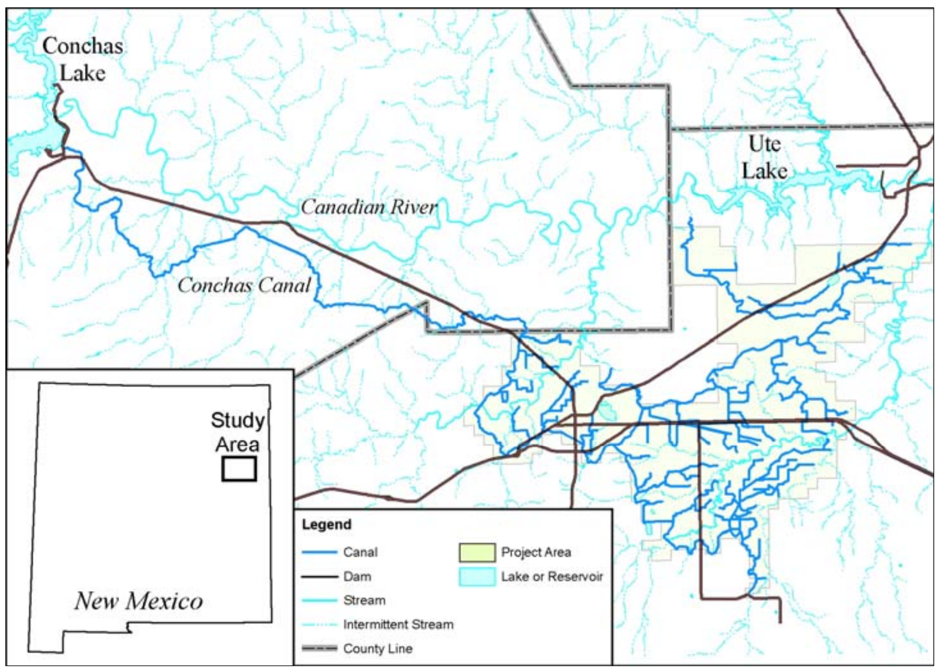
June 2006

STUDY OF POTENTIAL WATER SALVAGE ON THE TUCUMCARI PROJECT ARCH HURLEY CONSERVANCY DISTRICT

Phase I - A Pre-appraisal-level Study of the Potential Amount of Water That May Be Saved, and the Costs of Alternative Methods of Reducing Carriage Losses from District Canals

J. Phillip King
John W. Hawley
John Hernandez
John F. Kennedy
Eluid L. Martinez



NEW MEXICO WATER RESOURCES RESEARCH INSTITUTE
New Mexico State University
MSC 3167
Box 30001
Las Cruces, New Mexico 88003-8001
Telephone (505) 646-4337 Fax (505) 646-6418
Email: nmwrri@wrri.nmsu.edu

STUDY OF POTENTIAL WATER SALVAGE ON THE TUCUMCARI PROJECT ARCH HURLEY CONSERVANCY DISTRICT

Phase I

A Pre-appraisal-level Study of the Potential Amount of
Water that May Be Saved, and the Costs of Alternative Methods
of Reducing Carriage Losses from District Canals

By

J. Phillip King
John W. Hawley
John W. Hernandez
John F. Kennedy
Eluid Martinez

TECHNICAL COMPLETION REPORT

Account Number 01423921, 22, 23

June 2006

New Mexico Water Resources Research Institute

in cooperation with the
Department of Civil and Geological Engineering
New Mexico State University

The research on which this report is based was financed in part by the U.S. Bureau of Reclamation, Department of Interior through The Colorado Plateau Cooperative Ecosystem Studies Unit under a contract with the New Mexico Water Resources Research Institute.

DISCLAIMER

The purpose of the Water Resources Research Institute Technical Reports is to provide a timely outlet for research results obtained on projects supported in whole or in part by the Institute. Through these reports, we are promoting the free exchange of information and ideas and hope to stimulate thoughtful discussions and actions that may lead to the resolution of water problems. The WRRI, through peer review of draft reports, attempts to substantiate the accuracy of the information contained in its reports, but the views expressed are those of the authors and do not necessarily reflect those of the WRRI or of its reviewers. Contents of this publication do not necessarily reflect the views and policies of the Department of Interior nor does the mention of trade names or commercial products constitute their endorsement by the United States government.

ABSTRACT

Phase I of a two-phase pre-appraisal-level study of the potential reduction in carriage losses from the canal system of the Arch Hurley Conservancy District has been funded by the US Bureau of Reclamation. Water supply shortages have been a problem over the 50-year history of the Tucumcari Project. The principal problem has been the loss of over half of the District's surface water supply in the canal and distribution system that carries Canadian River water from Conchas Reservoir to the irrigated farms in the District. Phase I has been designed to identify sites of significant leakage from the 70 plus miles of canals that service the farm-delivery laterals and to quantify, to the extent possible, the magnitude of the canal seepage losses. A secondary goal has been to estimate the November 2005 costs of reducing canal seepage losses.

Strip-maps of the canal system were generated from aerial photographs and from USGS quad sheets. Materials from infrared photographs, from regional soils studies, and from area geography were added to maps and tables depicting conditions along the canal route. The project staff conducted a number of field studies at sites identified by infrared photography showing potential sources of water losses. During the summers of 2004 and 2005, field examinations of trees and grasses were made in areas that appeared to be sites of past leakage. Interpretations were made of the canal area soils and the geologic structure.

During the summer and fall of 2005, canal flow-losses were measured in the field on two occasions: early July and again in September. The strip-maps and tables generated in this study also contain information on leakage studies done by others and on line and grade of the canal. A new technique was used to compare infrared indications of leakage-associated vegetation during the 2003 period, when no irrigation water was released, and 2001 when a full supply was available to the District. This technique, known as change detection analysis, eliminated the need for extensive canal flow measurements.

The study found the cost of "saving" 12,600 acre-feet of water, now lost to canal seepage from the Main Conchas Canal, to be a little more than $25 million or about $2,000 per acre-foot of water saved. Further reduction of seepage losses will require the lining of laterals within the irrigation District. The 2005 cost of lining laterals was

estimated to be $500 to $1,000 per acre-foot. Reducing total system losses can be achieved most effectively by lining laterals used to supply farm turnouts.

ACKNOWLEDGEMENTS

The interest, cooperation, and collegiality of the Arch Hurley Conservancy District, its manager, Mr. Wayne Cunningham, and his very capable staff made this project successful and a pleasure to execute. The authors thank the District sincerely.

We also thank Mr. Steve Bowser of the U.S. Bureau of Reclamation, the funding agency for this work.

The authors appreciate the contributions of NMSU Civil Engineering students Sami Al Haddad, Brice Carpenter, Yeliz Cevik, Jimmy Moreno, and Suzanne Tillery, who carried out the seepage measurement field work and did much of the analysis.

Finally, we are grateful for the continuing contribution of the New Mexico Water Resources Research Institute, particularly Bobby Creel for his contribution to the GIS analysis; Kristine Kitchens for her contract administration; and Cathy Ortega Klett, Peggy Risner, and Sara Ash for their valuable support in report production and project management.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF PLATES

PART I

OBJECTIVES OF THE PRE-APPRAISAL STUDY

Water Resources Problems of the Arch Hurley Conservancy District

The Arch Hurley Conservancy District (District) suffers almost all of the water problems that confront many irrigation districts in the Bureau of Reclamation's west-wide panoply of projects. The phrase "almost all" is the right characterization: there are no Native American claims to the water resources on the Canadian River; there are no interstate claims awaiting settlement; there are no serious water quality issues; and while there are listed endangered species further downstream on the Canadian River, none have been found in the Conchas Reservoir, the only water storage site for the District.

The District's water problems are more fundamental, and some are subject to remediation given the necessary financial resources. Ira Clark describes the flow in the Canadian River as being "erratic" (1987, page 231). The variability and unpredictability of flows into Conchas Reservoir lead to two problems: first, the reservoir volume set-aside for irrigation-water storage in Conchas Lake has been depleted over time due to sediment deposition. There is not now sufficient irrigation storage in Conchas Lake to hold spills during wet periods that could provide needed over-year Project water for drier years. The three-year period beginning in July 2002 and including 2004 provides examples of times when there were no irrigation releases from Conchas Reservoir (2003 - 2004) because of the very low flows on the Canadian River into storage and when the irrigation releases were terminated early because of the lack of sufficient water in over-year storage to meet a full season's demand in 2002.

Water losses to evapotranspiration, evaporation, wastage, and canal seepage are the most significant of the District’s water problems. Because of sediment transport into the lake, a higher water level was needed in the reservoir in 2005 to store the same volume of water as in 1939. The higher lake levels result in greater evaporation losses. Canal losses are the District’s most pressing water problem. The canal system is very long: the Conchas Canal and the Hudson Canal have a combined length of more than 80 miles. Relatively large amounts of water are lost through seepage from these two canals to groundwater recharge and to evapotranspiration as the canals transport irrigation water to Project laterals. Seepage losses from some laterals are also significant.

Many of the District’s water problems are the consequence of the location, design, and construction of the irrigation system. Some water losses are the consequence of a combination of a lack of management alternatives, because of system structure, and of management policies. Wastage is one of the sources of water loss. Wastage occurs when water goes into canal bank storage and is then lost to seepage and evaporation. Wastage occurs during the annual initial-wetting of canal and lateral bottoms and banks and at the end of the irrigation season because of the need to flush and drain canals. Maintaining delivery-capable water-levels in the canals and laterals also leads to wastage at the terminals of the irrigation system and to wastage due to temporary, operational-spills. The control of water-consuming trees and plants in canals and laterals is an unending and costly maintenance problem.

Study Objectives

The U.S. Bureau of Reclamation (Reclamation) has a need for additional water supplies in the Pecos River system to off-set the depletions of Reclamation’s operations to enhance the habitat for an endangered fish species in the Pecos below the reservoir. One potential source of “new water” for the Pecos River system is to reduce canal losses in the Arch Hurley Conservancy District and to transport a part of the “saved water” from the Canadian River basin into the adjacent Pecos basin. Pre-appraisal-level studies are needed to determine the possibilities of a water-salvage project on the District’s canal system. Figure 1 is a map of the study area.

The first phase of the needed evaluations is a pre-appraisal study of the canal system losses, of the quality of “salvaged” water possible, of the alternative means of reducing losses, and the costs associated with methods and levels of seepage control. The canal system losses will be discussed at length in subsequent sections of this report.

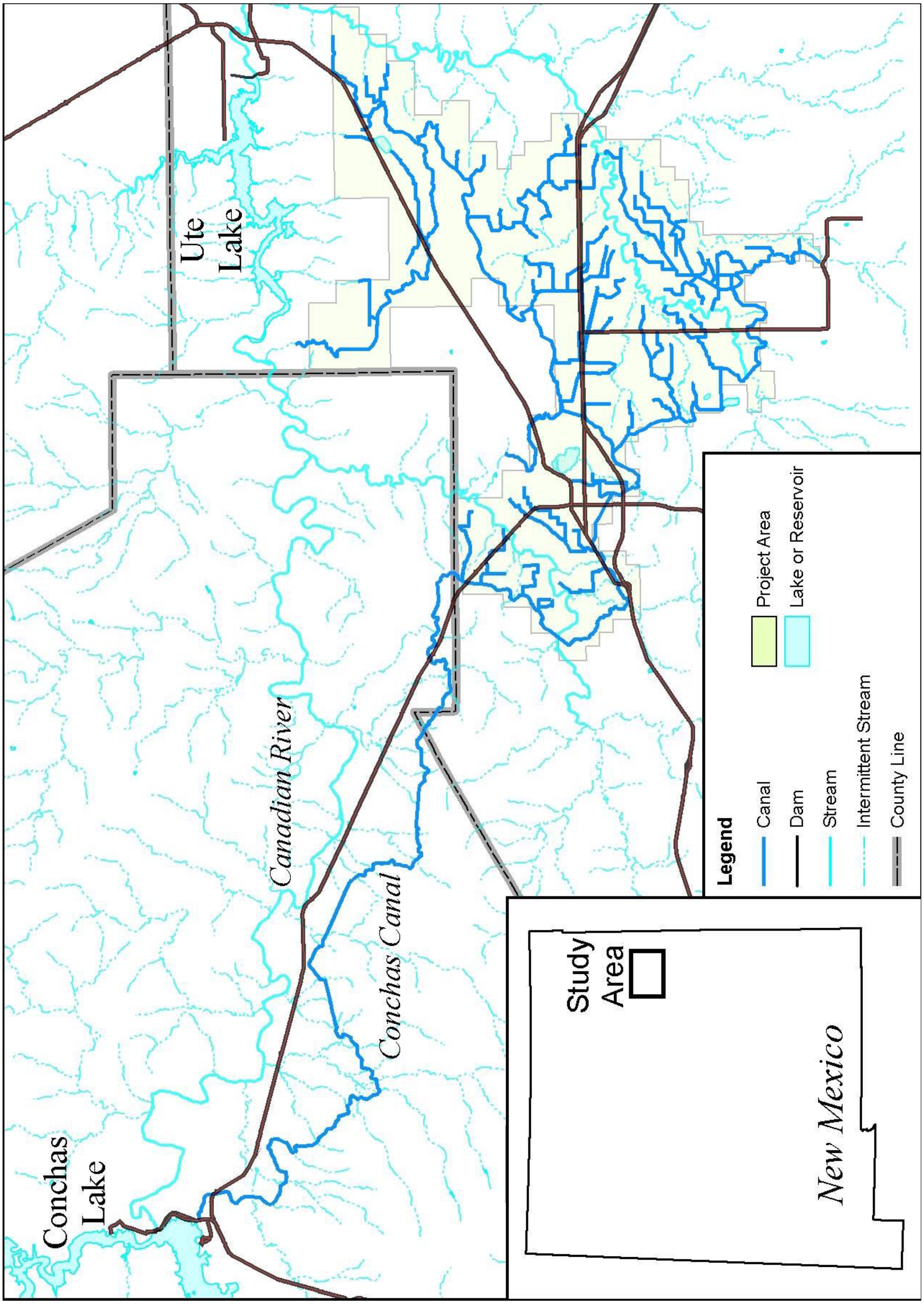


Figure 1. Study Area Map

PART II

CHARACTERISTICS OF THE DISTRICT'S WATER SUPPLY

A Brief History of the Arch Hurley Conservancy District

Interest in a flood control structure on the Canadian River reached the U.S. Congress in 1929 when New Mexico's delegation was able to include both the Cimarron and the Canadian rivers in the federal Mississippi River flood control plans. Funding for Conchas Dam was the product of depression era legislation designed to provide work-relief funds for regional water projects. Conchas Dam was nominated as a flood control structure by the New Mexico State legislature in 1931 and then approved under the Federal Relief Act of 1935 by President Franklin Roosevelt. Flood control concerns by downstream states were a key element for inclusion of the dam in the June 22, 1936 Corp of Engineers' (Corps) "General Flood Control Plan" (Clark 1987, page 262). Funding for Conchas Dam was a part of the lower Mississippi Valley flood control program under the Federal Flood Control Act of 1936. The 1936 estimated cost of the project was $12.5 million and the estimated 1936 maximum lake capacity was on the order of 600,000 acre-feet. The dam was completed in 1939 and is operated and maintained by the Corps.

In August of 1937, a federal act authorized Reclamation to use some of the impounded water for the Tucumcari Irrigation Project to be operated by the Arch Hurley Conservancy District (formed in April 1937) under a Reclamation repayment contract for the construction of irrigation works (Geyler 1998; Mutz 1998). An allocation of 281,000 acre-feet in the reservoir was made for the irrigation of 41,213 acres (see Appendix C for the District's water rights as recognized by the Office of the New Mexico State

Engineer). Construction of laterals, canals, tunnels and siphons was started in 1939 and completed in the mid-1950s.

<u>Physiographic Setting of the Conchas Canal System</u>

<u>General Setting</u>

The physiographic setting of the Arch Hurley Conservancy District study area includes the major landscape features or landforms, and the surficial geologic units of the corridor occupied by the Conchas and Hudson Canals run between Conchas Reservoir in San Miguel County and the eastern part of the irrigated land in Tucumcari Project in Quay County. This topic is more fully addressed in detail in Appendix B (Tables B1 to B5). Much of the descriptive materials on the physiographic setting of the Arch Hurley Conservancy District study area is summarized from recent review papers by Hunt (1998) and Hawley (2005, pages 22-27). The references cited in this section are given in Appendix A and in the reference section of Appendix B. Both sections offer a comprehensive presentation of the soils and geo-hydrology literature for the province. A number of general terms are used in this subsection. When technical soils and geologic terms are used, the reader should impute general interpretations of their meaning.

<u>Description of the Study-area Physiographic Setting</u>

The entire study area is located in the Pecos-Canadian Valley Section of the southern Great Plains Physiographic Province (Dolliver 1984, 1985; Hawley 1986, 2005). The Canadian Valley subsection of the upper Canadian River drainage basin is bounded of the northwest by the Raton Section characterized by the Canadian Escarpment and on the south by the Southern High Plains Section characterized by the

Llano Estacado-Caprock Escarpment. Conchas Dam and the upper Conchas Canal diversion structure (at an elevation of about 4,155 feet) are located at the confluence of Canadian River and Conchas Creek.

1. The Canadian River Drainage Basin

The Conchas Creek headwaters are at the southern edge of the Las Vegas Plateau above the Canadian Escarpment and along a low-lying watershed divide with the north-eastern Pecos River basin (northeast of the Town of Santa Rosa). Headwaters of the two major tributaries of the Canadian River, Mora and Cimarrón Rivers, are located in the southeasternmost part of the Southern Rocky Mountain Province, with peak elevations ranging from 12,000 to 13,000 feet.

2. Conchas Dam and Reservoir

Conchas Dam is sited in an inner-canyon reach that is cut into the Santa Rosa Sandstone (SS) Member at the base of the Upper Triassic-Chinle Group (Gp). It is located at the upper end of a narrow river-valley segment (southeastern section of San Miguel County) that extends to the Tucumcari Project irrigated area of western Quay County. Conchas Reservoir occupies the lower Conchas Creek Valley and a long reach of the Canadian Valley at elevations between 4,201 feet (at the crest of the dam spillway) and about 4,040 feet in the canyon floor. This broad lowland area with scattered tablelands (characterized as mesas and buttes) is eroded into a thick sequence of non-marine mudstones and inter-bedded sandstones of the middle and upper Chinle Group. The high Canadian Escarpment-Las Vegas Plateau region to the north is capped by resistant (marine) sandstones of the Dakota Group (including the Mesa Rica Sandstone); escarpment slopes are carved on weaker mudstones, siltstones and sandstones of the

Jurassic Age (that includes the non-marine Morrison Formation/Summerville Formations/ Entrada Sandstone sequence), which are mantled by extensive landslide deposits.

3. The Conchas Canal Corridor in San Miguel County

Mesa Rica (at elevations between 4,800-5,400 feet) is the major upland landscape feature of the upper Conchas Canal section, which extends roughly 39 miles from the Dam to the irrigation Project boundary at the San Miguel-Quay County Line. The Mesa is a large tableland-outlier capped by the Dakota Group-Mesa Rica Sandstone, and it marks the physiographic transition from the Las Vegas Plateau to the northwest and the Southern High Plains-Llano Estacado to the south. Most of the canal corridor (at elevations between 4,155 to 4,100 feet) in this reach is located at or near the base of the northern Mesa Rica escarpment, which has a local relief of almost 1,000 feet along the canal route; it includes three long-tunnels (for locations see Tables 13D, 13E and 13G, Tunnels numbered 2, 3 and 4). In this critical area of potential canal leakage (see Tables 13 and 15), most sections of the canal were excavated in the relatively impermeable mudstones and interbedded sandstones of the uppermost Chile Gp and overlying sandstones and mudstones of the lower Morrison/Summerville Formation/Entrada Sandstone sequence. Landslide deposits are locally a very important escarpment component (Hilley et al. 1981, San Miguel County SCS Soil Survey).

4. The Canal Corridor in Quay County

The Quay County section of the Tucumcari Project lies east of the Mesa Rica Sandstone. As you leave the Mesa Rica dominated reach, the middle to lower Conchas and Hudson Canal system enters an area of broad alluvial plains that are intermediate in elevation between inner Canadian Valley/Canyon reaches to the north and the high plateaus and mesa outliers to the south and west. These plains are extensively veneered with windblown deposits and *calcic* soils (Ross and Pease 1974), and this eolian/alluvial sedimentary sequence shallowly buries Chinle Group and the Summerville/Entrada Sandstone bedrock units in much of the lower Conchas-Hudson Canal section of the Tucumcari Project (that is the section beyond the "Y" where the Hudson Canal starts and the Conchas Canal continues on south and east).

In the immediate vicinity of Tucumcari (that is, north of Tucumcari Mountain and east of Pajarito Creek), the alluvial-eolian veneer is much thicker and overlies as much as 350 feet of older alluvial and playa-lake deposits that fill several large closed depressions and buried valleys. The latter features appear to be primarily of solution-subsidence origin and are related to Late Cenozoic dissolution of thick evaporite units that originally formed much of the Permian bedrock sequence that underlies the Triassic section of the entire study area (Trauger and Bushman 1964, Trauger 1972b, Dolliver 1985, Love 1985, Hunt 1998).

These thick, depression and buried-valley fills and contiguous parts of the Entrada Sandstone constitute the major aquifer system of Tucumcari municipal area (see Part III of this report and Appendix B for further discussion). Much of the recharge to this critical groundwater reservoir is from historic (post-1946) leakage associated with operation of the canals and farming of irrigated lands in Tucumcari Project (see Trauger and Bushman 1964, pages 10, 31, 33, 61-64, 74-76, 84-85, 90, and 103-107). Tucumcari Lake is a large, very shallow bedrock depression that is located southeast of the large, deep solution-subsidence basin that contains the Tucumcari Town well-field alluvial aquifer unit (see Appendix B for more details on the soils and geology of the study area).

Climatic Characteristics in the Tucumcari Area

Regional Climate

The irrigation season for the Arch Hurley District is typically from mid-April to mid-September as the frost-free period in Tucumcari is typically about 190 days with the last spring frost coming before the third week in April and the year's first freeze often coming after the third week of October (Reclamation 1951). The climate in the area is characteristic of most of the semi-arid southwest: dry air and warm sunny days during the growing season. Wide diurnal temperature changes are common on summer days: highs in the 90s during the day and dropping rapidly after sunset into the 60s on most nights (Reclamation May 2002). The weather is mild, sunny and dry during most of the year. Burnham (1953) provides an old, but comprehensive report of the area climate.

High rates of evaporation from Conchas Lake are the consequence of a lack of humidity, winds that average 12 miles per hour, and a high percentage of sunny days. The literature contains many estimates of Conchas evaporation rates: less than 0.1 inches per day in December, more than 0.33 inches per day in the summer months (Kirksey 2002, page 3), and 100 inches per year (Reclamation 1983, page 6). The net evaporation from the reservoir is a function of the surface area. When the lake is full (9,615 acres of surface area), evaporation is on the order of 200 acre-feet per day during the summer months (Kirksey 2002, page 1). If the average annual surface area of the lake ranges between 2,500 and 5,000 acres and the rate of evaporation is on the order of 100 inches per year, then the total annual evaporation loss from Conchas Reservoir would range from about 20,000 acre-feet to about 40,000 acre-feet per year.

Corps of Engineers data (District 1981) for monthly evaporation rates of loss from the lake for 1980 are shown in Table 1 when the total evaporation for the year was 93.5 inches:

TABLE 1

Conchas Monthly Evaporation Rates in 1980

Month	Monthly Evaporation Rate
April	7.85 inches
May	9.12 inches
June	12.89 inches
July	14.52 inches
August	10.71 inches
September	7.36 inches
October	7.33 inches

The Corps of Engineers (Corps) in Albuquerque maintains a comprehensive record of the computed surface area of the lake and the estimated reservoir evaporation losses based on pan studies and other information. During the summer, estimates of evaporation from the lake are made by the Corps using pan evaporation rates that are adjusted for lake surface area and other conditions. Winter rates are estimated using a standard land-pan (Kirksey 2002, page 3). The Corps records are the best information available. Table 2 below gives the Corps evaporation records from the lake, in acre-feet, for each of the most recent 14 years. Note that in 1998 and 1999, Conchas Reservoir was almost at the spillway level as the reservoir was nearly full. In 1999, the total evaporation was a little over 44,000 acre-feet, and in 2003 when no irrigation water was stored in the reservoir, the evaporative losses were 19,000 acre-feet. The estimate given above showing that annual evaporation from the lake will be somewhere in the range from

20,000 to 40,000 acre-feet appears to be an acceptable figure for future planning of irrigation releases.

TABLE 2

Reservoir Evaporation in Acre-feet

Calendar Year	**Evaporation Acre-feet**
1990	29,943
1991	30,215
1992	42,415
1993	40,305
1994	41,604
1995	43,687
1996	42,497
1997	41,758
1998	44,306
1999	44,021
2000	42,416
2001	28,550
2002	19,761
2003	19,112
2004	19,571

Precipitation in the Project area has been measured and recorded for over one-hundred years. Table 3 provides a summary of the monthly average and maximum monthly precipitation at the NMSU Agricultural Science Center in Tucumcari for the period 1905 to 2000. The average annual rainfall for the period was 16 inches and the maximum year was 34.9 inches. From Table 3 it can be seen that three-fourths of the annual rainfall comes during the growing season. Precipitation in the Tucumcari area plays a significant roll in the success or failure of the farming enterprise served by the District as summer rains supplement the District's irrigation supply. Local precipitation contributes some to the Project water supply that is stored in Conchas Reservoir, but not to the extent that regional rainfall contributes to the supply stored in the Lake. Regional rainfall on the Canadian River watershed, in May through September, is the major source of the Project water stored in Conchas Reservoir. Runoff from winter-spring precipitation in the upper Canadian River headwaters is also a significant source in some years.

TABLE 3
Average and Maximum
Monthly Precipitation
Tucumcari, New Mexico 1905 – 2000

MONTH	MONTHLY AVERAGE PRECIPITATION in inches	MAXIMUM MONTHLY PRECIPITATION in inches
JANUARY	0.36	1.25
FEBRUARY	0.47	2.40
MARCH	0.71	3.69
APRIL	1.13	4.51
MAY	2.01	8.72
JUNE	1.91	6.39
JULY	2.64	11.28
AUGUST	2.76	8.38
SEPTEMBER	1.50	7.23
OCTOBER	1.30	7.51
NOVEMBER	0.65	4.00
DECEMBER	0.59	4.27

Conchas Reservoir Water Supply

The Conchas Reservoir Watershed

Conchas Dam and Reservoir are located in San Miguel County at the junction of the Conchas Creek and the Canadian River, roughly 30 miles northeast of Tucumcari, New Mexico. The total area of the reservoir watershed is on the order of 7,300 square miles: 6,000 square miles in the Canadian River drainage basin, about 500 square miles in the Conchas Creek basin, and perhaps 800 square miles that is below USGS flow measuring stations (Kirksey 2002, page 1). The contributing watershed above the USGS station on the Canadian is about 5,700 square miles. Over 90 percent of the inflow into the reservoir is measured at the USGS station on the Canadian River near Sanchez, NM (07221500). The elevation of this gage is 4,495 feet above mean sea level, and stream-flow records are available for this station since 1913. There was also a USGS gage on Conchas Creek (07222500) at Variadero, New Mexico, about ten miles above the point where the creek enters the reservoir. This station was operated from 1936 to 1996.

Analysis of Annual Flows into Conchas Reservoir

The Corps estimates the inflow into the lake from the measurements on the Canadian by the gage at Sanchez plus estimates of the contribution of Conchas Creek and on other factors. Table 4 is a summary of the Corps estimates of inflow into Conchas from 1954 to 2004. These values are considered to be the best information available, but do differ somewhat from District records and from other sources. Some of these differences may result from the use of annual calendar-year reporting versus "water year" reports (October 1 to September 30). As a result, reported statistical values are inconsistent. The distribution of annual flows into the Reservoir is similar to most western rivers: a log-normal distribution as the arithmetic distribution is highly skewed to the right, because of some very high annual flows recorded in the past. The arithmetic average flow for the period 1954-2002 is 137,000 acre-feet, the median 112,000 acre-feet, the mode 90,000 acre-feet, and the standard distribution is 82,000 acre-feet. Calculating probabilities is not a useful exercise as there is no correlation between annual reservoir inflow and the annual releases made for irrigation. A linear least-squares analysis between annual reservoir inflows and reservoir releases yields a slope of 0.1 and a correlation coefficient of 0.01.

TABLE 4
RECORDS OF INFLOW INTO
CONCHAS RESERVOIR

YEAR	RESERVOIR INFLOW IN acre-feet
1954	79090
1955	252050
1956	46910
1957	193210
1958	278990
1959	120740
1960	166620
1961	182980
1962	109120
1963	71130
1964	30220
1965	406590
1966	99880
1967	146120
1968	109840
1969	227370
1970	71100
1971	72270
1972	164186
1973	179945
1974	29563
1975	37697
1976	42370
1977	86198
1978	59331

YEAR	RESERVOIR INFLOW IN acre-feet
1979	152704
1980	73626
1981	109505
1982	191620
1983	111401
1984	91243
1985	186521
1986	144490
1987	284370
1988	87479
1989	60002
1990	94637
1991	197105
1992	112932
1993	125375
1994	234318
1995	249434
1996	120456
1997	184612
1998	107849
1999	309916
2000	68820
2001	17954

Variability of Inflow in Conchas Reservoir

The variability and range of the annual flows into Conchas Reservoir are the prime characteristics of the Canadian River supply. In the 50 years between 1954 and 2003, the flow into Conchas has ranged from less than 18,000 acre-feet to more than 400,000 acre-feet. The arithmetic median annual inflow of 112,000 acre-feet is of interest: if the annual evaporation is only 30,000 acre-feet, then in one-half of the future years, a volume of about 80,000 acre-feet should be available to the District for release for irrigation from Conchas Reservoir. Unfortunately, it is impossible to predict the range of future inflows into the Reservoir. Researchers who have studied the supply are singularly unanimous about its unpredictability:

a. "…the timing and amount of…inflow is unknown" (Kirksey 2002, page 1)

b. "…it is not possible to predict the availability of water in Conchas Lake with any reliability" (Kirksey 2002, page 5)

c. "The water supply for the [Tucumcari] Project can best be described as 'undependable'" (NMSU Bulletin 707 1984)

d. "The major challenge [of the District] is to manage water resources during successive periods of low flow into Conchas" (Arch Hurley August 2000)

e. The District "must rely on rationing…when they anticipate a severe water shortage" (Reclamation May 2002)

f. "inflow [into the reservoir] is dependent upon spring and summer rains rather than on snowmelt and often leads to unpredictable timing of water allocations" (Reclamation February 1983, page 6)

Allocation of Storage Space in Conchas Reservoir

Table 5 is an area-capacity table provided by the Army Corps of Engineers, Albuquerque Office. Sediment surveys were done in 1987, and the values in Table 5 became effective January 1988.

TABLE 5
Conchas Reservoir Area-Capacity Table for Space Assigned to the Conservancy District Corps of Engineers January 1, 1988

Water Level Elevation in Feet	Reservoir Surface Area in Acres	Reservoir Capacity in Acre-feet	Capacity Assigned to the Conservancy District
4,155	2,694	61,532	0
4,156	2,802	64,280	2,748
4,157	2,919	67,140	5,608
4,158	3,059	70,130	8,598
4,159	3,116	73,217	11,685
4,160	3,202	76,376	14,844
4,161	3,280	79,617	18,085
4,162	3,359	82,936	21,404
4,163	3,454	86,343	24,811
4,164	3,555	89,848	28,316
4,165	3,667	93,458	31,926
4,166	3,775	97,180	35,648
4,167	3,859	100,996	39,464
4,168	3,957	104,904	43,372
4,169	4,042	108,904	47,372
4,170	4,144	112,997	51,465
4,171	4,268	117,203	55,671
4,172	4,363	121,518	59,986
4,173	4,475	125,938	64,406
4,174	4,612	130,481	68,949
4,175	4,740	135,157	73,625
4,176	4,877	139,966	78,434
4,177	5,024	144,916	83,384
4,178	5,161	150,008	88,476

TABLE 5 (continued)
Conchas Reservoir Area-Capacity Table
for Space Assigned to the Conservancy District
Corps of Engineers January 1, 1988

Water Level Elevation in Feet	Reservoir Surface Area in Acres	Reservoir Capacity in Acre-feet	Capacity Assigned to the Conservancy District
4,179	5,325	155,252	93,720
4,180	5,471	160,650	99,118
4,181	5,616	166,193	104,661
4,182	5,793	171,898	110,366
4,183	5,927	177,758	116,226
4,184	6,094	183,768	122,236
4,185	6,243	189,936	128,404
4,186	6,398	196,257	134,725
4,187	6,583	202,748	141,216
4,188	6,749	209,414	147,882
4,189	6,971	216,274	154,742
4,190	7,203	223,360	161,828
4,191	7,419	230,672	169,140
4,192	7,649	238,206	176,674
4,193	7,864	245,962	184,430
4,194	8,094	253,941	192,409
4,195	8,278	262,127	200,595
4,196	8,472	270,502	208,970
4,197	8,701	279,088	217,556
4,198	8,950	287,914	226,382
4,199	9,161	296,970	235,438
4,200	9,378	306,239	244,707
4,201	9,615	315,736	254,204

The original allocations of storage space in the lake were: an 84,000 acre-foot pool for sediment storage and recreation below elevation 4,155; an irrigation water storage-pool of 281,000 acre-feet between elevations 4,155 and 4,201 (spillway level); and about 200,000 acre-feet above the spillway level and elevation 4,218 for flood control protection for downstream communities. The elevation of the gravity flow from the reservoir into the Conchas Canal is at 4,157.35 making it impossible for the District to use their full storage allocation without pumping. The District enjoys access to an emergency pumping pool of roughly 24,000 acre-feet (Kirksey 2002) between elevations 4,152.5 and the gravity flow level of 4,157.35. The costs of pumping are often mitigated against the District's option to use the emergency pool.

By 1949 the irrigation pool was reduced to 269,000 acre-feet. When the Corps survey of the content of Conchas Reservoir was made in 1987, it was found that the recreation pool had been reduced to approximately 60,000 acre-feet and the irrigation pool to 254,000 acre-feet (see Table 5). The loss of approximately 25,000 acre-feet of storage space for recreation and for irrigation water storage have had an adverse impact on both recreation and on the Arch Hurley District. In the middle 1980s the New Mexico Office of the State Engineer considered the construction of silt control structures in the reaches of the Canadian upstream of the reservoir.

Spills and releases from Conchas Reservoir are measured at three points: spills are measured at sluice gates on the dam and at the spillway; District releases are measured at the outlet into the Conchas Canal; and releases made to the Bell Canal are made in the canal located on the north-side of the Canadian River. Water loss through seepage from the reservoir is not monitored.

<u>Characteristics of the Management of the District's Irrigation Releases</u>

<u>Management Policies in Making Releases from Conchas Reservoir</u>

An understanding of the long-term policies and procedures followed by the Arch Hurley Conservancy District in its management of the Project irrigation water, stored in Conchas Reservoir, is required if any of the supply is to be saved by reducing the high conveyance losses long suffered by the District. Three sources describe some of the current water management and pricing policies: 1) the District's <u>Water Rules and Regulations</u> of 1990; 2) the <u>Water Management Plan 2000;</u> and 3) Reclamation's, <u>Draft Water Conservation and Management Plan</u> dated 2002.

In making decisions on how much water to release from Conchas in any one year, the District begins to monitor the volume of water stored in the lake in late winter, and it considers other factors such as runoff rates into Conchas and late winter and early spring regional precipitation. Based on these factors, in February, or as early as possible in the spring, the District makes an irrigation-water allocation to Class A landowners, in inches of water per acre. Class A landowners are charged a basic per acre assessment and a water charge for the allocation, which was $6.00 per acre in 2000 (Reclamation 2002). A second and a third allocation of delivery water (in inches per acre) may also be made, if it appears that the prospects for the inflow into the reservoir have improved. To take advantage of this additional allotment, Class A landowners must pay a fee. A second allocation was priced at $12.00 per acre in 2000. The timing of releases and the amount released are both based "orders" for water from District farmers. It is the District's policy to deliver water to farm turn-outs "on demand." The District delivers water to any water user when an order is placed at least one-day earlier (in increments of 0.5 cubic feet per second) and when the total request for water deliveries, from all water users, equals or exceeds 40 cfs. As a consequence, area rainfall plays an enormous role in requests for water deliveries and in the timing and rate of reservoir releases.

Water Management Policy Questions

Many water management policy questions influence the timing and amount of irrigation releases made from Conchas Reservoir. For example: In setting annual allocations, does the District follow a policy that is designed to enhance the amount of "over-year" water held in the reservoir to provide some water for drought years? In periods of high reservoir inflow, does the District use what appears to be "excess" water to maintain room in the reservoir for July and August runoff and to prevent spills? Do the historic records show this to be the case? If seepage losses are curtailed, would some of the "excess" water be available for other uses? Does the District's "on demand" water delivery policy exacerbate wastage to canal and lateral bank storage due to the need to maintain high water-levels in the canals and laterals in order to comply with the District's policy of making farm deliveries, any where in the District, within twenty-four hours of a request? Does maintaining delivery-capable water-levels in the canals and laterals also leads to wastage at the terminals of the system and to wastage because of temporary operational spills?

The District is authorized to use as much as 300,000 acre-feet per year: does the District follow an active policy to use as much water as possible each year? Does the District follow a set of procedures that would act to reduce evaporation losses from the reservoir? Of the approximately 42,000 acres in the Project, how much land has the District historically irrigated? Is there a trend toward a reduction in Class A acreage farmed in the Project? Does the District start the irrigation season on roughly the same date each year? Does the District end the irrigation season at roughly the same time each year? How does the District allocate water stored in the reservoir at the start of each irrigation season? Does the District follow the same policy in wet years as during drought periods with respect to the start and end of irrigation? Has the District changed the allotment once the irrigation season is started? What is the monthly distribution of reservoir releases? How do peak months coincide with peak periods of storm water inflow into the reservoir? What is the largest monthly release that has been made in the past? The District and Reclamation should review the policy issues associated with this set of questions and consider the impact of management policies on water supply availability. The analysis that follows of historic water data addresses these and other issues.

Analysis of Historic Water Release Data

Tables 6 and 7 include historic data that provide some insight into the policies and management procedures that the District has followed over the past 50 years. Most of the procedures employed by the District in making reservoir releases have probably not been articulated in any formal manner. Over the 50+ years of the District's operation of reservoir releases, there have been many ditch-riders, many District managers, and many different Board members; all probably followed somewhat the same policies, but there may have been different sets of procedures. Various operating procedures have come and gone, but by reviewing the past actions, the District may be able to make better decisions in the future.

Table 6 is broken into four periods: 6A is the early years of irrigation (1947-1958) when new lands were added to the Class A inventory; 6B is the period from 1959 to 1975, the middle years when the acreage under cultivation remained about the same; 6C is the middle years between 1976 and 1990 when irrigated acreage began to decline; and 6D includes the more recent years from 1991 to 2003. Note that Table 6A contains just four columns, and that Table 6C and 6D have six. This is because some of the same information from earlier years is not now easily found. Most of the data in Table 6 come from District and/or Reclamation records, but some are from other sources such as the Corps. The table includes extended and estimated values, and there is missing data in some years. The information given is intended to show trends and the consequences of water management policies. The information provided in the columns in Table 6C and 6D is as follows along with an interpretation of this information as it relates to past water management procedures.

TABLE 6A
MANAGEMENT OF IRRIGATION RELEASES IN THE EARLY YEARS 1947-1958

Year and Months of Irrigation Releases	Acres of Project Lands Irrigated During the Year	Irrigation Releases per Acre Irrigated Acre-feet per Acre	Reservoir Releases in Acre-feet
1947 January thru November	6,638	5.77	38,300
1948 April thru October	16,069	5.04	81,000
1949 March thru November	22,510	3.42	76,900
1950 February & April thru October	31,563	3.46	109,300
1951 March thru November	33,318	3.84	128,000
1954 Apr thru Aug	37,259	1.73	64,559
1955 Apr thru Oct	38,677	2.25	86,839
1956 Mar thru Sept & Dec	33,140	3.18	105,326
1957 Apr thru Sept	37,658	2.25	84,897
1958 May thru Sept & Dec	33,556	2.37	79,528

TABLE 6B

MANAGEMENT OF IRRIGATION RELEASES DURING THE MIDDLE YEARS 1959-1975

Year and Months of Irrigation Releases	Acres of Project Lands Irrigated During Year	Annual Delivery Allotment Acre-feet per Acre	Irrigation Releases per Acre Irrigated Acre-feet per Acre	Reservoir Releases in Acre-feet
1959 Mar thru Sept & Dec	33,727	1.00	3.05	102,746
1960 Apr thru Oct	31,854	1.50	1.95	62,200
1961 Mar thru Oct	34,398	2.00	2.41	82,998
1962 Mar thru Oct	34,532	2.00	3.42	117,962
1963 Mar thru Sept	36,540	2.00	3.11	113,613
1964 Apr thru Sept	32,668	1.08	2.42	79,166
1965 Jun/ Oct & Dec	33,714	3.00	2.37	79,886
1966 Apr thru Oct & Dec	35,559	4.00	2.97	105,532
1967 Mar thru Oct & Dec	37,588	4.00	2.64	99,131
1968 Apr thru Oct & Dec	37,688	4.00	3.01	113,467
1969 Apr thru Oct	36,300	4.00	2.22	80,444
1970 Apr thru Oct & Dec	35,283	3.00	2.59	91,402
1971 Apr thru Oct	34,822	2.00	2.78	96,926
1972 Apr thru Oct	33,177	1.50	2.09	69,382
1973 May thru Oct	36,353	3.00	2.61	94,863
1974 Feb & Apr thru Oct	35,542	2.00	3.26	115,751
1975 May thru Oct	33,752	0.75	1.80	60,738

TABLE 6C

MANAGEMENT OF IRRIGATION RELEASES DURING THE MIDDLE YEARS 1976-1990

Year and Months of Irrigation Releases	Acres of Project Lands Irrigated During Year	Annual Delivery Allotment Acre-feet per Acre	Irrigation Releases per Acre Irrigated Acre-feet per Acre	Start of the Irrigation Season Reservoir Content In Acre-feet	Reservoir Releases in Acre-feet
1976 Aug & Sept	35,086	0.08	0.59	25,000 est.	20,780
1977 June thru Oct	37,417	0.54	1.02	173,100	38,103
1978 April thru Sept	33,173	0.67	1.56	29,300	51,686
1979 May thru Oct	31,497	1.50	2.08	14,400	65,547
1980 Apr thru Oct	32,874	1.50	2.21	75,700	72,748
1981 February thru Nov	32,994	0.83	1.45	37,100	47,915
1982 Apr thru Oct	29,584	1.50	2.24	175,000 estimated	66275
1983 April thru October	20,265	2.00	3.90	209,000	79,100
1984	30,000 estimated	1.50	2.50	148,000	75,000
1985 April	30,000 estimated	2.00	2.30	162,000	69,000
1986 April	30,000 estimated	1.50	2.17	150,000 estimated	65,000
1987 April	30,000 estimated	2.00	2.37	254,000	71,000
1988 March	30,000 estimated	2.00	2.13	226,000	64,000
1989 March	30,000 estimated	2.00	2.33	200,000	70,000
1990 April	30,000 estimated	1.50	2.60	148,000	78,000

TABLE 6D

MANAGEMENT OF IRRIGATION RELEASES DURING THE LATER YEARS 1991-2003

Year and Months of Irrigation Releases	Acres of Project Lands Irrigated During Year	Annual Delivery Allotment Acre-feet per Acre	Irrigation Releases per Acre Irrigated Acre-feet per Acre	Start of the Irrigation Season Reservoir Content In Acre-feet	Reservoir Releases in Acre-feet
1991 April	30,000 estimated	1.50	2.00	120,000	60,000
1992 April	30,000 estimated	2.00	2.84	244,000	85,100
1993 April	30,000 estimated	2.00	3.11	220,000	93,400
1994 March	30,000 estimated	2.00	3.18	190,000 Spill	95,400
1995 April	30,000 estimated	2.50	3.57	225,000 Spill	107,000
1996 March	30,000 estimated	2.00	3.20	235,000	96,000
1997 April	30,000 estimated	1.50	3.40	226,000	102,000
1998 April	30,000 estimated	2.00	3.63	245,000	109,000
1999 April	30,000 estimated	1.50	3.20	184,000	96,000
2000 April	30,000 estimated	2.00	3.93	225,000	118,000
2001 April	30,000 estimated	1.50	3.10	200,000	93,000
2002 April thru May & June	30,000 estimated	0.25	0.52	35,000	15,500
2003	No Irrigation	No Reservoir Releases	No Reservoir Releases	No Reservoir Releases	No Reservoir Releases

- Column 1 – contains the irrigation year and the month in which releases of water from Conchas Reservoir began. Table 6C and 6D show that the irrigation season has started as early as February and lasted as late as November.

- Column 2 – Table 6C and 6D give estimates of the number of acres under irrigation during each year. The number of acres irrigated was as high as 37,400 and as low as 20,200 during the period 1975 to 2003. During the period some Class A lands have been fallowed and placed in federal reserve status.

- Column 3 – contains the District's total annual water delivery allocation in acre-feet per acre during the indicated year. Values found in Table 6C and 6D range from 0.08 feet per acre to a delivery of 2.5 acre-feet per acre. This allocation of 2.5 feet came in 1995 when the reservoir spilled (see column 5). Noting the information in column 3 and 5 could lead to the belief that when large amounts of water are stored in the lake the District will allocate large amounts of water to be delivered to Class A lands.

- Column 4 – the values shown are calculated by dividing the estimated number of acres irrigated (column 2) by the release of water from the reservoir in each year. The acre-feet per acre reservoir releases ranged from 0.52 to 3.90 during the years 1976 to 2002. Again, the District's procedure on reservoir releases appears to be not to save water in Conchas for drier years, but to allocate as much as the farming community requests.

- Column 5—is an estimate of the amount of water in storage in the reservoir at the time that the irrigation season starts. Comparing high values in column 5 with those for the same year in column 4 leads to the conclusion that when there is water in the reservoir, it will be released for use, if requested by the farmers. The consequence of doing this can be seen by looking at these two columns in 2002 when there was only 35,000 acre-feet in Conchas in April. The District's water stored in the reservoir was essentially exhausted despite the fact that the lake was at high levels in 2000 and 2001.

- Column 6 – is the amount of water released by the District into its conveyance canal in each of the indicated years. In each year from 1993 to 2001 the District released above average amounts from Conchas Reservoir only to have the District's storage supply reduced to unusable amounts in 2002 and 2003.

Table 7 contains monthly reservoir release data made from 1954 to 1983. Monthly data after 1983 were not available for review. July and August are the peak months for releases. The largest monthly release in Table 7 was almost 25,000 acre-feet (August 1956). For the District to release 30,000 acre-feet in a month, Conchas Canal would have to flow at an average of 500 cfs. This would be a release of 1 acre-foot per acre, if the irrigated area in the Project is 30,000 acres.

TABLE 7

Monthly Reservoir Releases to the Conchas Canal (acre-feet)

YEAR	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov Dec	TOTALS
1954			15,180	11,754	14,084	11,484	12,057				64,559
1955			9,646	12,474	15,206	14,209	24,811	8,024	2,489		86,859
1956		1,004	20,478	16,507	11,422	12,448	24,958	14,565		3,944	105,326
1957			12,809	11,504	7,286	19,020	20,068	14,210			84,897
1958				9,921	11,654	21,269	19,936	8,541			71,321
1959		3,256	15,319	20,257	9,872	20,068	12,744	16,639			98,155
1960			9,198	18,437	4,904	2,783	10,846	12,445	3,587		62,200
1961			2,180	15,700	11,706	15,156	19,850	10,066			74,658
1962		9,940	15,248	18,744	13,775	16,984	23,211	14,438	5,622		117,962
1963		4,402	23,440	20,345	10,943	23,715	21,450	9,318			113,613
1964			16,252	16,930	13,766	14,100	12,628	5,490			79,166
1965					7,452	29,134	19,424	15,269	4,730	3,877	79,886
1966			20,161	19,467	9,103	19,431	10,327	13,457	7,290	6,296	105,532
1967		3,826	20,406	18,386	12,012	6,787	16,183	13,307	5,949	3,069	99,925
1968			15,338	14,745	18,594	17,391	20,671	15,741	5,871	5,116	113,467
1969			15,727	7,411	10,327	17,146	23,330	2,170	4,334		80,445
1970			5,004	17,760	18,080	16,820	14,230	10,606	3,490	5,412	91,402

TABLE 7 (continued)

Monthly Reservoir Releases to the Conchas Canal (acre-feet)

YEAR	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov Dec	TOTALS
1971			19,370	17,630	10,340	17,980	10,290	17,046	4,270		96,926
1972			14,500	13,887	11,860	8,495	14,376	1,040	5,224		69,382
1973				17,282	18,360	13,970	22,876	13,201	9,174		94,863
1974	6,630		22,679	21,387	18,702	19,852	14,252	8,202	4,047		115,751
1975				17,754	8,695	5,637	12,660	9,007	6,985		60,738
1976							15,848	4,932			20,780
1977					9,100	10,157	868	14,760	3,218		38,103
1978			900	4,000	2,700	14,400	12,600	8,700			43,300
1979			500	4,000	4,000	12,200	16,400	16,100	15,100	400	68,700
1980			6,344	3,553	14,915	22,492	9167	5,274	11,003		72,748
1981	300	400	11,900	1,100	9,800	4,600	3,300	6,600	5,500	100	43,600
1982			11,968	9,709	2,569	11,780	10106	13,805	6,438		66,375
1983				13,407	5,885	14,411	14,721	18,844	11,825		79,093

Month	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov Dec	
Percent of Total	0.3%	1.0%	12.7%	15.6%	13.3%	18.1%	19.4%	13.5%	5.3%	1.2%	

PART III

THE DISTRICT'S CONVEYANCE AND DELIVERY SYSTEM AND LOSSES

Characteristics of the Arch Hurley Irrigation System

Characteristics of the Irrigation System Canals and Laterals

The literature contains descriptions of the elements of the District's canals and lateral system. The District's irrigation-water conveyance and delivery system was built in the period just before and after World War II. It includes a complex main canal that traverses difficult terrain. The canals were designed to carry flows up to 700 cfs; however, over the years, the canals have lost their original design shape (Arch Hurley 2000, page 9).

General description of canals and laterals comprising the Tucumcari Project:

- The system has one storage reservoir (Conchas) and one set of pumps
- The system includes 110 miles of canals and 171 miles of laterals
- There are 30 siphons in the total system measuring more than 4 miles
- There are 5 tunnels in the system covering almost 6 miles
- The length of the earth-lined section of the Conchas Canal is 56 miles from the reservoir to the junction with the Hudson Canal
- The canal and lateral elevations run from 4,155 at the dam to 3,900 at the end of the delivery system

General description of the Conchas Main Canal outside of the irrigated area:

- The canal has 22 concrete siphons, 11.5 feet ID covering 12,128 feet
- The canal has 4 concrete tunnels 11.5 feet ID covering 27,209 feet
- The canal has two sections of 20-wide, 9 feet-9 inches high, open concrete box-flume on a 0.02 % slope; the 2 box flumes cover 0.49 miles
- The canal from the reservoir to the Quay County line runs 39 miles
- The canal slope varies from 0.0001 feet per foot to 0.0008 feet per foot
- The wetted area of the main canal is about 68 acres at conventional flows
- The canal, roughly trapezoidal in shape, now has irregular dimensions
- The canal design bottom-width dimension of the main canal was 24 feet
- The canal bottom width has widened to as much as 35 feet in places
- The canal side-slopes design was 1.5:1; they are now steeper and/or flatter
- The average top width of the canal when flowing full is about 48 feet

General description of the canal and lateral system within the irrigated area:

- The delivery system includes 20 laterals broken into 7 units
- The delivery system serves 580 customers
- The delivery system has 566 turnouts of which 475 are measured by weirs (425) or by orifices (50), but condition of measuring devices is poor
- The delivery system includes roughly 4-5 miles of pipe and 50 miles of lined laterals and canal sections; 10-15% of larger laterals are lined
- There are 75 miles of drains in the delivery system
- Within the irrigated area there are one tunnel and 12 siphons
- Within the irrigated area there are 250 miles of canals and laterals
- The capacity of larger laterals in the system is 70 cfs; smaller laterals 5 cfs
- There are a number of low bridges that cross over the canals and laterals
- There are a number of culverts under the canal to carry local area run-off
- Tucumcari Lake covers most of Section 18 in T11N R31E
- There is a small dry lake in Section 16 T10N R31E

District Irrigated Farm Lands, Soils and Terrain

The District's farmed area is located in a valley eroded by the Canadian River or by Canadian tributaries leaving sandy and clayey alluvial deposits (Reclamation 1983, page 7). District farmlands are broadly dispersed across the Tucumcari area: lands are located in 125 different sections in Township 12 North, Ranges 30-33 East; Township 11 North, Ranges 29-33 East; Township 10 North, Ranges 31-32 East. The elevation of the farming area is from about 4,100 to about 3,900 feet. The Project lands are divided into seven units as given in Table 8. The Conchas Main Canal delivers water to laterals that serve a little more than half of the Project lands (Units A, B, C, and D). The Main Canal delivers water to the Hudson Canal that serves Units E, F, and G. Flow measurement in laterals and at turnouts to farms is problematic. One of the District goals as listed in the Water Management Plan 2000 is to replace or retrofit defective and inadequate measuring devices in the system.

TABLE 8

ARCH HURLEY IRRIGATED PROJECT LANDS

Canal Sources of Water, Laterals, and Unit Boundaries

Unit	Acreage	Canal	Laterals	Boundaries
A	4,568	Conchas Main Canal	Bell Lateral and Roberts Lateral	Conchas Canal and Pajarito Ck.
B	5,341	Conchas Canal & Hudson Canal	Tucumcari Lat. & Club Lateral; Farm Lateral	Pajarito Ck., Conchas Canal, & Hudson Canal
C	5,490	Conchas Main Canal	Savage Lateral, Wharton Lateral, and Plaza Larga Lateral	Conchas Canal & Plaza Larga Creek
D	7,433	Conchas Main Canal	Conchas Lateral, Thomas Lateral, & Farrow Lat.	Plaza Larga Ck., Conchas Canal, & Barranca Creek
E	6,753	Hudson Canal	Benson Lateral, Gaudin Lateral, Felk Lateral	Hudson Canal and Hittson Creek
F	6,221	Hudson Canal	Bugg Lateral, McCaskey Lat.	Hudson Canal and Plaza Larga Creek
G	5,606	Hudson Canal	Hudson Lateral, Matter Lateral, Homer Lateral	Hudson Canal, and Tucumcari Creek

About half of the farmed-area soils drain well and are in loamy-sands with some clay. While they may have calcareous sub-soils, the better farmland does not have major salinity problems. Lands with clayey soils suffer poorer drainage characteristics.

There are no Class I farm soils in the Project. Some of the farmlands in the District are marginal with severe limitations as to crops and/or cultivation practices needed for successful farming (NMSU Bulletin 707 1984).

Most of the irrigated fields are flat, but some are so steep that crop choice is so limited that sprinkler systems are required. Farmlands in the irrigated acreage of the

Project are best characterized as: variable, challenging to farm, nutrient demanding, crop-limiting in areas, and Class II and III soils at best (NMSU Bulletin 707). A District report, Water Management Plan 2000 (Arch Hurley Conservancy 2002), notes that efficient farming is "highly variable." Factors that reduce efficiency are listed as: soil type, field slope, surface roughness, and root zone water demands. The report also cites failure to reuse tail-water as a source of farm-water inefficiency. The report concludes that "it would not be surprising to find on-farm water application efficiency" on Project lands to be less than 50 percent.

A History of Water Shortages and Canal Losses from Earlier Studies

General Review of District Problems

The District has had a history of water shortages that were, and are related in part, to the very significant water losses from the conveyance canals and delivery laterals that make up the irrigation system. One other serious short-coming in the District's system is frequently mentioned: the high cost of canal maintenance. The solution of these two problems that are linked together (lining canals and laterals, and/or the use of pipe) will help solve both problems and will greatly enhance the operation of the Project. Another problem is loss of reservoir storage because of silt. The loss of irrigation storage capacity aggravates problems associated with the unpredictability of inflow into the reservoir and the occasional loss of water through reservoir spills.

Serious water shortages occurred in the 1950s and in 1964 but the District was able to make unusually large annual allocations of delivery water, three and four acre-feet per acre every year, beginning in 1965 and going through 1970 (Table 6B, Column 3).

State Engineer Office Report Number 30

This report by Fred Trauger and F.X. Bushman was not designed to quantify or locate areas of seepage from the District's conveyance and delivery system, but they reported on it because of the impact that the leakage and irrigation return flow has on recharge of the Tucumcari groundwater system. They noted that by 1945, before irrigation began, pumping of railroad and City wells had "resulted in the formation of a large cone of depression in the alluvial deposits under the City." By 1958, just ten years after irrigation was started, leakage from the irrigation system had completely filled the 36,000 acre-foot cone of depression. Trauger and Bushman estimated irrigation-related recharge in the area to be on the order of 2,000 acre-feet per year. They found that fluctuations in water levels in City wells were related to irrigation season water losses (page 75). Trauger noted that by 1953 "water levels in some wells had risen to elevations higher than levels in the wells when they were originally drilled." Trauger found that water quality in the City wells had become poorer because of recharge from "sulfate-rich" irrigation water (page 103). Trauger and Bushman (1964) also commented on wet areas and springs in some of the local creeks. They noted that Pajarito Creek had become a year-round perennial stream from Section 13 in T11N R290E to the creek's confluence with the Canadian River. They assigned irrigation return flow and canal leakage as the sources of this new water, and identified wet-spots and springs in Blue Water Creek and Smith Creek as irrigation related. Trauger and Bushman also discussed irrigation as the source of the perennial water in Tucumcari Lake. It is interesting to note that early trading expeditions and military/geological surveys (1840s and 1850s) of the area did not mention the existence of even intermittent flooding of "Tucumcari Lake."

Reclamation Study of 1967 – Revised October 1971

Despite the "good years" in the middle 1960s, Reclamation carried out a study in 1967 that was revised in 1971, on a project to install higher crest-gates on Conchas Dam in order to increase the conservation or irrigation storage in the reservoir and to reduce the likelihood of spills. The project did not go forward because of potential damage to residential housing and recreational facilities at the lake and because the additional storage would not add significantly to the Project supply.

The Arch Hurley Conservancy District Study of 1981

The District conducted its own study of canal leakage in 1981: Report on the Irrigation Canal Rehabilitation Project. The study was designed to locate sections where significant amounts of seepage occur from the main Conchas Canal, both in the section from Conchas Reservoir to the crossing of State Highway 104 and within Project lands to the point of junction with the Hudson Canal. A number of areas were found where wet soils, wet farm conditions, and/or water requiring vegetation appeared near the Canal. One indication of seepage was found just down the canal from the SH 104 crossing; a farmhouse basement was flooded during the irrigation season.

The report identified 16 reaches of the Conchas Canal for rehabilitation. These sections are shown in Table 9. The 1981 District seepage study found that there were at least 10,000 feet of main Canal, above SH 104, that were subject to leakage and 6,000 feet of Conchas Canal within the Project lands that merited rehabilitation to reduce canal losses. Records of the actual measurement process used by the District have not been preserved. The District found that lining 16,000 feet of the Conchas Canal with reinforced concrete could result in a saving of 4,671 acre-feet per year.

The 1981 study found that some of the losses were significantly related to evaporation and to transpiration by canal bank vegetation. The 1981 report describes this vegetation as being “thousands of cottonwood saplings and acres of native grasses.” The report estimated that the 56 miles of Conchas Canal had a surface area of 68 acres and that the evaporation losses during the irrigation season would be 529 acre-feet. This estimate is based on the District’s assumption that the evaporation rate from a water surface was 93 inches in the 7-month irrigation season. Transpiration losses were estimated to be 34 percent of the evaporation loss or about 225 acre-feet per year. The District’s report concluded that seepage losses from the system’s canals become greater, in quantity, each year.

TABLE 9
District Identified Reaches of the Conchas Canal Where Seepage Occurs

Arch Hurley Seepage Area	Project Mile Where Seepage Area Starts	Length of Seepage Section in Feet
S1	4	500
S2	6	1,300
S3	8.5	800
S4	9.5	300
S5	11	300
S6	15.5	800
S7	19	800
S8	22.5	800
S9	24	1,200
S10	26	500
S11	33	600
S12	35	1,100
S13	37	1,000
S14	40.5	4,600
S15	47	600
S16	54.5	800
Totals		16,000

Reclamation's Canal Rehabilitation Report of 1983

Based on the 1981 District report on canal seepage, in February 1983 Reclamation published a report on canal seepage losses, on alternative methods of remediation, on environmental consequences, and on associated costs of rehabilitation. Reclamation accepted the results of the District's 1981 study and added five additional canal reaches with leakage and modified the length of some of the reaches selected by the District (see Table 10). A comparison of Tables 9 and 10 shows the changes recommended by Reclamation. Reclamation's study added to the total length of canal reach where seepage was considered a problem from the 16,000 feet recommended by the District to 25,250 feet.

Reclamation asked the U.S. Geological Survey (USGS) to perform seepage runs on some of the suspected canal reaches to obtain estimates of water losses. As will be noted later in this report, the results of the USGS inflow-outflow seepage study are problematic. Based on the USGS canal tests, Reclamation reached the following conclusions in the 1983 report:

- Conchas Canal reaches with the highest rates of leakage include S12 (1,100 feet long near the canal crossing at SH 104), S 13 (1,700 feet long just north of the start of Project lands and the Quay County line), S14 (8,000 feet beginning about 1/4 mile south of Quay County line to the turnout of the first irrigation lateral in the system), and S17 (2,000 feet near Dry Lake, 1 mile north of where the Conchas Canal crosses Plaza Larga Creek)
- Reach S14 showed the greatest seepage loss, estimated to be 9.5 cubic feet per second or 3,768 acre-feet in a 200-day irrigation season
- Reinforced concrete lining of reaches S12, S13, and S14 can salvage 3,968 acre-feet per year
- Reinforced concrete lining of reaches S7, S8, S10, S18 and S20 can salvage about 1,000 acre-feet per year
- Reinforced concrete lining (19,000 feet) of reaches S7, S8, S10, S12, S13, S14, S16, S17, S18 and S20 can salvage about 5,000 acre-feet per year

TABLE 10

Reclamation Identified Additional Reaches of the Hudson & Conchas Canals Where Seepage Occurs and Proposed Changes in the Length of Sections

Seepage Reach Designation	Project Mile Where Seepage Area Starts	Length of Seepage Section in Feet
S1	4	500
S2	6	700
S3	8.5	800
S4	9.5	300
S5	11	300
S6	15.5	300
S7	19	500
S8	22.5	800
S9	24	500
S10	26	750
S11	33	600
S12	35	1,100
S20	36	700
S13	37	1,700
S21	38	500
S14	40.5	8,000
S15	47	600
S16	54.5	2,400
Split of the Hudson C. from the Conchas C.	56	
S19	57	900
S17	58	2,000
S18	Hudson C. Conchas C.	1,300
Totals		25,250

NMSU Agricultural Extension Service Bulletin 707 of 1985

In a discussion of problems that beset the Arch Hurley District, the Agriculture Extension Service reported that "serious water shortages have occurred periodically" and then listed the years 1953, 1964, 1975, 1977, and 1980 noting that shortages in 1975 to 1977 were "especially devastating to farmers." The Bulletin also reported that there were "water shortages that occurred during other years, but problems were adverted when it rained during the irrigation season."

Arch Hurley Water Management Plan 2000

This planning document, issued by the Arch Hurley Conservancy Board, is one of the most candid available about the problems associated with canal and lateral seepage losses. This report notes that in order to deliver 40,000 acre-feet annually to Project farms, the amount required in a "typical year," almost 78,000 acre-feet must be released from Conchas Reservoir, as almost 50 percent of the water will be lost in transit (page 9). The Plan assigns 75 percent loss to the canal system and 25 percent to the delivery laterals. The Plan notes that seepage losses can be seen in the form of "aquatic vegetation" growing adjacent to the canal. The Plan calls for the enhanced measurement of flows along Conchas Canal, at Unit boundaries, at major turnouts and on farms. The lack of good measurements handicaps the District and results in "spillage and low water levels within the canal system" that contributes to system losses.

Report for the District Prepared by DuMars and Associates

This report uses data from the 1980s and 1990s to show that "more than 30,000 acre-feet of water is lost annually" from canals by seepage and proposes that this water be salvaged, by lining canals, and be used to mitigate shortages in the Pecos River basin.

The Kirksey Report, March 2002

Kirksey notes that to estimate the amount of water available to farmers, a standard rule-of-thumb is to assume that the quantity released from Conchas Reservoir should be reduced by 50 percent; this is the standard figure for delivery losses for the District. Kirksey states that losses occur as a result of seepage, evaporation, wastage, and the inaccuracy of flow measurements. In commenting on the history of water shortages since 1985, annual delivery allocations of 1.5 feet per acre have been made in each year, except in 1994, when the initial farm allocation was only one foot. Kirksey adds that "additional allocations have been made in many years when lake levels increased." In summary, Kirksey makes the point that annual farm delivery allocations have equaled or exceeded 1.5 feet per acre since 1982.

Reclamation Water Management Plan, May 2002

The 2002 Water Management Plan contains entries by the District and was prepared with help from Reclamation. In a discussion of water losses, the plan assigns the average annual evaporation loss from Conchas Reservoir as being 25,000 acre-feet and notes that "nothing can be done about this loss." Much of the discussion of water losses in this version of the 2002 water management plan mirrors that of the 2000 water plan.

The plan found that the District was unable to control water levels adequately in the canal system "as evidenced by spillage [from the canals] and by low water levels" in the canals. The study places "a significant portion" of the water losses as occurring in the sub-laterals as the poor condition of this part of the delivery system requires higher flows than necessary to deliver farmer-requested water. The plan calls for frequent flow estimates using better measurement devices and for the installation of pipe in place of unlined ditches.

PART IV

QUANTIFICATION OF SEEPAGE LOSSES AS OBTAINED FROM HISTORICAL DATA, GIS ANALYSIS, AND FIELD MEASUREMENTS

Review of Historic Releases and Delivery Data

The District and/or Reclamation do have records of annual releases from Conchas Reservoir and estimates of farm deliveries. These two figures permit the extraction of the total water losses in both the canal and lateral systems. For many years, records were kept of the losses in the canal system separate from those in laterals. In some years there are also data, based on estimated flow over weirs, of deliveries from the canal system to the seven farm units in the Project. The depth of water in the canal system (4 feet deep or more in places at 50 percent of maximum flow), the turbidity of the irrigation supply, and the movement of canal bottom deposits make it difficult to read gages or to even find the top of a weir plate. These conditions raise questions as to the accuracy of field measurements. In many years, monthly values have been extracted from ditch-rider records and are available. The weakest records are those related to “spills” from the canal and lateral systems and losses at the start and end of each season. These records would be very helpful in identifying the sources of District water losses.

With the exception of the flow measurements into the Conchas Canal at the lake, other flow records and measurements may not be as reliable. In some years, it is clear that values have been rounded to the nearest hundred acre-feet and in some cases, the nearest thousand acre-feet. Records from multiple sources for the same year are often different. Part of this problem may stem from the use of “irrigation water years” where November and December reservoir releases appear as water uses in the following year in one set of records and as part of the calendar year in another agency's records. In spite of these noted inaccuracies and estimates, the results of an analysis of the data give consistent and rational results. The historic water loss data are given in Table 11 A, B, C, and D.

TABLE 11A

ARCH HURLEY CONSERVANCY DISTRICT
Annual Reservoir Releases, Farm Deliveries, Canal Losses, and Total System Losses 1954 - 1961

YEAR	Reservoir Release in Acre-feet	Conchas Canal Losses in Acre-feet	Farm Deliveries in Acre-feet	Total Lateral Losses Acre-feet	Total of All Canal and Lateral Losses and Waste Water in Acre-feet	Total Losses as a Percent of Reservoir Releases	Farm Deliveries as a Percent of Reservoir Releases
1954	64,559	13,720	39,216	10,085	25,343	39.3%	60.7%
1955	86,839	19,688	50,807	13,844	36,032	41.5%	58.5%
1956	105,326	30,257	58,909	11,957	46,417	44.1%	55.9%
1957	84,897	24,323	47,821	10,805	37,076	43.7%	56.3%
1958	79,528	25,673	36,529	9,750	42,999	54.1%	45.9%
1959	102,746	28,761	51,981	15,954	50,765	49.4%	50.6%
1960	62,200	17,631	29,041	10,712	33,159	53.3%	46.7%
1961	82,998	16,101	46,013	14,581	36,985	44.6%	55.4%

TABLE 11B

ARCH HURLEY CONSERVANCY DISTRICT
Annual Reservoir Releases, Farm Deliveries, Canal Losses, and Total System Losses 1962 - 1973

YEAR	Reservoir Release in Acre-feet	Main Conchas and Hudson Canal Losses 1962-1973	Farm Deliveries in Acre-feet	Total Lateral Losses Acre-feet	Total of All Canal and Lateral Losses and Waste Water in Acre-feet	Total Losses as a Percent of Reservoir Releases	Farm Deliveries as a Percent of Reservoir Releases
1962	117,962	31,086	68,110	16,436	49,852	42.3%	57.7%
1963	113,613	33,714	64,187	13,116	49,426	43.5%	56.5%
1964	79,166	24,096	40,806	11,267	38,360	48.5%	51.5%
1965	79,886	26,058	42,851	6,036	37,035	46.4%	53.6%
1966	105,532	29,556	61,939	12,350	43,593	41.3%	58.7%
1967	99,131	29,652	55,741	12,723	43,390	43.8%	56.2%
1968	113,467	34,198	63,841	13,705	49,626	43.7%	56.3%
1969	80,444	27,447	43,244	8,097	37,200	46.2%	53.8%
1970	91,402	24,634	53,427	9,945	37,975	41.5%	58.5%
1971	96,926	28,834	56,435	8,080	40,491	41.8%	58.2%
1972	69,382	23,186	37,567	6,720	31,815	45.9%	54.1%
1973	94,863	28,422	55,777	9,066	39,086	41.2%	58.8%

TABLE 11C

ARCH HURLEY CONSERVANCY DISTRICT
Annual Reservoir Releases, Farm Deliveries, Canal Losses, and Total System Losses 1974 - 1987

YEAR	Reservoir Release in Acre-feet	Conchas Canal Losses in Acre-feet	Farm Deliveries in Acre-feet	Total Lateral Losses Acre-feet	Total of All Canal and Lateral Losses and Waste Water in Acre-feet	Total Losses as a Percent of Reservoir Releases	Farm Deliveries as a Percent of Reservoir Releases
1974	115,751	33,977	69,512	8,089	46,239	39.9%	60.1%
1975	60,738	22,345	32,052	4,306	28,686	47.2%	52.8%
1976	20,780	8,315	9,065	2,803	11,715	56.4%	43.6%
1977	38,103	9,859	18,532	8,820	19,571	51.4%	48.6%
1978	51,686	15,100	25,950	7,025	25,736	49.8%	50.2%
1979	65,547	18,240	34,474	8,480	31,073	47.4%	52.6%
1980	72,748	19,118	41,128	8,565	31,620	43.5%	56.5%
1981	47,915	11,690	24,991	11,234	22,924	47.8%	52.2%
1982	66,275		38,716		27,559	41.6%	58.4%
1983	79,100	24,500	48,000	6,600	31,100	39.3%	60.7%
1984	75,000	28,000	40,000	5,600	35,000	46.7%	53.3%
1985	69,000	22,000	40,000	5,400	29,000	42.0%	58.0%
1986	65,000	22,000	37,000	5,000	28,000	43.1%	56.9%
1987	71,000	29,000	34,000	7,200	37,000	52.1%	47.9%

TABLE 11D

ARCH HURLEY CONSERVANCY DISTRICT
Annual Reservoir Releases, Farm Deliveries, Canal Losses, and Total System Losses 1988 - 2002

YEAR	Reservoir Release in Acre-feet	Conchas Canal Losses in Acre-feet	Farm Deliveries in Acre-feet	Total Lateral Losses Acre-feet	Total of All Canal and Lateral Losses and Waste Water in Acre-feet	Total Losses as a Percent of Reservoir Releases	Farm Deliveries as a Percent of Reservoir Releases
1988	64,000	24,000	33,000	6,500	31,000	48.4%	51.6%
1989	70,000	24,000	38,000	6,200	32,000	45.7%	54.3%
1990	78,000	28,000	41,000	8,700	37,000	47.4%	52.6%
1991	60,000	24,000	28,000	6,100	32,000	53.3%	46.7%
1992	85,100	32,000	43,000	10,100	42,100	49.5%	50.5%
1993	93,400	33,000	50,000	10,400	43,400	46.5%	53.5%
1994	95,400	34,000	50,000	11,400	45,400	47.6%	52.4%
1995	107,000	37,000	55,000	14,200	52,000	48.6%	51.4%
1996	96,000	38,000	45,000	12,700	51,000	53.1%	46.9%
1997	102,000	45,000	41,000	15,000	61,000	59.8%	40.2%
1998	109,000	41,000	50,000	18,000	59,000	54.1%	45.9%
1999	96,000	34,000	46,000	15,600	50,000	52.1%	47.9%
2000	118,000	43,000	60,000	15,000	58,000	49.2%	50.8%
2001	93,000	34,000	45,000	14,000	48,000	51.6%	48.4%
2002	15,500	5,800	7,200	2,500	8,300	53.5%	46.5%

TABLE 12

LOSSES IN FARM-UNIT LATERALS

YEAR	Laterals with Greatest Percentage Loss	Percent Delivery by Main Canal in First Month of Season
1983	Units E (85%) & F (87%)	=====
1984	Units E (77%) & F (80%)	43.5% March release 3,400 AF
1985	Units F (80%) & G (84%)	58.5% April release 8,200 AF
1986	Units E (82%) & F (80%)	65.8% April release 14,900 AF
1987	Units E (72%) & F (70%)	19% April release 5,500 AF
1988	Units D (74%) & F (72%)	0% March release 1,500 AF
1989	Units D (77%) & E (77%)	39% March release 5,670 AF
1990	Units D (73%) & E (78%)	50% April release 5,600 AF
1991	Units D (76%) & F (72%)	57.6% April release 11,000 AF
1992	Units D (70%) & F (74%)	55% April release 12,300 AF
1993	Units D (76%) & F (76%)	55% April release 13,900 AF
1994	Units D (74%) & F (79%)	1% March releases 1,700 AF

TABLE 12 (continued)

LOSSES IN FARM-UNIT LATERALS

YEAR	Laterals with Greatest Percentage Loss	Percent Delivery by Main Canal in First Month of Season
1995	Units D (76%) & F (76%)	55% April release 12,500 AF
1996	Units D (72%) & F (70%)	37% March release 5,900 AF
1997	Units B (69%) & F (70%)	33% April release 4,900 AF
1998	Units A (71%) & C (72%)	41% April release 8,200 AF
1999	Units C (76%) & G (76%)	30% April release 8,100 AF
2000	Units F (68%) & G (78%)	51% April release 13,850 AF
2001	Units F (72%) & G (69%)	18% April release 3,000 AF
2002	Units C (75%) & G (56%)	64% May release 14,300 AF
2003	No irrigation	

Canal Leakage Potential Based on GIS Analyses and on the Hydrogeologic/Soils-Landscape Setting of the Canal

Study Conceptual Model

A significant part of this study involves the estimation of leakage potential from various sections of the Arch Hurley Canal system (both the Conchas and the Hudson Canals). The study team believes that seepage losses along various reaches of the canal system are due, in great part, to the hydrologic conductivity of 1) the earthen materials that form the bulk of the canal structure and 2) the soils and surficial-hydrogeologic units into which the canal was excavated.

To test this conceptual model, a geographic information system (GIS) database was constructed using the best available information on the soil-landscape and hydrogeologic setting of the Arch Hurley Canal *corridor* (the *corridor* includes the canal and the immediately adjacent areas). This information was used to document better the complex interplay between hydraulic properties related to canal structures and operation and physical constraints imposed by the soil-geomorphic and surficial-geologic conditions. Standard remote-sensing procedures (e.g., satellite-image and aerial-photo interpretation) were initially used to identify and map important hydrogeologic and soils features for further detailed field evaluation. The emphasis of this part of the study and subsequent study elements has been on canal-system reaches that were suspected to be areas with moderate to high leakage potential.

LANDSAT infrared imagery, which shows vegetation/soil-moisture conditions along and down-slope from the canal *corridor*, is the most valuable tool available to verify leakage predictions effectively based on other factors such as soil/hydrogeologic conditions and canal operation. Hydrogeologic fieldwork and related studies needed for locating areas of suspected leakage along the canal system were done by Dr. John Hawley. See Appendix B for additional discussion and interpretation of hydrogeologic and soil-landscape relationships along the Conchas and Hudson Canal *corridors*.

GIS Mapping Methodology and Database Development

Geographic information system (GIS) and remote sensing tools were used to identify the geographic location of canal structures and potential surface-water seepage areas. The best available base-maps, at an appropriate scale (1:100,000 or greater map-scale), were acquired from the USGS Geographic GIS Data-Download website (USGS 2005a) and from the New Mexico Resource Geographic Information System (RGIS 2005). Remote sensing imagery was acquired from the Pan-American Center for Earth and Environmental Studies at the University of Texas at El Paso (PACES 2005). Data conversion tools were used to transform the GIS data obtained from the USGS (2005a, b) and RGIS (2005) into an enhanced GIS database for use in the Environmental Science Research Institute's (ESRI) GIS software package, ArcInfo Desktop.

The ArcInfo Desktop software was used to locate the "as designed" structures along the Conchas-Hudson Canal system, to compare the "as designed" structures with the USGS digital orthographic quarter-quadrangle aerial photographs (DOQQs) obtained from RGIS (2005), and to create tables of locations for the "as built" structures along the canal. The "as built" canal and structures were layered with published surficial-geologic and soils data (NMBGMR 2003; NRCS 2005) to identify possible areas of increased seepage. As a final check, the GIS databases were layered with a LANDSAT 7 satellite-image to compare areas with dense (phreatophytic) vegetation along the canal *corridor* with suspect reaches of moderate and high leakage potential as determined from historic canal operations and interpretation of hydrogeologic and soil conditions (see Appendix B). The soils data were acquired from the NRCS (2005) website, while the New Mexico surface geology data (Green and Jones 1997) was downloaded from RGIS (2005). The surface geology map (Green and Jones 1997) was updated using a scanned and geo-referenced image of the NMBGMR (2003) Geologic Map of New Mexico. As already noted, hydrogeologic and soil-landscape conditions that relate to canal-leakage potential are covered in detail in Appendix B, which also includes data and interpretive summaries in Table B1 and Tables B2-B5.

The GIS databases needed for this study were enhanced by including data-layers for political boundaries, township and range, roads, and surface elevation with soils data and surface geology. Most of the needed boundary data were available at the USGS GIS Data Download website (USGS 2005a). This information required processing (USGS 2005b) to convert the data to a format that could be used with the ArcInfo Desktop software. The aerial imagery (DOQQs), and the scanned 7.5' USGS quadrangle maps were acquired from RGIS (2005). The acquisition date for the LANDSAT 7 satellite image for path 32 and row 36 is September 7, 2000 and for path 32 and row 35 is August 12, 2002.

The base-map of the Arch Hurley Project Area (Plate 1, in the map-pocket at end of report) was created from the GIS databases described above and by utilizing tabular information listed for the physical structures along the main Conchas-Hudson Canal alignment. The tabular data for the canal identifies structures by station number. The station number is related to the distance in feet from the beginning, or head, of the canal at Conchas Dam. Two different ways were used to determine distances along the canal.

The first involved making measurements on published maps of the area, and the second took advantage of distances, as stations, shown on the “as designed” canal drawings provided by the Bureau of Reclamation. The distances measured and the station numbers from the Reclamation canal design were recorded in an Excel spreadsheet. This information was plotted along the canal route, using an ArcInfo Desktop function for linear references as points. The points were layered with black and white DOQQs (digital orthographic quarter-quadrangle aerial photographs) from RGIS (2005) to determine if the measured distances were correct by comparing visually the mapped features with those that can be seen in the images (i.e., did the line representing the canal actually overlay the canal seen in the image). After comparing the two data-sets, it was apparent that there were some discrepancies between the “as designed” drawings and the “as built” canal structures. The canal structures and the assigned station numbers were modified to correspond with the “as built” features visible on the B&W DOQQs and a new table of distances, canal slope, and canal structures was created. This information is included in Tables B2-B5 in Appendix B.

Application of the Database Information

Plates 1 through 5 illustrate the final GIS database, and Plates 6 through 8 illustrate the results of change-detection analysis in map-format (in the map-pocket at the end of report). Plate 1, which includes the entire Arch Hurley Project Area, shows the southeastern portion of the Conchas Reservoir, the Conchas-Hudson Canal system, major canal structures, and Project boundaries. Plate 2, the LANDSAT 7 image-map of the Arch Hurley Project Area, combines the satellite image with the base-map information shown in Plate 1. Plate 3, Soil Associations of the Arch Hurley Project Area, shows the

NRCS (2005) soil associations that intersect the Conchas-Hudson Canal *corridor* downstream from the Conchas Reservoir. Plate 4, Surface Geology in the Arch Hurley Project Area, shows the distribution patterns of surficial hydrogeologic units with respect to major reaches and station-control points along the canal system (Appendix B-Tables B1 to B5). Plate 5 is a LANDSAT 7 image dated August 12, 2002 for the project area. Plates 6 and 7 are normalized-difference vegetation-index maps (NDVI; Jensen 1996) for Plates 2 and 5 respectively. Plate 8 is a product of the change-detection analysis performed on Plates 6 and 7.

Of the plates listed above, Plate 2 is the most informative. The satellite image chosen for this project is particularly useful because the date of acquisition, September 7, 2000, is late in the growing season for the Arch Hurley Project irrigators; both crops and natural vegetation along and down-gradient from the canal have had two to four months to respond to seepage losses. The LANDSAT 7 image of Plate 2 is displayed using three (7, 4, and 2) of the available bands (1 through 7) of spectral information for LANDSAT 7 imagery. Each of the three bands is assigned to one of the "color-guns" used by the computer monitor. The "color-guns" are identified as the "red-gun," the "green-gun," and the "blue-gun." The spectral data for band 7 (infrared band) are assigned to red, band 4 (infrared band that can be used to identify healthy vegetation) are assigned to green, and band 2 (visible green band) is assigned to blue.

Note that much of the "healthy" vegetation up-canal from the Project canal route includes phreatophytic varieties such as cottonwood, tamarisk, and willow. An examination of the upper-canal *corridor*, starting at the Conchas Reservoir and ending where the first irrigation lateral turn-outs begin (Quay County line), reveals sections with significant seepage. Reaches of the upper Conchas Canal that appear to suffer high seepage losses can be seen in Plate 2 as bright green areas along the canal. A majority of the canal corridor shows increased vegetation down-slope from the canal (e.g., compare the local-valley topography shown in Plate 1 with the bright green areas of Plate 2).

The final infrared imagery database was intersected with both surficial-geologic and soils databases in order to identify sections of the Conchas-Hudson Canal system with areas of “healthy” vegetation that coincided with reaches where soils and hydrogeologic data independently indicated significant leakage potential. Major elements of the complex interrelationships between canal-structural components and contiguous soils and hydrogeologic units are noted in the tables and canal-corridor strip maps that have been developed during the GIS and field-hydrogeologic phases of the investigation. This information is summarized in Tables B2–B5 in Appendix B, which also includes elevation control and source-document data. Reaches with significant (moderate to high) suspected leakage potential, as well as those with inferred low-seepage losses, are identified in Tables 13 and 14.

TABLE 13A ARCH-HURLEY CONSERVANCY CONCHAS MAIN CANAL LEAKAGE POTENTIAL BASED ON SOILS, SURFICIAL GEOLOGY, AERIAL PHOTOGRAPHY, AND COLOR-IR SATELLITE IMAGERY

NOTE: BOR refers to USBOR 1983 study; AH refers to 1981 District study

Distance Down Canal in Feet and (in miles)	Major Structures on the Canal System	Potential for Canal Leakage Based on Major Controlling Soils & Surficial Geologic Factors + Landsat Imagery	Drainage Features and Leakage Potential Identified by Others
4	Diversion and start of Canal at outlet from Conchas Reservoir	Includes a 2,000-ft reach with high leakage potential, permeability and piping hazard	Conchas Dam
5,031	Releases measured	moderate permeability, moderate piping hazard	USGS Gage
5,101 (0.9 miles)	Tunnel No. 1, upstream portal	moderate permeability, moderate piping hazard	Start of first tunnel, one half mile long
7,673 (1.4 miles)	downstream Tunnel No. 1	moderately to well drained over fractured hard sandstone	End of first tunnel, one half mile long
11,320		A short reach with moderate leakage potential in area of wasteway; moderate permeability and piping hazard	
15,321 (2.8 miles)	Siphon 1 inlet; La Manga Creek	permeability and piping hazard highly variable	Siphon 0.3 miles long
16,766 (3.1 miles)	Siphon 1 outlet	A short reach with high leakage potential starts about 500' downstream; permeability and piping hazard highly variable	End of siphon 0.3 miles long
19,942 (3.7 miles)	Siphon 2 inlet	large range in permeability and shrink-swell potential; form deep cracks when dry	Short siphon section; 0.13 miles long
20,599 (3.8 miles)	Siphon 2 outlet	large range in permeability and shrink-swell potential; form deep cracks when dry	End short siphon section; 0.13 miles long
22,937	Culvert under Canal	large range in permeability and shrink-swell potential; form deep cracks when dry	Local drainage; Reach S-1 AH proposed for seepage reduction control in 500 foot section at Mile 4.
23,335	Culvert under Canal	Includes 3,000-ft reach with high to moderate leakage potential; large range in permeability and shrink-swell potential; forms deep cracks when dry	Reach S-1 BOR proposed for seepage reduction control; BOR estimates 500 feet of lining needed
25, 573 (4.7 miles)	Siphon 3 inlet; Saladita Creek	large range in permeability and shrink-swell potential; form deep cracks when dry	Crossing of Saladita Creek
25, 805	Siphon 3 outlet	Moderately well drained to well drained over fractured hard sandstone	Outlet for short siphon

TABLE 13B ARCH-HURLEY CONSERVANCY CONCHAS MAIN CANAL LEAKAGE POTENTIAL BASED ON SOILS, SURFICIAL GEOLOGY, AERIAL PHOTOGRAPHY, AND COLOR-IR SATELLITE IMAGERY

NOTE: BOR refers to USBOR 1983 study; AH refers to 1981 District study

Distance Down Canal in Feet and (in miles)	Major Structures on the Canal System	Potential for Canal Leakage Based on Major Controlling Soils & Surficial Geologic Factors + Landsat Imagery	Drainage Features and Leakage Potential Identified by Others
27,000	Canal bends to north near Mile 5	moderately well drained to well drained over fractured hard sandstone	
28,000	Enter lowland area	Includes 2,000-ft reach with high leakage potential; large range in permeability and shrink-swell potential; forms deep cracks when dry	Reach S-2 BOR proposed for seepage reduction control; BOR estimates 700 feet of lining needed
30,600	Leave lowland area	moderately well drained to well drained over fractured hard sandstone	
33,645	Bridge over Canal	Central part of 3,000-ft reach with moderate to high leakage potential; moderate permeability, and piping hazard	Reach S-2 AH Proposed reach for seepage control of 1,300 feet near Mile 6
41,047 (7.7 miles)	Siphon 4 inlet	moderate permeability, moderate piping hazard	
41,212 (7.7 miles)	Siphon 4 outlet	Start of a 2,000-ft reach with high leakage potential; moderate permeability and piping hazard	Reach S-3 BOR proposed for seepage reduction control; BOR estimates 800 feet of lining needed
44,905	Drainage inlet to Canal	moderately well drained to well drained over fractured hard sandstone	Reach S-3 AH proposed for leakage reduction 800 feet long
46,951	Culvert under Canal	About 2,000-ft up-canal of 2,500-ft reach with moderate to high leakage potential; moderate permeability and piping hazard	Reach S-4 BOR proposed for seepage reduction control ; BOR estimates 300 feet of lining needed
51,596	Culvert under Canal; Oso Creek	moderate permeability, moderate piping hazard	Area of proposed Lined Reach S-4 AH 300 feet long
53,477 (10 miles)	Siphon 5 inlet	large range in permeability and shrink-swell potential; form deep cracks when dry	Crossing West branch of Oso Creek
53,700 (10.1 miles)	Siphon 5 outlet	large range in permeability and shrink-swell potential; form deep cracks when dry	
57,033 (10.7 miles)	Siphon 6 inlet	moderate permeability, moderate piping hazard	

TABLE 13C ARCH-HURLEY CONSERVANCY CONCHAS MAIN CANAL LEAKAGE POTENTIAL BASED ON SOILS, SURFICIAL GEOLOGY, AERIAL PHOTOGRAPHY, AND COLOR-IR SATELLITE IMAGERY

NOTE: BOR refers to USBOR 1983 study; AH refers to 1981 District study

Distance Down Canal in Feet and (in miles)	Major Structures on the Canal System	Potential for Canal Leakage Based on Major Controlling Soils & Surficial Geologic Factors + Landsat Imagery	Drainage Features and Leakage Potential Identified by Others
57,164 (10.8 miles)	Siphon 6 outlet	A long canal reach (extending about 1,000 ft beyond outlet of Siphon 9) with moderate to high leakage potential; moderate permeability and piping hazard	Area of proposed Lined Reach S-5 BOR & AH (300 feet long)
61,319 (11.52 miles)	Siphon 7 inlet, Oso Creek	In a long canal reach to about 1,000 ft beyond outlet of Siphon 9; moderate to high leakage potential; moderate permeability and piping hazard	Down-canal from area of proposed Lined Reach S-5 BOR
61,512 (11.57 miles)	Siphon 7 downstream exit	In a long canal reach to about 1,000 ft beyond outlet of Siphon 9; moderate to high leakage potential; moderate permeability and piping hazard	
63,343	Drainage inlet to Canal	In a long canal reach to about 1,000 ft beyond outlet of Siphon 9; moderate to high leakage potential; moderate permeability and piping hazard	
65,431 (12.3 miles)	Siphon 8 inlet	In a long canal reach to about 1,000 ft beyond outlet of Siphon 9; moderate to high leakage potential; moderate permeability and piping hazard	
65,788 (12.4 miles)	Siphon 8 outlet, Oso Creek	In a long canal reach to about 1,000 ft beyond outlet of Siphon 9; moderate to high leakage potential; moderate permeability and piping hazard	
67,735 (12.7 miles)	Siphon 9 inlet	In a long canal reach to about 1,000 ft beyond outlet of Siphon 9; moderate to high leakage potential; moderate permeability and piping hazard	
67,987 (12.8 miles)	Siphon 9 outlet	In a long canal reach to about 1,000 ft beyond outlet of Siphon 9; moderate to high leakage potential; moderate permeability and piping hazard	
70,871 (13.3 miles)	Siphon 10 inlet	large permeability range, medium to high piping hazard	

TABLE 13D ARCH-HURLEY CONSERVANCY CONCHAS MAIN CANAL LEAKAGE POTENTIAL BASED ON SOILS, SURFICIAL GEOLOGY, AERIAL PHOTOGRAPHY, AND COLOR-IR SATELLITE IMAGERY

NOTE: BOR refers to USBOR 1983 study; AH refers to 1981 District study

Distance Down Canal in Feet and (in miles)	Major Structures on the Canal System	Potential for Canal Leakage Based on Major Controlling Soils & Surficial Geologic Factors + Landsat Imagery	Drainage Features and Leakage Potential Identified by Others
71,281 (14 miles)	Siphon 10 outlet	Start of 2,000-ft reach with moderate to high leakage potential; large range in permeability and shrink-swell potential; forms deep cracks when dry	
76,849 (15 miles)	Siphon 11 inlet	large permeability range, medium to high piping hazard	
77,044 (15.1 miles)	Siphon 11 outlet	Start of a 3,000-ft canal reach with high to moderate leakage potential; large permeability range, moderate to high piping hazard	Up-canal from area of proposed Lined Reach S-6 BOR; BOR estimates 300 feet of lining
79,418	Culvert under Canal	In a 3,000-ft canal reach with high to moderate leakage potential; large permeability range, moderate to high piping hazard	Down-canal from area of proposed Lined Reach S-6 BOR
80,094	Culvert under Canal	In a 3,000-ft canal reach with high to moderate leakage potential; large permeability range, moderate to high piping hazard	
80,718	Culvert under Canal	Upstream from end of 3,000-ft canal reach with moderate to high leakage potential; moderate permeability, moderate piping hazard	Area of proposed Lined Reach S-6 AH 800 feet long section
84,489 (16.4 miles)	Siphon 12 inlet	moderate permeability, moderate piping hazard	
84,819 (16.5 miles)	Siphon 12 outlet	permeability and piping hazard highly variable	
85,151 (16.6 miles)	Tunnel No. 2 entrance portal	permeability and piping hazard highly variable	
93,128 (18.1 miles)	Tunnel No. 2 exit portal	Start of 2,500-ft reach with high leakage potential; permeability and piping hazard highly variable	
94,636 (18.4 miles)	Siphon 13 inlet	In a 2,500-ft reach with high leakage potential; permeability and piping hazard highly variable	
95,223 (18.5 miles)	Siphon 13 outlet	Near end of reach with high leakage potential (as above); permeability and piping hazard highly variable	

TABLE 13E ARCH-HURLEY CONSERVANCY CONCHAS MAIN CANAL LEAKAGE POTENTIAL BASED ON SOILS, SURFICIAL GEOLOGY, AERIAL PHOTOGRAPHY, AND COLOR-IR SATELLITE IMAGERY

NOTE: BOR refers to USBOR 1983 study; AH refers to 1981 District study

Distance Down Canal in Feet and (in miles)	Major Structures on the Canal System	Potential for Canal Leakage Based on Major Controlling Soils & Surficial Geologic Factors + Landsat Imagery	Drainage Features and Leakage Potential Identified by Others
98,863	Bridge over Canal	Start of long canal reach with high to moderate leakage potential; moderate permeability, moderate piping hazard; cited by the BOR as an area of major seepage	Down-canal from area of proposed Lined Reach S-7 BOR; BOR estimates 500 feet of lining
99,134	Drainage inlet to Canal	In a long canal reach with high to moderate leakage potential; moderate permeability, moderate piping hazard	Reach S-7 is among 10 identified as areas of serious seepage
101,743	Culvert under Canal	In a long canal reach with high to moderate leakage potential; moderate permeability, moderate piping hazard	Area of proposed Lined Reach S-7 AH 800 feet long section
103,168	Culvert under Canal; Alamosa Creek	In a long canal reach with high to moderate leakage potential; moderate permeability, moderate piping hazard	
104,868 (20.33 mi; 107,342 ft)	Siphon 14 inlet	Near end of reach with high to moderate leakage potential; moderate permeability and piping hazard	Tunnel beneath Alamosa Creek
105,428 (20.4 miles)	Siphon 14 outlet	moderate permeability, moderate piping hazard	
105,516 (20.5 miles)	Tunnel No. 3 entrance portal	moderate permeability, moderate piping hazard	
115,186 (22.3 miles)	Tunnel No. 3 exit portal	Start of a 5-mile reach between Tunnels 3 and 4 with high leakage potential; moderate permeability and piping hazard; cited by the BOR as an area of major seepage	Up-canal from area of proposed Lined Reach S-8 BOR; BOR estimates 800 feet of lining
116,946 (22.6 miles)	Siphon 15 inlet	In a 5-mile canal reach between Tunnels 3 and 4 with high leakage potential; moderate permeability and piping hazard	Area of proposed Lined Reach S-8 AH 800 feet long
117,248 (22.7 miles)	Siphon 15 outlet	In a 5-mile canal reach between Tunnels 3 and 4 with high leakage potential; moderate permeability and piping hazard	Reach S-8 is among 10 identified as areas of serious seepage

TABLE 13F ARCH-HURLEY CONSERVANCY CONCHAS MAIN CANAL LEAKAGE POTENTIAL BASED ON SOILS, SURFICIAL GEOLOGY, AERIAL PHOTOGRAPHY, AND COLOR-IR SATELLITE IMAGERY

NOTE: BOR refers to USBOR 1983 study; AH refers to 1981 District study

Distance Down Canal in Feet and (in miles)	Major Structures on the Canal System	Potential for Canal Leakage Based on Major Controlling Soils & Surficial Geologic Factors + Landsat Imagery	Drainage Features and Leakage Potential Identified by Others
118,363	Culvert under Canal	In a 5-mi canal reach between Tunnels 3 and 4 with high leakage potential; moderate permeability and piping hazard	
120,205	Culvert under Canal	In a 5-mi canal reach between Tunnels 3 and 4 with high leakage potential; moderate permeability and piping hazard	
121,983	Culvert under Canal	In a 5-mi canal reach between Tunnels 3 and 4 with high leakage potential; moderate permeability and piping hazard	Up-canal from area of proposed Lined Reach S-9 BOR**;** BOR estimates 500 feet of lining
124,923	Culvert under Canal	In a 5-mi canal reach between Tunnels 3 and 4 with high leakage potential; moderate permeability and piping hazard	Down-canal from area of proposed Lined Reach S-9 BOR
126,157	Culvert under Canal	In a 5-mi canal reach between Tunnels 3 and 4 with high leakage potential; moderate permeability and piping hazard	Area of proposed Lined Reach S-9 AH 1,200 feet long
128,257	Culvert under Canal	In a 5-mi canal reach between Tunnels 3 and 4 with high leakage potential; moderate permeability and piping hazard	
131,248 (near mile 25)	Culvert under Canal; Johnson Creek	In a 5-mi canal reach between Tunnels 3 and 4 with high leakage potential; moderate permeability and piping hazard	Near original "design site" of Siphon 16 (mile 24.72 - 24.76)
132,845 (25 miles)	Siphon 17 inlet	In a 5-mi canal reach between Tunnels 3 and 4 with high leakage potential; moderate permeability and piping hazard	Johnson or Rincon Creek
134,092 (25.6 miles)	Siphon 17 outlet	In a 5-mi canal reach between Tunnels 3 and 4 with high leakage potential; moderate permeability and piping hazard	

TABLE 13G ARCH-HURLEY CONSERVANCY CONCHAS MAIN CANAL LEAKAGE POTENTIAL BASED ON SOILS, SURFICIAL GEOLOGY, AERIAL PHOTOGRAPHY, AND COLOR-IR SATELLITE IMAGERY

NOTE: BOR refers to USBOR 1983 study; AH refers to 1981 District study

Distance Down Canal in Feet and (in miles)	Major Structures on the Canal System	Potential for Canal Leakage Based on Major Controlling Soils & Surficial Geologic Factors + Landsat Imagery	Drainage Features and Leakage Potential Identified by Others
135,126 (25.9 miles)	Culvert under Canal	In a 5-mi canal reach between Tunnels 3 and 4 with high leakage potential; moderate permeability and piping hazard	Johnson Creek
136,629	Culvert under Canal; Johnson Creek	In a 5-mi canal reach between Tunnels 3 and 4 with high leakage potential; moderate permeability and piping hazard; cited by the BOR as an area of major seepage	Up-canal from area of proposed Lined Reach S-10 BOR; BOR estimates 750 feet of lining & S-10 AH lined section, 500 feet long
138,145	Culvert under Canal	In a 5-mi canal reach between Tunnels 3 and 4 with high leakage potential; moderate permeability and piping hazard	Down-canal from area of proposed Lined Reach S-10 BOR
139,542	Culvert under Canal	In a 5-mi canal reach between Tunnels 3 and 4 with high leakage potential; moderate permeability and piping hazard	
140,952	Culvert under Canal	In a 5-mi canal reach between Tunnels 3 and 4 with high leakage potential; moderate permeability and piping hazard	
141,760 (27.3 miles)	Tunnel No. 4 entrance portal	End of 5-mi reach with high leakage potential; moderate permeability, low to moderate piping hazard	
148,913 (28.7 miles)	Tunnel No. 4 exit portal	Start of 1.6-mi canal reach between Tunnel 4 and Siphon 18 with moderate to high leakage potential; slow to moderate permeability, medium to high piping hazard	
149,832	Culvert under Canal	In a 1.6-mi canal reach between Tunnel 4 and Siphon 18 with moderate to high leakage potential; slow to moderate permeability, medium to high piping hazard	
152,735	Culvert under Canal	In a 1.6-mi canal reach between Tunnel 4 and Siphon 18 with moderate to high leakage potential; slow to moderate permeability, medium to high piping hazard	

TABLE 13H ARCH-HURLEY CONSERVANCY CONCHAS MAIN CANAL LEAKAGE POTENTIAL BASED ON SOILS, SURFICIAL GEOLOGY, AERIAL PHOTOGRAPHY, AND COLOR-IR SATELLITE IMAGERY

NOTE: BOR refers to USBOR 1983 study; AH refers to 1981 District study

Distance Down Canal in Feet and (in miles)	**Major Structures on the Canal System**	**Potential for Canal Leakage Based on Major Controlling Soils & Surficial Geologic Factors + Landsat Imagery**	**Drainage Features and Leakage Potential Identified by Others**
153,497	Culvert under Canal	In a 1.6-mi canal reach between Tunnel 4 and Siphon 18 with moderate to high leakage potential; slow to moderate permeability, medium to high piping hazard	
157,233 (30.2 miles)	Siphon 18 inlet	End of 1.6-mi reach with moderate to high leakage potential; permeability and piping hazard highly variable	Canal Spillway and Canal check
157,676 (30.3 miles)	Siphon 18 outlet	permeability and piping hazard highly variable	
157,676 (30.3 miles)	Western Bench Flume	permeability and piping hazard highly variable	
160,803 (30.9 miles)	Eastern Bench Flume	permeability and piping hazard highly variable	Bench flume
162,372	San Miguel-Quay County Line	permeability and piping hazard highly variable	
162,500 (31.2 miles)	Siphon 19 inlet	permeability and piping hazard highly variable	
163,242 (31.4 miles)	Siphon 19 outlet	Start of 1.6-mi reach with high leakage potential; permeability and piping hazard highly variable	
167,012	San Miguel-Quay County Line	In 1.6-mi reach with high leakage potential; permeability and piping hazard highly variable	
168,564 (32.2 miles)	Siphon 20 inlet	End of 1.6-mi reach with high leakage potential; permeability and piping hazard highly variable	
168,844 (32.4 miles)	Siphon 20 outlet	permeability and piping hazard highly variable	
169,955	Culvert under Canal	permeability and piping hazard highly variable	

TABLE 13I ARCH-HURLEY CONSERVANCY CONCHAS MAIN CANAL LEAKAGE POTENTIAL BASED ON SOILS, SURFICIAL GEOLOGY, AERIAL PHOTOGRAPHY, AND COLOR-IR SATELLITE IMAGERY

NOTE: BOR refers to USBOR 1983 study; AH refers to 1981 District study

Distance Down Canal in Feet and (in miles)	Major Structures on the Canal System	Potential for Canal Leakage Based on Major Controlling Soils & Surficial Geologic Factors + Landsat Imagery	Drainage Features and Leakage Potential Identified by Others
171,901 (33 miles)	Siphon 21 inlet	permeability and piping hazard highly variable	
172,293 (33.2 miles)	Siphon 21 outlet	Start of ~3000-ft reach with moderate leakage potential; permeability and piping hazard highly variable	Up-canal from area of proposed Lined Reach S-11 BOR; BOR estimates 600 feet of lining
175,082 (33.7 miles)	Siphon 22 inlet	In a 3000-ft reach with moderate leakage potential; permeability and piping hazard highly variable	Down-canal from area of proposed Lined Reach S-11 BOR & AH S-11 lined section 600 feet long
176,073 (33.9 miles)	Siphon 22 outlet	Start of a long reach with moderate to high leakage potential; permeability and piping hazard highly variable	
179,078	Culvert under Canal	In a long reach with moderate to high leakage potential; permeability and piping hazard highly variable	
182,871 (near mile 35)	NM 104 Bridge over Canal	In a long reach with moderate to high leakage potential; upstream from reach with high leakage potential; moderate permeability, low to moderate piping hazard	Up-canal from area of proposed Lined Reach S-12 BOR; BOR estimates 1,100 feet of lining & AH S-12 lined section 1,100 feet long
189,492 (36.4 miles)	Siphon 23 inlet	moderate permeability, low to moderate piping hazard; Reach S-12 is among 10 identified as areas of most serious seepage	Down-canal from area of proposed Lined Reach S-12 BOR
189,897 (36.5 miles)	Siphon 23 outlet	moderate permeability, low to moderate piping hazard; Reach S-20 is among 10 identified as areas of serious seepage	Up-canal from area of proposed Lined Reach S-20 BOR; BOR estimates 700 feet of lining
192,818	Culvert under Canal	Near end of a long reach with high leakage potential; moderate permeability, low to moderate piping hazard; cited by the BOR as an area of major seepage; Reach S-13 is among 10 identified as areas of most serious seepage	Up-canal from area of proposed Lined Reach S-13 BOR; BOR estimates 1,700 feet of lining; AH S-13 lined section 1000 feet long

TABLE 13J ARCH-HURLEY CONSERVANCY CONCHAS MAIN CANAL LEAKAGE POTENTIAL BASED ON SOILS, SURFICIAL GEOLOGY, AERIAL PHOTOGRAPHY, AND COLOR-IR SATELLITE IMAGERY

NOTE: BOR refers to USBOR 1983 study; AH refers to 1981 District study

Distance Down Canal in Feet and (in miles)	Major Structures on the Canal System	Potential for Canal Leakage Based on Major Controlling Soils & Surficial Geologic Factors + Landsat Imagery	Drainage Features and Leakage Potential Identified by Others
205,077 (39.3 miles)	Bridge over Canal at Quay County Line	About 1 mi down-canal from long reach with high leakage potential; moderate permeability, low to moderate piping hazard	About 1 mi down-canal from area of proposed Lined Reach S-21 BOR, 500 feet lined; Main Canal Project Boundary
206,941	Bell Lateral	large range in permeability and shrink-swell potential; form deep cracks when dry	
207,141	Culvert under Canal	large range in permeability and shrink-swell potential; form deep cracks when dry	
208,135	NM 104 Bridge over Canal	large range in permeability and shrink-swell potential; form deep cracks when dry; cited by the BOR as an area of major seepage	Start of long section (8000 feet) proposed as Lined Reach S-14 BOR; irrigated lands impacted by seepage
210,990 (211,200) (near 40.0 miles)	Roberts Lateral (may also be called Jack County Lateral)	Within 1 mile reach with high leakage potential; moderate permeability, low to moderate piping hazard; cited as the BOR as being the reach where a majority of the leakage occurs, estimated at 3,000 acre-feet per year	Area proposed Lined Reach S-14 BOR; area of start of AH S-14 lined canal 4600 feet long; Reach S-14 is among 10 identified as areas of most serious seepage
218,474 (41.8 miles)	Siphon 24 inlet; Pajarito Creek	moderate permeability, low to moderate piping hazard	Canal Spillway and Canal check
219,053 (42 miles)	Siphon 24 outlet	moderate permeability, low to moderate piping hazard	Area of seepage identified by Trauger
221,415	Liberty Lateral	Near upper end of 1.5-mi reach with high leakage potential; moderately rapid permeability	
226,053	Coulter Lateral	In 1.5-mi reach with high leakage potential; moderately rapid permeability	
228,202	Culvert under Canal	Moderately rapid permeability	
229,415	Bridge over Canal	Moderately rapid permeability	Pajarito Creek seepage area
229,648	Culvert under Canal	Near lower end of 1.5 mi reach with high leakage potential; moderately rapid permeability	

TABLE 13K ARCH-HURLEY CONSERVANCY CONCHAS MAIN CANAL LEAKAGE POTENTIAL BASED ON SOILS, SURFICIAL GEOLOGY, AERIAL PHOTOGRAPHY, AND COLOR-IR SATELLITE IMAGERY

NOTE: BOR refers to USBOR 1983 study; AH refers to 1981 District study

Distance Down Canal in Feet and (in miles)	Major Structures on the Canal System	Potential for Canal Leakage Based on Major Controlling Soils & Surficial Geologic Factors + Landsat Imagery	Drainage Features and Leakage Potential Identified by Others
231,010 (44.2 miles)	Siphon 25 inlet	moderate permeability, moderate piping hazard	Tunnel beneath valley of Pajarito Creek
232,500 to 234,000	Siphon 25	moderate permeability, moderate piping hazard	Pajarito Creek area of springs
235,606 (near 45 miles)	Siphon 25 outlet	Many (long and short) reaches between Siphons 25 and 26 with apparent moderate to high leakage potential; moderate permeability, low to moderate piping hazard	Exit tunnel beneath valley of Pajarito Creek
239,736	W. Gaynell Ave & Bridge	slow to moderate permeability, medium to high piping hazard	
243,373	Culvert under Canal	moderate to high leakage potential; moderate permeability, low to moderate piping hazard	Area of proposed Lined Reach S-15 BOR; BOR estimates 600 feet of lining
247,257	Culvert under Canal	moderate permeability, low to moderate piping hazard	Area of AH S15 proposed canal lining 600 feet long
249,679	Bridge over Canal	moderate permeability, low to moderate piping hazard	Tunnel beneath Old US-66 and SPRR
251,757 (48.13 miles)	Siphon 26 inlet	Many (long and short) reaches between Siphons 25 and 26 with apparent moderate to high leakage potential; moderate permeability, low to moderate piping hazard	Tunnel beneath Old US-66 and SPRR
252,543 (48.30 miles)	Siphon 26 outlet	moderate permeability, moderate piping hazard	
256,138	Farm-road & bridge	moderate permeability, moderate piping hazard	
256,758 (49.1 miles)	Siphon 27 inlet	moderate permeability, moderate piping hazard	
256,937 (49.11 miles)	Siphon 27 outlet	moderate permeability, moderate piping hazard	

TABLE 13L ARCH-HURLEY CONSERVANCY CONCHAS MAIN CANAL LEAKAGE POTENTIAL BASED ON SOILS, SURFICIAL GEOLOGY, AERIAL PHOTOGRAPHY, AND COLOR-IR SATELLITE IMAGERY

NOTE: BOR refers to USBOR 1983 study; AH refers to 1981 District study

Distance Down Canal in Feet and (in miles)	**Major Structures on the Canal System**	**Potential for Canal Leakage Based on Major Controlling Soils & Surficial Geologic Factors + Landsat Imagery**	**Drainage Features and Leakage Potential Identified by Others**
257,644	Culvert under Canal	moderate permeability, moderate piping hazard	
260,819	Bridge over Canal	moderate permeability, moderate piping hazard	
261,184	Lateral to north	Near start of long reach with apparent moderate to high leakage potential (including area of Siphon 28); moderate permeability and piping hazard	
263,192 (50.4 miles)	Siphon 28 inlet	In long reach with apparent moderate to high leakage potential (including area of Siphon 28); moderate permeability and piping hazard	
263,833 (50.5 miles)	Siphon 28 outlet	In long reach with apparent moderate to high leakage potential (including area of Siphon 28); moderate permeability and piping hazard	
265,291	Bridge over Canal	In long reach with apparent moderate to high leakage potential (including area of Siphon 28); moderate permeability and piping hazard	
265,784	Tucumcari Lateral goes to north	Near end of long reach with apparent moderate to high leakage potential (including area of Siphon 28); moderate permeability and piping hazard	
267,884	Bridge over Canal	Within reach with low to moderate leakage potential; moderate permeability and piping hazard	
270,997	Bridge over Canal	Within reach with low to moderate leakage potential; moderate permeability and piping hazard	
272,416 (52.1 miles)	Tunnel No. 5 upstream entrance	At lower end of reach with low to moderate leakage potential; moderate permeability and piping hazard	Tunnel under south part of Tucumcari from Seventh to First Avenues
275,476 (52.7 miles)	Tunnel No. 5 downstream exit	Start of a 2-mi reach extending to Siphon 29 and Siphon 30 with moderate to high leakage potential; moderate permeability and piping hazard	

TABLE 13M ARCH-HURLEY CONSERVANCY CONCHAS MAIN CANAL LEAKAGE POTENTIAL BASED ON SOILS, SURFICIAL GEOLOGY, AERIAL PHOTOGRAPHY, AND COLOR-IR SATELLITE IMAGERY

NOTE: BOR refers to USBOR 1983 study; AH refers to 1981 District study

Distance Down Canal in Feet	Major Structures on the Canal System	Potential for Canal Leakage Based on Major Controlling Soils & Surficial Geologic Factors + Landsat Imagery	Drainage Features and Leakage Potential Identified by Others
277,644	Club Lateral to north	In a 2-mi reach extending to Siphon 29 and Siphon 30 with moderate to high leakage potential; moderate permeability and piping hazard	
278,910	Culvert under Canal	In a 2-mi reach extending to Siphon 29 and Siphon 30 with moderate to high leakage potential; moderate permeability and piping hazard	
280,373	I-40W Bridge over Conchas Canal	In a 2-mi reach extending to Siphon 29 and Siphon 30 with moderate to high leakage potential; moderate permeability and piping hazard	
280,464	I-40E Bridge over Canal	In a 2-mi reach extending to Siphon 29 and Siphon 30 with moderate to high leakage potential; moderate permeability and piping hazard	
280,989	Outlet or drain to Tucumcari Lake	In a 2-mi reach extending to Siphon 29 and Siphon 30 with moderate to high leakage potential; moderate permeability and piping hazard	
283,204	Siphon 29 inlet	In a 2-mi reach extending to Siphon 30 with moderate to high leakage potential; moderate permeability and piping hazard	
283,396	Siphon 29 outlet	In a 2-mi reach extending to Siphon 30 with moderate to high leakage potential; moderate permeability and piping hazard	Tucumcari Mountain to the south
285,400	Culverts under Canal	In a 2-mi reach extending to Siphon 30 with moderate to high leakage potential; moderate permeability and piping hazard; leakage in area reported by BOR to affect irrigated lands	Area of proposed Lined Reach S-16 BOR; BOR estimates 2,400 feet of lining just upstream from AH selected section S-16 length 800 feet; Reach S-16 is among 10 identified as areas of serious seepage

TABLE 13N ARCH-HURLEY CONSERVANCY CONCHAS MAIN CANAL LEAKAGE POTENTIAL BASED ON SOILS, SURFICIAL GEOLOGY, AERIAL PHOTOGRAPHY, AND COLOR-IR SATELLITE IMAGERY

NOTE: BOR refers to USBOR 1983 study; AH refers to 1981 District study

Distance Down Canal in Feet and (in miles)	Major Structures on the Canal System	Potential for Canal Leakage Based on Major Controlling Soils & Surficial Geologic Factors + Landsat Imagery	Drainage Features and Leakage Potential Identified by Others
288,068	Siphon 30 inlet	Lower end of a 2-mi reach with moderate to high leakage potential; slow permeability, with bedrock at 18 to 42 inches limiting losses	
288,368 (mile 55)	Siphon 30 outlet	slow permeability, with bedrock at 18 to 42 inches limiting losses	
292,816 (near mile 56)	Canal splits at the "Y"	Near upper end of 1.5-mi reach with high leakage potential; moderate permeability and piping hazard	Hudson Canal starts and goes to the northeast, and Conchas Main Canal continues to southeast
297,723 (mile 57)	Lateral, drains to Hittson Creek	Near lower end of 1.5-mi reach with high leakage potential; moderate permeability and piping hazard	
299,753	Bridge	moderate permeability, moderate piping hazard	
306,973	Lateral	In upper part of 1-mi reach with moderate leakage potential; large range in permeability and shrink-swell potential; forms deep cracks when dry	Area of proposed Lined Reach S-19 BOR; BOR estimates 900 feet of lining
308,120	Savage Lateral	In upper part of 1-mi reach with moderate leakage potential; large range in permeability and shrink-swell potential; forms deep cracks when dry	
310,174	Siphon 31	In lower part of 1-mi reach with moderate leakage potential; large range in permeability and shrink-swell potential; forms deep cracks when dry	
314,266 - 314,346	Lateral; bridge		
320,204	Bridge and lateral; near a spillway and check into Tucumcari Creek	Up-canal from and adjacent to areas of "artificial ponding"; large range in permeability and shrink-swell potential; forms deep cracks when dry; BOR estimates this to be major leakage area	Start of area of proposed Lined Reach S-17 BOR; BOR estimates 2,000 feet of lining; Reach S-17 is among 10 identified as areas of most serious seepage
324,979	Bridge	Near upper end of reach with low to moderate leakage potential; moderate permeability, moderate piping hazard	

TABLE 13O ARCH-HURLEY CONSERVANCY CONCHAS MAIN CANAL LEAKAGE POTENTIAL BASED ON SOILS, SURFICIAL GEOLOGY, AERIAL PHOTOGRAPHY, AND COLOR-IR SATELLITE IMAGERY

NOTE: BOR refers to USBOR 1983 study; AH refers to 1981 District study

Distance Down Canal in Feet	Major Structures on the Canal System	Potential for Canal Leakage Based on Major Controlling Soils & Surficial Geologic Factors + Landsat Imagery	Drainage Features and Leakage Potential Identified by Others
320,204	Bridge and lateral; near a spillway and check into Tucumcari Creek	Up-canal from and adjacent to areas of "artificial ponding"; large range in permeability and shrink-swell potential; forms deep cracks when dry; BOR estimates this to be major leakage area	Start of area of proposed Lined Reach S-17 BOR; BOR estimates 2,000 feet of lining; Reach S-17 is among 10 identified as areas of most serious seepage
324,979	Bridge	Near upper end of reach with low to moderate leakage potential; moderate permeability, moderate piping hazard	
328,174	Wharton Lateral	Near lower end of reach with low to moderate leakage potential; moderate to high permeability, moderate piping hazard	
333,896	Siphon 32 inlet	Near lower end of reach with low to moderate leakage potential; moderate to high permeability, moderate piping hazard	Entrance to tunnel beneath Plaza Larga Creek Valley
336,286	Siphon 32 outlet	Near upper end of reach with moderate leakage potential; moderate permeability	Exit tunnel beneath Plaza Larga Creek Valley
343,308	Siphon 33 inlet	In lower part of reach with moderate leakage potential; moderate to high permeability, moderate piping hazard	
343,568	Siphon 33 outlet	In lower part of reach with moderate leakage potential; moderate to high permeability, moderate piping hazard	
348,855	Bridge	Near upper end of reach with moderate to high leakage potential; moderate permeability and piping hazard	
354,250	Siphon 34	Within reach with moderate to high leakage potential; moderate permeability	
361,104	Lateral	Within short reach with moderate to low leakage potential; moderate permeability	
363,100	Conchas and Farrow Laterals	Within reach with moderate to high leakage potential; moderate permeability, low to moderate piping hazard	End of the Main Conchas Canal

TABLE 14A ARCH-HURLEY CONSERVANCY HUDSON CANAL LEAKAGE POTENTIAL BASED ON SOILS, SURFICIAL GEOLOGY, AERIAL PHOTOGRAPHY, AND COLOR-IR SATELLITE IMAGERY

NOTE: BOR refers to USBOR 1983 study; AH refers to 1981 District study

Distance Down Canal in Feet	**Major Structures on the Canal System**	**Potential for Canal Leakage Based on Major Controlling Soils & Surficial Geologic Factors + Landsat Imagery**	**Drainage Features and Leakage Potential Identified by Others**
0.00 Hudson Canal 292,816 feet on Conchas	Conchas and Hudson Canals split at the "Y"	Near upper end of long reach with high leakage potential; moderate permeability and piping hazard	BOR notes leakage in vicinity of "Y"
9,423	Bridge over Canal (I-40 and Tucumcari Blvd)	Near lower end of long reach with high leakage potential; moderate permeability and piping hazard	
9,536	Siphon H1 inlet	At lower end of long reach with high leakage potential	Start of tunnel under I-40, about 0.9 miles
9,627	I-40E Bridge over Siphon H1	moderate permeability and piping hazard	
9,745	I-40W Bridge over Siphon H1	moderate permeability and piping hazard	
14,015	Siphon H1 outlet	Upper end of long reach with moderate leakage potential; moderate permeability and piping	End of tunnel under I-40, 0.9 mi long
24,519	Benson/Gaudin Lateral to south (near Hittson Creek)	In lower part of long reach with low to moderate leakage potential; moderate permeability and piping	
31,046	Bridge over Canal (Airport-Jones Road to south)	Down-canal from long reach with moderate leakage potential; large range in permeability shrink-swell potential; deep cracks when dry	
36,334	Felk Lateral (to southeast)	Near lower end of long reach with moderate to high leakage potential; moderate to high permeability, moderate piping hazard	
43,529	Lateral (to south)	In a 1.5-mi reach with moderate leakage potential; large range in permeability/shrink-swell potential; forms deep cracks when dry	
44,632	Bridge over Canal	In a 1.5-mi reach with moderate leakage potential; slow to moderate permeability	

TABLE 14B ARCH-HURLEY CONSERVANCY HUDSON CANAL LEAKAGE POTENTIAL BASED ON SOILS, SURFICIAL GEOLOGY, AERIAL PHOTOGRAPHY, AND COLOR-IR SATELLITE IMAGERY

NOTE: BOR refers to USBOR 1983 study; AH refers to 1981 District study

Distance Down Canal in Feet	Major Structures on the Canal System	Potential for Canal Leakage Based on Major Controlling Soils & Surficial Geologic Factors + Landsat Imagery	Drainage Features and Leakage Potential Identified by Others
63,668	Bridge over Canal	Near lower end of a 3.5-mile reach with moderate leakage potential; moderate to high permeability, moderate piping hazard	Start of proposed lined canal; 1800 feet long proposed by BOR
65,013	Bugg Lateral (to south)	Near lower end of a 3.5-mile reach with moderate leakage potential; moderate to high permeability, moderate piping hazard	End of lined section proposed by BOR
69,224	Bridge over Canal	At end of 3.5-mile reach with moderate leakage potential; moderate permeability and piping	
73,798	Troutman Lateral (to east)	Reach with moderate leakage potential; moderate permeability and piping hazard	
77,923	Lateral (short to east-Revuelto Ck)	In upper part of 3-mile reach with moderate leakage potential; moderate permeability and piping	
87,396	short lateral to the east	Lower end of 3-mile reach with moderate leakage potential; moderate permeability, moderate piping hazard	
94,843	Hudson and "Mater" Laterals	In area with moderate leakage potential; moderate permeability and piping hazard	End of Hudson Canal

The Use of Change Detection Analysis

Observed Changes in Moisture Conditions

As mentioned above, Plate 2 represents the project area under “normal” wet conditions during September 2000. Vegetation along the canal and within the agricultural areas around Tucumcari can be seen as bright green regions in Plate 2. The Conchas

Reservoir at near average capacity is seen in the upper left corner of the plate. In contrast, the LANDSAT 7 image (Path 32 Row 35) dated August 12, 2002 of Plate 5 shows signs of drought conditions. The Conchas Reservoir water line, in the upper left corner of the plate, is much reduced from the water level seen in Plate 2. Vegetation along the canal appears to be dry in Plate 5, and there is less growth and active agriculture in the fields in the irrigation District.

These observations, made from LANDSAT imagery, are confirmed by the District's water supply records as reported in Table 6D. Table 6D reports that Conchas Reservoir was at near "spill conditions" (225,000 acre-feet in storage) in April 2000 and that the District released 118,000 acre-feet from the Reservoir during the 2000 irrigation season. By the time the 2002 irrigation season started, there was only 35,000 acre-feet in storage in the Reservoir and only 15,500 acre-feet were released into the canal system. No irrigation releases were made after July 1, 2002 as there was no irrigation water left in the Reservoir. Clearly, both the LANDSAT imagery and the District's water supply records indicate that significant changes in moisture conditions had taken place along the canal system and on the irrigated lands between September 2000 and August 2002.

Performing Change Detection Analysis

Two primary areas of consideration exist when performing change-detection analysis (Jensen 1996, page 258). The first is the remote-sensing system-resolution, and second are the environmental conditions. Jensen (1996, page 259) splits the remote-sensing system considerations into four categories: temporal, spatial, spectral, and radiometric. He divides the environmental considerations into four categories:

atmospheric, soil moisture, phonological characteristics, and tidal stage for regions near large bodies of water (i.e., oceans).

Issues of remote system resolution are greatly reduced if the imagery used in change-detection analysis is collected from the same system (Jensen 1996, page 259). Temporal resolution of the image data is important when attempting change-detection (Jenson 1996, page 259). If the images used for comparison are from the same system (i.e., data collected from LANDSAT 7), then the time-of-day concerns are muted. Ideally, the time-of-year the data are collected will be on or near the anniversary date of the first image (Jenson 1996, page 259). Differences in sun angle, plant-growth cycles (phenological), and atmospheric conditions, due to seasonal variations, can be reduced when anniversary-date image-data are used (Jensen et al. 1993). Ideally, soil moisture should be nearly the same between images for the purpose of change detection (Jensen 1996, page 260). Even though dry soils could pose a significant challenge to change-detection (Jensen 1996, page 260), the differences of soil moisture between anniversary dates can be a benefit identifying areas of seepage because of change conditions.

Published data from NRCS soil surveys (Plate 3) and surface geology maps (Plate 4) were initially used to identify reaches of the canal with significant seepage potential. Canal reaches with seepage potential have been listed in Tables 15 and 16 and have been tied to the station location nearest the seepage area. Seepage along individual reaches of the canal system is noted at stations marked on Plates 1 and 2. Two LANDSAT images were used in change-detection analysis to identify areas of decreased vegetation. The two were approximately two years apart in time (September 7, 2000 and August 12, 2002, respectively). Assuming that the areas of healthy vegetation along the Conchas canal seen in Plate 2 are due to seepage along the canal, and if drought conditions prevailed in August 2002 (Plate 5), then areas of decreased vegetation can be identified by comparing the two images.

Both Plates 2 and 5 use LANDSAT 7 bands 7, 4, 2 to depict surface reflectance for the study area. Band 4, reflective infrared, is used to map healthy vegetation and is shown in these two plates (2 and 5) as bright green areas. Conchas Reservoir can be seen in both Plates 2 and 5. The Reservoir area is noted to be greatly reduced when comparing Plate 5 to Plate 2. The difference between these two images represents a decrease in annual precipitation for the region and reduced runoff into the Reservoir.

The process of change-detection analysis for the Tucumcari Project began with the creation of NDVI (Jensen 1996) maps for each image; then areas of decreased vegetation can be identified by comparing the two images. The NDVI is created by dividing the difference between LANDSAT 7, Band 4 and Band 3, with the summation of these two bands. The dark areas of a NDVI map represent areas of little or no vegetation, and the bright areas represent abundant vegetation. The first image, scanned in September 2000 (Plate 2), represents the Tucumcari Project lands at the end of an irrigation season where full water supply conditions prevailed. The second image, scanned in August 2002 (Plate 5), represents the irrigation system during a drier period of much reduced irrigation. The NDVI for the September 2000 image is shown in Plate 6 and the NDVI for the August 2002 image is shown in Plate 7. Note that the areas of healthy vegetation are greatly reduced between the two plates.

The next step in this process is to create a ratio-image (dividing the first image by the second) of the two images and then classifying the new image based on the amount of difference between the two images. Plate 8 is the result of this process. The areas with increased values (10 percent or greater NDVI in the August 2002 image) are marked as green in Plate 8. The areas with decreased values (10 percent or greater NDVI in the September 2000 image) are marked as red in Plate 8. In general, the canal *corridor* from the Reservoir to the District's irrigated lands shows areas of "slight decrease" to a "decrease" in NDVI values. Some notable areas of vegetation change include the reaches between Siphons 2 and 3, the area between Siphons 4 and 5, a down-slope area between Siphons 11 and 12, a large area near Siphon 15, a small area above Siphon 22, a large area near Siphon 23, and a number of small areas just above Bell Lateral. Each of these regions corresponds with identified areas of potential seepage noted in Table 13. There are regions of "increased" NDVI on Plate 8. The vegetation in those areas may thrive in dry conditions as it appears that there was more biomass produced in these areas in 2002 than during 2000.

Summary of the Canal Leakage Analysis

Plate 1 is a strip-map of the canal route and is found in the map-pocket at the end of this report. The strip-map of the canal route shows area soils, contains notes on geologic structure, canal stationing, elevations at critical points, and notes on principal physical features such as local drainage, bridges, tunnels and siphons. Location and elevation data on physical canal features are provided in Table 13 for the Conchas Canal and in Table 14 for the Hudson Canal. Canal slope, for various sections of the Conchas Canal is provided in Table 13. These two tables also show the leakage potential of identified sections along the canal system based on soils and hydrogeologic conditions (also see Appendix B) and on the observations of previous investigators. Seepage potential for each identified section is rated “low,” “moderate,” or “high,” or some combination of these predictors.

Suspect reaches of the Conchas and Hudson Canals with moderate and high leakage potential were identified based on interpretation of the hydrogeologic conditions and soil-landscape relationships, with investigations involving GIS and remote-sensing analyses and field verification. The availability of LANDSAT imagery for two recent, but very different water-years has made it possible to verify leakage from suspect sections of the canal system using change-detection analysis. Imagery for September 2000, a “wet” year was compared to imagery for August 2002, a “dry” period when no irrigation water was released from Conchas Reservoir after July 1, 2002. Significant changes were noted in soil moisture between the two LANDSAT images for a number of reaches of the Conchas Canal. All of these reaches had been identified as being potential locations of canal leakage using hydrogeologic and soil-landscape conditions. This verification of canal leakage has been noted in Table 15 using the statement: “Leakage in this reach has been confirmed using change-detection analysis.” This study illustrates the usefulness of investigative approaches that correlates seepage losses with not only canal-hydraulic factors, but also with surficial soil/hydrogeologic conditions and with change-detection analysis based on LANDSAT imagery. The data developed are given in Tables 15 for the Conchas Canal and Table 16 for the Hudson Canal. These two tables also include an estimate of the length (in feet) of each reach that is believed to be the source of “moderate” to “high” canal seepage. A total of 152,400 feet of suspect canal-length with moderate to high leakage potential was identified on the Conchas Canal and 20,500 feet of “leaky” reaches on the Hudson Canal.

TABLE 15 ARCH-HURLEY CONSERVANCY DISTRICT CONCHAS CANAL REACHES WITH SUSPECTED HIGH LEAKAGE POTENTIAL			
Approximate Distances Down the Canal in Feet	**Major Structures on the Canal System in the Indicated Reach**	**Potential for Canal Leakage Based on Major Controlling Soils & Surficial Geologic Factors + Landsat Imagery and Identification by Others**	**Length of Reach with Suspected High Leakage Potential in Feet**
Outlet to 2,000 feet down-canal	Diversion and start of Canal at outlet from Conchas Reservoir	High leakage potential, permeability and piping hazard	1,500 feet
16,500 - 17,500	Siphon 1 outlet	Moderate to high leakage potential starts about 500' downstream; permeability and piping hazard highly variable	300 feet
23,000 - 23,500	Culvert under Canal	Start of reach with high leakage potential; large range in permeability and shrink-swell potential; form deep cracks when dry; includes 500 foot section at Mile 4 with significant leakage potential	3,000 feet
28,000 - 30,000	Enter lowland area	High leakage potential; large range in permeability and shrink-swell potential; forms deep cracks when dry	2,000 feet
33,000 - 36,500	Bridge over Canal	Moderate to high leakage potential; moderate permeability, and piping hazard	3,000 feet
41,000 - 43,000	Siphon 4 outlet	Start of reach with high leakage potential; moderate permeability and piping hazard	2,000 feet
47,000 - 50,000	Culvert under Canal	About 2000 ft up-canal from reach with moderate to high leakage potential; moderate permeability and piping hazard	2,500 feet
57,000 - 61,500	Siphon 6 outlet to Siphon 7	Start of long reach with moderate to high leakage potential; moderate permeability and piping hazard	4,000 feet
61,500 - 68,000	Siphon 7 outlet to Siphon 9	Moderate to high leakage potential; moderate permeability and piping hazard	6,000 feet

TABLE 15 ARCH-HURLEY CONSERVANCY DISTRICT CONCHAS CANAL REACHES WITH SUSPECTED HIGH LEAKAGE POTENTIAL			
Approximate Distances Down the Canal in Feet	**Major Structures on the Canal System in the Indicated Reach**	**Potential for Canal Leakage Based on Major Controlling Soils & Surficial Geologic Factors + Landsat Imagery and Identification by Others**	**Length of Reach with Suspected High Leakage Potential in Feet**
71,000 - 74,000	Siphon 10 outlet	Start of reach with moderate to high leakage potential; large range in permeability and shrink-swell potential; forms deep cracks when dry	2,000 feet
77,000 - 81,000	Siphon 11 outlet	Start of reach with high to moderate leakage potential; large permeability range, moderate to high piping hazard	3,000 feet
93,000 - 95,500	Tunnel No. 2 exit portal	Start of reach with high leakage potential; permeability and piping hazard highly variable	2,500 feet
98,000 - 105,500	Bridge over Canal to Siphon 14 inlet	Start of reach with high to moderate leakage potential; moderate permeability, moderate piping hazard; cited by the BOR as an area of major seepage	7,000 feet
115,000 - 142,000	Tunnel No. 3 exit portal to Tunnel No. 4 entrance	Very long reach with high leakage potential; moderate permeability and piping hazard; cited by the BOR as an area of major seepage	26,000 feet
149,000 - 157,500	Tunnel No. 4 exit portal to Siphon 18 inlet	Long reach with moderate to high leakage potential; slow to moderate permeability, medium to high piping hazard	8,000 feet
163,000- 168,500	Siphon 19 outlet to inlet of Siphon 20	High leakage potential; permeability and piping hazard highly variable	5,500 feet
172,000 - 175,000	Siphon 21 outlet	Reach with moderate to low leakage potential; permeability and piping hazard highly variable; BOR proposed lined reach	600 feet
176,000- 183,000	Siphon 22 outlet to NM 105 Bridge over Canal	Start of long reach with moderate to high leakage potential; permeability and piping hazard highly variable	13,000 feet
183,000 - 193,000	NM 105 Bridge to culvert beyond Siphon 23	Up-canal from long reach with high leakage potential; moderate permeability, low to moderate piping hazard; BOR proposed lined reach; among identified areas of serious seepage	8,000 feet

TABLE 15 ARCH-HURLEY CONSERVANCY DISTRICT CONCHAS CANAL REACHES WITH SUSPECTED HIGH LEAKAGE POTENTIAL			
Approximate Distances Down the Canal in Feet	**Major Structures on the Canal System in the Indicated Reach**	**Potential for Canal Leakage Based on Major Controlling Soils & Surficial Geologic Factors + Landsat Imagery and Identification by Others**	**Length of Reach with Suspected High Leakage Potential in Feet**
192,000 - 194,000	Culvert under Canal	High leakage potential; moderate permeability, low to moderate piping hazard; cited by the BOR as an area of major seepage; among 10 identified as areas of most serious seepage	1,000 feet
202,000 – 208,000	Bridge over Canal at Quay County Line	Within long reach with high leakage potential; moderate permeability, low to moderate piping hazard	6,000 feet
208,000-216,000	NM 104 Bridge over Canal	Reach with high leakage potential; Large range in permeability and shrink-swell potential; form deep cracks when dry; cited by the BOR as an area of major seepage; BOR estimate of 3,000 acre-feet per year	8,000 feet
221,000 - 229,500	Liberty Lateral, Coulter Lateral	Near upper end of 1.5-mi reach with high leakage potential; moderately rapid permeability	7,500 feet
232,900 – 234,900	Pajarito Creek crosses Siphon 25	Indicated reach has significantly more vegetation on down-slope of siphon than on upslope as seen on LANDSAT imagery	2,000 feet
235,500-252,000	Siphon 25 outlet to Siphon 26 inlet	Many (long and short) reaches between Siphons 25 and 26 with moderate to high leakage potential; moderate permeability, low to moderate piping hazard; BOR estimates 600 feet of lining	2,000 feet
261,000-265,000	Lateral to north; Siphon 28 inlet and outlet	Reach with moderate to high leakage potential (including area of Siphon 28); moderate permeability and piping hazard	2,000 feet
275,500-288,000	Tunnel No. 5 exit portal to Siphon 30 inlet	Reach extending to Siphon 29 and Siphon 30 with moderate to high leakage potential; moderate permeability and piping hazard	11,000 feet

TABLE 15 ARCH-HURLEY CONSERVANCY DISTRICT CONCHAS CANAL REACHES WITH SUSPECTED HIGH LEAKAGE POTENTIAL			
Approximate Distances Down the Canal in Feet	**Major Structures on the Canal System in the Indicated Reach**	**Potential for Canal Leakage Based on Major Controlling Soils & Surficial Geologic Factors + Landsat Imagery and Identification by Others**	**Length of Reach with Suspected High Leakage Potential in Feet**
292,000-297,500	Hudson Canal goes to the northeast; Conchas Canal continues to southeast	Upper end of reach with high leakage potential; moderate permeability and piping hazard	6,000 feet
307,000 - 310,000	Lateral to Siphon 31	Reach with moderate leakage potential; large range in permeability and shrink-swell potential; forms deep cracks when dry; BOR estimates 900 feet of lining needed	1,000 feet
320,000 – 322,000	Bridge and lateral; near a spillway and check into Tucumcari Creek	Up-canal from and adjacent to areas of "artificial ponding"; large range in permeability and shrink-swell potential; forms deep cracks when dry; BOR estimates this to be major leakage area	2,000 feet
349,000 - 363,000	NM 88 Bridge to end of the Conchas Canal	Upper end of long reach (incl. Siphon 34) with moderate to high leakage potential; moderate permeability	4,000 feet

TABLE 16 ARCH-HURLEY CONSERVANCY DISTRICT HUDSON CANAL REACHES WITH SUSPECTED HIGH LEAKAGE POTENTIAL

Approximate Distances Down the Canal in Feet	Major Structures on the Canal System in the Indicated Reach	Potential for Canal Leakage Based on Major Controlling Soils & Surficial Geologic Factors + Landsat Imagery and Identification by Others	Length of Reach with Suspected High Leakage Potential in Feet
0.00 Hudson Canal to 9,536	Conchas and Hudson Canals split at the "Y" to Siphon 1H inlet	Upper end of long reach with high leakage potential; moderate permeability and piping hazard; BOR notes leakage in vicinity of "Y"	9,500 feet
14,000 - 31,000	Siphon 1H outlet to Bridge over Canal near Airport Road	Long reach with moderate to high leakage potential; moderate permeability and piping hazard	5,000 feet
34,000 - 36,500	Up-canal from Felk Lateral	Near lower end of reach with moderate to high leakage potential; moderate to high permeability and shrink-swell potential; deep cracks when dry	1,000 feet
43,500 - 69,000	From Lateral (to south) to Bridge over Canal	Very long reach with moderate leakage potential; moderate to high permeability, moderate piping hazard. Start of BOR proposed lined canal at ~69,224 ft	3,000 feet
74,000 - 87,500	From Troutman Lateral to Lateral (to Revuelto Ck)	Long reach with moderate leakage potential; moderate to high permeability, and low to moderate piping hazard	2,000 feet

PART V

QUANTIFICATION OF SEEPAGE LOSSES: RESULTS OF FIELD STUDIES AND SEEPAGE REDUCTION COST-ESTIMATES

Objective of Quantifying Seepage Losses

Phase I of this pre-appraisal study has been funded by Reclamation to determine the feasibility of reducing canal seepage losses in the Arch Hurley Conservancy District in order to "save water" for District use and for the transport of a part of any "saved water" from the Canadian River basin into the adjacent Pecos basin. The goal of Phase I studies has been to determine the possibilities of a water-salvage project by reducing losses from the District's canal system.

The field studies of the hydrogeologic setting of the canals and of the soils systems found along the Arch Hurley canal-corridor have made it possible to identify canal reaches that are suspect as being the sources of significant seepage losses. This process was further refined by the use of GIS analysis and LANDSAT imagery to perform "change detection analysis." This work allowed the study team to reduce the number of field seepage loss measures required and to pinpoint reaches with the greatest losses. What was needed was an evaluation of the rate-of-loss of water in key canal reaches.

Methods of Measuring Seepage Losses from Canals

Conceptual Aspects of the Inflow-Outflow Method

The inflow-outflow method is based on measuring the difference between the quantity of water flowing into the upper end of the test section of the canal and the quantity of water flowing out at the lower end. This method is applicable to operating canals, both unlined and lined. It requires that steady-state conditions be maintained in the test reach so that changes in storage volume within the reach are negligible and that any change in storage can be attributed to seepage losses out of the canal walls and bottom in the selected reach.

Current meters are generally used to measure the flow in large canals, while portable weirs, Parshall flumes, gates, and valves can be used in small canals and ditches. Measuring devices of these latter types require careful calibration and are usually expensive to install (Warnick 1951).

The inflow-outflow method should only be used on long sections because the percentage of seepage loss must be significantly larger than any random metering errors. With modern, calibrated current meters, this type of error is typically about 3 percent at best, with 5 percent being more common for good metering (Warnick 1963). In addition, seepage losses must be significantly larger than the random metering error. The accuracy of measurements made with a current meter can be improved by numerous measurements at a good gauging station. Some of the conditions needed for a "good" gauging station will be discussed later in this section. The seepage evaluation made within the District, by the USGS in 1982 (USBR 1983), utilized the inflow-outflow method. A discussion of the 1982 USGS measurements is incorporated into this evaluation.

Conceptual Aspects of the Ponding Method

The ponding method has been used for a number of years to determine seepage losses in certain types of canals and is designed to obtain leakage characteristic from canals in the same soils and geologic setting. To obtain seepage losses by this method, a canal section is isolated by temporary bulkheads or berms at each end of the section.

For small canals, an ordinary canvas dam can be installed and sealed tightly to form a good, temporary bulkhead. For larger canals, it is necessary to place a temporary, relatively waterproof dam or berm across both ends of the test section (Warnick 1951). Berms can be built with compacted soil at pre-selected sites to form ponding test sections (Sheng et al. 2003). Using the ponding method, the seepage rate can be obtained based on the difference between the volume of water in the test section at the beginning of the test and at the end of the test.

There are two ways to conduct the ponding test. The first way, the falling head method, is to fill the test section with water. The quantity of seepage loss is found by observing the continuous drop in water level during the test period. The decrease in volume of water due to seepage can be calculated knowing the measured decline in water levels and the dimensions of the canal test section. Figure 2 provides an example of a typical cross-section in a pending seepage study.

Another way of conducting a ponding test is the constant head method where a constant water depth is maintained in the test section and by measuring accurately the water supply into the pond (Warnick 1951). The quantity of seepage at any point in time is then the amount of water that has been added to maintain the constant water level.

The disadvantage of the ponding method is that it must be conducted when the particular section of the canal system is not in use. Care must be exercised to make sure that leakage from the ends of the test section and from any gates or turnouts within the test section is insignificant. The ponding method is considered the most accurate method of determining seepage loss, if these requirements are met.

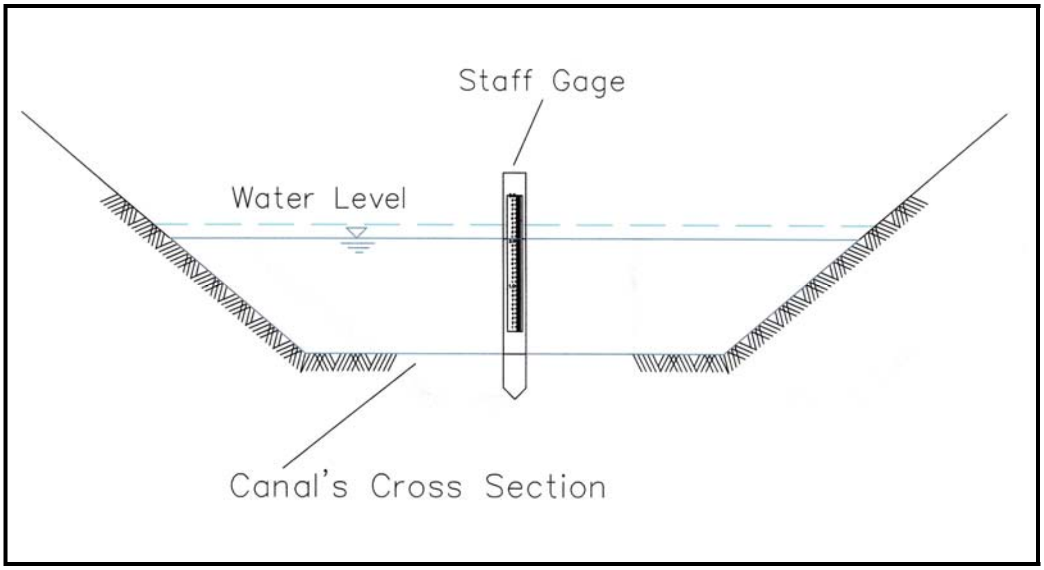


Figure 2. Schematic Cross-Section of a Typical Ponding Method Test Section

Field Flow Measurements and Seepage Loss Analysis

Flow Measurements on the Main Conchas Canal

In this study, the inflow-outflow method was used to characterize seepage losses on the Conchas Canal between Conchas Dam and the irrigated lands of the Tucumcari Project. This reach is about 39 miles long with no discrete inflow or outflow points other than the point of release from Conchas Dam and the delivery to District laterals. Some storm-water flows into the canal, but there was no storm-water discharge into the canal at any point of interest during the time that measurements were being made.

An Ott current meter on a wading rod was used to determine the flow at each test-reach studied. Standard USGS metering procedures were followed. While the USGS typically uses a Price-Gurley meter, the Ott meter used is accepted, and it has been calibrated in the New Mexico State University hydraulics laboratory.

Inflow-outflow tests on the Conchas Main Canal were carried out on the 12th and 13th of July 2005. The main canal had been in operation for about three months, so it was assumed that the canal was in steady state equilibrium with the hydrologically connected groundwater, so that if the inflow remained steady long enough to establish constant storage in the canal, the difference between inflow and outflow is due to seepage.

A change in the gate setting on Conchas Dam occurred on the morning of July 12, so that a transient change-in-flow was propagating through the system on the 12th, and the inflow-outflow method's assumption of steady-state flow was violated. Data from the 12th were not used in this analysis. Isolated thunder showers occurred on the evening of July 12, but the reaches of the canal that were measured were not affected. Releases from Conchas Dam were constant from the morning of the 12th through the conclusion of the test so that any transients from the flow change on the 12th did not affect the measurements on the 13th.

On the 13th, the canal flow was metered sequentially at three stations:

1. Downstream of Tunnel 1 (Latitude N 35°21'48.5", Longitude W 104°10'13.8")
2. Downstream of Tunnel 2 (Latitude N 35°19'05.9", Longitude W 104°01'30.9")
3. Upstream of Tunnel 4 (Latitude N 35°15'44.9", Longitude W 103°56'33.5")

The selection of these three stations was based on the need for straight, uniform control-sections for metering sites, the need for sufficiently long test-reaches between metering sites, and the need for sections where it was technically feasible to meter flows. In many areas saturated clay/shale mud made footing impossible, and the canal bottom was quite indistinct. The metering sites that were selected were at sandstone outcrops in the canal bed, and this provided acceptable control sections and locations for safer access for the metering team. Sites were also selected to provide sections that indicated distinctly different seepage behavior in the infrared imagery discussed in PART IV. Results from inflow-outflow metering are given in Table 17.

TABLE 17
Summary of Inflow-Outflow Data for Conchas Main Canal, July 13, 2005

Location	Down Stream of Tunnel 1	Down Stream of Tunnel 2	Up Stream of Tunnel 4
Start time	9:42	12:51	14:29
Finish time	10:43	13:42	15:22
Flow, Q, cubic feet per sec.	140	145	133
Cross Section Area A, sq.ft	113	84	99
Avg. Velocity v, feet/sec.	1.2	1.7	1.3
Wetted Perimeter WP, feet	36	34	34
Hydraulic Radius R, feet	3.1	2.5	2.9
Top width T, feet	33	33	31
Hydraulic Depth D, feet	3.4	2.6	3.2
Froude Number N_F	0.12	0.19	0.13

The cross-sectional area, the wetted perimeter (WP), and the hydraulic depth (D) are based on the cross-sectional measurements acquired during metering. The first metering point, the inflow for Reach 1, was located downstream from the exit portal of Tunnel 1 (shown as D/S Tunnel 1 in Table 17). Some large rocks on the bottom and banks made the section less than ideal for metering (~4 percent precision), but it was acceptable. The other two metering points had nearly ideal metering conditions. Note that the flow measured at D/S Tunnel 1 had 5 cfs less flow than that measured downstream of the exit portal of Tunnel 2 (D/S Tunnel 2). D/S Tunnel 2 serves as the outflow for Reach 1 and the inflow for Reach 2. While this appears to suggest that Reach 1, between D/S Tunnel 1 and D/S Tunnel 2 is gaining, the relative difference (3 percent) is within the precision of the metering technique (~5 percent combined precision), particularly considering the channel condition for D/S Tunnel 1. Basically, the data given in Table 17 indicate that there was no measurable loss in Reach 1.

Inflow-outflow measurements on Reach 2 between D/S Tunnel 2 and the metering point upstream of Tunnel 4 (U/S Tunnel 4, the outflow for Reach 2) show a loss of 12 cfs, a significant loss (8 percent) considering the high quality (~5 percent combined precision) of the inflow and outflow metering sites. The higher loss-rate in this reach is consistent with the infrared imagery discussed in PART IV.

Analysis of Seepage Measurements on the Main Conchas Canal

The results of seepage calculations for the two metered reaches (Reach 1 and Reach 2) are presented in Table 18. The gross reach-length of the three sections includes unlined canal sections, tunnels, siphons, culverts, and the bench flume. It is assumed that all of the seepage loss occurs in the unlined canal segments, so that the length of siphons, tunnels, and the bench flume must be subtracted from the gross reach-length of each section to obtain the net length of canal where leakage occurs. Culvert lengths are considered to be negligible.

Seepage rates are calculated as the flow-rate loss divided by the wetted area, which is the average wetted perimeter times the net length of canal in the reach. The reach from up-stream of Tunnel 4 (U/S Tunnel 4) to the Quay County line would constitute a third reach, though no suitable measurement-site could be located below U/S Tunnel 4 that would provide adequate length of reach. As the canal nears the Quay County line, it runs through poorly consolidated shale, and the flow deepens and slows, making instream metering problematic. To resolve these problems, the measured loss-rate for Reach 2 was extended on the basis of wetted area to the unmetered Reach 3.

Flow in Reach 3 tends to be slower and to run deeper than in Reach 2, so that the average wetted perimeter was increased to 36 feet to determine a comparable loss.

TABLE 18
Seepage Calculations by Reach for the Conchas Main Canal

Measured and Calculated Parameters	Reach 1	Reach 2	Un-metered Reach 3
Gross Reach Length, feet	85,455	47,632	64,317
Gross Reach Length, miles	16.2	9.0	12.2
Tunnel/Flume Length, feet	7,977	9,670	10,280
Total Siphon Length, feet	5,177	2,109	3,253
Net Length of Canal, feet	72,301	35,853	50,784
Net Length of Canal, miles	13.7	6.8	9.6
Average Wetted Perimeter, feet	35	34	36
Seepage Loss, cubic feet/ sec.	0*	12	18#
Seepage Loss, cubic feet/mile		1.75	1.86#
Loss/Wetted Area, feet per sec.		0.85	0.85#
* No significant loss. # Values are extrapolated from Reach 2.			

Based on these field measurements, the total seepage loss for the Main Conchas Canal at the measured flow-rate of 145 cfs is estimated to be 30 cfs or about 20 percent of the flow. This seepage loss occurs primarily in the middle 21 miles of the canal, 16 miles of which is unlined channel. The seepage rate per unit area was derived for Reach 2 based on the wetted perimeter and was calculated using the Manning formula. The seepage loss will vary with flow rate in the canal, as shown in Figure 3, though the rate of seepage is fairly insensitive to flow rate. At a flow rate of 300 cfs, the seepage loss would be expected to increase to about 34 cfs, so for a doubling of the flow rate, the seepage loss increases only 12 percent. At a flow rate of 500 cfs, the seepage loss would be about 39 cfs, or 7.5 percent of the flow.

The rate of canal-loss does increase with canal flow-rate, but for the purposes of estimating the total seepage losses over an irrigation season, the increase at higher flows may not be that important because of the relative insensitivity of seepage to flow. The typical operating range of the Conchas Canal is between 150 and 300 cfs, though higher flows occur during periods of peak demands. If the main Conchas Canal is lined to eliminate seepage losses of 30 cfs over a 214-day irrigation season, about 12,700 acre-feet of seepage reduction will be obtained.

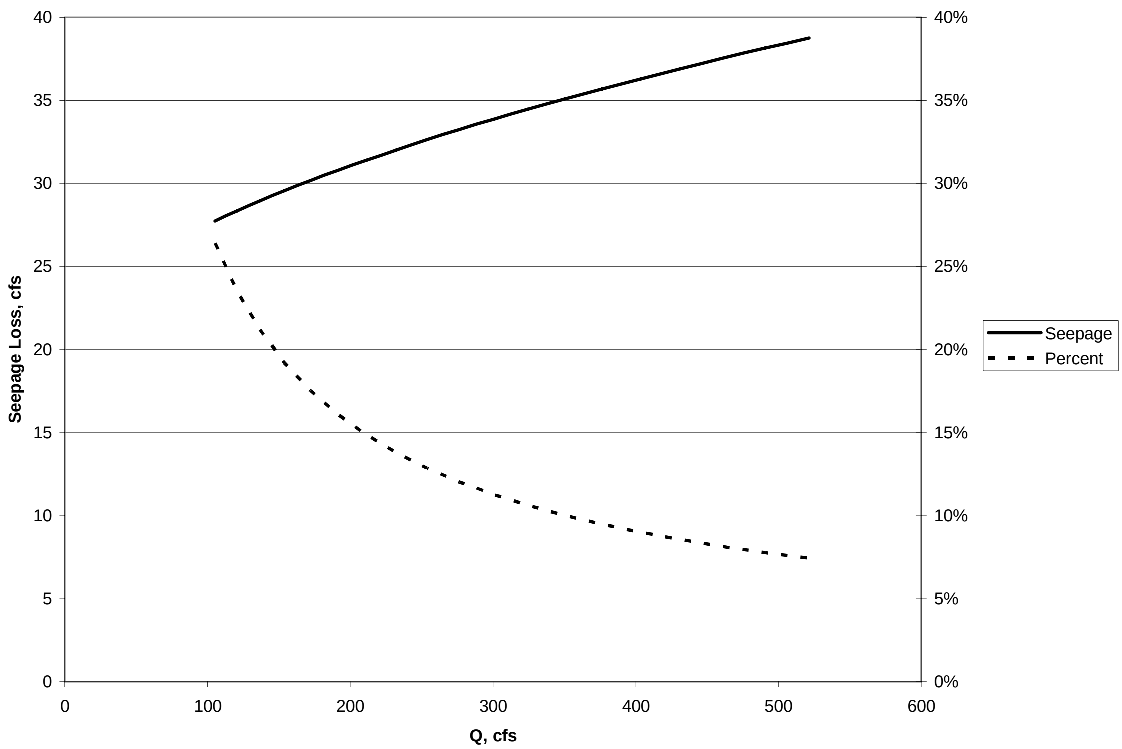


Figure 3. Estimated Seepage Rate as a Function of Flow Rate Conchas Canal

<u>Measurement of Seepage Losses Using Ponding Tests</u>

Two falling-head ponding tests were conducted simultaneously on the Bell and Jim Laterals on October 1, 2005. This being near the end of the season, the laterals were at or near steady state in terms of seepage. While the laterals were empty before being filled for the tests, intermittent use throughout the season should have brought the regional groundwater table into equilibrium with the terminal seepage rate. The Jim Lateral is a sub-lateral off the Roberts Lateral. The Bell Lateral test-segment was 605 feet long. Cross-sectional surveys showed an average bottom width of 3.06 feet and a side slope of 1.3:1 (H:V). A review of the SCS (now NRCS) Soil Survey of the Tucumcari area (Ross and Pease 1974) shows that the lateral test-segment is 60 percent in Kinkhead (Km) heavy clay loam soil and 40 percent in Toyah (Th), which is loam from the upper 8 inches, sandy-clay loam from 8-20 inches, and clay loam from 20-60 inches. The lower permeability of the sandy-clay loam in the 8-20 inch depth interval would be expected to control the terminal seepage-rate in this case. A length-weighted permeability for the lateral is given below in Table 19.

The test section on the Jim Lateral was 357 feet long. The test section was entirely in Canez (Ce), fine sandy loam underlain at 8 inches depth by sandy-clay loam. The underlying sandy-clay loam controls the terminal seepage rate, and its permeability is stated in the Soil Survey as 0.62–2.0 inches per hour. The measured seepage-rate was initially much higher on the Jim Lateral than on the Bell Lateral test section due to a more permeable soil and a drier initial condition on the Jim Lateral. The Jim Lateral, serving a smaller area, is operated more intermittently, so this probably a representative condition for the sub-lateral. The Jim Lateral’s higher infiltration rate and shallower pending-depth made for a relatively short seepage test, as the ponded water infiltrated in just under 5 hours.

TABLE 19

Ponding Test Results Summary for Bell and Jim Laterals

	Bell Lateral	Jim Lateral
Test Length, feet	605	357
Test Duration, hours and minutes	14:52	4:54
Soil Texture	Clay Loam, Loam	Sandy-Clay Loam
Soil Survey Permeability, in/hour	0.29 - 0.92	0.63 - 2.0
Terminal Seepage Rate, in/hour	0.82	1.64
Seepage Loss, cubic feet/hour/foot	0.47	0.71
Test Reach Seasonal Seepage Loss, acre-feet	25	22
Seasonal Seepage Loss, acre-feet/mile	221	332

Comparing the measured terminal seepage-rate with the permeability range derived from the NRCS Soil Survey of the Tucumcari area (Ross and Pease 1974) indicates that the Soil Survey's permeability is a good estimate of the range in which the terminal seepage rate will fall. This is consistent with the findings of Al Haddad (2005). Generally following Al Haddad's methodology, seepage losses for the two laterals were determined using Vedernikov's method (Vedernikov 1934) to estimate the steady-state seepage loss per unit length during operation. For the analysis given in Table 19, a 214-day irrigation season was assumed, as were operating factors of 75 percent and 67 percent for the Bell Lateral and Jim Lateral, respectively.

The results show that while the Jim Lateral is a smaller canal with a slightly lower total loss for the test reach. The higher seepage-rate in the Jim Lateral leads to higher seepage-loss per unit length and a higher loss per unit water delivered from the lateral. While this analysis concerns test lengths of only two laterals, the lesson here is that lining the District's individual laterals can be evaluated and prioritized to maximize seepage reduction using Vedernikov's method when an estimate of hydraulic conductivity is made based on the published range of permeability in NRCS Soil Surveys of the Tucumcari area (Ross and Pease 1974). The District could target smaller, high seepage-rate laterals for lining. This has the advantage of relatively high seepage reduction per length of lining, but it also has the advantage of requiring lining that is less expensive per unit length than that for larger laterals.

Seepage Losses from the Conchas Canal and Hudson Canal in Quay County

No field-based seepage analyses were done on the Conchas Main Canal beyond the Quay County line, and the Hudson Canal was also not included in field test. Direct measurements on these canals are problematic. The necessity of constant use during the irrigation season precludes ponding tests from March through October. The necessity of making diversions from these main canals into laterals makes inflow-outflow impractical.

In July of 1982, the USGS attempted inflow-outflow analyses of four reaches of the Conchas Main Canal between the first crossing of Highway 104 and Plaza Larga Creek. The segments had been targeted, by ground-level reconnaissance, as having potential high seepage-loss rates. Unfortunately, because the primary reaches were so short and diversions occurred between reaches during periods when measurements were made, the USGS was not conclusive in their findings, and metering errors were large relative to potential seepage losses (USBR 1983).

The Conchas Canal in Quay County and the Hudson Canal are difficult to characterize using infrared imagery as there is so much irrigated agriculture adjacent to the canals making it difficult to tell seepage from irrigation. Reclamation's report (1983) and the GIS/hydrogeologic/soils analysis presented in section IV generally agree on the location of areas with high potential for seepage, but specific quantification of that seepage will require further work. If seepage in these canals is to be quantified, a special release from Conchas Dam would need to be made before or, preferably, at the end of the irrigation season. All lateral diversion would have to be closed so that a steady-state flow condition is established and maintained and so that long canal-reaches can be established for metering. Using these study conditions will help make measured seepage-losses significant with respect to inherent metering errors

Siphon Leakage

The focus of this study has been on seepage losses through the banks and bed of District's Main Conchas Canal. In addition to seepage losses, the Conchas Main Canal probably loses significant quantities of water from discrete leaks in some of the system's siphons. The siphons are used to carry canal flow under arroyo valleys, and they operate under several feet of positive pressure-head. These arroyos are dynamic features that are commonly sites of high flood discharge and active erosion of steep hill slopes. Deep arroyo incision tends to expose the concrete of the siphon structures, and flow with associated coarse sediment load can damage the siphons.

Leakage from some siphons is evidenced in the geologic reconnaissance and in the infrared images presented in this report. Heavy vegetation in the area of some siphons indicates that losses from these structures are an ongoing problem. Because much of the leakage appears to occur in the unmetered Reach 3, the loss due to siphon leakage is not included in the above estimate of seasonal seepage loss. It would be prudent to inspect, repair, and protect the siphons both to reduce the leakage and to protect the functionality of the entire canal system.

Cost Estimates

Lining of Laterals to Reduce Seepage Losses

The quantity of water saved is the primary benefit to lining, and it must be considered against the cost of lining. In 2003, King and Maitland presented the following cost formula for concrete lining smaller canals as a function of size:

$$\text{Cost per linear foot} = \$2.22 \times \left(B + 2D\sqrt{1+z^2}\right)$$

where B is the bottom width in feet, D is the overall lined depth in feet, and z is the side slope horizontal to vertical ratio [H:V]. This approximate formula includes typical lining thickness, reinforcing-steel, and labor costs and is based on data from the Las Cruces and El Paso area. Tucumcari has a somewhat higher cost for concrete than the Las Cruces and El Paso area. Concrete and reinforcing steel have risen in price significantly since the derivation of this formula in 2003, and so a unit cost term of $3.00 is assumed for lining laterals. A cost estimate is given in Table 20 for lining the two laterals studied. It should be noted that, due to its relatively high seepage-rate and smaller lined section, lining the Jim Lateral is nearly twice as cost-effective as lining the Bell Lateral.

TABLE 20
Cost and Cost/Benefit Comparison for Lining Bell and Jim Laterals

	Bell Lateral	Jim Lateral
Lined Depth D, feet	3	2.5
Bottom Width B, feet	3	2
Side Slope z (H:V)	1.5	1.5
Cost per linear foot	$41	$33
Cost for test reach	$25,077	$11,796
Cost per acre-foot saved	$990.56	$525.90

Another option for reducing seepage from the laterals is to consider use of pipe rather than concrete lining. Elephant Butte Irrigation District (EBID) is in the process of placing 48-inch aluminized steel-pipe in some of their laterals with high seepage losses. Data for the most recent two-years indicate that the cost of 48-inch pipe, in place, is about $60 per linear foot, including pipe, fixtures, labor, turnouts, and flow measurement instrumentation. This has many advantages, including lower maintenance and lower hazard-risks than using concrete lining. Another advantage is the ability to stop and start irrigation in an intermittently operated lateral without having to fill and drain the lateral. Using pipe is an option that the District should consider, although concrete lining would likely be less expensive. The District has been active the past three years in installing pipe in leaky laterals.

Costs of Lining the Main Conchas Canal

Lining reaches of the main canals has been the principal consideration in past studies. The concrete lining on a canal as large as the Main Conchas Canal is generally thicker than that used on smaller canals. King and Maitland (2003) found that lining larger canals is about twice as costly per unit area as that for smaller canals. There may well be a diseconomy of scale with respect to lining reaches of the Main Conchas Canal, as access to the site is very difficult and the sheer quantity of concrete required will require exploiting the less-than-optimal sources available in the Tucumcari area. A unit cost of $8.50 per unit area was assumed for lining the Main Conchas Canal.

It is assumed that lining Reach 2 from Tunnel 3 to Tunnel 4 (a distance of just over 25,000 feet) will eliminate the loss of 12 cfs of seepage. This part of the reach demonstrates a high rate of seepage in the infrared imagery. The gross reach-length is reduced by the lengths of siphons. Results of the analysis for lining Reach 2 between Tunnels 3 and 4 for design capacities of 700 cfs and 500 cfs are given in Table 21. A design capacity of 500 cfs may be adequate to meet future irrigation needs, if seepage losses downstream are reduced significantly, thereby reducing the flow needed in Main Conchas Canal to make a given farm delivery.

The infrared imagery and geological reconnaissance suggest that most of the seepage in Reach 3 occurs between the bench flume and the Quay County line near the Bell Lateral. It is assumed that the rate of seepage loss per foot of unlined canal that occurred in Reach 2 also occurs between Tunnel 3 and Tunnel 4. Repeating the same analysis as for Reach 2 yields similar cost/benefits for Reach 3 and is shown in Table 22.

TABLE 21
Cost and Cost/Benefit for Lining Reach 2
from Tunnel 3 to Tunnel 4

Design Conditions	700 cfs	500 cfs
Reach 2 net channel length, feet	25,025	25,025
Bottom width B, feet	24	24
Flow depth d, feet	5	4.14
Freeboard*, feet	1.4	1.3
Overall depth D, feet	6.4	5.44
Side slope z (H:V)	1.5	1.5
Cost per linear foot	$400	$371
Cost per mile	$2,112,750	$1,957,405
Total cost to line reach	$10,013,553	$9,277,285
Seepage reduction, cubic feet/second	12	12
Annual seepage reduction, acre-feet	5,055	5,055
Cost/annual acre-foot	$1,981	$1,835

*From USBR 1983

TABLE 22
Cost and Cost/Benefit for Lining Reach 3 from the Bench Flume to the Bell Lateral

Design Conditions	700 cfs	500 cfs
Channel length, feet	41,464	41,464
Bottom width B, feet	24	24
Flow depth d, feet	5	4.14
Freeboard*, feet	1.4	1.3
Overall depth D, feet	6.4	5.44
Side slope z (H:V)	1.5	1.5
Cost per linear foot	$400	$371
Cost per mile	$2,112,750	$1,957,405
Total cost to line reach	$16,591,487	$15,371,563
Seepage reduction, cubic feet/second	18	18
Annual seepage reduction, AF	7,606	7,606
Cost/annual acre-foot	$2,181	$2,021

It appears from the cost analysis given in Tables 21 and 22 when compared to the costs shown in Table 20 that the most cost-effective way of reducing seepage losses now suffered by the District is to line less efficient laterals with the greatest leakage. Note that the cost of reducing an acre-foot of seepage on the Main Conchas Canal is on the order of $2,000 (for both Reach 2 and Reach 3) and that the cost of reducing the leakage on the two laterals studied ranged from $500 to about $1000 per acre-foot, as shown in Table 20. These leaky laterals can be identified by the use of infrared photos and by comparison of the soil type, soil permeability, geometry and operating frequency of various laterals in the Arch Hurley system.

The option to use pipe rather than the lining of the Main Conchas Canal does not appear to be feasible. Pipelines offer many more incentives than do lined canal sections. One example would be the reduced maintenance costs and the reduction in associated risks for pipelines versus a lined canal. The best use of pipelines would be to go from siphon to siphon or tunnel to tunnel. A pipeline acceptable to the District would have to carry at least 700 cfs. In most sections of the Main Conchas Canal this will require a 12-foot diameter pipe. Three or four cost estimates for 12-foot diameter pipe have been made over the course of this study. Costs have gone up about 20 percent in the past two years. A September 2005 cost estimate for 12-foot diameter concrete cylinder pipe, made in the Amarillo area and transported to the canal site, would cost about $2,000 per foot when pipe materials, pipe bedding materials, pipe cover materials, transition forming, labor and profit are taken in account. This is far more than the $400 per foot estimate (see Table 21 and 22) for canal lining.

PART VI

FINDINGS AND RECOMMENDATIONS

Study Findings

By lining District canals, significant amounts of Arch Hurley irrigation water may be "saved" in a year with an average or greater water supply from Conchas Reservoir. To cost-effectively reduce District seepage losses by 20,000 to 25,000 acre-feet, lining of both very leaky reaches of the Main Conchas Canal and lining of the District's lateral system will be necessary.

The cost of "saving" 12,000 to 13,000 acre-feet of water now lost to seepage from the Main Conchs Canal will be a little more than $25 million or about $2,000 per acre-foot of water saved (2005 prices). The 66,600 feet of canal studied represent some of the Main Canal reaches with the greatest rate-of-leakage per foot. Unfortunately, to save more than 12,000 to 13,000 acre-feet in Main Canal seepage losses will require much greater expenditures. The losses from laterals within the irrigation District can be controlled by canal lining at a cost of $500 to $1,000 per acre-foot (See Table 20). Reducing total system losses can be best achieved by lining laterals used to supply farm turn outs.

Legal and Cost Considerations

While legal issues remain unanswered (see Appendix C), there does not appear to be any significant legal impediments to the conveyance of Canadian River water to another drainage basin for use. Concurrence of the District, Reclamation, and the New Mexico State Engineer will be required. Some of the legal issues raised in this report can be addressed in Phase II of this study.

Cost sharing and “saved water” sharing between the District and Reclamation remain an issue. Lining the Main Conchas Canal and portions of the lateral system could be considered to be a Bureau of Reclamation task, if Reclamation shares in the water savings and if Reclamation intends to transport its share of any “saved water” to the Pecos basin for use. In any event, Reclamation may wish to assist the District to be more efficient by cost-sharing on projects to reduce seepage losses from some of the District laterals.

Should Reclamation decide that it is desirable to obtain Conservancy-District water for export from the Canadian River system and conveyance to the Pecos River basin, there are a number of cost considerations that should be studied other than lining of the District laterals. For example, Reclamation might chose to pay owners of lands in the Arch Hurley District to forgo their water use during certain years, or Reclamation may chose to purchase irrigated District lands. It would be more attractive for Reclamation to buy District lands rather than line canals, if an acre of Arch Hurley irrigated land can be purchased for about $2,000.

Reclamation should consider funding of Phase II of this study to answer questions raised in this sub-section, and particularly those related to “saved water” sharing and to the cost and location of a conveyance system to take water from the Canadian watershed and to discharge it into the Pecos basin.

Benefits of Reducing Canal Losses

The reduction of the seepage losses now suffered by the Conservancy District from its canal system could represent a significant conservation achievement of benefit to the District farmers and to the State of New Mexico. Conveyance of the Project water supply through sections of lined channel will offer the District a more uniform supply from year to year, an enhanced supply in terms of volume, and a more reliable supply in terms of intra-season deliveries. Reconstruction of the canal by lining will greatly reduce the maintenance costs now borne by the District. Every year the earth-lined canal must be dredged and all vegetation removed from banks. Because of the size and density of the trees and bushes along the canal, this is a costly effort that is a dangerous operation to carry out. There are many benefits that the District can enjoy by lining system canals and laterals.

Potential Disincentives of Canal Leakage Reduction

The greatest disincentive for significantly reducing water loss from the canals and laterals will be the reduction of recharge into the local groundwater system. A separate study of the effects of canal leakage and irrigation return-flow on groundwater levels in the Tucumcari area is merited. Lining of the Main Conchas Canal may have little if any impact on the Tucumcari groundwater supply. Lining laterals may have a more profound impact. The water now lost by seepage from the delivery canal system also waters a number of acres of grasslands and trees along the canal route. The areas of greatest loss provide habitat for some wildlife and birds, but observation of rabbits and small rodents is sparse. No sightings of species that have been listed as being threatened or endangered in the region have occurred. The trees do not appear to be major nesting areas for native birds. The grasslands do offer some grazing for cattle.

Recommendations for District Action with Reclamation Support

The District, with Reclamation support, should consider a number of water management and water-savings recommendations. These are:

1. The Conchas Main Canal probably loses significant quantities of water from discrete leaks in the siphons. The siphons are used to carry canal flow under arroyo valleys, and they operate under several feet of positive pressure head. All siphons in the District should be inspected for leaks and damage to the structures. It would be prudent to inspect, repair, and protect the siphons both to reduce the leakage and to protect the functionality of the entire canal system.

2. High seepage laterals can be identified based on soil type obtained from the Tucumcari Area, Northern Quay County Soil Survey, on channel geometry, and operating schedule as described in PART V. The use of IR photographs will also help in selecting laterals with greatest seepage. A lateral lining project should be phased in to address the highest seepage rate laterals first.

3. The District should review and revise its policies on water demands by area farmers and on releases from Conchas Lake that impact over-year storage in the Reservoir. By revising these policies, the District may avoid years like 2003 when no irrigation water was available for release from Conchas Reservoir.

4. This report quantifies the potential water conserved under various lining scenarios and estimates the associated cost performances. Other options for making water available for other uses should be studied, including seasonal forbearance of irrigation water and outright purchase of water-righted land.

5. The District should review all of the sites where flow measurements, diversions, and deliveries are made. The District’s ability to monitor and control flows and to meter farm deliveries needs to be improved. Information in some of the historic diversion and delivery records appears to be based on estimates rather than on actual measurements. Good measurements of diversion and deliveries and better controls will lead to lower start- and end-of-season losses, to fewer canal spills, and to fewer end-of-canal and end-of-lateral losses.

6. Some elements of the District’s water supply and delivery records for the historic period were not available for review in this study. Record keeping does not appear to be a new problem, but a long-term situation. The systems used to develop and preserve these records should be reviewed.

7. Measurement of seepage losses in the Conchas Main Canal in Quay County and the Hudson Canal can be best accomplished by the inflow-outflow method at a time when all diversions from the canals can be shut off. The District should consider measuring losses in the sections of the canal system, if it intends to consider lining the canals in Quay County as an alternative to lining laterals.

REFERENCES

Al Haddad, Sami. 2005. *Estimating Seepage from Irrigation Canals in the Elephant Butte Irrigation District, New Mexico.* Masters Thesis, New Mexico State University, Department of Civil and Geological Engineering.

Arch Hurley Conservancy District. 1981. *Report on the Irrigation Canal Rehabilitation Project*. Prepared by the Project staff. January 1981. Tucumcari, NM.

Arch Hurley Conservancy District. 2000. *Water Management Plan 2000*. Unpublished planning document. August 8, 2000.

Berkstresser, C.F., Jr. and W.A. Mourant. 1966. *Ground-water resources and geology of Quay County, New Mexico*. New Mexico Bureau of Mines and Mineral Resources. Ground-Water Report 9. 115 pp.

Broadhead, R.F. 1984. *Subsurface petroleum geology of Santa Rosa Sandstone (Triassic), northeast New Mexico*. New Mexico Bureau of Mines and Mineral Resources. Circular 193. 22 pp.

Broadhead, R.F. and W.E. King. 1988. *Petroleum geology of Pennsylvanian and lower Permian strata, Tucumcari basin, east-central New Mexico*. New Mexico Bureau of Mines and Mineral Resources. Bulletin 119. 75 pp.

Burnham, D.R. 1953. *Climatological data at the northeastern substation, Tucumcari, NM.* Published in a Bulletin by New Mexico State University, Agricultural Experiment Station.

Clark, I.G. 1987. *Water in New Mexico, A History of Its Management and Use*. University of New Mexico Press.

DuMars, C. 2002. *Analysis of Diversions of Captured Carriage Loss from Conchas Lake to the Pecos River*. Report prepared for the Arch Hurley Conservancy District. February 2002.

Dolliver, P.N. 1984. *Cenozoic evolution of the Canadian River basin*. Baylor Geological Studies. Baylor University Bulletin 42. 96 pp.

Dolliver, P.N. 1985. *The Plio-Pleistocene Canadian breaks of New Mexico: A profile*. New Mexico Geological Society Guidebook 36. pp. 315-318.

Dolliver, P.N. 1991. *Pre-Coyote Creek landscape and High Plains Origins*. New Mexico Geological Society Guidebook 41. pp. 73-75.

Foster, R.W., R.M. Frentess, and W.C. Riese. 1972. *Subsurface geology of east-central New Mexico*. New Mexico Geological Society. Special Publication No. 4. 22 pp.

Geyler, J. 1998. Persistence: Brief development history of the Tucumcari Irrigation Project (Arch Hurley Conservancy District). In *Proceedings of the 42nd Annual New Mexico Water Conference: Water Issues of Eastern New Mexico*. Edited by

C.T. Ortega Klett. New Mexico Water Resources Research Institute, Technical Report No. 304, New Mexico State University, Las Cruces, NM. pp. 47-50.

Green, G.N. and G.R. Jones. 1997. *Geologic Map of New Mexico-digital database*. U.S. Geological Survey Open-File Report OF-97-52. Scale 1:500,000.

Griggs, R.L. and G.E. Hendrickson. 1951. *Geology and ground-water resources of San Miguel County, New Mexico*. New Mexico Bureau of Mines and Mineral Resources. Ground-Water Report 2 [reprinted 1985]. 121 pp.

Gustavson, T.C. 1986. *Geomorphic development of the Canadian River valley, Texas Panhandle: An example of regional salt dissolution and subsidence*. Geological Society of America Bulletin. 97:459-472.

Gustavson, T.C. and R.J. Finley. 1985. *Late Cenozoic geomorphic evolution of the Texas Panhandle and northeastern New Mexico: Case histories of structural controls on regional drainage development*. The University of Texas at Austin, Bureau of Economic Geology, Report of Investigations No. 148. 42 pp.

Hawley, J.W. 1984. The Ogallala Formation in eastern New Mexico. In *Proceedings of Ogallala Aquifer Symposium II*. Edited by G.A. Whetstone. Texas Tech University Water Resources Center, Lubbock, TX. pp. 157-176.

Hawley, J.W. 1986. Physiographic provinces [and] landforms of New Mexico. *New Mexico in Maps: Albuquerque*. Edited by J.L. Williams. The University of New Mexico Press. pp. 28-31.

Hawley, J.W. 2005. *Five million years of landscape evolution in New Mexico: An overview based on two centuries of geomorphic conceptual-model development*. Edited by S.G. Lucas, G. Morgan, and K.E. Zeigler. New Mexico's Ice Ages: New Mexico Museum of Natural History & Science Bulletin No. 28. pp. 90-93.

Hem, J.D. and L.S. Hughes. 1948. *Quality of water in the Tucumcari Irrigation Project, Quay County, New Mexico*. New Mexico State Engineer 18th, 19th, and 20th Biennial Reports 1946-52. pp. 12-13.

Hilley, T.E., T.E. McCarty, P.G. Martin, S.G. Sellnow, and C. Taylor. 1981. *Soil Survey of San Miguel County area, New Mexico*. U.S. Soil Conservation Service, U.S. Government Printing Office. p. 169.

Hunt, A.P. 1998. An overview of the Geology of northeastern New Mexico. In *Proceedings of the 42nd Annual New Mexico Water Conference: Water Issues of Eastern New Mexico*. Edited by C.T. Ortega Klett. New Mexico Water Resources Research Institute, Technical Report 304, New Mexico State University, Las Cruces, NM. pp. 17-26.

Hunt, A.P. 2001. *Conchas and Ute Reservoirs and water issues in eastern New Mexico*. New Mexico Geological Society Guidebook 52. pp. 48-49.

Hunt, A.P. 2001. *Laguna Colorado: A forgotten Holocene lake in Quay County, New Mexico*. New Mexico Geological Society Guidebook 52. pp. 38-39.

Hunt, A.P., S.G. Lucas, and A.B. Heckert. 2001. *Paleocurrents in the Trujillo formation (Chinle Group; Upper Triassic), east-central, New Mexico, and the myth of a Dockum Lake*. New Mexico Geological Society Guidebook 52. pp. 22-23.

Hunt, A.P. and S.G. Lucas. 2001. *The Laramide Tucumcari structural zone, east-central, New Mexico*. New Mexico Geological Society Guidebook 52. pp. 41-43.

Jensen, J.R., Narumalani, S., Weatherbee, O., Morris, K.S., and Mackey, H.E.. 1993. *Predictive Modeling of Cattail and Waterlily Distribution in a South Carolina Reservoir Using GIS*. Photogrammetric Engineering & Remote Sensing 58(11):1561-1568.

Jensen, J.R. 1996. *Introductory Digital Image Processing*. 2nd Edition. Prentice Hall, Upper Saddle River, New Jersey. 318 pp.

Kelley, V.C. 1972. *Triassic rocks of the Santa Rosa Country [with geologic map of the Guadalupe-San Miguel County area]*. New Mexico Geological Society Guidebook 23. pp. 84-97.

Kelley, V.C. and F.D. Trauger (eds.). 1972. *Guidebook of east-central New Mexico*. New Mexico Geological Society Guidebook 23. 223 pp.

King, J.P. and J. Maitland. 2003. *Water for River Restoration: Potential for Collaboration between Agricultural and Environmental Water Users in the Rio Grande Project Area.* World Wildlife Fund, Chihuahuan Desert Program. July.

Kirksey, R.E. 2002. *Water outlook for the Arch Hurley Conservancy District in 2002*. NMSU Agricultural Science Center, Tucumcari, NM. March 2002. Unpublished report.

Kunkler, J.L. 1972. *Saline ground water in east-central New Mexico.* New Mexico Geological Society Guidebook 23. pp. 201-207.

Love, D.W. 1985, *Geomorphic history of part of the Tucumcari Lake drainage basin, New Mexico.* New Mexico Geological Society Guidebook 36. pp. 319-324.

Lovelace, A.D. 1972. *Aggregate resources in central eastern New Mexico*. New Mexico Geological Society Guidebook 23. pp. 208-209.

Lucas, S.G. (ed.). 1985. *Santa Rosa—Tucumcari region*. New Mexico Geological Society Guidebook 36. 344 pp.

Lucas, S.G. 1995. *Triassic stratigraphy and chronology in New Mexico*. New Mexico Geology. 17:1:8-13, 17.

Lucas, S.G. and D.S. Ulmer-Scholle (eds.). 2001. *Geology of the Llano Estacado*. New Mexico Geological Society Guidebook 52. 340 pp.

Lucas, S.G., A.P. Hunt, and M. Morales. 1985. *The Jurassic System in east-central New Mexico*. New Mexico Geological Society Guidebook 36. pp. 213-242.

Lucas, S.G., K.K. Kietzke, and A.P. Hunt. 1985. *Stratigraphic nomenclature and correlation of Triassic rocks of east-central New Mexico: A preliminary report*. New Mexico Geological Society Guidebook 36. pp. 171-184.

Lucas, S.G., A.P. Hunt, A.B. Heckert, B.S. Kues, and V.T. McLemore. 2001. *Third-day road log, from Tucumcari to Conchas Dam, New Mexico*. New Mexico Geological Society Guidebook 52. pp. 41-58.

Maker, H.J., V.G. Link, J.U. Anderson, and W.B. Gallman. 1971. *Soil associations and land classification for irrigation, Quay County*. New Mexico State University Agricultural Experiment Station, Research Report 202. 45 pp.

McGookey, D.A., T.C. Gustavson, and A.D. Hoadley. 1988. *Regional cross sections of mid-Permian to Quaternary strata of the Texas Panhandle and eastern New Mexico: Distribution of evaporites and areas of evaporite dissolution and collapse*. The University of Texas at Austin, Bureau of Economic Geology, Cross Sections. 17 pp. 12 plates.

Melhase, J. 1927. *Report on the geology and water resources of the Tucumcari district, New Mexico.* Southern Pacific Co., San Francisco. Manuscript report. 17 pp.

Murray, C.R. 1945. *Notes on recent ground-water development of Tucumcari, New Mexico*. U.S. Geological Survey Open-File Report. 7 pp.

Murray, C.R. 1948. *Two brief reports the water supply and recent ground-water development at Tucumcari, New Mexico*. New Mexico State Engineer 16th and 17th Biennial Reports 1942-46. pp. 335-347.

Murray, C.R. 1962. *Memorandum on recent ground-water development at Tucumcari, New Mexico, 1945*. New Mexico State Engineer 16th and 17th Biennial Reports 1942-46. pp. 343-347.

Murray, C.R. 1962. *Memorandum on the water supply of Tucumcari, New Mexico, 1944*. New Mexico State Engineer 16th and 17th Biennial Reports 1942-46. pp. 337-342.

Mutz, P.B. 1998. Reservoir storage development in the Canadian River Basin and related litigation. In *Proceedings of the 42nd Annual New Mexico Water Conference: Water Issues of Eastern New Mexico*. Edited by C.T. Ortega Klett. New Mexico Water Resources Research Institute, Technical Report No. 304, New Mexico State University, Las Cruces, NM. pp. 11-16.

NMBGMR. 2003. Geologic Map of New Mexico. Scale 1:500,000. New Mexico Bureau of Geology and Mineral Resources. http://geoinfo.nmt.edu/publications/maps.html.

NMSU. 1984. *An Economic Analysis of Enterprise Adjustments to Water Availability and Risk*. Agricultural Extension Bulletin 707. February 1984.

NRCS. 2005. *Soils GIS data for San Miguel and Quay counties*. Data download. April 2005. http://soildatamart.nrcs.usda.gov/.

PACES. 2005. *LANDSAT 7 imagery*. Data download. Accessed April 2005. http://paces.geo.utep.edu.

RGIS. 2005. GIS data download. Accessed April 2005. http://rgis.unm.edu.

Ross, W.J. and D.S. Pease. 1974. *Soil Survey of Tucumcari area, New Mexico, northern Quay County*. U.S. Soil Conservation Service. 94 pp.

Sheng, Z., J.P. King, L.S. Aristizabal, and J. Davis. 2003. *Assessment of Water Conservation by Lining Canals in the Paso Del Norte Region: The Franklin Canal Case Study.* World Environmental and Water Resources Conference, Environmental and Water Resources Institute, Philadelphia, PA, June 23-26, 2003. ASCE, Conference Proceedings 118.

Soil Conservation Service. 1974. *Soil Survey of Tucumcari Area, New Mexico, Northern Quay County.* In cooperation with NM Agricultural Experiment Station. US Dept. of Agriculture, Washington, DC.

Sweeting, M.M. 1972. *Karst and solution phenomena in the Santa Rosa area, New Mexico*. New Mexico Geological Society Guidebook 23. pp. 168-170.

Texas Bureau of Economic Geology. 1983. *Geologic Atlas of Texas, Tucumcari Sheet (NM-TX)*. The University of Texas at Austin. Scale 1:250,000.

Trauger, F.D. 1953. *Interim report on the investigation of ground-water resources, in the vicinity of Tucumcari, Quay County, New Mexico*. U.S. Geological Survey Open-File Report. 27 pp.

Trauger, F.D. 1954. *Geology of the Tucumcari area and its relation to the ground-water supply*. U.S. Geological Survey Open-File Report. 1 pp.

Trauger, F.D. 1954. *Geology of the Tucumcari area and its relation to the ground-water supply*. (abs.) New Mexico Geological Society Program 8th Annual Meeting.

Trauger, F.D. 1957. *Geology and ground-water supply of the Tucumcari area*. (abs.) 8th Field Conference, Southwestern San Juan Mountains, Colorado. New Mexico Geological Society Guidebook. pp. 250-251.

Trauger, F.D. 1972a. *Ground water in east-central New Mexico*. New Mexico Geological Society Guidebook 23. pp. 201-207.

Trauger, F.D. 1972b. *Urban geology of Tucumcari*. New Mexico Geological Society Guidebook 23. pp. 201-207.

Trauger, F.D. and F.X. Bushman. 1964. *Geology and ground water in the vicinity of Tucumcari, Quay County, New Mexico*. New Mexico State Engineer Office. Technical Report 30. 178 pp.

Trauger, F.D., C.J. Mankin, and J.P. Brand. 1972. *Road log of Tucumcari, Mosquero and San Jon country*. New Mexico Geological Society Guidebook 23. pp. 12-45.

U.S. Army Corps of Engineers. 2001. *Annual Inflow into Conchas Reservoir*. Albuquerque Office of the COE. December 26, 2001. Unpublished report.

U.S. Bureau of Reclamation. 1939. *Analysis of Soil Samples from Siphon Sites, Conchas Canals, Tucumcari Project*. USBOR Denver Cement Laboratory. September 21, 1939. Unpublished report.

U.S. Bureau of Reclamation. 1951. *General Descriptive Statement [of] the Tucumcari Project, New Mexico*. Amarillo, Texas. 1951.

U.S. Bureau of Reclamation. *Monthly Water Distribution, Arch Hurley Conservancy District*. Data sheets giving quantities of water in acre-feet. 1954-1977.

U.S. Bureau of Reclamation. 1971. *Study of Water Supply for Tucumcari Project.* November 1967. October 1971. Revised.

U.S. Bureau of Reclamation. 1978. *Design of Small Canal Structures.* Water Resources Technical Publication, U.S. Dept. of the Interior.

U.S. Bureau of Reclamation. 1983. *Report on Proposed Rehabilitation and Betterment Program, Tucumcari Project, New Mexico*. Bureau of Reclamation, Southwest Region, Amarillo, Texas. Maps, tables and appendices. February 1983. 22 pp.

U.S. Bureau of Reclamation. 2002. *Draft Water Conservation and Management Plan*. Arch Hurley Conservancy District. Unpublished plan prepared and submitted to the U.S. BOR. May 7, 2002.

USGS. 2005a. GIS data download. Accessed April 2005. http://edc.usgs.gov/geodata/.

USGS. 2005b. GIS tool download. April 2005. http://rockyweb.cr.usgs.gov/software/.

Vedernikov, V.V. (Wedernikow, V.V.) (1934). *Seepage from Channels (Versickerungen aus Kanälen).* Hydropower and Water Resources Management (Wasserkraft und Wasserwirtschaft), München und Berlin, Germany, 29 (11): 128-130, 29 (12): 137-140, 29 (12): 149-152.

Warnick, C.C. 1951. *Methods of measuring seepage loss in irrigation canals.* Bulletin of the Engineering Experiment Station, University of Idaho, Moscow, ID. No. 8.

Warnick, C.C. 1963. *Problems in seepage evaluation and control*. Proceedings seepage symposium, Phoenix, AZ. Feb 19-21, 1963.

Wilson, C.R. 1998. Overview of the hydrology of northeastern New Mexico. In *Proceedings of the 42nd Annual New Mexico Water Conference: Water Issues of Eastern New Mexico*. Edited by C.T. Ortega Klett. New Mexico Water Resources Research Institute, Technical Report No. 304, New Mexico State University, Las Cruces, NM. pp. 37-46

Wilson, L. and L.E. Esparza. 1998. Lake Meredith Salinity Control Project. In *Proceedings of the 42nd Annual New Mexico Water Conference: Water Issues of Eastern New Mexico*. Edited by C.T. Ortega Klett. New Mexico Water Resources Research Institute, Technical Report No. 304, New Mexico State University, Las Cruces, NM. pp. 131-141.