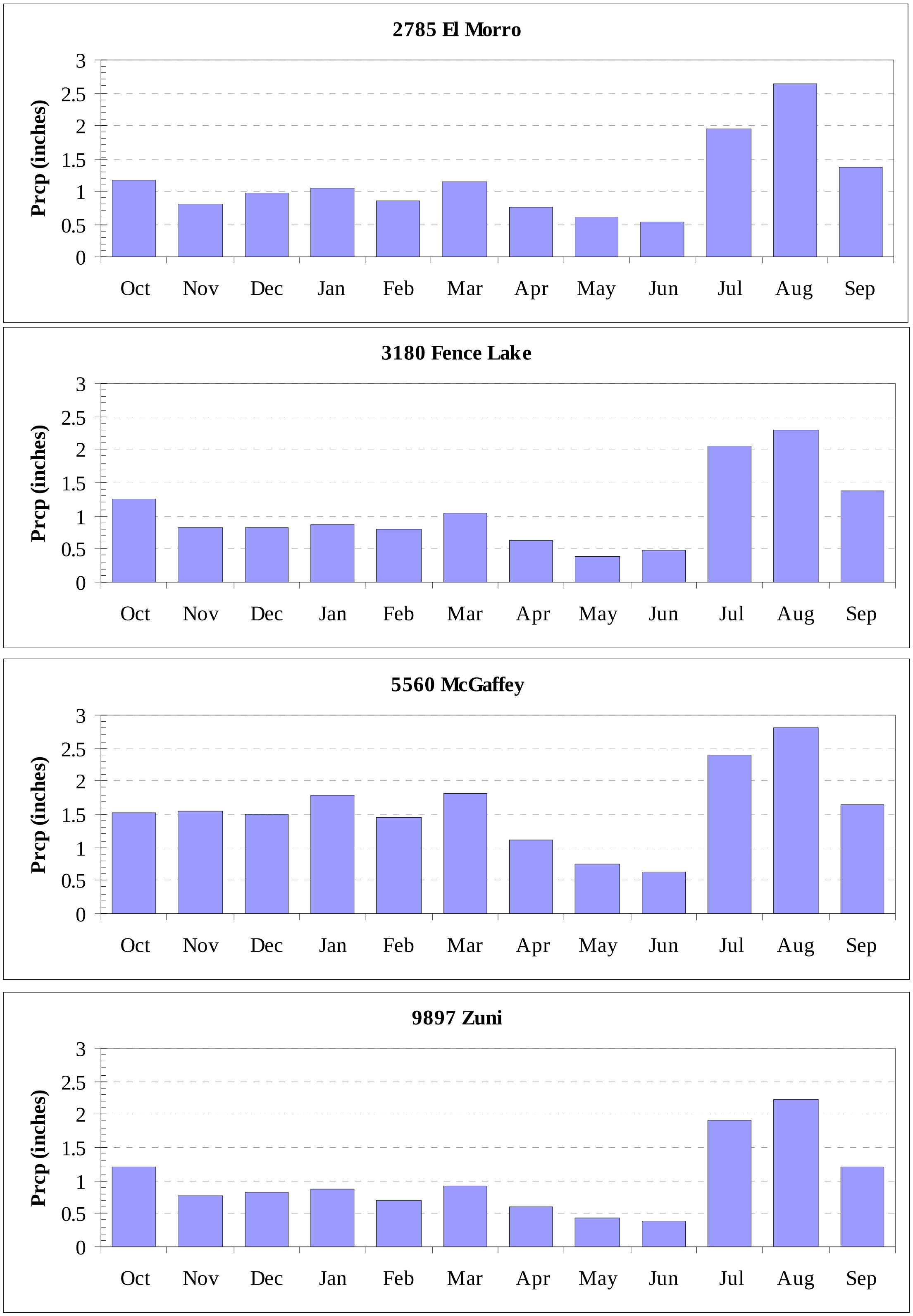


Figure E-2: Average Monthly Precipitation.

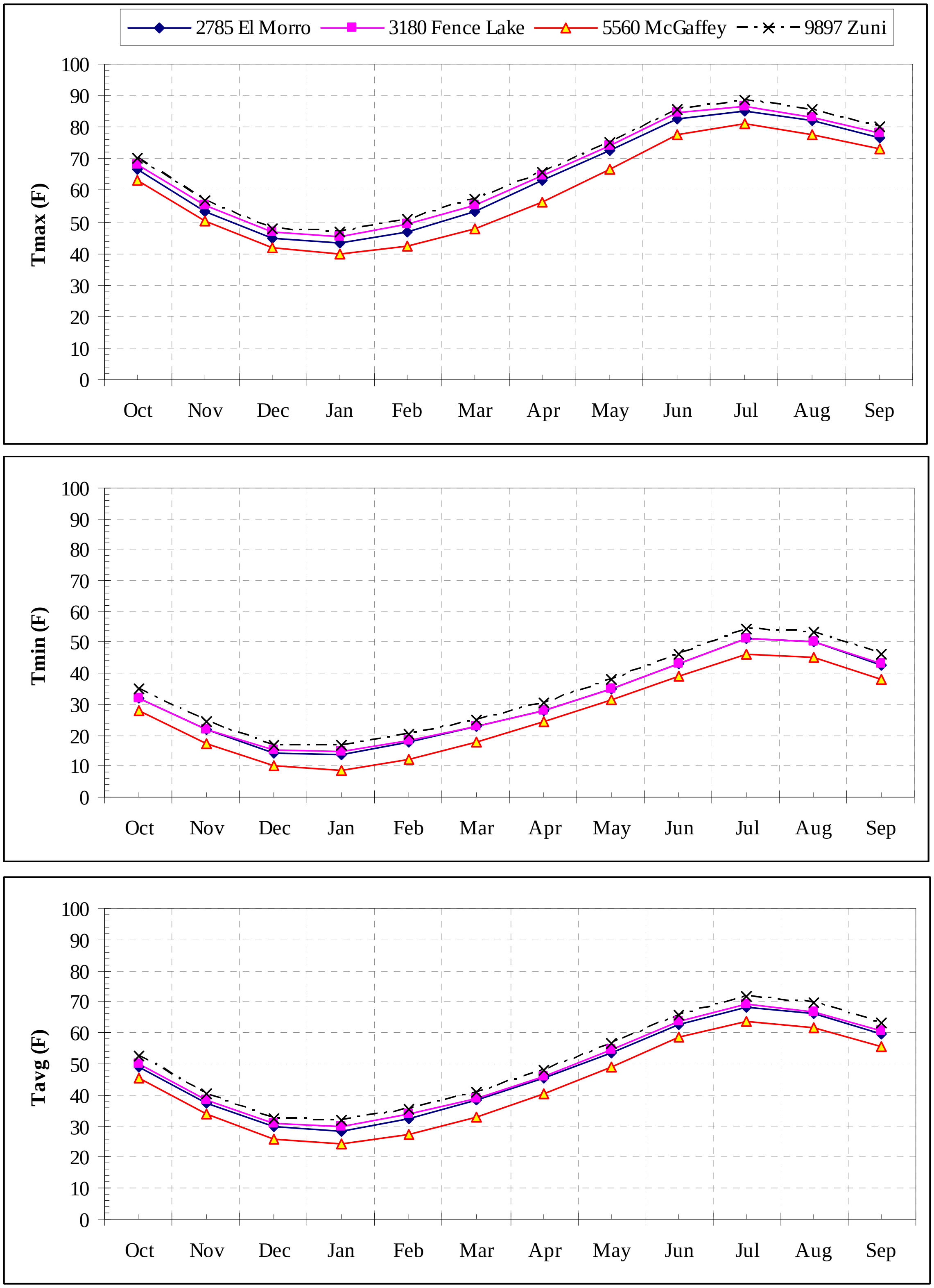
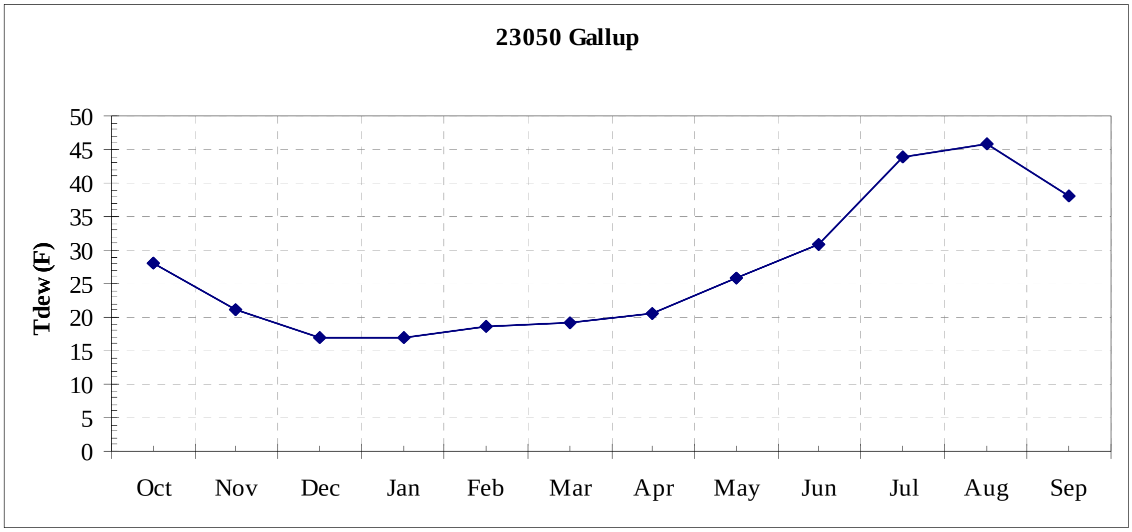
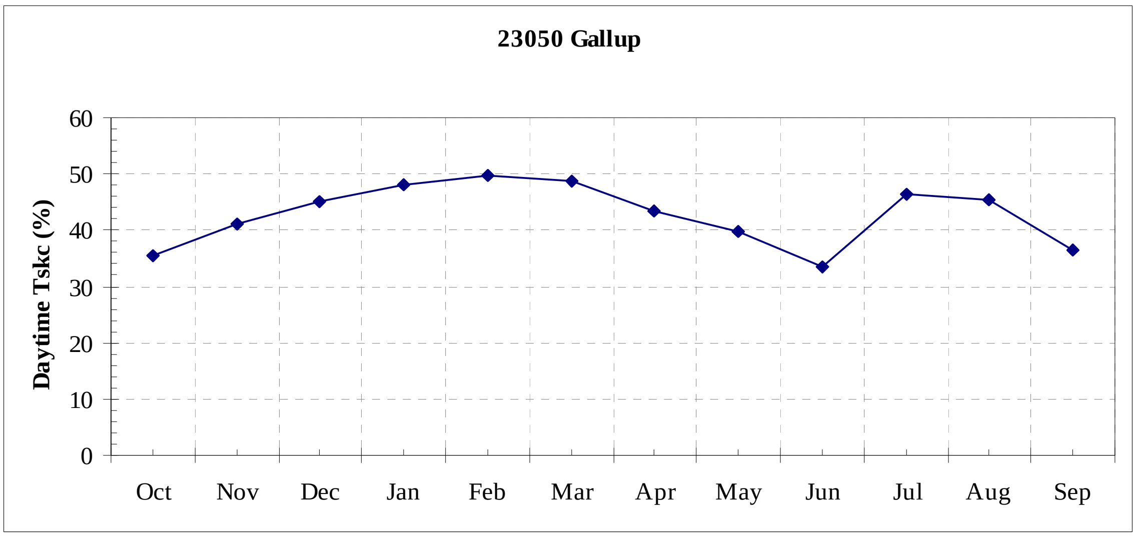


Figure E-3: Average Monthly Temperature.





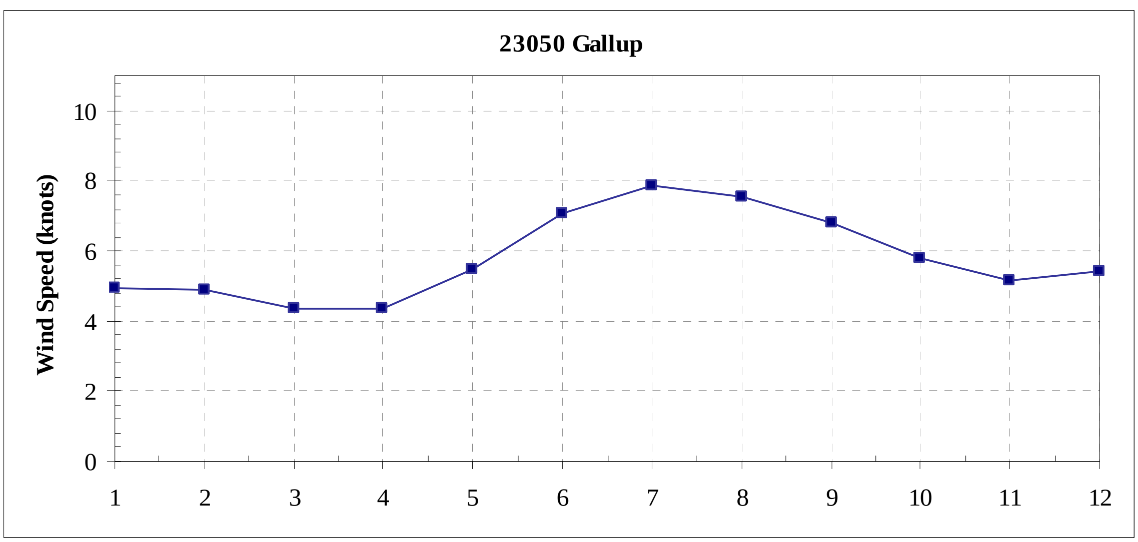


Figure E-4: Average Monthly Dew Point Temperature, Total Sky Cover, and Wind Speed.

E.5 Regional Analysis of Long-Term Climatic Data

Since the precipitation, maximum air temperature, minimum air temperature, and dew point temperature generally exhibit strong dependencies on elevation, these dependencies should be taken into account.

The elevation adjustment factors ("lapse rates") for the precipitation, maximum air temperature, and minimum air temperature were developed through regional analysis as described below. A set of sixteen climatic stations in the Little Colorado River Basin for which the NCDC "normal" long-term averages were available was selected for the regional analysis. The NCDC "normal" long-term averages were developed by the NCDC for the period 1971-2000. The selected stations are located either along the mainstem Little Colorado River or in basins of its northern tributaries, including the Zuni River Basin. Locations of these stations are shown in Figure E-5. Table E-3 shows the station elevation and the long-term average precipitation, maximum air temperature, and minimum air temperature for the sixteen stations used in the regional analysis. This table also shows the USGS Hydrologic Unit Code (HUC) number and name of the watershed in which each climatic station is located.

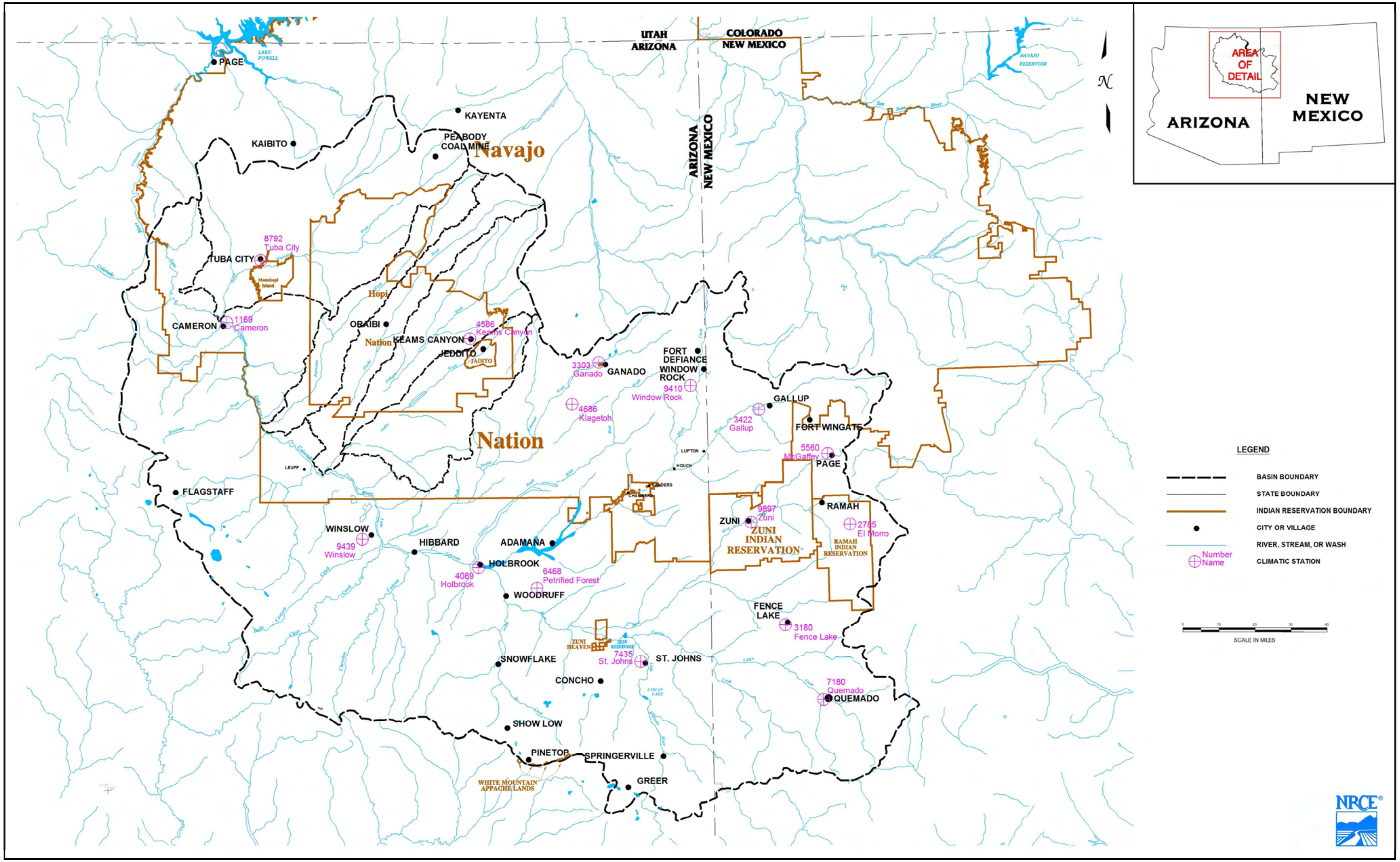


Figure E-5: Hydrologic Map of the Little Colorado River Basin with Climatic Stations Used in the Regional Climatic Analysis.

Table E-13: Stations Used in the Regional Analysis of the Long-Term Climatic Data

Station ID	Station Name	Elev. (ft)	Prcp (in)	Tmax (F)	Tmin (F)	State	USGS HUC	USGS HUC Name
1169	Cameron	4,164	5.56	75.5	42.6	AZ	15020016	Lower Little Colorado
9439	Winslow	4,890	8.03	70.4	40.0	AZ	15020008	Middle Little Colorado
8792	Tuba City	5,030	6.35	69.6	40.9	AZ	15020018	Moenkopi Wash
4089	Holbrook	5,070	9.20	73.6	38.6	AZ	15020008	Middle Little Colorado
6468	Petrified Forest	5,444	10.44	70.8	38.8	AZ	15020007	Lower Puerco
7435	Saint Johns	5,790	11.47	69.8	37.2	AZ	15020002	Upper Little Colorado
4586	Keams Canyon	6,205	10.16	67.0	34.6	AZ	15020013	Polacca Wash
9897	Zuni	6,310	12.78	68.7	33.4	NM	15020004	Zuni
3303	Ganado	6,340	11.59	65.2	34.7	AZ	15020011	Cottonwood Wash
3422	Gallup	6,466	11.45	66.9	28.8	NM	15020006	Upper Puerco
4686	Klagetoth	6,500	9.34	65.6	39.7	AZ	15020009	Leroux Wash
7180	Quemado	6,860	11.18	66.5	29.6	NM	15020003	Carrizo Wash
9410	Window Rock	6,920	11.31	63.1	32.7	AZ	15020006	Upper Puerco
3180	Fence Lake	7,065	14.23	65.8	31.4	NM	15020004	Zuni
2785	El Morro	7,227	15.30	64.3	31.4	NM	15020004	Zuni
5560	McGaffey	8,000	20.32	59.0	26.4	NM	15020004	Zuni

The elevation adjustment factors were developed from the correlation-based relationships between the long-term average climatic data and elevation. Figure E-6 shows the plots of the long-term average data versus elevation along with the best-fit straight lines obtained by the linear regression analysis. The lapse rate is defined as the slope of the best-fit straight line. It can be seen from the coefficients of determination, R^2, shown on the figure that there is a good correlation between the long-term average data and elevation. Therefore, the correlation-based relationships can be used to describe the dependence of the long-term average climatic data on the elevation.

The lapse rates determined from the regional analysis described above are:

- Annual precipitation lapse rate is 3.059 inches per 1,000 feet.
- Maximum temperature lapse rate is –3.743 degrees Fahrenheit per 1,000 feet.
- Minimum temperature lapse rate is –4.205 degrees Fahrenheit per 1,000 feet.

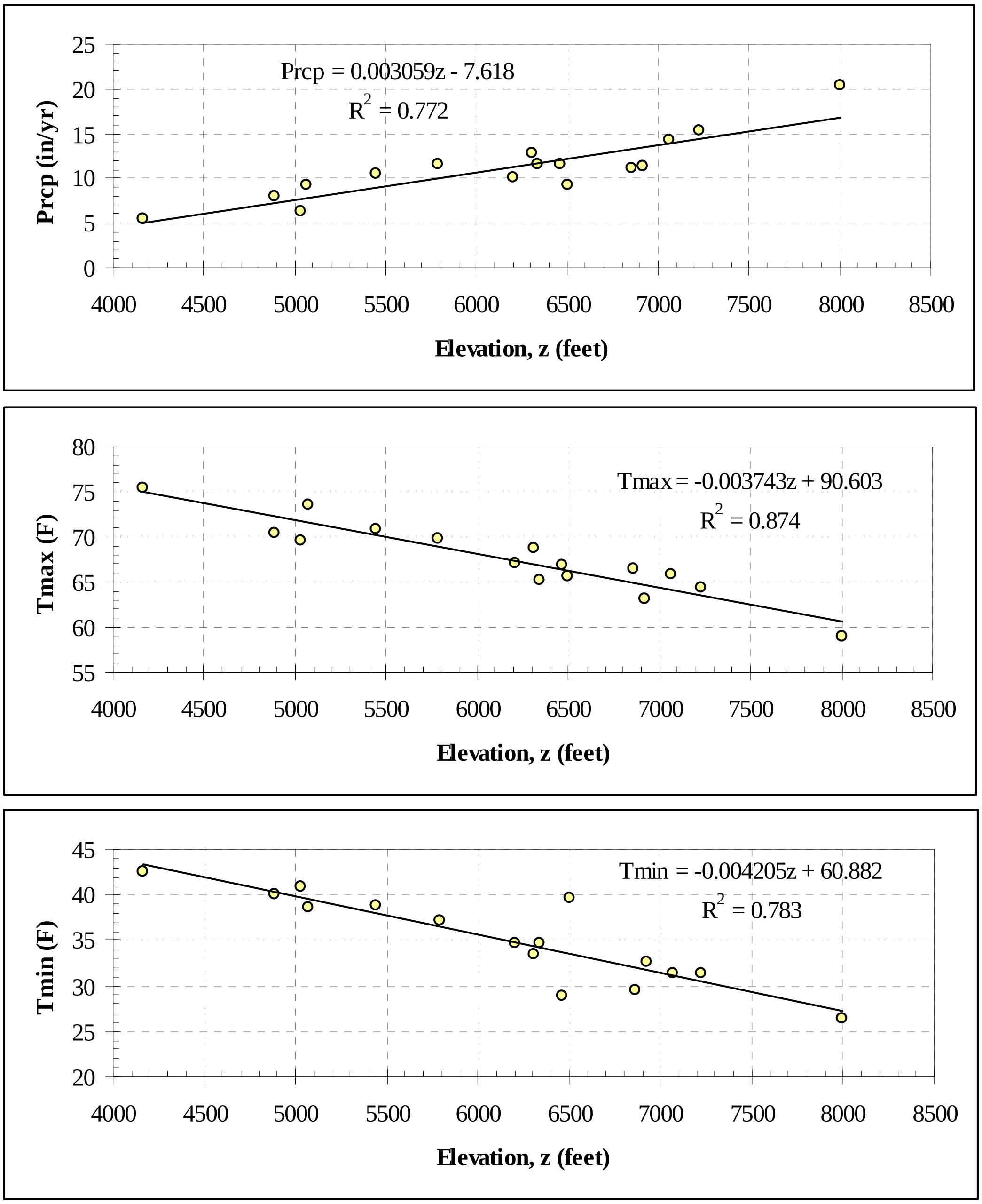


Figure E-6: Regional Analysis of the Long-Term Average Climatic Data.

E.6 Elevation-Adjusted Climatic Inputs

The climatic inputs for the air temperature and precipitation for each elevation band present in each sub-basin were developed by performing elevation adjustments of the air temperature and precipitation recorded at the climatic station (El Morro, Fence Lake, McGaffey, or Zuni) assigned to the sub-basin. The climatic inputs for the dew point temperature for each elevation band present in the study area were developed by performing elevation adjustments of the dew point temperature data recorded at the Gallup station. Based on maps of mean wind speed and of mean total sky cover percentage (sunrise to sunset) for the contiguous United States, these variables do not exhibit clear elevation dependencies (NCDC, 2002). Therefore, the total sky cover and wind speed data from the Gallup station were applied throughout the study area without elevation adjustments. The methodology for calculation of the elevation-adjusted climatic inputs is described in the following sections.

E.6.1 Air Temperature

The maximum and minimum daily air temperature for each elevation band is calculated as the sum of the daily data recorded at the climatic station and the appropriate regional lapse rate (with a negative sign) times the elevation difference between the mean elevation of the elevation band and the elevation of the station. This is accomplished using the following equations:

$$M_{band}(t) = M_{station}(t) - 0.003743(z_{band} - z_{station}),$$

$$N_{band}(t) = N_{station}(t) - 0.004205(z_{band} - z_{station}),$$

where $M_{band}(t)$ and $N_{band}(t)$ are the maximum and minimum daily air temperatures for the elevation band, in degrees Fahrenheit, $M_{station}(t)$ and $N_{station}(t)$ are the maximum and minimum daily air temperatures at the climatic station, in degrees Fahrenheit, z_{band} is the mid-elevation of the elevation band, in feet, and $z_{station}$ is the elevation of the climatic station, in feet.

The average daily air temperature for each elevation band is calculated as the mean of the maximum and minimum daily air temperatures:

$$T_{band}(t) = \frac{1}{2}\left[M_{band}(t) + N_{band}(t)\right],$$

where $T_{band}(t)$ is the average daily air temperature for the elevation band.

E.6.2 Precipitation

The daily precipitation for each elevation band is calculated by multiplying the daily data recorded at the climatic station by a precipitation adjustment factor. This factor is calculated such that the average annual precipitation for the elevation band equals the sum of the average annual precipitation for the station and the regional precipitation lapse rate times the elevation difference between the mean elevation of the elevation band and the elevation of the station. This is accomplished using the following equation:

$$P_{band}(t) = P_{station}(t)\left[1 + \frac{0.003059}{\overline{P}_{station}}(z_{band} - z_{station})\right]$$

where $P_{band}(t)$ is the daily precipitation for the elevation band, $P_{station}(t)$ is the daily precipitation at the station, $\overline{P}_{station}$ is the long-term average annual precipitation at the station, in inches, z_{band} is the mid-elevation of the elevation band, in feet, and $z_{station}$ is the elevation of the climatic station, in feet.

E.6.3 Dew Point Temperature

The daily dew point temperature for each elevation band is calculated as:

$$D_{band}(t) = D_{station}(t) + D_{adjust},$$

where $D_{band}(t)$ is the daily dew point temperature for the elevation band, $D_{station}(t)$ is the daily dew point temperature data at the climatic station, and D_{adjust} is the dew point temperature elevation adjustment, all in degrees Fahrenheit. The dew point temperature elevation adjustment D_{adjust} is calculated as:

$$D_{adjust}^{C} = -\frac{\frac{(z_{band} - z_{station})}{128780}(237.3 + \overline{D}_{station})}{\frac{(z_{band} - z_{station})}{128780} + \frac{237.3}{237.3 + \overline{D}_{station}}}, \qquad D_{adjust} = 32 + \frac{9}{5} D_{adjust}^{C}$$

where D_{adjust}^{C} is the dew point temperature elevation adjustment in Celsius degrees, z_{band} is the mid-elevation of the elevation band, in feet, $z_{station}$ is the elevation of the climatic station, in feet, and $\overline{D}_{station}$ is the long-term average dew point temperature at the station, in degrees Celsius.

The above equation for the dew point temperature elevation adjustment was derived based on the following relationship between the actual vapor pressure and elevation, as reported by Reitan (1963):

$$\frac{e(z_{band})}{e(z_{station})} = \exp\left[-\frac{(z_{band} - z_{station})}{7457}\right].$$

The following standard equation for the actual vapor pressure (ASCE, 2005) was also used in the derivation:

$$e = 0.6108 \cdot \exp\left[\frac{17.27D}{D + 237.3}\right],$$

where e is the vapor pressure in kilopascals (kPa) and D is the dew point temperature in degrees Celsius.

E.7 Solar Radiation Calculations

The daily solar radiation for each elevation band in the study area was calculated as a function of day of the year, the dew point temperature, and the total sky cover, using equations from Dingman (1994).

The solar radiation depends on the latitude. Within the range of latitudes in the study area, the effect of the latitude is extremely small. For simplicity, the latitude was set to 35 degrees in all computations.

The solar radiation depends on the value of the reflectivity coefficient (albedo), denoted by α. Solar radiation was used for the calculation of the reference evapotranspiration, with $\alpha = 0.23$. Dingman's (1994) equations were selected for use in the present study because they explicitly consider the effect of albedo, unlike the radiation equations presented in FAO-56 (1998) and ASCE (2005), which are based on a fixed albedo of 0.23. As such, the FAO-56/ASCE equations cannot be used to calculate radiation for snow covered surfaces. Sensitivity tests that were performed during this study indicated that, for $\alpha = 0.23$, Dingman's equations yield results that closely agree with results from the FAO-56/ASCE equations.

Solar radiation is calculated as a function of the latitude, day of the year, dew point temperature, and total sky cover using equations presented in Appendix E of Dingman (1994). These equations are presented below.

The position of the Earth in its orbit is given by the **day angle**, Γ (in radians), which is calculated as:

$$\Gamma = \frac{2\pi(J-1)}{N},$$

where J is the day number of the year (1 for January 1, etc.), and N is the number of days in a given year (either 365 or 366).

The **solar declination**, δ (in radians), is calculated from the day angle as:

$$\delta = \frac{180}{\pi}\{0.006918 - 0.399912\cos\Gamma + 0.070257\sin\Gamma - 0.006758\cos 2\Gamma + 0.000907\sin 2\Gamma - 0.002697\cos 3\Gamma + 0.00148\sin 3\Gamma\}\ .$$

The **time of sunrise before the solar noon**, T_r (in days), is given by:

$$T_r = \frac{\cos^{-1}(-\tan\delta\tan\Lambda)}{\omega},$$

where Λ is the latitude in radians and $\omega = 2\pi$ radians per day is the angular velocity of the Earth's rotation.

The dimensionless **eccentricity correction** E_o is calculated as:

$$E_o = 1.00011 + 0.034221\cos\Gamma + 0.001280\sin\Gamma + 0.000719\cos 2\Gamma + 0.000077\sin 2\Gamma$$

The **daily extra-terrestrial solar radiation flux on a horizontal plane**, R_{ET} (in Langleys), is calculated as:

$$R_{\mathrm{ET}} = 2 I_{sc} E_o \left\{ \cos\delta \cos\Lambda \frac{\sin(\omega T_r)}{\omega} + T_r \sin\delta \sin\Lambda \right\},$$

where $I_{SC} = 2821$ Langleys per day is the solar constant.

The **daily optical air mass**, M_{opt}, is determined from the given latitude Λ by interpolation from Figure E-4, page 533, in Dingman (1994).

The **precipitable water content of the atmosphere** above a point, W_p (in centimeters), is estimated from the surface dew point temperature as:

$$W_{\mathrm{p}} = 1.12 \exp(0.0614 T_d),$$

where T_d is the dew point temperature in degrees Celsius.

The **total atmospheric transmissivity**, τ, is estimated as:

$$\tau = \tau_{sa} - \gamma_{dust},$$

where τ_{sa} is the transmissivity of the atmosphere due to scattering and absorption by water vapor and constant atmospheric gases, and γ_{dust} is the attenuation due to dust. τ_{sa} is calculated as:

$$\tau_{sa} = \exp(a_{\mathrm{sa}} + b_{\mathrm{sa}} M_{\mathrm{opt}}),$$

where:

$$a_{\mathrm{sa}} = -0.124 - 0.0207 W_{\mathrm{p}},$$

$$b_{\mathrm{sa}} = -0.0682 - 0.0248 W_{\mathrm{p}}.$$

The value of γ_{dust} has been observed to vary from 0 to 0.2, with typical values for moderate-sized cities in the range of 0.03 to 0.10 (Dingman, 1994). For the Gallup station, a value of 0.03 was used for this study.

The **attenuation of the solar beam** due to scattering by water vapor and permanent atmospheric constituents, γ_s, is given by:

$$\gamma_{\mathrm{s}} = 1 - \tau_{\mathrm{s}} + \gamma_{dust},$$

where

$$\tau_{\mathrm{s}} = \exp(a_{\mathrm{s}} + b_{\mathrm{s}} M_{\mathrm{opt}}),$$

$$a_{\mathrm{s}} = -0.0363 - 0.0084 W_{\mathrm{p}},$$

$$b_{\mathrm{s}} = -0.0572 - 0.0173 W_{\mathrm{p}}.$$

The **total clear sky solar radiation** incident on a horizontal plane at the surface, R_{so} (in Langleys per day), is calculated as:

$$R_{so} = R_{\mathrm{ET}}\left(\tau + \frac{\gamma_{\mathrm{s}}}{2} + \frac{\alpha\gamma_{\mathrm{s}}\tau}{2} + \frac{\alpha\gamma_{\mathrm{s}}{}^{2}}{4}\right),$$

where α is the reflectivity coefficient (albedo).

The **actual solar radiation** incident on a horizontal plane at the surface, R_s (in Langleys per day), is determined by adjusting R_{so} for the presence of cloud cover according to the following relationship:

$$R_s = f_{cloud} \cdot R_{so}, \qquad f_{cloud} = 1 - A\left(\frac{Tskc}{100}\right)^2,$$

where *Tskc* is the daily total sky cover expressed in percent. This relationship was determined empirically by the Tennessee Valley Authority (TVA, 1972), in which they determined the coefficient *A* to be 0.65.

On days when *Tskc* data is not available, the value of f_{cloud} was estimated from the diurnal range in air temperature using the Thornton and Running (1999) equation:

$$f_{cloud} = 1.0 - 0.9 \cdot \exp\left(-B \cdot \Delta T^{C}\right),$$

where C is equal to 1.5 and ΔT is the diurnal temperature range, in Celsius degrees, calculated for each day i using the Bristow and Campbell (1984) equation:

$\Delta T(i) = Tmax(i) - [Tmin(i) + Tmin(i+1)]/2$.

The **parameter *B*** is calculated from the expression:

$$B = b_0 + b_1 \cdot \exp\left(-b_2 \cdot \overline{\Delta T}\right),$$

where the parameters b_0, b_1, and b_2 are respectively equal to 0.031, 0.201, and 0.185, and $\overline{\Delta T}$ is the 30-day moving average ΔT for the period starting with the current day and going back in time. On days with precipitation, the value of f_{cloud} predicted by the above equation was multiplied by a constant correction factor of 0.75.

To complete the filling/extension of the Gallup *Tskc* record, the equation for $\mathrm{f_{could}}$ was solved for *Tskc* as a function of f_{cloud} as follows:

$$Tskc = 100\sqrt{\frac{1 - f_{cloud}}{A}}$$

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APPENDIX F

CROP EVAPOTRANSPIRATION CALCULATIONS

Appendix F desribes the ASCE Penman-Montieth methodology of calculating a reference ET value based on climate data. Methods provided in SCS-NEH are described and used to calculate crop coefficients. Crop ET is the product of the reference ET and the crop coefficients for any given month.

F.1 Reference Evapotranspiration

The daily reference evapotranspiration (ET_{ref}) for each elevation band was calculated as a function of the solar radiation (general land surface), maximum air temperature, minimum air temperature, dew point temperature, total sky cover, and wind speed using the ASCE Penman-Monteith equation for the reference crop of clipped, cool season grass (ASCE, 2005).

E.2.6 Reference ET Equation

The ASCE Penman-Montieth equation is:

$$ET_{ref} = \frac{0.408\Delta(R_n - G) + \gamma \frac{C_n}{T + 273} u_2 (e_{sat} - e)}{\Delta + \gamma(1 + C_d u_2)}$$

Where: ET_{ref} = reference ET (mm/day); R_n = net radiation at the crop surface (MJ/m^2/day); G = soil heat flux density at the soil surface (MJ/m^2/day); T = mean daily air temperature at 2 meter height (°C); u_2 = mean daily wind speed at 2 meter height (m/s); e_{sat} = mean saturation vapor pressure at 2 meter height (kPa); e = mean actual vapor pressure at 2 meter height (kPa); Δ = slope of the vapor pressure-temperature curve (kPa/°C); γ = psychrometric constant (kPa/°C); C_n, C_d = constants for reference type and calculation time step.

Equations used in calculating the required inputs into the ASCE Penman-Montieth equation are provided below.

The **latent heat of vaporization**, λ (in megaJoules per kilogram (MJ/kg)), is calculated from the average air temperature for each day as:

$$\lambda = 2.501 - 0.00236 T_{avg}$$

where T_{avg} is the average daily temperature in degrees Celsius, which is calculated as the arithmetic average of the maximum and minimum temperatures.

The **saturated vapor pressure**, e_{sat} (in kiloPascals (kPa)), is calculated from the maximum and minimum daily temperatures as:

$e_{sat} = \frac{e_{sat}^{T_{\max}} + e_{sat}^{T_{\min}}}{2}$, where $e_{sat}^{T_{\max}}$ and $e_{sat}^{T_{\min}}$, both in kPa, are given by:

$e_{sat}^{T_{\max}} = \exp\left[\frac{16.78T_{\max} - 116.9}{T_{\max} + 237.3}\right]$, $e_{sat}^{T_{\min}} = \exp\left[\frac{16.78T_{\min} - 116.9}{T_{\min} + 237.3}\right]$, where $T_{\max}$ and $T_{\min}$ are the maximum and minimum daily temperatures in degrees Celsius.

The **actual vapor pressure**, e (in kPa), is calculated from the dew point temperature as:

$$e = \exp\left[\frac{16.78T_{dew} - 116.9}{T_{dew} + 237.3}\right],$$

where T_{dew} is the dew point temperature in degrees Celsius.

The **slope of the saturation vapor pressure versus temperature curve**, Δ (in kPa/CE), is calculated as:

$$\Delta = \left(\frac{2049e_{sat}^{T_{\max}}}{T_{\max} + 237.3}\right)^2 + \left(\frac{2049e_{sat}^{T_{\min}}}{T_{\min} + 237.3}\right)^2.$$

The **psychrometric constant**, γ (in kPa/CE), is calculated as:

$$\gamma = \frac{C_p P_{atm}}{0.622\lambda},$$

where $C_p = 0.001013$ MJ/(kg KE) is the specific heat of air at constant pressure and P_{atm} is the atmospheric pressure in kPa. KE indicates Kelvin degrees.

P_{atm} is approximately constant in time for a given elevation and is calculated as:

$$P_{atm_1} = P_{atm_0}\left[\frac{T_o^K + L_T(z_1 - z_0)}{T_o^K}\right]^{g/\alpha R},$$

where $g = 9.81$ m/s^2 is the acceleration due to gravity, $R = 287$ J/(kg KE) is the specific gas constant, $L_T = -0.0065$ KE/m is the lapse rate for saturated air, $T_o^K = 293$ EK is the average temperature at the sea level, z_0 = 0 m is the elevation at the sea level, z_1 is the elevation in m, P_{atm_0} = 101.3 kPa is the average atmospheric pressure at the sea level, and P_{atm_1} is the average atmospheric pressure, in kPa, at elevation z_1.

The **net emissivity**, ε, between the atmosphere and the ground is calculated from the actual vapor pressure as:

$$\varepsilon = 0.34 - 0.14\sqrt{e}.$$

The **net clear sky long-wave radiation**, R_{nlo} (in MJ/(m^2 day)), is calculated as:

$$R_{nlo} = -\varepsilon\sigma\frac{\left(T_{\max}^K\right)^4 + \left(T_{\min}^K\right)^4}{2},$$

where $T_{\max}^{K}$ and $T_{\min}^{K}$ are the maximum and minimum daily temperatures in degrees Celsius and σ = 4.903×10^{-9} MJ/(m^2 day KE) is the Stefan-Boltzmann constant.

The **net long-wave radiation**, adjusted to account for the effect of the cloud cover, is given by:

$$R_{nl} = R_{nlo}\left(1.35\frac{R_s}{R_{so}} - 0.35\right),$$

where R_s is the short wave solar radiation in MJ/(m^2 day) and R_{so} is the short wave solar radiation for clear skies in MJ/(m^2 day)). Using the relationship determined by TVA (1972),

$$R_s / R_{so} = 1 - 0.65(C/100)^2,$$

where C is the total sky cover expressed in percent.

The **net radiation**, R_n (in MJ/(m^2 day)), is then calculated as:

$$R_n = (1-\alpha)R_s + R_{nl},$$

where the α is albedo, set to 0.23 for general land surfaces and to 0.08 for water surfaces.

The **soil heat flux** is approximated from the average air temperature as:

$$G = 0.38\left(T_{avg} - T_{avg}^{prev}\right),$$

where T_{avg}^{prev} is the air temperature (in degrees Celsius or Kelvin) for the previous day.

The **constants C_n and C_d** are provided as 900 and 0.34, respectively, for a short (0.12m) reference crop and calculations performed on a daily time-step.

Table F- provides reference ET calculation results at various elevation bands, for the two climate stations used in calculating crop water requirements for the historically irrigated lands.

Table F-1: Average Climate Inputs and ET_{ref} Calculations for Stations and Elevations.

Station	Band	Tmax (F)	Tmin (F)	Tavg (F)	Tdew (F)	Rs land (MJ/m^2)	Rs snow (MJ/m^2)	ET_{ref} (in)
5560	68	62.12	29.3	45.71	28.57	19.13	20.14	48.56
9897	60	66.22	32.72	49.47	31.14	19.02	20.05	52.06
9897	62	65.49	31.9	48.7	30.35	19.05	20.08	51.55
9897	64	64.82	31.14	47.98	29.69	19.08	20.1	51.05
9897	66	64.17	30.4	47.29	29.09	19.1	20.12	50.54

F.1.1 Aridity Effects

ASCE defines reference evapotranspiration as "the ET rate from a uniform surface of dense, actively growing vegetation having a specified height and surface resistance, not short of soil water, and representing an expanse of at least 100 m of the same or similar vegetation" (2005). They also state: "weather data should be measured at stations that are located in open, well-watered, vegetated settings (preferably grass)." … "Humidity, temperature, and wind speed variables change when entering an irrigated field surrounded by dry or poorly irrigated fields. It is important, when making calculations of [ET_{ref}], that weather measurements are accurate and that weather measurements reflect the environment that is defined by the reference surface." Appendix D of ASCE (2005) refers the reader to Annex 6 in FAO-56 (1998), which presents procedures for evaluating and adjusting humidity and air temperature data for the effects of aridity, i.e., non-reference conditions, at the weather station site. These procedures were used to evaluate and adjust the dew point temperature and air temperature inputs to the solar radiation and ET_{ref} calculations for the diversion-irrigated lands. As can be seen from the top panel in Figure F-1, the effects of the FAO-56 adjustments for aridity on the calculated solar radiation are very small, less than 1% on the long-term average. The bottom panel in Figure F-2, shows the average monthly ET_{ref} for the four climatic stations for the elevation band 70 under natural conditions (i.e., without adjustments for the effects of aridity). It can be seen that all four ET_{ref} distributions are similar to each other.

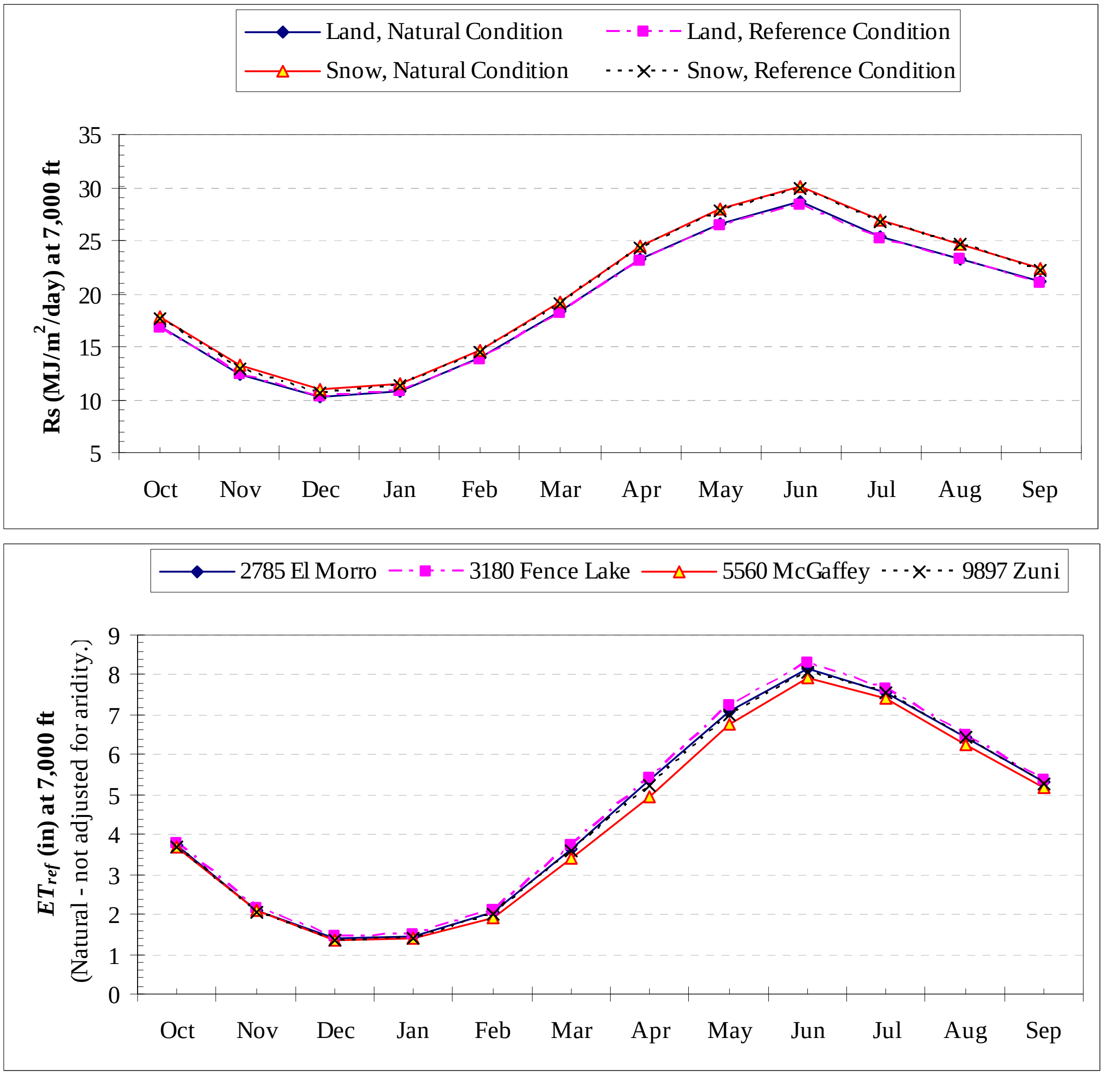

Figure F-1: Average Monthly R_s and ET_{ref} Showing Aridity Effects

F.1.2 Comparison to Alternative Methods

The ASCE Penman-Monteith equation is considered one of the more accurate methods to estimate reference ET from climate data; however, the equation requires climate parameters that are often found only at a limited number of climate stations. Wind, dew point temperature, and sky cover data were not available for climate stations in the Zuni River Basin, and therefore data for these parameters were obtained from the Gallup climate station. As a check on applying these non-local climate parameters in calculating reference ET with the ASCE Penman-Monteith method, alternative methods of calculating ET_{ref} which do not require non-local climate inputs were applied and results were compared. These alternative methods included the 1985 Hargreaves equation (Hargreaves et al., 1985):

$$ET_{ref} = (6.593x10^{-4})(0.0023)R_{aL}(T_{\max} - T_{\min})^{0.5}(T_{avg} + 17.8)$$

and the Hargreaves-Samani equation (Hargreaves and Hargreaves; Hargreaves and Samani, 1982):

$$ET_{ref} = 0.00094R_a(T_{\max} - T_{\min})^{0.5}T_{avg}$$

Where: ET_{ref} = reference ET (in); R_a = extraterrestrial solar radiation (MJ/m^2/day); R_{aL} = extraterrestrial solar radiation (Langleys); T_{max} = maximum daily air temperature (°F); T_{min} = minimum daily air temperature (°F); T_{avg} = mean daily air temperature (°F).

These alternative equations only require temperature data as climate inputs. Annual and monthly comparisons of the reference ET calculation methods are shown in Figure F-2 and Figure F-3. The comparison shows that the difference in ET_{ref} calculated using the various methods is relatively small (<5% annually).

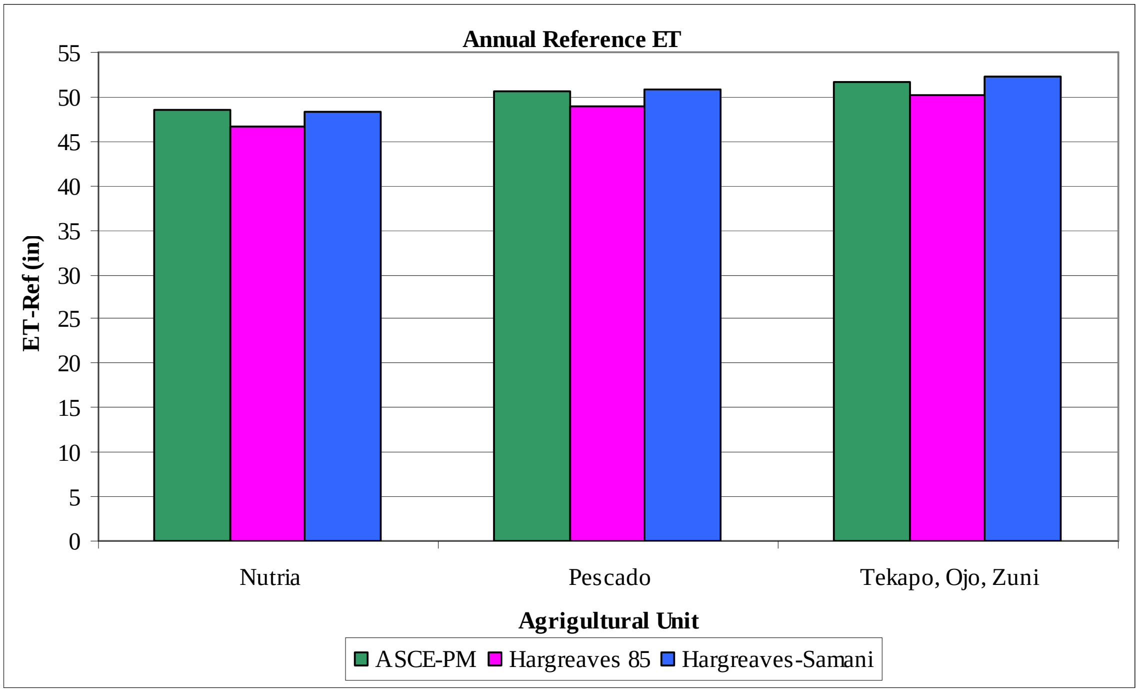

Figure 0-2 Comparison of Annual Reference ET Calculation Methods.

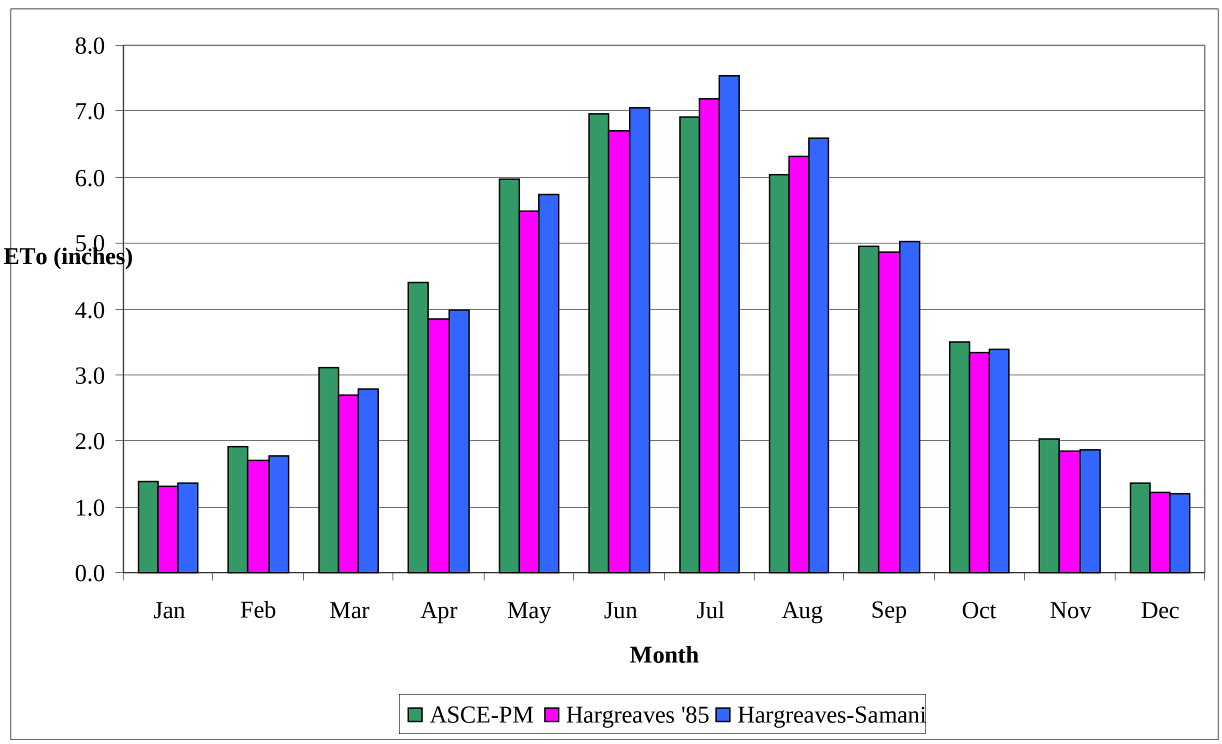

Figure F-3: Comparison on Monthly Reference ET Calculation Methods (Nutria Unit).

F.2 Crop Coefficients

Crop coefficients are used to modify the reference ET values to match specific growth and water use characteristics unique to each crop. Crop ET can be calculated using the following equations (SCS-NEH, 1993):

$$ET_c = K_c ET_o \quad \text{or} \quad ET_c = (K_{cb} K_s + K_w) ET_o$$

Where: ET_c = crop ET; K_c = overall crop coefficient; ET_o = reference ET; K_{cb} = basal crop coefficient; K_s = water stress coefficient; K_w = soil water evaporation coefficient.

The crop coefficients were determined by methods given in the USDA Soil Conservation Service National Engineering Handbook (SCS-NEH 1993). The general relationship between the basal crop coefficient (K_{cb}) and time is shown in Figure F-4. For a given crop, this relationship is defined by the growing season of the crop and six parameters: initial crop coefficient, K_{in}, mid-season crop coefficient, K_{cp}, end-of-season crop coefficient, K_{cm}, fraction of the growing season where canopy development begins, F_{S1}, fraction of the growing season where canopy development is completed, F_{S2}, and fraction of the growing season until physical maturity or harvest, F_{S3}.

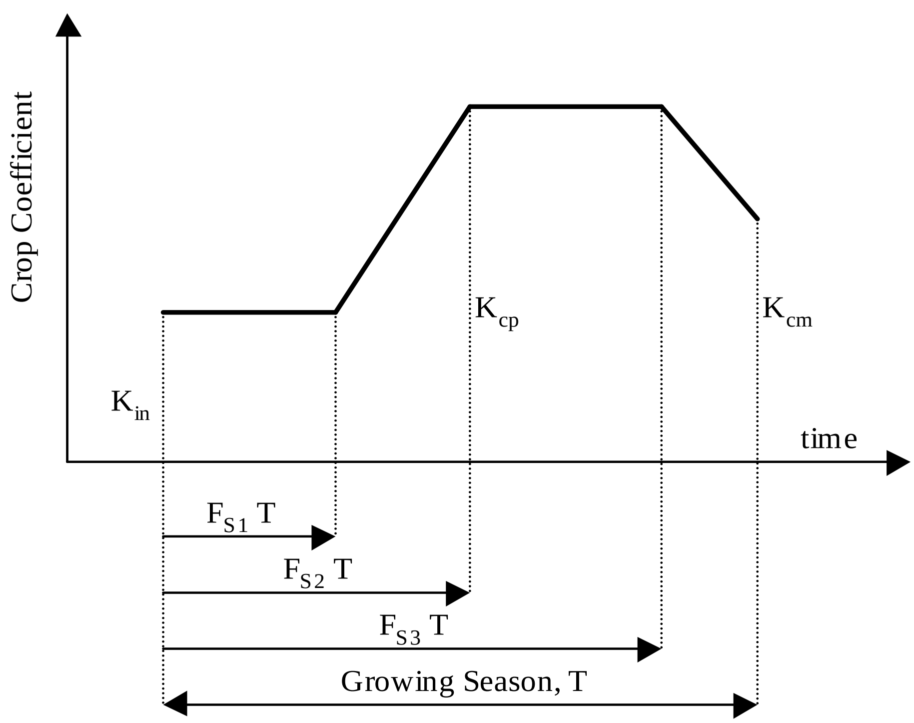

Figure F-4: Basal Crop Coefficients during Growing Season

The growing seasons and the values of these six parameters for each agricultural area along with the respective crops are shown in Table F-1. The basal crop coefficient parameters shown in the table were used in calculating the crop water requirements for all agricultural areas. Sufficient data are not available in order to quantify the small differences that may exist between areas within the Zuni River Basin. The values for the mid-seasons (K_{cp}) an end of the season (K_{cm}) were chosen based on a climate with arid conditions and moderate wind.

Table F-1: Basal Crop Coefficients for each Crop

Crop	Crop Coefficient Parameters					
	K_{in}	K_{cp}	K_{cm}	F_{s1}	F_{s2}	F_{s3}
Small Grains, Grain	0.25	1.15	0.2	0.13	0.33	0.75
Small Grains, Hay	0.25	1.15	0.2	Cut at 80% of Small Grains		
Irrigated Pasture	0.4	0.85	0.85	10 days	30 days	--
Alfalfa	0.4	1.15	1.15	Dependent On Harvesting Schedule		
Corn	0.25	1.15	0.55	0.17	0.48	0.8
Garden	0.6	1.07	0.85	0.21	0.52	0.85

For alfalfa crops, the basal crop coefficient values do not follow the general relationship shown in Figure F-4. After each mid season harvesting of alfalfa, the K_{cb} value will return to the K_{in} value, at which time re-growth begins and the K_{cb} value will steadily increase until reaching a value equal to K_{cp}.

The water stress coefficient (K_s) was not included in the crop coefficient calculations. The water stress coefficient is typically included to account for reduced rates of crop ET that occur when there is a shortage of water in the crop root zone. For an Indian water rights adjudication, past water shortages or water stress are not factors that should be considered because the water right quantification is meant to provide a full water supply to the irrigated lands in the future.

Water evaporation from the soil (K_w) is a concern when the crop canopy does not provide complete ground cover. The amount of evaporation depends on the amount of canopy development, hydraulic properties of the soil, and the amount of available energy to drive the evaporation. In order to adjust the crop coefficients for the consideration of wet soil evaporation, Wright (1982) described the following relationship:

$$K_W = F_W \left(1 - K_{cb}\right) f\left(t\right)$$

Where K_W is the wet soil evaporation factor and is added to the basal crop coefficient to determine the average crop coefficient. F_W is the fraction of soil surface that is wetted depending on the irrigation method and $f(t)$ is the evaporation decay function which depends on the hydraulic properties of the soil and the wetting interval. Irrigation frequency was estimated as 14 days for hay and garden crops and 21 days for all other crops.

The wet soil evaporation factor is only applicable in the initial, development, and late stages of the crop growing season when canopy cover is minimal. The wet soil evaporation factor is not applied when $K_{cb} < 1$. Figure F-5 shows how the wet soil evaporation modifies the original crop coefficient.

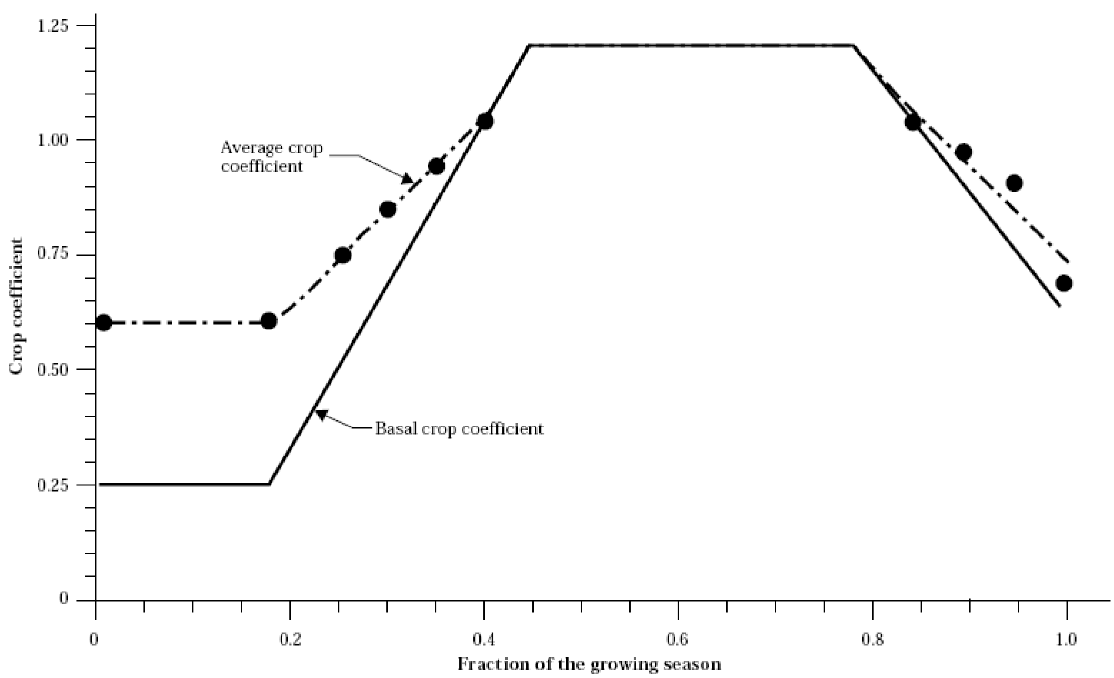

Figure F-5: Average Crop Coefficient (from SCS-NEH, 1993)

The overall crop coefficient is the sum of the basal crop coefficient and the wet soil evaporation factor. Overall crop coefficients used in calculating crop ET are provided in Table F-2.

Table F-2: Overall Crop Coefficients.

Crop	Crop Coefficient Parameters		
	Kin	**Kcp**	**Kcm**
Small Grains, Grain	0.34	1.15	0.3
Small Grains, Hay	0.34	1.15	0.3
Irrigated Pasture	0.47	0.87	0.87
Alfalfa	0.47	1.15	1.15
Corn	0.34	1.15	0.61
Garden	0.67	1.07	0.88

F.3 Effective Precipitation

The calculation of crop ET represents an estimate of the crop water requirements over the course of a growing season in order to have a healthy productive crop that does not experience water stress. A portion of this crop water requirement is satisified by irrigation water applied to the field and a portion is satisfied by natural rainfall falling on the field. Obviously, these proportions change depending in large part on the amount of precipitation that occurs over the growing season. In addition to considering the amount of precipitation, other factors influence how much of the falling precipitation actually infiltrates into the crop root zone and is available to the crop. These factors include the characteristics of precipitation such as intensity and frequency, soil properties such as the infiltration rate and water holding capacity, crop ET characteristics, and irrigation management practices. The portion of the total precipitation that becomes available as a water source to the crop is termed the effective precipitation. Monthly effective precipitation can be estimated as (SCS-NEH, 1993):

$$P_e = SF\left(0.70917 P_t^{0.82416} - 0.11556\right)\left(10^{0.02426 ET_c}\right)$$
$$SF = (0.531747 + 0.295164D - 0.057697D^2 + 0.003804D^3$$

Where: P_e = average monthly effective precipitation (in); P_t = monthly mean precipitation (in); ET_c = crop ET (in); SF = soil water storage factor; D = usable soil water storage (in).

The usable soil water storage (D) was estimated to be three inches. In place of using the monthly mean precipitation for P_t in the above equation, the 80 percent exceedance monthly precipitation was used in order to calculate a more conservative estimate of the amount of crop water requirement that would be satisfied by rainfall. Effective precipitation values for each crop and each unit are provided in Appendix G.

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APPENDIX G

EVAPOTRANSPIRATION, CROP ET, EFFECTIVE PRECIPICATION,

NET IRRIGATION REQUIREMENTS AND CROPPING PATTERN TABLES

ETo, Crop ET, Effective Precipitation, Net Irrigation Requirement and Cropping Pattern for Nutria

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Grass Reference ET (inches water) ASCE standardized Penman Montieth	1.38	1.91	3.12	4.41	5.97	6.95	6.92	6.05	4.96	3.51	2.02	1.35	48.56
80% Exceedance monthly Precipitation (1948-2004)	1.03	0.85	1.04	0.63	0.43	0.39	1.41	1.62	0.94	0.88	0.87	0.86	10.95
Crop ET													
Small Grains, Grain				1.74	6.38	8.00	5.23	0.06					21.41
Small Grains, Hay				3.28	6.39	8.00	2.03						19.70
Alfalfa				0.15	4.73	6.25	6.98	6.13	4.27	2.74			31.26
Irrigated Pasture				0.69	4.44	6.04	6.01	5.25	4.31	2.67			29.40
Garden					2.32	5.49	7.26	6.19	0.16				21.42
Corn					1.18	4.15	7.55	6.76	2.15				21.79
Calculated Effective Precipitation													
Small Grains, Grain				0.36	0.34	0.33	1.10	0.00					2.14
Small Grains, Hay				0.39	0.34	0.33	0.10						1.17
Alfalfa				0.00	0.31	0.30	1.22	1.32	0.71	0.36			4.22
Irrigated Pasture				0.07	0.30	0.30	1.15	1.26	0.71	0.51			4.29
Garden					0.11	0.29	1.24	1.33	0.00				2.96
Corn					0.11	0.27	1.26	1.37	0.32				3.32
Calculated Net Irrigation Requirement													
Small Grains, Grain				1.38	6.04	7.66	4.13	0.06					19.27
Small Grains, Hay				2.89	6.06	7.66	1.93						18.53
Alfalfa				0.15	4.42	5.95	5.77	4.81	3.57	2.38			27.04
Irrigated Pasture				0.63	4.13	5.74	4.86	3.99	3.60	2.16			25.11
Garden					2.21	5.20	6.02	4.86	0.16				18.46
Corn					1.07	3.88	6.29	5.39	1.83				18.47
Cropping Pattern	**Monthly Weighting Factors for Each Crop**												
Small Grains, Grain (9%)				0.12	0.54	0.69	0.37	0.01					1.73
Small Grains, Hay (4%)				0.12	0.24	0.31	0.08						0.74
Alfalfa (31%)				0.05	1.37	1.84	1.79	1.49	1.11	0.74			8.38
Irrigated Pasture (24%)				0.15	0.99	1.38	1.17	0.96	0.86	0.52			6.03
Garden (2%)					0.04	0.10	0.12	0.10	0.00				0.37
Corn (30%)					0.32	1.16	1.89	1.62	0.55				5.54
Weighted Average Monthly NIR (inches)				**0.44**	**3.51**	**5.49**	**5.41**	**4.17**	**2.52**	**1.26**			**22.79**
Unit Diversion Requirement (inches)				**1.04**	**8.37**	**13.06**	**12.88**	**9.92**	**6.01**	**2.99**			**54.27**

ETo, Crop ET, Effective Precipitation, Net Irrigation Requirement and Cropping Pattern for Pescado

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Grass Reference ET (inches water) ASCE standardized Penman Montieth	1.44	2.09	3.42	4.79	6.28	7.16	7.09	6.20	5.07	3.56	2.06	1.38	50.54
80% Exceedance monthly Precipitation (1948-2004)	0.70	0.57	0.74	0.48	0.35	0.32	1.51	1.73	0.97	0.96	0.61	0.66	9.60
Crop ET													
Small Grains, Grain			0.42	3.53	7.22	7.42	1.67						20.27
Small Grains, Hay			0.63	3.79	7.22	5.83							17.48
Alfalfa					3.55	6.95	6.71	5.65	4.35	3.23			30.44
Irrigated Pasture				0.08	4.02	6.21	6.15	5.39	4.40	3.02			29.28
Garden					2.69	5.78	7.49	6.10					22.07
Corn					1.37	4.53	7.85	6.84	1.88				22.47
Calculated Effective Precipitation													
Small Grains, Grain			0.16	0.33	0.27	0.25	0.51						1.52
Small Grains, Hay			0.16	0.33	0.27	0.14							0.91
Alfalfa					0.17	0.24	1.28	1.37	0.74	0.50			4.31
Irrigated Pasture				0.00	0.23	0.23	1.24	1.35	0.74	0.65			4.45
Garden					0.10	0.23	1.34	1.37					3.03
Corn					0.09	0.21	1.37	1.47	0.28				3.42
Calculated Net Irrigation Requirement													
Small Grains, Grain			0.26	3.20	6.95	7.17	1.16						18.75
Small Grains, Hay			0.47	3.46	6.95	5.69							16.57
Alfalfa					3.38	6.70	5.42	4.28	3.61	2.72			26.13
Irrigated Pasture				0.08	3.80	5.98	4.91	4.03	3.66	2.36			24.83
Garden					2.60	5.56	6.15	4.74	0.00				19.04
Corn					1.28	4.32	6.48	5.37	1.60				19.05
Cropping Pattern	**Monthly Weighting Factors for Each Crop**												
Small Grains, Grain (9%)			0.02	0.29	0.63	0.65	0.10						1.69
Small Grains, Hay (4%)			0.02	0.14	0.28	0.23							0.66
Alfalfa (31%)					1.05	2.08	1.68	1.33	1.12	0.84			8.10
Irrigated Pasture (24%)				0.02	0.91	1.44	1.18	0.97	0.88	0.57			5.96
Garden (2%)					0.05	0.11	0.12	0.09					0.38
Corn (30%)					0.38	1.29	1.95	1.61	0.48				5.72
Weighted Average Monthly NIR (inches)			**0.04**	**0.45**	**3.30**	**5.79**	**5.03**	**4.00**	**2.48**	**1.41**			**22.51**
Unit Diversion Requirement (inches)			**0.09**	**0.93**	**6.87**	**12.07**	**10.48**	**8.34**	**5.17**	**2.94**			**46.89**

ETo, Crop ET, Effective Precipitation, Net Irrigation Requirement and Cropping Pattern for Tekapo

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Grass Reference ET (inches water) ASCE standardized Penman Montieth	1.49	2.16	3.52	4.90	6.40	7.26	7.18	6.29	5.16	3.64	2.13	1.43	51.55
80% Exceedance monthly Precipitation (1948-2004)	0.65	0.53	0.69	0.45	0.32	0.30	1.41	1.61	0.91	0.89	0.57	0.61	8.93
Crop ET													
Small Grains, Grain			0.83	4.53	7.36	6.83	1.03						20.58
Small Grains, Hay			0.94	4.58	7.36	4.20							17.07
Alfalfa				0.64	5.54	6.35	7.10	6.48	4.76	3.76			34.63
Irrigated Pasture				1.19	5.10	6.31	6.24	5.46	4.48	3.16	0.23		32.16
Garden					3.29	6.18	7.66	5.37					22.51
Corn					1.70	5.17	8.14	6.70	1.31				23.02
Calculated Effective Precipitation													
Small Grains, Grain			0.24	0.32	0.25	0.22	0.27						1.30
Small Grains, Hay			0.24	0.32	0.25	0.05							0.86
Alfalfa				0.00	0.22	0.21	1.23	1.34	0.70	0.57			4.28
Irrigated Pasture				0.08	0.22	0.21	1.17	1.27	0.69	0.63	0.00		4.27
Garden					0.12	0.21	1.26	1.07					2.67
Corn					0.11	0.20	1.30	1.36	0.16				3.13
Calculated Net Irrigation Requirement													
Small Grains, Grain			0.59	4.21	7.11	6.61	0.76						19.29
Small Grains, Hay			0.70	4.26	7.11	4.14							16.21
Alfalfa				0.64	5.32	6.14	5.88	5.13	4.06	3.19			30.36
Irrigated Pasture				1.10	4.88	6.10	5.07	4.19	3.79	2.53	0.23		27.88
Garden					3.17	5.97	6.40	4.30	0.00				19.84
Corn					1.59	4.97	6.84	5.34	1.15				19.89
Cropping Pattern	**Monthly Weighting Factors for Each Crop**												
Small Grains, Grain (9%)			0.05	0.38	0.64	0.59	0.07						1.74
Small Grains, Hay (4%)			0.03	0.17	0.28	0.17							0.65
Alfalfa (31%)				0.20	1.65	1.90	1.82	1.59	1.26	0.99			9.41
Irrigated Pasture (24%)				0.26	1.17	1.46	1.22	1.01	0.91	0.61	0.05		6.69
Garden (2%)					0.06	0.12	0.13	0.09					0.40
Corn (30%)					0.48	1.49	2.05	1.60	0.35				5.97
Weighted Average Monthly NIR (inches)			**0.08**	**1.01**	**4.28**	**5.74**	**5.29**	**4.29**	**2.51**	**1.60**	**0.05**		**24.85**
Unit Diversion Requirement (inches)			**0.17**	**2.11**	**8.93**	**11.95**	**11.01**	**8.93**	**5.24**	**3.33**	**0.11**		**51.77**

ETo, Crop ET, Effective Precipitation, Net Irrigation Requirement and Cropping Pattern for Ojo Caliente

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Grass Reference ET (inches water) ASCE standardized Penman Montieth	1.49	2.16	3.52	4.90	6.40	7.26	7.18	6.29	5.16	3.64	2.13	1.43	51.55
80% Exceedance monthly Precipitation (1948-2004)	0.65	0.53	0.69	0.45	0.32	0.30	1.41	1.61	0.91	0.89	0.57	0.61	8.93
Crop ET													
Small Grains, Grain			0.83	4.53	7.36	6.83	1.03						20.58
Small Grains, Hay			0.94	4.58	7.36	4.20							17.07
Alfalfa				0.64	5.54	6.35	7.10	6.48	4.76	3.76			34.63
Irrigated Pasture				1.19	5.10	6.31	6.24	5.46	4.48	3.16	0.23		32.16
Garden					3.29	6.18	7.66	5.37					22.51
Corn					1.70	5.17	8.14	6.70	1.31				23.02
Calculated Effective Precipitation													
Small Grains, Grain			0.24	0.32	0.25	0.22	0.27						1.30
Small Grains, Hay			0.24	0.32	0.25	0.05							0.86
Alfalfa				0.00	0.22	0.21	1.23	1.34	0.70	0.57			4.28
Irrigated Pasture				0.08	0.22	0.21	1.17	1.27	0.69	0.63	0.00		4.27
Garden					0.12	0.21	1.26	1.07					2.67
Corn					0.11	0.20	1.30	1.36	0.16				3.13
Calculated Net Irrigation Requirement													
Small Grains, Grain			0.59	4.21	7.11	6.61	0.76						19.29
Small Grains, Hay			0.70	4.26	7.11	4.14							16.21
Alfalfa				0.64	5.32	6.14	5.88	5.13	4.06	3.19			30.36
Irrigated Pasture				1.10	4.88	6.10	5.07	4.19	3.79	2.53	0.23		27.88
Garden					3.17	5.97	6.40	4.30	0.00				19.84
Corn					1.59	4.97	6.84	5.34	1.15				19.89
Cropping Pattern	**Monthly Weighting Factors for Each Crop**												
Small Grains, Grain (9%)			0.05	0.34	0.57	0.53	0.06						1.54
Small Grains, Hay (4%)			0.03	0.17	0.28	0.17							0.65
Alfalfa (31%)				0.20	1.65	1.90	1.82	1.59	1.26	0.99			9.41
Irrigated Pasture (24%)				0.26	1.17	1.46	1.22	1.01	0.91	0.61	0.05		6.69
Garden (2%)					0.06	0.12	0.13	0.09					0.40
Corn (30%)					0.49	1.54	2.12	1.66	0.36				6.16
Weighted Average Monthly NIR (inches)			**0.08**	**0.97**	**4.23**	**5.72**	**5.35**	**4.34**	**2.52**	**1.60**	**0.05**		**24.86**
Unit Diversion Requirement (inches)			**0.14**	**1.79**	**7.83**	**10.59**	**9.90**	**8.03**	**4.68**	**2.96**	**0.10**		**46.03**

ETo, Crop ET, Effective Precipitation, Net Irrigation Rates and Cropping Pattern for Zuni

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Grass Reference ET (inches water) ASCE standardized Penman Montieth	1.49	2.16	3.52	4.90	6.40	7.26	7.18	6.29	5.16	3.64	2.13	1.43	51.55
80% Exceedance monthly Precipitation (1948-2004)	0.65	0.53	0.69	0.45	0.32	0.30	1.41	1.61	0.91	0.89	0.57	0.61	8.93
Crop ET													
Small Grains, Grain			0.83	4.53	7.36	6.83	1.03						20.58
Small Grains, Hay			0.94	4.58	7.36	4.20							17.07
Alfalfa				0.64	5.54	6.35	7.10	6.48	4.76	3.76			34.63
Irrigated Pasture				1.19	5.10	6.31	6.24	5.46	4.48	3.16	0.23		32.16
Garden					3.29	6.18	7.66	5.37					22.51
Corn					1.70	5.17	8.14	6.70	1.31				23.02
Calculated Effective Precipitation													
Small Grains, Grain			0.24	0.32	0.25	0.22	0.27						1.30
Small Grains, Hay			0.24	0.32	0.25	0.05							0.86
Alfalfa				0.00	0.22	0.21	1.23	1.34	0.70	0.57			4.28
Irrigated Pasture				0.08	0.22	0.21	1.17	1.27	0.69	0.63	0.00		4.27
Garden					0.12	0.21	1.26	1.07					2.67
Corn					0.11	0.20	1.30	1.36	0.16				3.13
Calculated Net Irrigation Requirement													
Small Grains, Grain			0.59	4.21	7.11	6.61	0.76						19.29
Small Grains, Hay			0.70	4.26	7.11	4.14							16.21
Alfalfa				0.64	5.32	6.14	5.88	5.13	4.06	3.19			30.36
Irrigated Pasture				1.10	4.88	6.10	5.07	4.19	3.79	2.53	0.23		27.88
Garden					3.17	5.97	6.40	4.30	0.00				19.84
Corn					1.59	4.97	6.84	5.34	1.15				19.89
Cropping Pattern	**Monthly Weighting Factors for Each Crop**												
Small Grains, Grain (9%)			0.05	0.34	0.57	0.53	0.06						1.54
Small Grains, Hay (4%)			0.03	0.17	0.28	0.17							0.65
Alfalfa (31%)				0.20	1.65	1.90	1.82	1.59	1.26	0.99			9.41
Irrigated Pasture (24%)				0.26	1.17	1.46	1.22	1.01	0.91	0.61	0.05		6.69
Garden (2%)					0.06	0.12	0.13	0.09					0.40
Corn (30%)					0.49	1.54	2.12	1.66	0.36				6.16
Weighted Average Monthly NIR (inches)			**0.08**	**0.97**	**4.23**	**5.72**	**5.35**	**4.34**	**2.52**	**1.60**	**0.05**		**24.86**
Unit Diversion Requirement (inches)			**0.18**	**2.31**	**10.07**	**13.62**	**12.73**	**10.33**	**6.01**	**3.80**	**0.13**		**59.18**

APPENDIX H

MODIFICATION OF ET CALCULATIONS

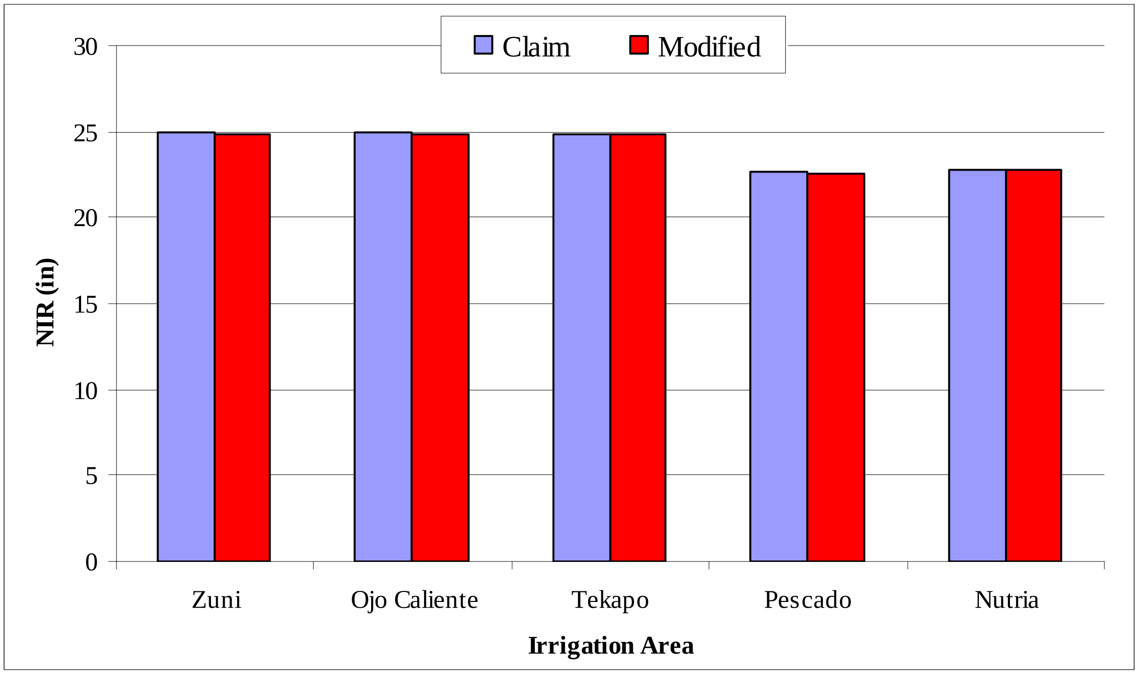
After submittal of the Zuni historical irrigation water rights claims, subsequent work identified two modifications to the crop ET calculations. These modifications can be viewed as improvements to the previous crop ET estimates. The first modification involved the wind speed climate input when calculating the reference ET. In the original claims, the daytime average wind speed was used in calculating reference ET. Further investigation indicated that the 24-hour daily average wind speed should be used with the ASCE Penman-Montieth equation for reference ET. The wind speed inputs were modified and the reference ET calculations were revised. The second modification was to the crop coefficients. In the original claims, the crop coefficients were calculated as the basal crop coefficients and did not include the soil water evaporation factor. The soil water evaporation factor (K_w) was included in the revised crop coefficients and the crop ET calculations were revised.

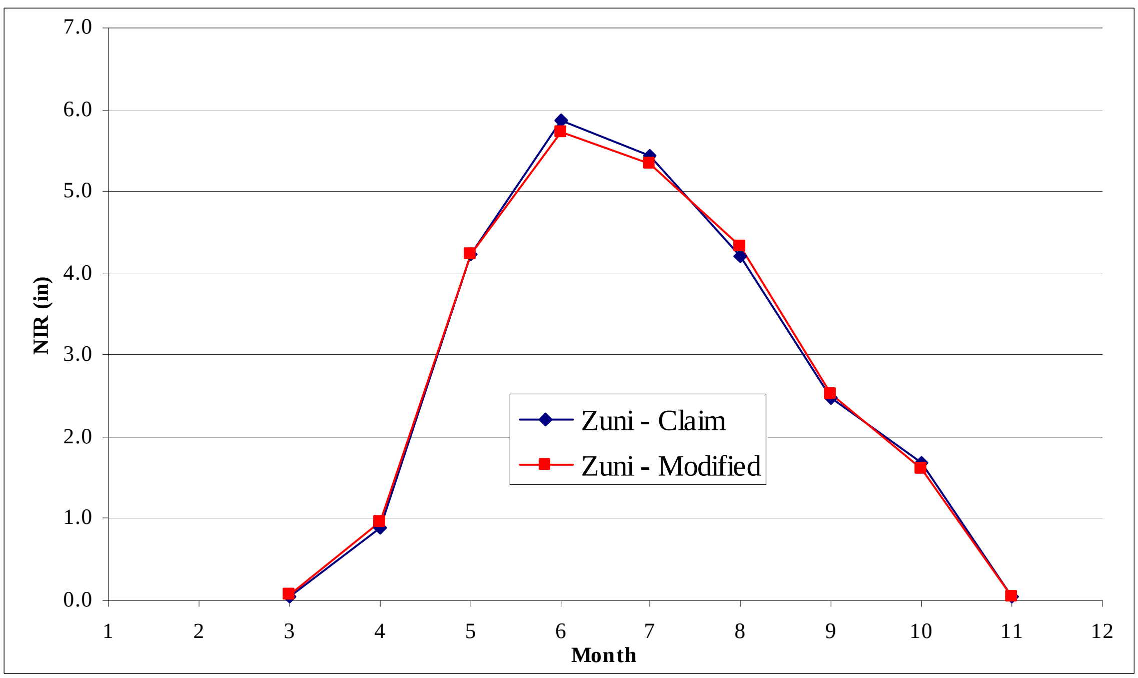
Figure H-1 shows a comparison between the claim values and modified values of net irrigation requirement. The effect of applying the daytime average wind speed was to reduce the reference ET results relative to the claim values. The effect of applying the soil water evaporation factor was to increase the crop ET results relative to the claim values. The overall effect, seen in comparing the net irrigation requirement values for the claim and modified values, was very little. Table H-1 shows that the net irrigation requirements changed by less than one percent for all irrigation areas after making the above modifications. This difference is considered to be within the accuracy of the irrigation water use estimation methods. The conclusion is that the original diversion and depletion estimates provided in the claim do not need to be modified.

Table H-1: Comparison of the Claim and Modified Scenarios.

Scenario	**Zuni**	**Ojo Caliente**	**Tekapo**	**Pescado**	**Nutria**
Claim	24.90	24.90	24.90	22.71	22.79
Modified	24.86	24.86	24.85	22.51	22.79
Difference	0.18%	0.18%	0.20%	0.86%	0.00%

Figure H-1: Net Irrigation Requirement under the Claim and Modified Scenarios.





Note: Monthly NIR Figure shows data for the Zuni Unit only.