Economic Performance of Irrigation Water Conservation Programs in the American Southwest

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Problem

Growing attention to food and water security to support a UN-forecast world population of 9.6 billion by 2050 raises the stakes for raising the performance of crop irrigation, the world's largest water user. These challenges are heightened in the face of climate variability and from growing demands for protecting the water environment. One important adaptation measure is investing in improved irrigation system delivery efficiency, from which a higher valued suite of crops can be grown. Water users in the Upper Canadian Basin headwaters in the American southwest have faced a long history of high water supply fluctuations combined with heavy canal delivery losses, producing low-valued cropping patterns. To date, little research grade analysis has investigated economically productive and sustainable measures for irrigaton water conservation to adjust to high natural fluctuations in water supply. This deficiency has made it difficult to inform water resource policy decisions on economically sound measures to adapt to climate in the world's dry rural areas where irrigation delivery system losses are often high and expensive to mitigate.

This paper's contribution is to conceptualize, formulate, and apply a state-of-the-arts methodology to investigate the economic performance from investments in water conservation measures in the Upper Canadian Basin of the American Southwest. An empirical optimization framework using mathematical programming is developed to forecast farm income under two scenarios (1) status quo conditions without seepage loss mitigation and (2) the alternative plan with seepage loss reduction measures installed to mitigate effects of low and unreliable water supplies. Results show that irrigation canal delivery system upgrades that reduces seepage losses raise the discounted net present value of farm income in this region by about $19 million, about 67 percent of its current value. Public subsidies of these investments would raise the economic performance of water conservation. Despite its limited scale, our findings illustrate a generalizable framework for assessing repayment capacity for protecting and enhancing water and food security in rural communities of the world's arid regions.

According to Gopalakrishnan (2000), the problems of irrigated agriculture in the American West are with respect of water supply, demand, allocation and management. The Arch Hurley Conservancy District has experienced almost all these water challenges. On a report submitted to New Mexico Water Resources Research Institute's Water Issues of Eastern new Mexico by Geyler (1997), not realizing the full economic benefits of the irrigation project's water and limited production of higher economic value crops were other identified problems in the District. Thus, making more efficient use of the water must be a major concern in coping with the growing water scarcity (Gleick 2003). Finding economically attractive means of reducing losses through seepage control is one of the issues under consideration to ensure a more reliable, uniform and productive supply of water to the Tucumcari Irrigation Project area.

Gaps and Objectives

Little research to date has investigated in one study the performance of water conservation measures using methods that integrate the sciences of climate, agronomy, hydrology, and economics. The objective of this work is to contribute to filling this gap and strengthen the current weak integration of the various water sciences using state-of-the arts analytical methods to promote, sustain, and secure improved irrigation productivity. This work, specifically, estimates the marginal value or additional net farm income that the canal lining water conservation policy could bring through saved water from seepage losses.

Regional water managers can use the research results to inform debates of interest to local growers over reducing losses currently blocking full irrigation levels in the region. Moreover, the ongoing research project for better domestic water supply in the northeast counties of New Mexico can use this approach to find better ways of securing water at better locations and time periods.

Methodology

Study Area

Arch Hurley Conservancy Irrigation District is located in Quay County, East Central New Mexico between Union and Curry Counties, just west of the Texas border. The County has 2,883 square miles. Elevations range from near 3,700 feet above sea level in the eastern portion of the County to over 5,100 feet on the caprock. Quay County lies almost entirely within the Canadian River Basin, although a portion of the southwestern part of the county lies within the Pecos River Basin. The county includes four incorporated areas: Tucumcari, Logan, San Jon, and House. Nara Visa, in far northeastern Quay County, is unincorporated. The total County population in 2010 was just over 9,000. Historically, tourism and agriculture have been the economic bases of the County's economy (DuBois et al. 2015).

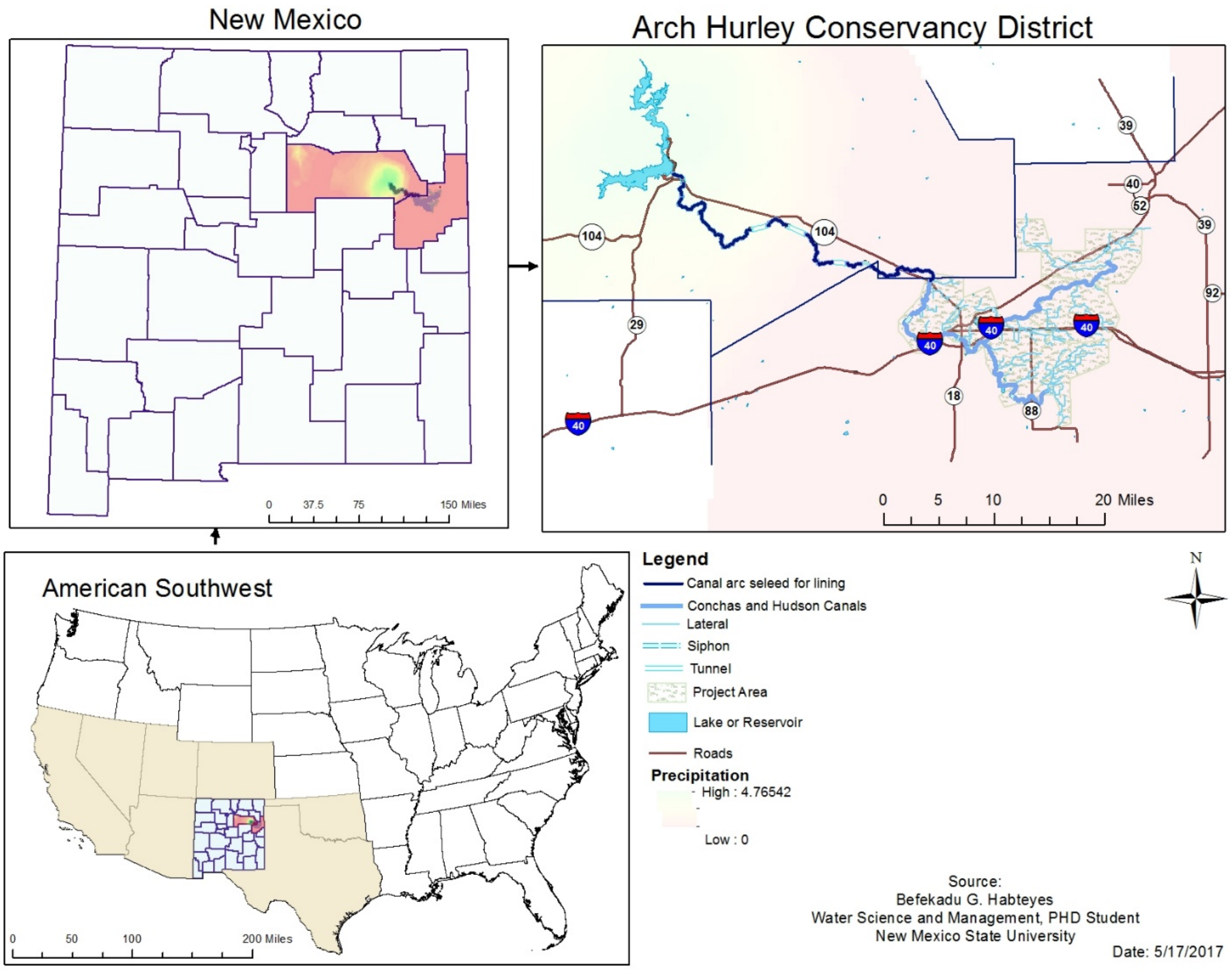


Figure 1. Map of the study Area Source: GIS shapefiles modified from King et al. (2006)

The Arch Hurley Conservancy district covers an area of 134,000 acres, out of which 42,213 acres are irrigated. The District office administers the distribution of water from Conchas Reservoir to the Tucumcari Irrigation Project lands. The Irrigation project secures water from the reservoir through the 50-mile-long main Conchas Canal, split into Hudson and Conchas Canals. Topographically, it is nearly level to strongly sloping. Surface soil textures vary from loamy sands of high permeability to friable clays of low permeability. The Tucumcari area has a semiarid, continental climate characterized by distinct seasonal and wide diurnal temperature changes, low humidity and generally clear skies (AHCD 2001).

Data

Headwater flow data come from USGS gages measured at Canadian River at Sanchez (07221500) and Conchas Creek at Variadero (07222500). The District office is another major source of data for our analysis. Acreage irrigated, water allocated or released and water delivered were compiled and summerized to serve as the primary data. The deliveries are highly dependent on the delivery efficiency of the canal which sometimes amounts to less than fifty percent of the release from the Conchas Reservoir. Thus the policy measure to be considered in this study, canal lining is expected to reduce canal seepage losses and increase the farmland irrigated by impoving the delivery efficiency and bringing more water delivered. The released water in turn depends highly on volume of water stored in the reservoir and regional precipitation.

The crop water requirement entered into the model was an amount of water required to produce maximum yield after average precipitation per acre in the region was subtracted. According to the result from ArcGIS analysis of USDA NASS CropShape and CropLand Shapefiles since 2008, the proportion of land irrigatted by crops for the Quay County and most of the land in the District is occupied by Irrigated pasture, Winter Wheat, Grain Sorghum and Alfalfa. NMSU cost and return crop budget data is the main source for crop detail financial enterprise budget data such as price, yield and costs of crop production in the irrigation project. Taking the yield from records, multiplied by average crop prices and subtracting an estimated cost of production is the general procedure for measuring annual net farm income. Accordingly, the net farm income is calculated by subtracting total cash expenses and total fixed costs from gross return in the cost and return per acre.

Basin Scale Framework

The basin scale analysis treats the entire basin as an integrated unit. The disciplines of climate, agronomy, hydrology, and economics is integrated within a single framework in the headwater reaches of the Canadian River Basin that includes the Conchas reservoir in San Miguel County and the Tucumcari Irrigation system to the southeastern part of Quay County of New Mecico.

In terms of total economic contributions of water, the two important water uses are irrigated agriculture and tourism-based recreation. However, in light of weak data on the economic value of water-based recreation, the current work applies quantitative measurement of irrigated agriculture. Hydro-economic models offer a management resource to efficiently and consistently integrate hydrologic, economic, and institutional impacts of policy proposals to support basin scale, cost-benefit environmental and economic assessments (Ward 2009). A study using portfolio analysis could also investigate the importance of larger benefits by considering sensitivity analysis for adapting to a diverse set of options in an extensive approach using integrated hydroeconomic analysis (Rosenberg et al. 2008).

Strategic Approach

A fact finding survey was conducted for understnding water issues in the Arch Hurley Conservancy District during summer 2016. Stakeholder meetings were arranged and interviews were conducted at the study area and the main agendas were focused on four key questions: (a) what are important water policy debates in this region about declining water availability, associated costs, and plans for adjustment? (b) What reliable information is now available to inform these debates? (c) What better information is needed to fill the gaps? (d) What kind of economic or policy analysis could or should be conducted to guide future water plans for handling water shortages?

Based on notes from the interviews and discussions, the following scenarios were identified:

(1) Climate Scenario (Base and Dry Scenarios)

(2) Policy Scenarios (‘Without Canal Lining’ and ‘With Canal lining’)

(3) Two Irrigation technologies (‘Flood’ and ‘Center Pivot’)

Model Formulation

A dynamic optimization framework was used to formulate the model presented here. The General Algebraic Modeling System (GAMS) permits the building of large maintainable models that can be adapted quickly to new water supply conditions, economic conditions, or policy debates that emerge. SAS and Excel are used in the calibration process of some of the governing equations, specifically the farmland as a function of water delivered used in the model. GIS methods are also used to analyze spatial data and illustrate the study area, crop distribution and schamatic diagram.

Based on historical water deliveries and acreage, the following model was estimated:

$$\mathrm{Acreage(t)} = \beta_o * \mathrm{Deliveries(t)}^{\beta_1} \quad (1)$$

Where t refers to the t-th historical year. The objective function is to maximize the discounted net present value of farm income subject to a water allocation and total water use constraints.

$$\text{Maximize TNPV} = \sum_{use}\sum_{t} AgBen_{use,t,p} \quad (2)$$

Subject to:

- Equity constraint: Total Benefit with_Canal_Lining > Total Benefit without_Canal_lining
- Water Constraint: Total water Used < Mean Annual Release from Conchas Reservoir
-

Where, TNPV of Ag Ben_p =Total Net Present Value of Agricultural Benefit by policy (p)

$\mathrm{AgBen}_{use,t,p}$ =Agricultural Benefit by use node (use), by time (t), and by policy (p)

Results from each policy choice require separate models and two models runs, one for the status-quo or ‘without canal lining’ policy and the second ‘with canal lining’ policy. The analysis seeks to improve the status quo or better in total benefits of water use, with development and operation of the Canal lining policies that could increase the reservoir volume and expand the irrigated acreage of the study area by bringing more saved water into production.

Results

Agriculture

Land

As discussed in the methodology section, the historical water delivered from Conchas Reservoir explains 98 percent of the variation in the acreage irrigated for the Arch Hurley Conservancy District. The best estimated model was found to be:

$$\text{Acreage}(t) = 6.50 * \text{Deliveries}(t)^{0.41} \quad (3)$$

Where R^2 value is 98%.

A closer look at the graph in Figure 4 shows that, canal lining policy could reduce the highly fluctuating annual land in production. With the canal lining policy, it would be possible to bring more lands into production, rising the lowest irrigated land to some higher econoimc value. For example, there was no irrigated land in 2003, 2009, and 2011-2013 ‘without canal lining policy’. However, with the canal lining policy, it was possible to bring more lands into production rising the lowest irrigated land to some higher value. Averaged over 20 years, the irrgated farm land has increased by 56.78 percent ‘with canal lining’ as compared to ‘without canal lining’.

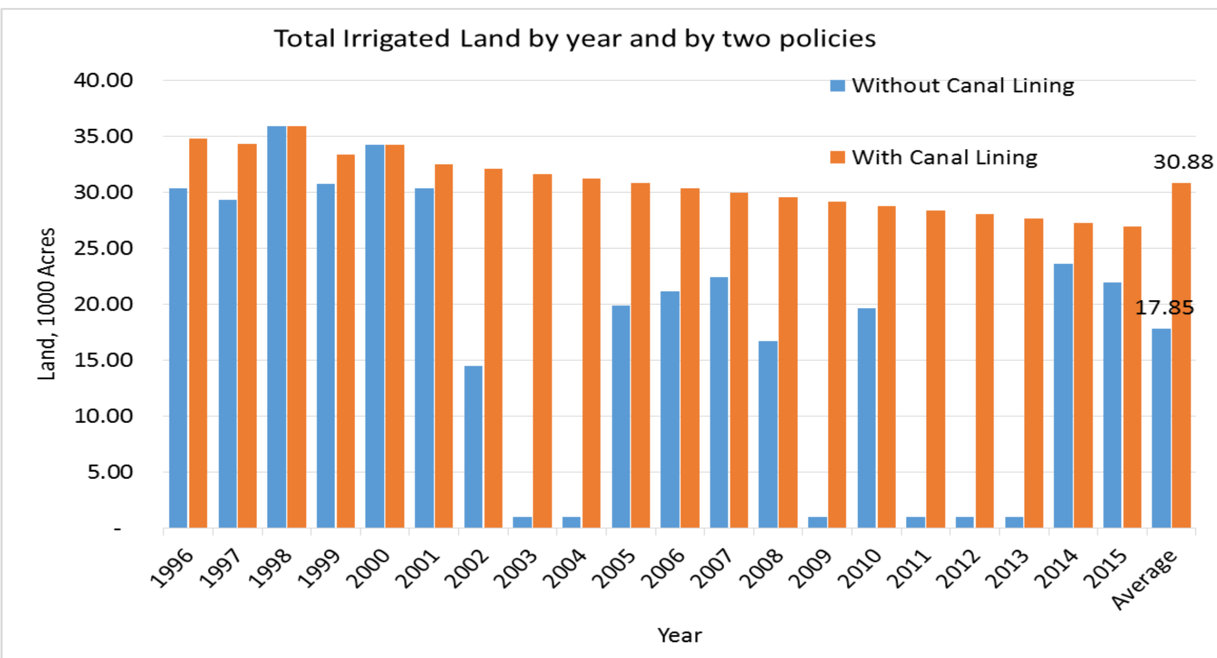


Figure 2. Total farmland by time and policy for Tucumcari Irrigation Project

Water use

Water use is dependent on crop water requirement and highly related to the farmland irrigated, as discussed in the previous section. Significant livestock grazing and agriculture take place throughout the Quay County where the irrigation district is located and water use in the region is primarily producing forages such as irrigated pasture.

Figure 3 shows the total water use by year and by policy within the Tucumcari Irrigation Project. The 'with canal lining' policy has shown two effects on the hydrology of the basin. First, it increases the flow volume by certain amount. For example, the water use average over the twenty years increases by around 23,420 acre-feet per year 'with canal lining' than without it. Second, zero water use periods have been replaced by some water uses that limits the fluctuations in water use across the 20-year time horizon. Significant livestock grazing and agriculture take place throughout the Quay County where the irrigation district is located and water use in the region is primarily producing forages such as irrigated pasture.

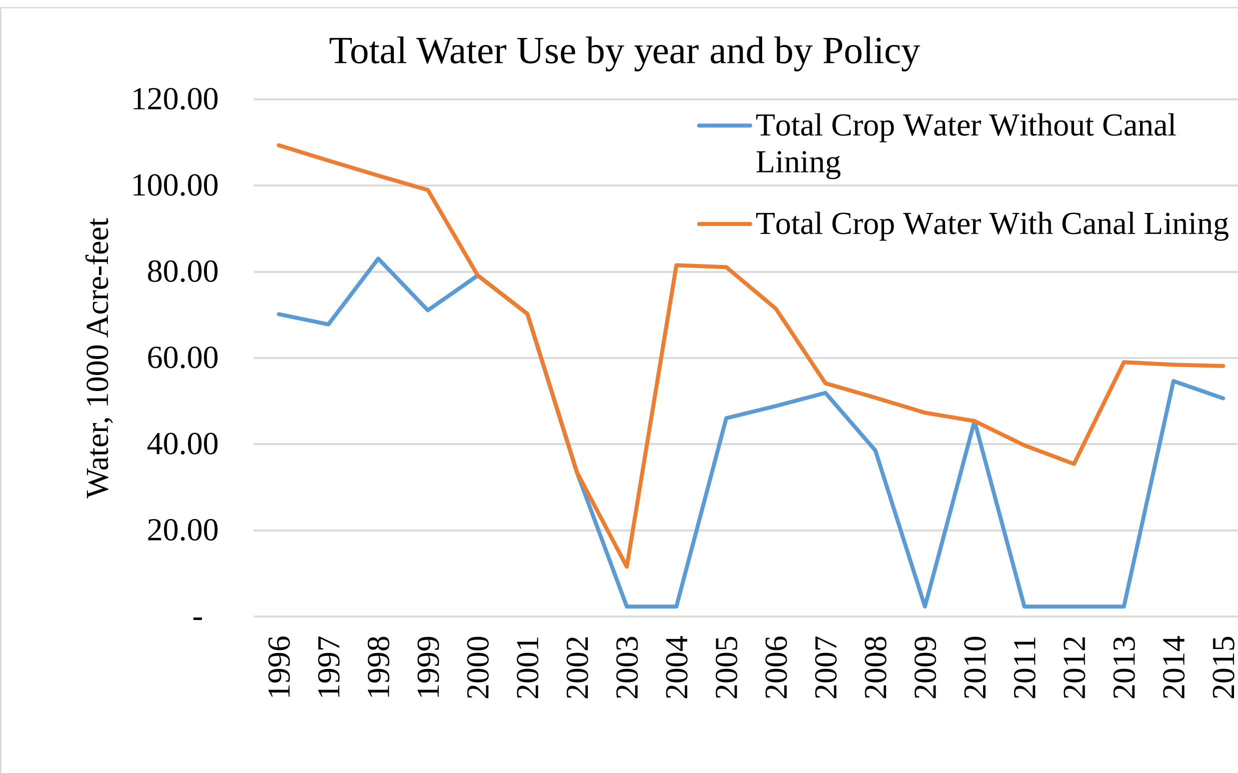


Figure 3. Water use by year and by policy in the Tucumcari Irrigation Project

Figure 3 is a very informative that the difference between the two line graphs indicates how much of the water delivered from the Conchas Reservoir has been used to irrigate the land located at Tucumcari Irrigation project after flowing over 50 miles of the Conchas Canal from the reservoir.

Economics

Economic Value of Agriculture

The total agricultural benefit would increase by around $20 million with canal lining policy as compared to 'without canal lining' policy. Tourism is also an important revenue factor for the inhabitants because a historic route and Ute and Conchas reservoirs are suitable for boating, fishing, camping, sightseeing, and picnicking of many travelers, tourists, and non-resident visitors. James and Thomas (1971),and James (1973) have studied the recreational benefits and the values varies with reservoir volume. A power function explains the relationship between the recreational benefit and reservoir volume. 'With canal lining' policy boosts the reservoir volume as stated in our assumptions and the recreational benefits can specifically be determined but not included in this research.

Table 3 below explains the net farm income that could be secured from the additional amount of water released from the Conchas Reservoir during the growing season. The growers in the District would be better off by 23.4 percent 'with canal lining' policy as compared to the 'without canal lining' policy.

Table 3. Net farm Income by year and by Policy, 1000$, NPV discounted at 5%

Year	Farm Income: Without Canal Lining	Farm Income: With Canal Lining	Additional Farrm Income due to Canal Lining
1996	2,967	3,400	432.71
1997	2,868	3,354	486.59
1998	3,512	3,512	-
1999	3,004	3,265	260.93
2000	3,347	3,347	-
2001	2,970	3,178	207.99
2002	1,415	3,135	1,719.93
2003	98	3,093	2,994.95
2004	98	3,052	2,953.45
2005	1,946	3,011	1,064.84
2006	2,067	2,970	902.81
2007	2,195	2,930	735.86
2008	1,630	2,891	1,260.80
2009	98	2,852	2,754.16
2010	1,917	2,814	896.98
2011	98	2,776	2,678.14
2012	98	2,739	2,640.90
2013	98	2,702	2,604.15
2014	2,311	2,666	355.13
2015	2,141	2,630	488.96
DNPV	**29,803**	**49,787**	19,983.77

Source: Model Output

Cost of Canal Lining policy

The study by King et al. (2006) 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. Assuming to include typical lining thickness, reinforcing-steel and labor cost, King and Maitland (2003) approximated cost per linear foot of canal P (feet) for a trapezoidal canal section with bottom width B (feet), side slope Z, and overall depth D (feet) as:

$$P = \$\, 5.13 * \left(B + 2D\sqrt{1 + Z^2}\right) \tag{4}$$

Assuming a design capacity of 500cfs, bottom width B of 24 feet, overall depth D of 5.44 feet, and side slope z (H:V) of 1.5, the cost per linear foot P will be $224 or $1,181,352 per mile. Assuming 35 miles are potential canal length for canal lining on the mail Conchas canal out of the 50 miles canal, lining each additional miles will cost the same marginal cost and the maximum cost of concrete lining expected to be incurred for the 35 miles will be $41,347,307.

Irrigators in the Arch Hurley Conservancy District (ARCD) can cover the cost of lining around 18 miles of the earthen canal by using the net farm income from the irrigated agriculture. If the Districts want to line the canals more than 18 miles, the economic performance would be improved from financial support or cost sharing from outside sources.

Figure 9 clearly shows scenario analysis for sharing cost of Canal Lining policy between ARCD and outside fund sources. As the proportion of cost by the ARCD decreases from 100 percent to zero percent, more miles of the potential canal reaches for concrete lining would be covered because there is an additional fund and the District need not pay the whole cost of lining.

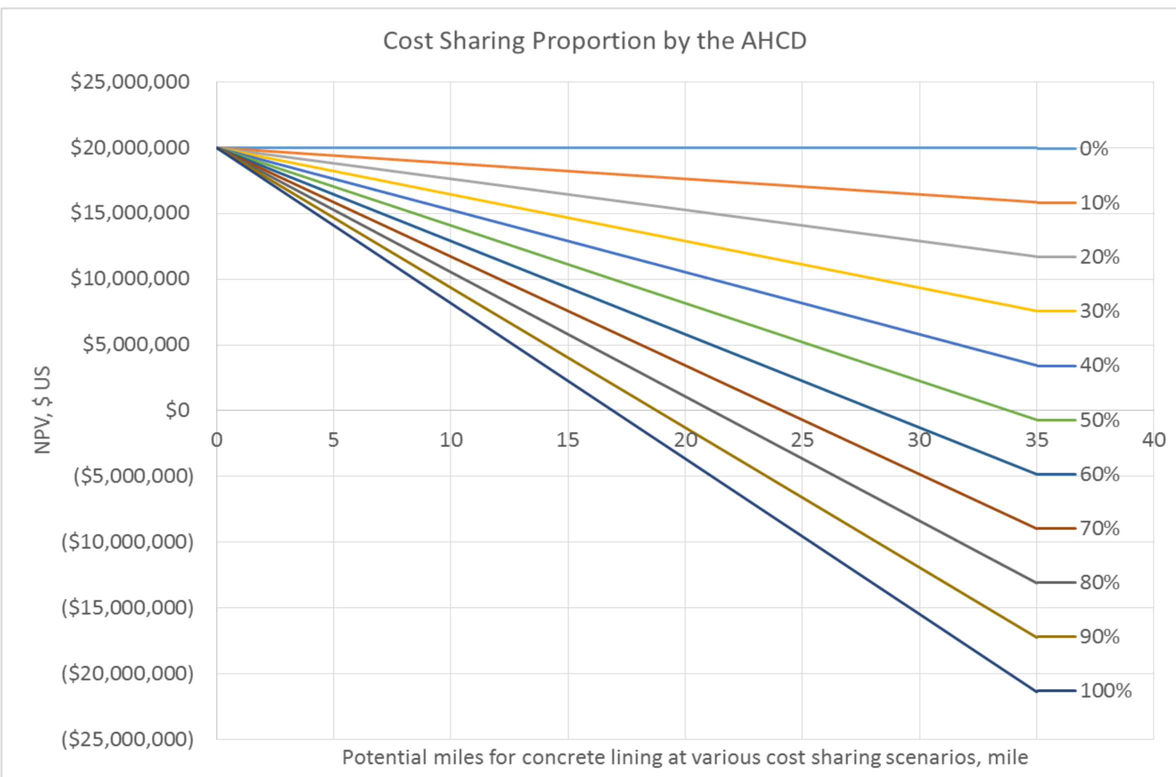


Figure 9. The NPV, Potential miles for lining and the cost sharing alternatives

With outside cost sharing support, for constructing concrete canals, the NPV values could be greater than zero, depending on the proportion of cost sharing between the District office and the outside source, such as the US Bureau of Reclamation. A 50 percent cost share would make the canal lining project pass the threshold of economic feasibility.

Conclusions

Irrigated acreage of Arch Hurley Conservancy District, New Mexico, USA, is highly influenced by the total quantity of water delivered to member farms, an amount that can vary widely from year to year. Remarkably, about 98 percent of the acreage variation is explained by annual water deliveries. A canal lining program in which water previously lost to canal seepage is stored in the reservoir for future use, could reduce the high variability and limited supplies of water delivery and irrigated lands in production. Saved water from reduced seepage can increase farm income from bringing more land into production, as well as growth in recreational benefits from added reservoir storage. Incremental values of $20 million in discounted net present value sets an upper bound on farmer payment capacity to control canal seepage. This measures the retun from the new policy and repayment ability of the District's growers. It covers almost half of the the policy's expenditure and a cost sharing is required to fully implement the policy and benefit from the saved water. More revenue are also expected to be realized if there is an additional source of water for the irrigation project.

More work is needed on accounting for adjusted cropping patterns with more water supply and greater water supply reliability. For example, By conducting audits of their irrigation system, irrigators can determine the system's output and application efficiency. This information is essential for optimizing crop production and effective irrigation scheduling.

More detailed agronomic analysis for each possible locally growing forage crops will be done in the future work. The amount and timing of release and delivery of water from the Conchas Reservoir on a monthly basis is another future work.

Appendix

Table 1. Net Farm Income for AHCD by year and crops, ($/acre)

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
Winter Wheat	28.9	30.5	32.1	33.7	35.5	37.4	39.4	41.4	-62.9	-80.3	-70.1	-68.1	-14.6	-81.3	-27	-91.2	-95.7	-101	-106	-111	-31.46
Grain Sorghum	13.6	14.3	15.1	15.9	16.7	17.6	18.5	19.5	-70.9	15.4	-23.6	18.3	168	165	1.18	194	203	214	224	235	73.71
Alfalfa	232	244	257	270	285	300	315	332	92.5	279	129	112	231	222	-80.2	325	341	358	376	395	250.79
Average	91.5	96.3	101	107	112	118	124	131	-13.8	71.5	11.8	20.9	128	102	-35.3	142	150	157	165	173	**97.68**

Source: NMSU Crop Cost & Return estimates, ttp://aces.nmsu.edu/cropcosts/index.html

Table 2. Tucumcari Irrigation project farmland by year and by policy, 1000 Acre

	Farmland	
Year	Without Canal Lining	With Canal Lining
1996	30.38	34.81
1997	29.36	34.34
1998	35.95	35.95
1999	30.75	33.42
2000	34.27	34.27
2001	30.40	32.53
2002	14.49	32.10
2003	1.00	31.67
2004	1.00	31.24
2005	19.92	30.82
2006	21.17	30.41
2007	22.47	30.00
2008	16.69	29.60
2009	1.00	29.20
2010	19.63	28.81
2011	1.00	28.42
2012	1.00	28.04
2013	1.00	27.66
2014	23.66	27.29
2015	21.92	26.93
Average	17.85	30.88

Source: Model Output

Figure 2. Head flow sources, Canadian River at Sanchez (blue) and Conchas Creek at Variadero (orange) and selected Sanchez for analysis (red)

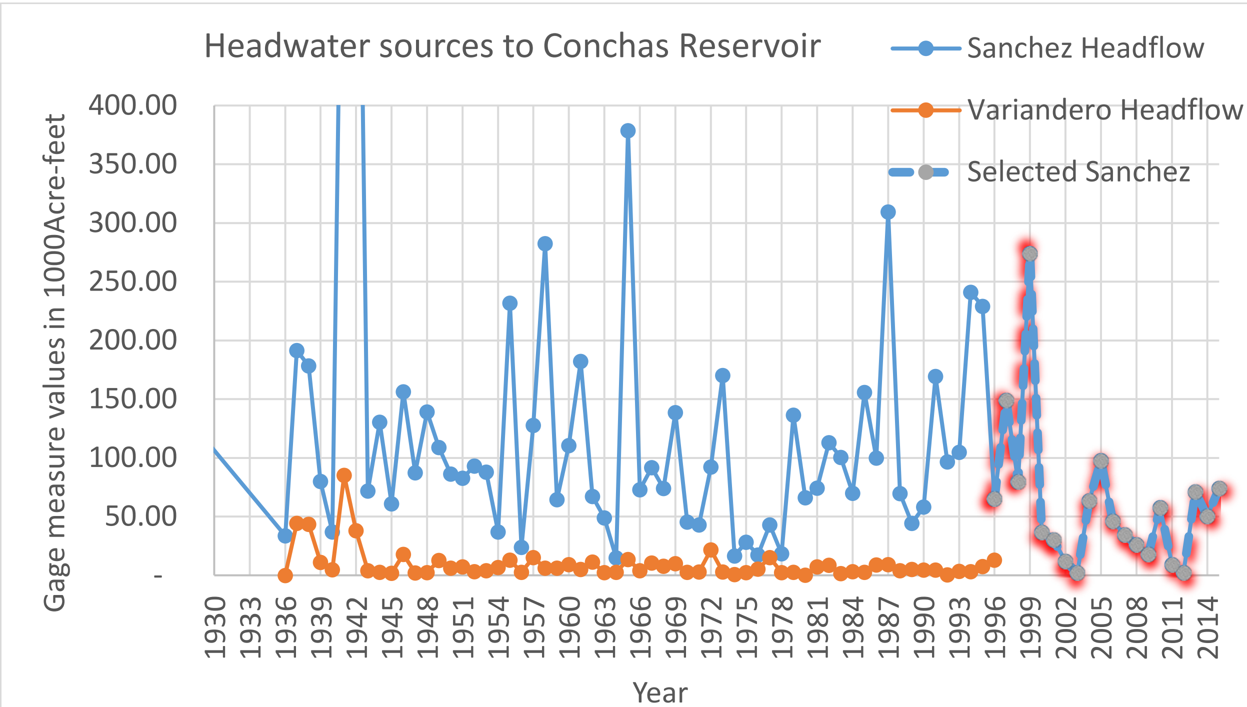


Figure 3. The relationship between Farmland (red) and Water Delivery (blue) in the Arch Hurley Conservancy District

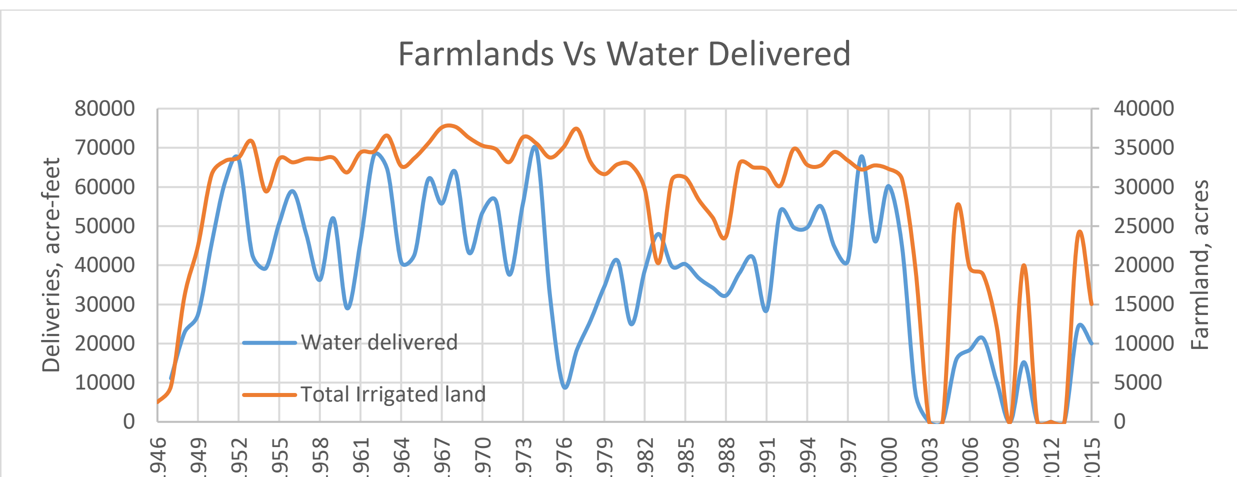


Figure 4. The relationship between water released from, stored in the Conchas Reservoir and precipitation

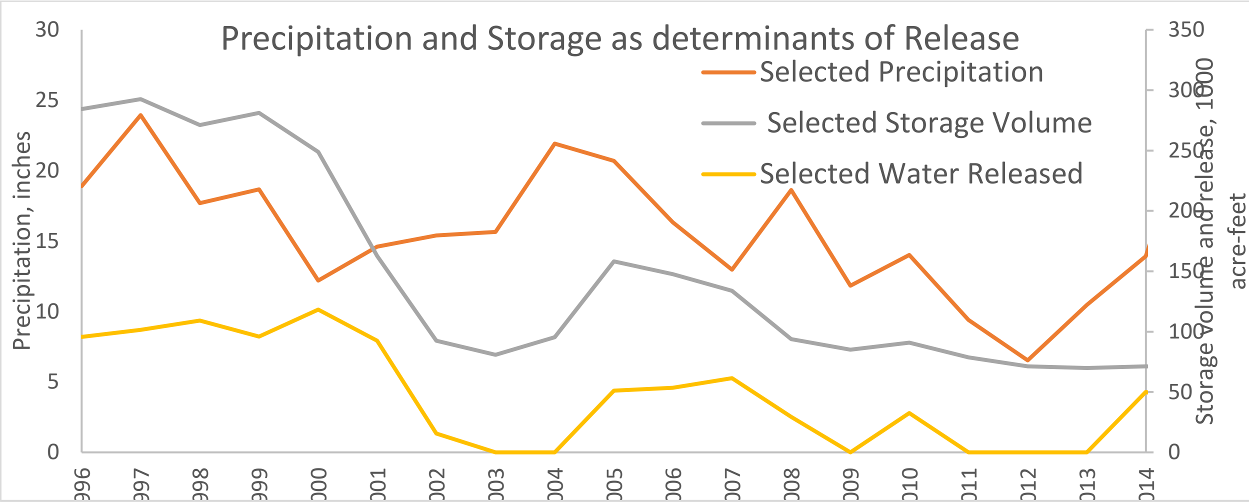
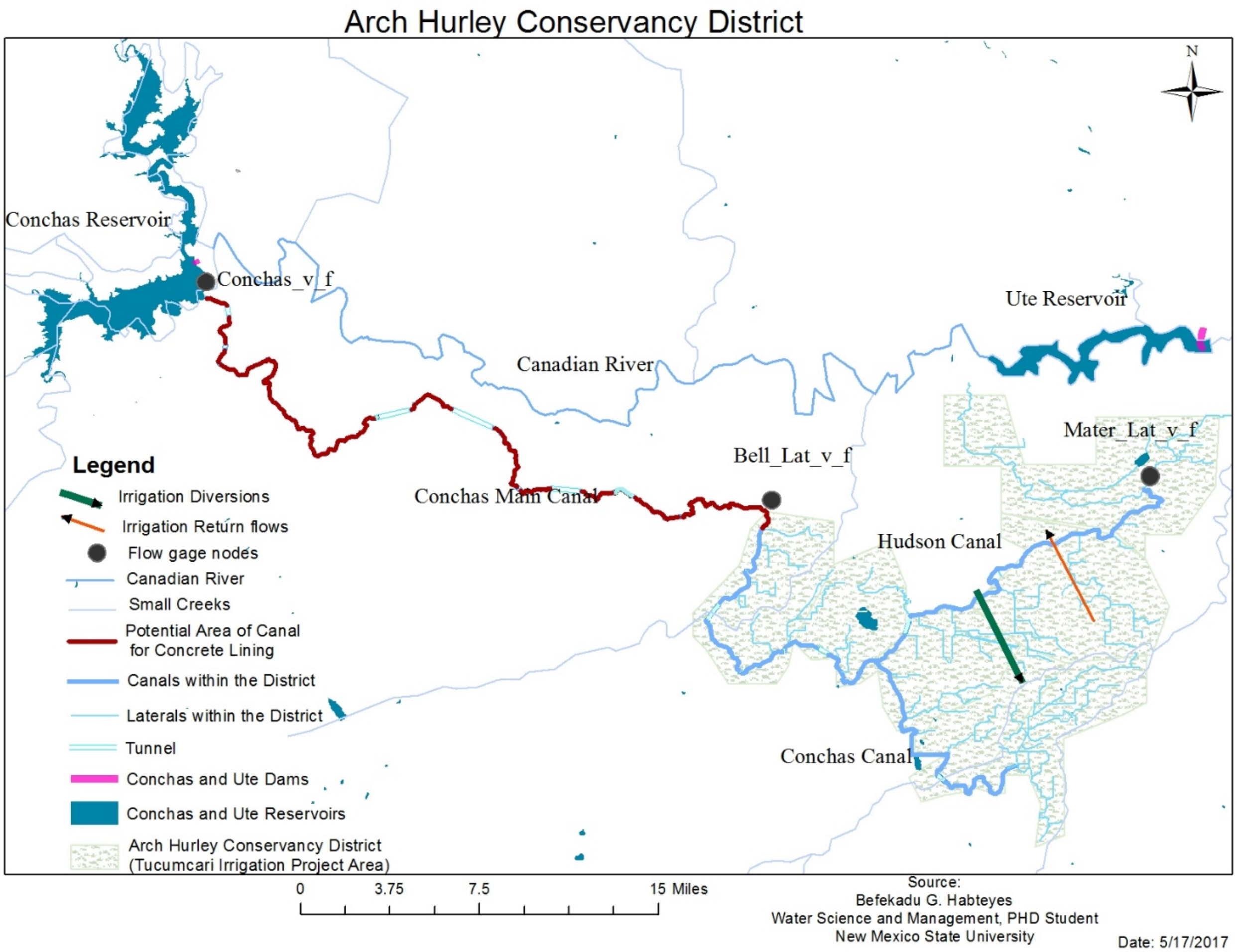


Figure 5. Schematic diagram of the Study Area



References

AHCD, 2001. Arch Hurley Concercancy District Water Conservation (ARCD) Plan Version 3.3.97. Unpublished report of the District office.

DuBois, E. A., S. K. Vaugh & G. F. Reed, 2015. Quay County 40-Year Water Plan Update. HDR Engineering, Inc.

Geyler, J., 1997. Persistence: Brief Development History of the Tucumcari Irrigation Project (Arch Hurley Conservancy District), Water Issues of the Eastern New Mexico: Get your Water Kicks on Route 66. New Mexico Water Resource Institute

Gleick, P., 2003. Soft Path'solution to 21st-century water needs. Science 320(5650):1524-1528.

Gopalakrishnan, C., 2000. Water Conservation, Competition and Quality in Western Irrigated Agriculture: An Overview of the W-190 Regional Research Project, 1994-99. International Journal of Water Resources Development 16(2):177-185.

James, R. G., 1973. Use and Development of Outdoor Recreation Resourcesin Northeastern New Mexico. New Mexico State Univ, Las Cruces AgriculturalExperiment Station Bulletin Office, Department of AgriculturalInformation, New Mexico State University, Drawer 3AI,Las Cruces, New Mexico 88003.

James, R. G. & J. B. Thomas, 1971. Characteristics of Recreationists in Northeastern New Mexico. New Mexico State Univ, Las Cruces Agricultural Experiment Station September, Report 209.

King, J. P., J. W. Hawley, J. W. Hernandez, J. F. Kennedy & E. Martinez, 2006. STUDY OF POTENTIAL WATER SALVAGE ON THE TUCUMCARI PROJECT ARCH HURLEY CONSERVANCY DISTRICT. New Mexico Water Resources Research Institute in cooperation with the Department of Civil and Geological Engineering New Mexico State University, Technical Completion Report.

King, J. P. & J. Maitland, 2003. Water for river restoration: potential for collaboration between agricultural and environmental water users in the Rio Grande Project Area. Report Prepared for Chihuahuan Desert Program.

Rosenberg, D. E., R. E. Howitt & J. R. Lund, 2008. Water management with water conservation, infrastructure expansions, and source variability in Jordan. Water Resources Research 44(11):11 doi:10.1029/2007wr006519.

Ward, F. A., 2009. Economics in integrated water management. Environmental Modelling & Software 24(8):948-958.