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Evaluation of Irrigation Efficiency Strategies for Far West Texas: Feasibility, Water Savings And Cost Considerations

Prepared for:
Far West Texas Water Planning Group,
Rio Grande Council of Governments and
Texas Water Development Board

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Texas Water Resources Institute
make every drop count

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DISCLAIMER

The information and opinions expressed are the responsibility of the authors and do not necessarily represent those of the funding agencies, irrigation districts or contributors.

ABSTRACT

Texas recently completed its second round of nationally recognized water planning. The Water Plan for the state addresses how each of 16 regions will supply projected water demands for the next 50 years. Water availability in these plans is based on supply conditions experienced during the drought of record, that is, the severe drought conditions in the 1950's. In arid Far West Texas, Region E in the State Plan, agriculture is projected to have the largest unmet demand for water during drought. This situation is similar to many other irrigated agricultural production regions in the U.S. and world that rely upon limited and variable water supplies. In the Far West Texas (Region E) 50-year Water Plan, the primary strategy proposed to mitigate the impact of insufficient water supplies for agriculture is implementation of water conservation best management practices. However, the conservation practices identified were generic and gave a wide range of potential water savings compiled from many other sources and for other locations and conditions. The feasibility and amount of water saved by any given conservation practice varies substantially across regions, specific location, type and quality of water supplies, delivery systems and operational considerations, crops produced, irrigation technologies in use, and location specific costs and returns of implementation. The applicability to and actual water savings of the proposed practices in Far West Texas were generally unknown.

This report evaluates the applicability, water savings potential, implementation feasibility and cost effectiveness of seventeen irrigated agriculture water conservation practices in Far West Texas during both drought and full water supply conditions. Agricultural, hydrologic, engineering, economic, and institutional conditions are identified and examined for the three largest irrigated agricultural areas which account for over 90% of total irrigated agricultural acreage in Far West Texas. Factors considered in evaluating conservation strategies included water sources, use, water quality, cropping patterns, current irrigation practices, delivery systems, technological alternatives, market conditions and operational constraints.

The overall conclusion is that very limited opportunities exist for significant additional water conservation in Far West Texas irrigated agriculture. The primary reasons can be summarized by: the most effective conservation practices have already been implemented and associated water savings realized throughout the region; reduced water quality and the physical nature of gravity flow delivery limit or prohibit implementation of higher efficiency pressurized irrigation systems; increased water use efficiency upstream has the net effect of reducing water supplies and production of downstream irrigators; and, water conservation implementation costs for a number of practices exceed the agricultural value and benefits of any water saved.

Those practices that suggest economic efficient additional water conservation included lining or pipelining district canals and the very small potential for additional irrigation scheduling and tail water recovery systems. In nearly all cases, these practices have been adopted to a large extent if applicable, further emphasizing the very limited opportunities for additional conservation. If all of these strategies were implemented, the water conserved would satisfy less than 25% of the projected unmet agricultural water demand in 2060 during drought-of-record conditions

Overall, there are no silver bullets for agricultural water conservation in Far West Texas short of taking irrigated land out of production when water supplies are limited.

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INTRODUCTION

The Upper Rio Grande is one of the main sources of surface water in Far West Texas and is characterized by water shortages that are complicated with international treaties and interstate compacts (Thomas, 1963). According to the Palmer Drought Severity Index, Far West Texas is currently undergoing a moderate drought[1], reinforcing the need for water conservation efforts. Surface water from the Rio Grande, along with limited groundwater resources, must be shared among industrial, municipal, agricultural interests, and environmental needs. Agricultural irrigation is the largest water-use category in Far West Texas, which makes irrigation conservation strategies a vital and initial target for water conservation.

In the wake of the 1950's Texas drought-of record, the Texas legislature established the Texas Water Development Board with the purpose of developing water supplies and preparing plans to meet the future water needs of the State (TWDB, 2007). The first State Water Plan was adopted in 1961. In 1997, Senate Bill 1 (SB1) passed by the Texas Legislature established a regional water planning process. Sixteen Regional Water Planning Groups were created to develop regional water plans for their respective areas. Regional water plans detail strategies to meet future water demand and alternatives to adequately respond to drought conditions (TWDB, 2007). The first State Water Plan using the new regional water planning process was adopted in 2002 and incorporates all 16 Regional Water Plans. The 2006 Far West Texas (Region E) second 50-year Water Plan was recently adopted for seven counties in Far West Texas: Brewster, Culberson, El Paso, Hudspeth, Jeff Davis, Presidio, and Terrell counties.

In the Far West Texas Water Plan, agriculture is projected to have the largest unmet demand for water during drought. The primary strategy proposed to mitigate the impact of insufficient water for agriculture is implementation of water conservation best management practices. A Best Management Practices Guide was developed by the TWDB as a reference for regional water conservation planning efforts (2004). However, the conservation practices listed in this report were generic and the applicability to and actual water savings of the proposed practices in Far West Texas were generally unknown.

In this study, the applicability, water savings potential, implementation feasibility and cost effectiveness of seventeen irrigated agriculture water conservation practices are evaluated for Far West Texas during both drought and full water supply conditions. The study focuses on three irrigation districts in El Paso and Hudspeth counties that account for 90 percent of the total irrigated agricultural acreage in Far West Texas. Numerous sources of published data and surveys, water manager and producer interviews, economic modeling, and engineering analysis were used to evaluate the recommended strategies in terms of their applicability to the study area and their potential for location specific water savings. Evaluation factors considered include water sources, use, water quality, cropping patterns, irrigation practices, delivery systems, technological alternatives, market conditions and operational constraints. Institutional and infrastructure considerations as well as economic costs and returns of each strategy were also considered.

[1] The Palmer Drought Severity Index by the Texas Climatic Divisions measures meteorological drought by considering precipitation, evaporation, and soil moisture. Information classifying Far West Texas as undergoing a moderate drought is current as of May 16, 2009.

This report begins with a brief background on Far West Texas, including general geography, climate, water use and supplies. The hydrology of the study area is reviewed and unique characteristics that impact water conservation opportunities are described. Next is a discussion of current and historical agricultural crop production. Proposed irrigation conservation strategies are then described, followed by detailed evaluation of each strategy by irrigation district. Estimates of the potential water savings and total and per acre foot costs of implementation of each applicable conservation strategy are provided by irrigation district. The final section provides summary conclusions and recommendations made by the study team.

BACKGROUND

The Texas State Water Plan's, Far West Texas region (Region E) is the most arid region in the State. This region is located in the Upper Rio Grande Basin along the U.S.-Mexico border and is comprised of seven counties. This desert environment includes Brewster, Culberson, El Paso, Hudspeth, Jeff Davis, Presidio and Terrell counties. Although comprised of only 7 counties, the area is very large at 24,069 square miles, where many counties exceed the size of several states (Far West Texas Water Plan, 2006). A map of Region E, the seven Far West Texas counties and three irrigation districts evaluated, is shown in Figure 1.

1. Climate

The Far West Texas region has a mean annual temperature of 65° F and temperatures that often exceed 100° F during the summer months. Most precipitation is usually occurs between June and October with annual precipitation averages that range from 9 inches to 21 inches at selected locations in higher elevations (SRCC, 1971-2000). The region is home to the Guadalupe Mountains National Park, Big Bend National Park, Big Bend Ranch State Park, and to all of Texas' true mountains. The floors of most basins are at elevations greater than 3,000 feet (most of Texas is at an elevation less than 2,500 feet above mean sea level) (Far West Texas Water Plan, 2006).

2. Water Withdrawals and Water Supplies

Total water withdrawal for the Region was 665,793 acre-feet in 2000. Of this total, 76 percent was used for agricultural irrigation while 20 percent was used for municipal purposes. The water-use categories and their percentages of the total for the Far West Texas Water Planning Region (Region E) in 2000 are shown in Table 1.

Total water withdrawal for the region is projected to increase to 721,071 acre-feet by 2060. A nine percent decrease is projected for irrigation water withdrawal over the planning period, going from 481,042 acre-feet in 2010 to 435,657 acre-feet in 2060 (FWTWP, 2006). Despite the projected decreases in agricultural irrigation water withdrawal, it remains the largest category of water use through 2060. Projected water withdrawal and supply for all counties, by category in Far West Texas, through 2060 are shown in Table 2. Projected water deficits during drought of record conditions exist for the following categories: county-other, manufacturing, irrigation, and steam electric from 2010 through 2060, and for municipal from 2030 through 2060.

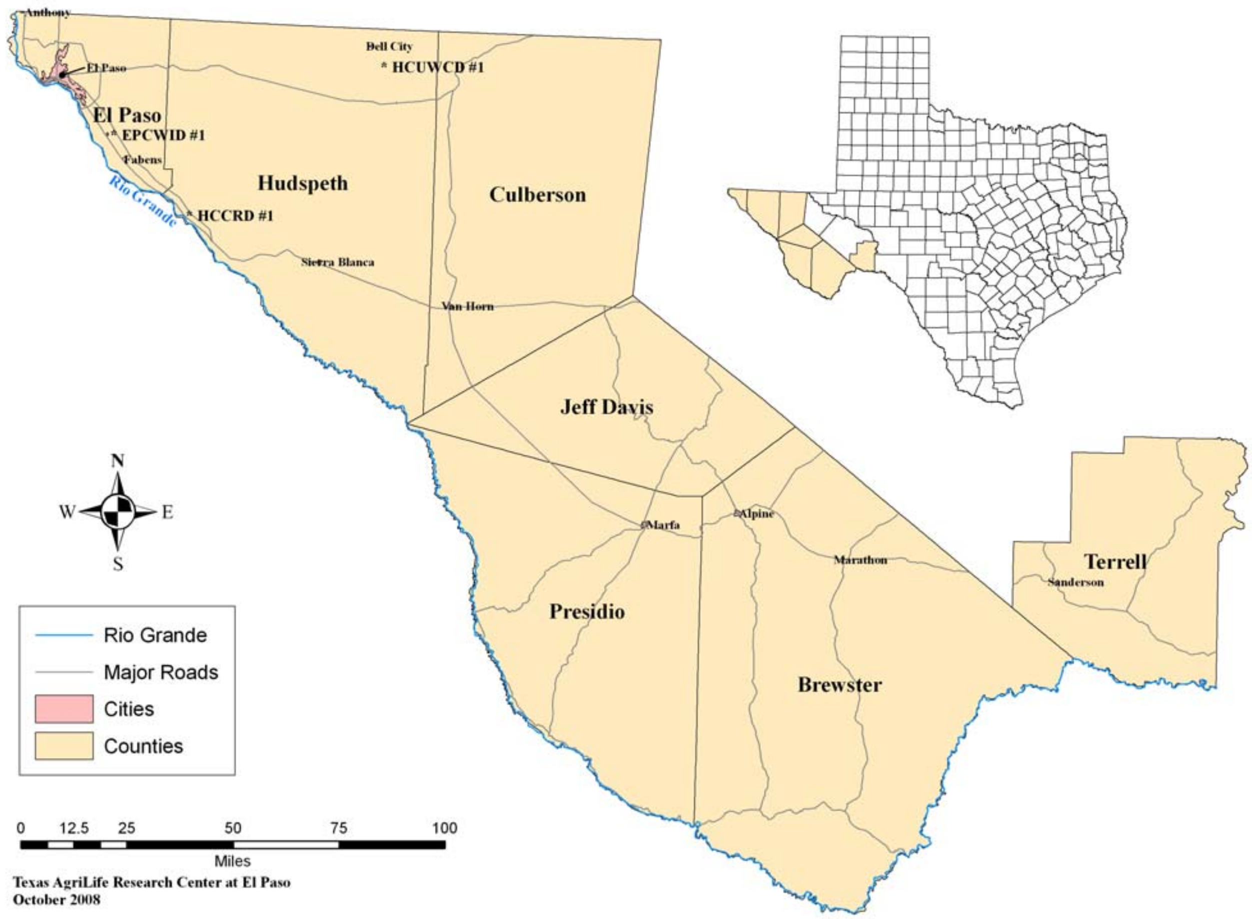

Figure 1 Far West Texas region (Region E) and irrigation districts evaluated.
Source: Figure 1-1 in Far West Texas Water Plan 2006, pp. 1-10.

Table 1 Total Far West Texas Water Withdrawal in 2000.

Category	Water-Use (acre-feet)	Percent of Total
County-Other	4,145	0.62%
Irrigation	**508,266**	**76.34%**
Livestock	4,843	0.73%
Manufacturing	7,750	1.16%
Mining	2,282	0.34%
Municipal	135,545	20.36%
Steam Electric	2,962	0.44%
Total	**665,793**	**100.00%**

Source: Compiled from Table 2-2, Far West Texas Water Plan, 2006, pp. 2-9 to 2-10.

Table 2 Projected Water Withdrawal and Supply, by Sector for Far West Texas.

Year	2010		2020		2030		2040		2050		2060	
Category	With-drawal	Supply	With-drawal	Supply	With-drawal	Supply	With-drawal	Supply	With-drawal	Supply	With-drawal	Supply
Municipal	155,375	179,336	173,920	179,336	190,119	179,336	203,969	179,336	218,709	179,336	234,351	179,336
County-Other	6,757	4,310	9,638	4,310	11,938	4,310	13,699	4,310	15,507	4,310	17,623	4,310
Manu-facturing	9,187	7,759	10,000	7,759	10,698	7,759	11,373	7,759	11,947	7,759	12,861	7,759
Irrigation	**481,042**	**321,602**	**471,910**	**321,602**	**465,241**	**321,602**	**452,152**	**321,602**	**443,827**	**321,602**	**435,657**	**321,602**
Mining	2,273	3,080	2,292	3,080	2,299	3,080	2,307	3,080	2,314	3,080	2,326	3,080
Livestock	4,843	5,252	4,843	5,252	4,843	5,252	4,843	5,252	4,843	5,252	4,843	5,252
Steam Electric	3,131	2,962	6,937	2,962	8,111	2,962	9,541	2,962	11,284	2,962	13,410	2,962
Total	**662,608**	**524,301**	**679,540**	**524,301**	**693,249**	**524,301**	**697,884**	**524,301**	**708,431**	**524,301**	**721,071**	**524,301**

Source: Compiled from Table 2-2, Far West Texas Water Plan, 2006, pp. 2-9 to 2-10.

METHODS AND PROCEDURES

Irrigated agriculture in the region is primarily (90%) within three irrigation water districts: El Paso County Water Improvement District #1 (EPCWID#1); Hudspeth County Conservation and Reclamation District #1 (HCCRD#1); and Hudspeth County Underground Water Conservation District #1 (HCUWCD#1). Therefore the analysis in this report focused around these irrigation districts. To address expected irrigated agriculture water savings and costs of applicable management and technology strategies, existing studies and data were reviewed, and meetings and interviews with water managers and users were conducted. Agricultural production and water use in drought and full water supply conditions along with current conservation practices were identified, the potential for proposed conservation practices evaluated, and estimates of water savings and costs were developed for feasible conservation practices.

Initially, material included in the Far West Texas Water Plan 2006 was reviewed. This provided background information and projected levels of water demand and supply across sectors. In addition, the drought of record water supply values were obtained from the Water Plan. To be as inclusive as feasible, the study included: a review of literature and data; meetings with irrigation district managers, board members, and farmers to gain insight of current practices and applicability and adoption of alternative water conservation strategies, analysis of potential water savings and associated costs for each applicable strategy; and a final review by irrigation district managers and irrigators.

Review of literature included basic Bureau of Reclamation reports and data on water deliveries to all users by year for 2000-2005; reports and unpublished information on the irrigation district's organization, operation and water management, canals, ditches, etc.; and reports from South Texas, Great Plains, and California which were used to estimate water losses (potential savings) of selected strategies along with associated costs such as initial investment, operating cost, and recurring investment over time.

A survey instrument was developed for potential water conserving technologies and completed jointly by the evaluation team and irrigation district manager, board members, and farmers. This was done separately for each of the three Irrigation Districts. This was essential to get local on-the-ground input on what had been adopted, what was being considered, and what are current levels of adoption.

This was followed by individual study team members providing n and estimates of water savings and costs, which served as the bases for follow-up team meetings. Study team workshops were held in the Texas A&M AgriLife Research and Extension Center in El Paso. Each item was reviewed and adjustments were incorporated based on the literature, local responses in surveys and on-site interviews, and general discussion. A draft of the report following the workshop was provided to the irrigation districts for their review and comments. Based on this last interaction, a final report was developed.

HYDROLOGY

The Rio Grande, used primarily for agricultural irrigation in El Paso and part of Hudspeth County, is the main source of surface water for the area and supplies up to half of the City of El Paso's water. Groundwater from the Rio Grande Alluvium Aquifer within Hueco-Mesilla Bolsons is used to supplement irrigation along the Rio Grande in El Paso and Hudspeth counties, particularly in times of drought. Reclaimed water from El Paso Water Utilities provides an additional source of irrigation water. The remainder of the study region (Hudspeth County, in the Dell City area) relies on groundwater from the Bone Spring-Victorio Peak Aquifer.

1. Surface Water

The Rio Grande, which originates in the southern Colorado Rocky Mountains, flows 600 miles to El Paso, Texas where it forms the international boundary between the United States and Mexico. It eventually discharges into the Gulf of Mexico. It is the main source of surface water for both El Paso County and Hudspeth County.

i. Rio Grande Project

The Rio Grande Project starts from the Elephant Butte Dam (Reservoir) in New Mexico, extending 135 river miles south to the American Dam in El Paso, Texas and continuing another 81 miles southeast from El Paso to Fort Quitman, Texas (IBWC, 2004). There are two major storage sites for the Project, Elephant Butte and Caballo Reservoirs in New Mexico, as well as six diversion dams, 141 miles of main canals, 462 miles of lateral canals, 457 miles of drains, and a hydroelectric plant. Authorized in 1905, the Project is overseen by the U.S. Bureau of Reclamation which is responsible for allocating the river's water between New Mexico and Texas under the Rio Grande Compact, providing irrigation water and electric power to the region, and later water for urban use. Determination of Rio Grande Project water allocation was based on the amount of irrigable land. This resulted in 57 percent (88/155) of the total 159,650 water-right acres are located in New Mexico while the remaining 43 percent (67/155) are in El Paso County (USBR 2007). The historical allocation of released water is also divided in this proportion. A new operation agreement between EBID, EPCWID#1 and the USBR was implemented in 2008 (see more details in later section). Drainage and return flows from the Project are used to irrigate up to an estimated 18,000 acres of crop land in Hudspeth County. The Project also allows for the diversion of up to 60,000 acre-feet of water to Mexico as a result of an international Convention signed in 1906 (IBWC 2008).

ii. Rio Grande Water Quality

Water quality has long been a concern for agricultural producers in Far West Texas. Increasing salinity, as well as sodicity (an excess of sodium in soil which imparts a poor physical condition to the soil) and the release of treated sewage effluent, all affect the water quality of the Rio Grande and can adversely affect crop production. According to Miyamoto, Fenn, and Swietlik (1995), "salinity of the Rio Grande main flow reaching El Paso averages 1.0dS m^{-1} with an SAR of 3.1 and a C1 to SO_4 ratio of 0.61 in chemical equivalent during the period of March 15 to September 15," the main irrigation season. Water quality influences the selection of crops (salinity tolerant), reduces yields and impedes the use of pressurized irrigation systems, thereby impacting water conservation choices for the region.

iii. El Paso County Water Improvement District #1

Delivering surface water to water-right users in El Paso County is the responsibility of the El Paso County Water Improvement District #1 (EPCWID #1). The District is allocated a set quantity of water by the U.S. Bureau of Reclamation based on water actually in storage and available in Elephant Butte and Caballo Reservoirs. This allocation is increased, typically monthly, as water becomes available from snow pack runoff (70% of reservoir inflow) and other precipitation above the reservoirs. The District then allocates this water equally on a per acre basis among the 69,010 acres of water-right lands. There are 350 miles of main and lateral canals in the District's distribution system as well as 269 miles of drainage systems (Figure 2). A total of 256 miles of main and lateral canals calculated from the District Water Guide (EPCWID#1, 2000) were used in estimate of water savings by lining District Canals. The District uses the canals to deliver water to water-right holders (EPCWID #1 website, http://www.epcwid1.org, accessed 04/08/08). Individual water allotments have typically been 4.0 acre-feet per acre for a full supply water year since 1990 (Personal communication, Jesus Reyes, March 25, 2008).

Operational procedures for delivery of irrigation water to growers in this District requires an irrigation decision be made a week in advance of the on-farm irrigation event. It takes typically 3 to 7 days to allow for travel time from the reservoir to the user. Essentially the irrigation management decision requires the selection of the expected optimum date of the next irrigation. The dominant irrigation method in the District is surface (flood) irrigation. There is no on-farm or District irrigation water storage below the Rio Grande Project reservoirs so once water is released it must be used at that time or passed through below the District.

A new Rio Grande Project operating agreement signed by Elephant Butte Irrigation District and El Paso County Water Improvement District #1 on February 14, 2008 established new procedures for allocating Project water supply to Elephant Butte Irrigation District and El Paso County Water Improvement District #1. This agreement was 29 years in the making and resolved a number of key issues, some of which were the subject of law suits which have now been dismissed by both parties. Key provisions of the agreement include (USBR, 2007):

- Water allocations to Project water users would be made using a method which provides EPCWID and Mexico water deliveries at their river headings based on historical river performance and decreases EBID's allotment to make up for any losses in performance of the Rio Grande which may have been caused by changes in hydrologic conditions in New Mexico. This is an accounting change which does not impact the overall amount of water utilized by the Rio Grande Project.

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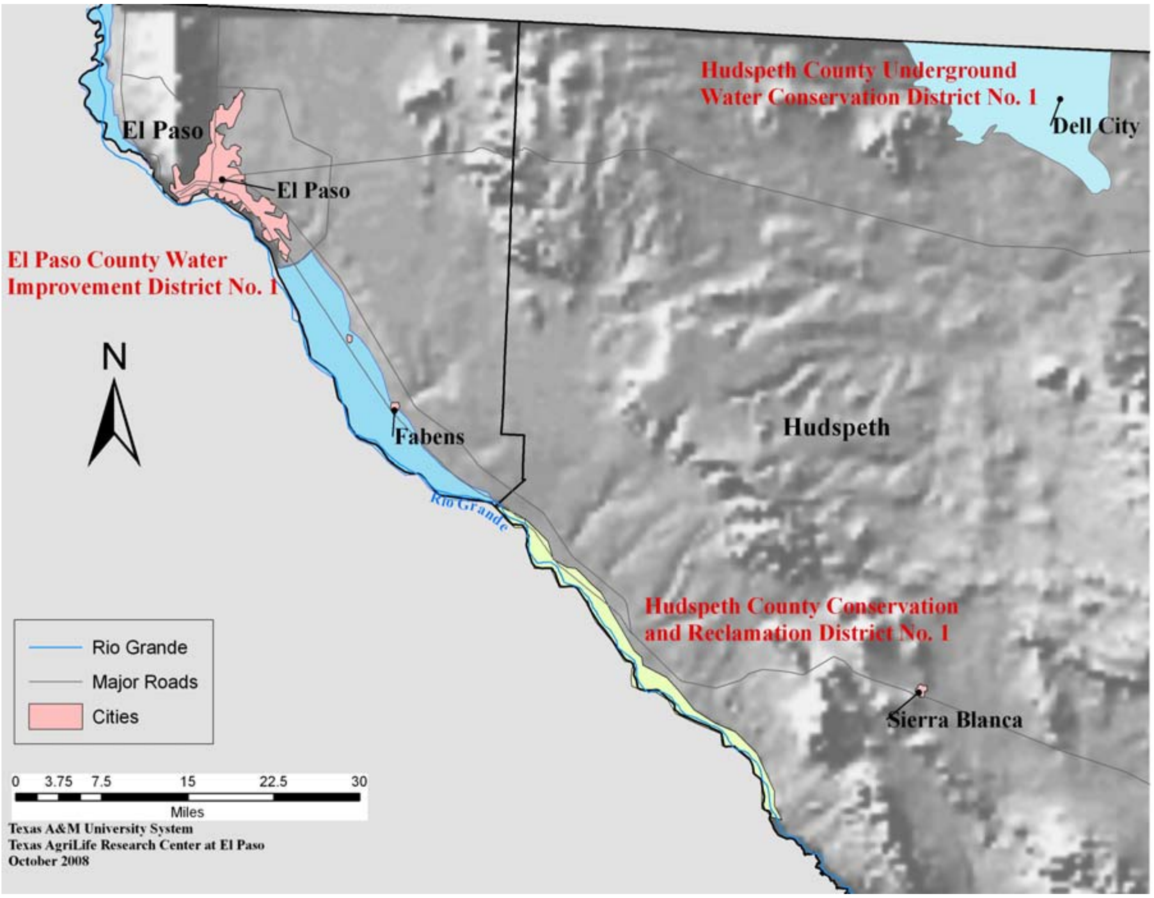

Figure 2 Irrigation districts in El Paso and Hudspeth Counties in Far West Texas

- Each district may carry-over in Project storage of the current year's unused final allocation in a given year and will be able to accumulate and maintain a carry-over water account of a maximum amount of 60 percent of a full allocation.

- In accordance with Rio Grande Compact provisions, Reclamation would utilize a normal release from Project storage of 790,000 acre feet, when available, as the amount needed to provide a full allocation to EBID and EPCWID at their respective accounting points.

- Monitoring of deliveries to all water users and flows in the Rio Grande would be improved and closely coordinated with the Districts.

- The effects of the City of El Paso's Canutillo well field would continue to be monitored.

EBID's and EPCWID's yearly allocation shall be determined using the empirically derived linear regression analysis equation. There is no change in Mexico allocation.

iv. Hudspeth County Conservation and Reclamation District #1

Downstream from the EPCWID #1 is the Hudspeth County Conservation and Reclamation District #1 (HCCRD #1) (Figure 2). The District, headquartered in Fort Hancock, Texas, was created in 1924 and occupies approximately 18,300 acres, of which an estimated 6,400 to 13,500 are currently irrigated. The HCCRD #1 does not supply potable water but instead diverts any tailwater, returns, and excess flows from EPCWID#1 use. Water for the District is completely dependent upon the EPCWID #1 in terms of return flows, spills, and releases, resulting in unpredictable water supplies. This means increased conservation or improved irrigation in EPCWID #1 which increases consumptive use of water essentially reduces the HCCRD #1 supply. Land owners in the HCCRD #1 own the water rights and have contractual rights to Project water and adjudicated rights from the State of Texas.

There are approximately 74 miles of District main and lateral canals, all of which are unlined. Three regulating reservoirs are located within the District with capacities of 2,500 acre-feet, 1,000 acre-feet, and 700 acre-feet. In addition, the District owns 20 groundwater wells that are used to supplement Rio Grande surface water. Similar to the EPCWID #1's operating procedures, growers must place an order for irrigation water no more than 7 days in advance. If water is available, the water may be delivered to the grower immediately; however, because of limited storage they may need to wait for return flow to supply the water and therefore delivery times vary and can be anywhere from 10 days to two weeks later (Personal communication, Jim Ed Miller and Jake Cline, April 23, 2008).

2. Groundwater

While the Rio Grande is the major source of water for agricultural irrigation in the EPCWID #1 and the HCCRD #1, groundwater from the Rio Grande Alluvium Aquifer is only used to supplement surface water during drought due to elevated groundwater salinity. The major aquifers used for irrigation in Far West Texas are shown in Figure 3. Between 2002 and 2007, sixty-two groundwater wells were drilled and maintained by EPCWID#1. The Bone-Spring-Victorio Peak Aquifer and the Hueco-Mesilla Bolsons are the main aquifers that provide groundwater for irrigation purposes to the study area (El Paso and Hudspeth counties). Several other aquifers are located throughout Far West Texas but are outside the scope of this report.

i. Hueco-Mesilla Bolsons

The Hueco Bolson Aquifer extends through New Mexico, Texas, and Mexico and is the major source of drinking water for the City of El Paso and Ciudad Juarez (Sheng and Devere 2005; Sheng, Mace, and Fahy, 2001). Rio Grande Alluvium Aquifer overlying the Hueco Bolson provides supplemental water for irrigation during drought. Water quality in the aquifer has deteriorated over the last 100 years due to pumping and leakage of poor quality irrigation return flows (Sheng and Devere 2005). According to Ashworth and Hopkins (1995), water quality varies by location and depth, with dissolved solid concentration ranging from less than 500mg/l to over 1,500 mg/l.

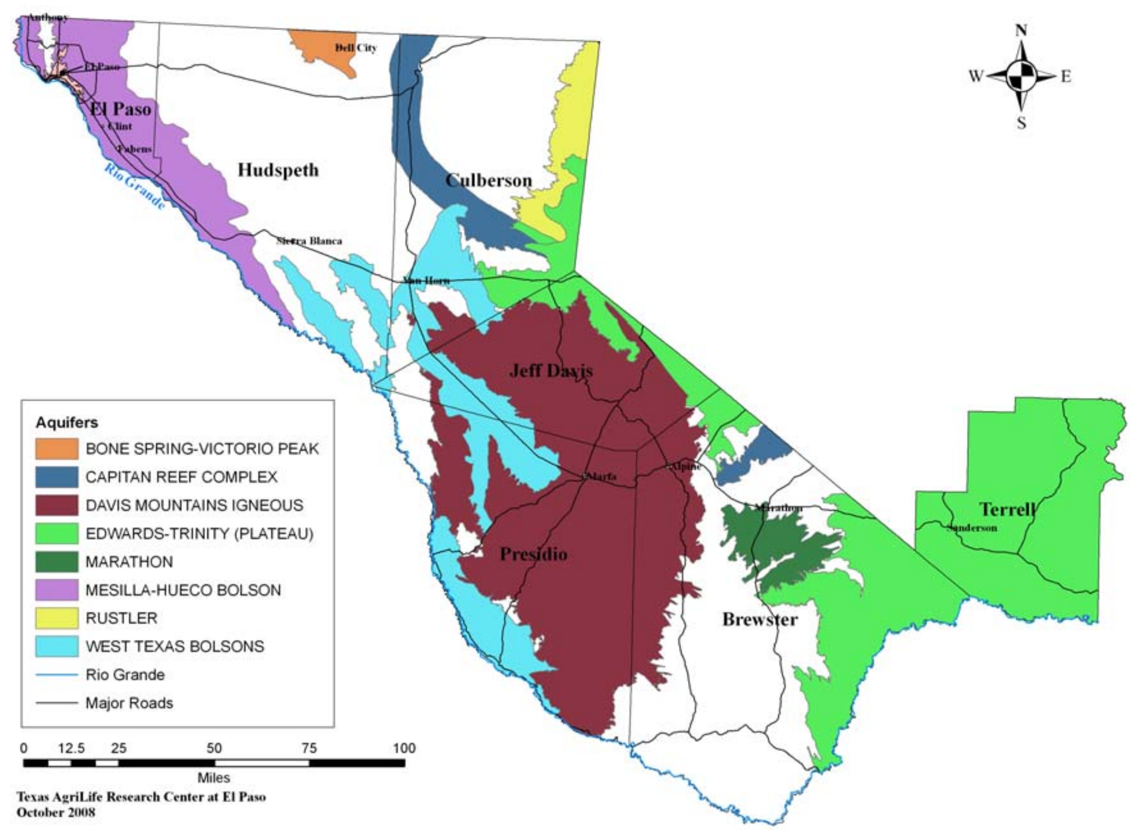

Figure 3 Major aquifers in Far West Texas Water Planning Region.
Source: Figure 3-1, Far West Texas Water Plan, 2006, pp. 3-24.

ii. Bone Spring-Victorio Peak Aquifer

The Bone-Spring Victorio Peak Aquifer is the sole source of groundwater for the Dell City area of Hudspeth County and except for a small amount taken for Dell City, is used almost exclusively for agricultural irrigation. Dissolved solids in the water range from 2,000 mg/l to 6,000 mg/l (Ashworth and Hopkins, 1995). Prior to 1950, groundwater in the Dell City area had a calcium-sulfate mix; however, after 1950, along with increasing salinity, groundwater shifted to a calcium-sodium-sulfate-chloride mix (George, Mace, and Mullican, 2005). An estimated 63,000 acre-feet per year of groundwater is available on a sustainable basis for agriculture irrigation from the aquifer (HCUWCD #1 Management Plan, 2007).

iii. Hudspeth County Underground Water Conservation District #1

Managing the production of groundwater from the Bone Spring-Victorio Peak aquifer is the Hudspeth County Underground Water Conservation District #1 (HCUWCD #1). The District monitors specific wells within the District to help identify and implement efficient water use practices. Validation permits are issued to qualified water-users. Current permitted water withdrawals are based on historical water-use from 1990 to 2000. (HCUWCD #1 Management Plan, 2007).

3. Reclaimed Water

Municipal irrigation demand for golf courses, parks, schools, and cemeteries is partially met through the use of reclaimed water. Forty miles of reclaimed water lines can be found throughout the City of El Paso (FWTWP, 2006). High salinity from reclaimed water results in salt-induced foliar damage as well as soil salinization. Miyamoto (2003) stated that "salinity of reclaimed water in Far West Texas and southeastern New Mexico routinely exceeds 1,000 mg/l, the upper limit of salinity recommended by the United States Golf Association for irrigation." Scientific studies are currently being conducted to analyze the effects of reclaimed water on agricultural crops.

4. Drought-of-Record

Water availability varies dramatically from year to year in this desert environment. Since the 1950's drought-of-record, restrictions on water use have been placed to help conserve water during drought years ("dry" years), often reducing water supply capacity by source. Water supply is listed in Table 3 by source for drought-of record and full supply conditions for each of the three irrigation districts in this study.

Table 3. Drought-of-Record and Full Water Supplies (Surface water and Groundwater) (Acre-feet/year)*.

Districts	Sources of Supply	Drought-of Record Supply	Full Water Supply
EPCWID #1	Rio Grande Project	56,154	323,500
	Groundwater from Rio Grande Alluvium (Hueco)	80,000	0
	Indirect Reuse (return flow/reclaimed water)	37,597	40,000
	Total Supply	**173,751**	**363,500**
HCCRD #1	Groundwater from Rio Grande Alluvium (Hueco)	15,000	0
	Upper Rio Grande Return Flow	298	46,466
	Indirect Reuse (within District 10%)	334	4,646
	Total Supply	**15,632**	**51,112**
HCUWCD #1	Groundwater from Bone Spring-Victorio Peak Aquifer (Dell City excluding Diablo Farms)	62,843	99,367
	Total Supply	**62,843**	**99,367**

*Note: Base-year 2000 information used for calculations.
Source: Table 3-2, "Water User Group Water Supply Capacity," 2006 Far West Texas Water Plan, p. 3-6

AGRICULTURE

Agricultural crop production in Far West Texas occurs mainly along the Rio Grande corridors in El Paso, Hudspeth and Presidio counties. Of the estimated 508,266 acre-feet of water used for agricultural irrigation in 2000, 270,424 acre-feet and 186,494 acre-feet were used for irrigation in El Paso and Hudspeth counties, respectively, representing 90 percent of total irrigation water-use in the region. Agricultural irrigation water withdrawal by county in Far West Texas for 2000 is shown in Table 4.

Table 4 Total Irrigation Water Withdrawals for Region E, By County in 2000.

	Water withdrawal (acre/feet)	% of Total Irrigation Water Use
El Paso County	270,424	53%
Hudspeth County	186,494	37%
Presidio County	20,475	4%
Culberson County	29,593	6%
Total Irrigation Water Withdrawal	**508,266**	**100%**

Source: Table 2-2, Far West Texas Water Plan, 2006 pp. 2-9 to 2-10. Brewster Jeff Davis and Terrell use a total of 1,280 acre-feet of water for irrigation, less than 0.3 % of the region total.

Prior to analyzing proposed conservation strategies, information on current and historical crop production and agricultural water use was compiled for the study area. Data for irrigation acreage and water use came from several different sources: the 2006 Far West Texas Water Plan, the U.S. Bureau of Reclamation, and local water districts and producers. Differences in reported values exist for different categories and between sources. Crop specific data from 1980 through 2005 for both the EPCWID #1 and the HCCRD #1 were obtained from the U.S. Bureau of Reclamation; however, reported category definitions have changed over the years causing inconsistencies in the data, with information for some categories not reported in all years. The 2006 Far West Texas Water Plan reports generalized data, such as crops produced and total water use for the entire region. Irrigated acreage, water use by crop, and water delivered for the EPCWID #1 and the HCCRD #1, reflect information reported by the U.S. Bureau of Reclamation in their Crop and Water Data, Form 7-2045.

1. El Paso County

An estimated 50,000 acres are in agricultural production in the EPCWID #1 (U.S. Bureau of Reclamation, Crop and Water Data, 2000-2005). Principal crops for the area include cotton, pecans, alfalfa, grains, and limited vegetables. Total agricultural acreage is projected to decline in El Paso County due to urbanization. Pecans are anticipated to continue to be a valuable crop in the region with a continued mix of cotton, alfalfa and grains.

Common irrigation techniques used in the area are flood irrigation with borders for pecans and alfalfa, and furrow irrigation for all other row crops including cotton and most vegetables. There is little to no tailwater associated with individual irrigations in El Paso, making water availability a larger issue for downstream neighbor, Hudspeth. The number of irrigated acres, by crop, produced in El Paso County between 2000 and 2005, are summarized in Table 5. The total volume of surface water used to irrigate crops in El Paso County for the same timeframe is provided in Table 6. The crop acreage in 2005 was low due to various factors: low reservoir storage, low initial allotment, limited availability of good quality groundwater, and fear of drought. As it turns out, total annual precipitation for 2005 was 13.6 inches, which is above the historical average of 8.76 inches.

Table 5 Agricultural Production Summary: El Paso County Irrigated Acres by Crop, 2000-2005.

Year	2000	2001	2002	2003	2004	2005
Alfalfa	5,115	4,738	5,910	3,909	3,875	3,339
Cotton (Pima)	17,414	19,962	19,881	17,258	19,744	21,021
Cotton (Upland)	4,943	4,315	2,617	2,545	1,428	1,571
Irrigated Pastures	467	550	540	672	342	854
Onions	822	905	861	623	927	927
Pecans	10,673	11,484	11,262	11,466	10,893	10,525
Peppers	851	321	683	383	152	232
Family Gardens & Orchards[a]	49	111	110	-	-	25
Melons & Fruits[b]	-	-	-	-	40	7
Vegetables[c]	-	-	-	-	4	135
Other Grains[d]	8,339	7,010	8,264	1,255	1,740	2,513
Other[e]	3,069	1,314	1,668	159	159	159
Total	**51,742**	**50,710**	**51,796**	**38,270**	**39,304**	**41,308**

(a) Includes fruit trees
(b) Includes melons, cantaloupes, grapes, and other fruits
(c) Includes beans, cabbage, corn, lettuce, sweet corn and other vegetables
(d) Includes barley, corn fodder, corn silage, milo, oats, other forage, other hays, rye, silage, sorghum, Sudan grass, wheat, winter forage, and yard grass
(e) Includes multi-cropped acres and nursery crops
Source: U.S. Bureau of Reclamation, Crop and Water Data 2000-2005, Form 7-2045.

Table 6 Project Water Withdrawal Summary for EPCWID #1: 2000-2005.

Year	2000	2001	2002	2003	2004	2005*
Total (acre-feet)	**166,430**	**192,471**	**253,448**	**111,730**	**111,718**	**112,300**

Source: U.S. Bureau of Reclamation, Crop and Water Data 2000-2005, Form 7-2045. EPCWID#1 Rio Grande Project water was supplemented with groundwater from the Rio Grande Alluvium Aquifer in 2003 and 2004.
* Rio Grande release data showed a higher value (237,684 acre-feet, including city diversion of ~50,000 acre-feet).

2. Hudspeth County

Agricultural crop production in Hudspeth County can be divided into two irrigation districts: the HCCRD #1 and the HCUWCD#1, with an estimated total of 37,000 acres irrigated, varying with water availability and agricultural market conditions. The HCCRD#1 primarily uses return flow from the Rio Grande project, supplemented by groundwater from the Rio Grande alluvium aquifer during drought. The HCUWCD#1 in the Dell City area fully relies on groundwater from the Bone Spring-Victorio Peak Aquifer.

i. Hudspeth County Conservation and Reclamation District #1

An estimated 6,400 to 14,750, acres are irrigated in the HCCRD #1 depending largely on water supply conditions. Principal crops include cotton, alfalfa, and grains. Furrow and flood irrigation are used to irrigate row crops such as cotton, while flood irrigation is used on alfalfa and similar crops. The number of irrigated acres, by crop produced in the HCCRD #1 is shown in Table 7. The total amount of water withdrawal for crops between 2000 and 2005 is listed in Table 8.

Table 7 Agricultural Production Summary: HCCRD #1 Irrigated Acres by Crop, 2000-2005.

Year	2000	2001	2002	2003	2004	2005
Alfalfa	1,444	1,363	1,450	920	973	1,102
Cotton (Pima)	3,161	3,361	4,861	2,432	1,991	4,257
Cotton (Upland)	6,998	6,743	7,156	2,586	3,176	2,731
Vegetables[a]	675	638	650	260	190	-
Other Grains[b]	1,126	2,085	585	200	-	-
Other[c]	46	46	46	46	46	46
Total	**13,450**	**14,236**	**14,748**	**6,444**	**6,376**	**8,136**

(a) Includes corn, onions - dry, onions - green, peppers, and other vegetables
(b) Includes barley, corn fodder, forage - other, oats, other hays, silage, sorghum (sorgo, kaffir, etc), and wheat
(c) Includes cotton seed - Upland and pecans
Source: U.S. Bureau of Reclamation, Crop and Water Data 2000-2005, Form 7-2045.

Table 8 Water Withdrawal Summary for HCCRD #1, 2000-2005.

Year	2000	2001	2002	2003	2004	2005
Total (acre-feet)	**46,466**	**42,378**	**46,606**	**23,390**	**20,077**	**21,333**

Source: U.S. Bureau of Reclamation, Crop and Water Data 2000-2005, Form 7-2045. Surface water supplies were supplemented with groundwater from the Rio Grande Alluvium Aquifer in 2003 and 2004.

ii. Hudspeth County Underground Water Conservation District #1

A total of 22,550 acres in the Dell City valley were irrigated in 2000 from the Bone Spring-Victorio Peak Aquifer. Alfalfa production led in total acreage. Surface irrigation of laser leveled fields along with low pressure center-pivot irrigation systems are commonly used to irrigate a majority of acreage, namely alfalfa. Linear-move irrigation systems have only recently been introduced to the area. Drip irrigation is limited to high value crops such as grapes, which comprised 150 acres in 2000. Agricultural crop production and water withdrawals are listed in Table 9 and Table 10 respectively for 2000. Due to the water supply coming from an aquifer that is recharged in New Mexico on a relatively consistent basis, the annual water quantity available has also been relatively constant.

Table 9 Agricultural Production Summary: HCUWCD #1 Irrigated Acres by Crop, 2000.

Name	HCUWCD #1	Diablo Farms	**Total**
Cotton	0	0	**0**
Silage	1,000	0	**1,000**
Corn	600	0	**600**
Grain	2,000	0	**2,000**
Alfalfa	16,000	830	**16,830**
Chile	2,000	0	**2,000**
Pasture	800	0	**800**
Vineyard	150	0	**150**
Totals	**22,550**	**830**	**23,380**

Note: Diablo Farms is located outside HCUWCD #1 near the Hudspeth/Culberson County lines in northern Hudspeth County.
Source: Hudspeth County Underground Water Conservation District #1, Management Plan, November 2007.

Table 10. Water Withdrawal Summary, HCUWCD #1, 2000.

Name	HCUWCD #1	Diablo Farms	**Total**
Totals (acre-feet)	**99,367**	**4,150**	**103,517**

Note: Diablo Farms is located outside HCUWCD #1 near the Hudspeth/Culberson County lines in northern Hudspeth County.
Source: Hudspeth County Underground Water Conservation District #1, Management Plan, November 2007.
Note: Of water pumped an estimated 30% returns to the aquifer (consumptive use approximated 63,000 acre feet).

Figure 4 Dell City: The Valley of Hidden Waters.
(courtesy of A. Michelsen)

PROPOSED IRRIGATION STRATEGIES

Municipal and industrial water users across Texas and in other states have made advances in water use efficiency motivated by diverse goals and factors such as increasing costs, preventing land subsidence, addressing short-term or long-term water shortages, providing water quality and environmental protection, reducing costs of resources (such as the water itself), energy needed to pump, treat, and heat water in industrial processes, and meeting the challenges of drought. Since agricultural growers using groundwater from the Ogallala Aquifer pioneered water efficiency in agricultural irrigation in the Texas panhandle region as early as the 1970s, irrigation efficiency has increased both in the sophistication of irrigation methods as well as increased efficiency in other agriculture irrigation and water management methods in agricultural production.

While there are a number of successful conservation efforts in Texas, there is an opportunity for a more comprehensive effort by all sectors of the State. The legislation that created the Water Conservation Task Force was passed in order to further conservation efforts in the State. One of the objectives of the Task Force was to gather information about the elements of successful conservation programs, good cost estimates and reliable water savings estimates for use in water resource planning (TWDB, 2004). The following working definition of conservation was used by the Task Force: Those practices, techniques, programs, and technologies that will protect water resources, reduce the consumption of water, reduce the loss or waste of water, improve the efficiency in the use of water, or increase the recycling and reuse of water so that a water supply is made available for future or alternative uses. Experience in water conservation program implementation over the decades has resulted in a body of knowledge in Texas, across the United States and around the world. Practitioners have shared these experiences and adopted the approach of Best Management Practices (BMP). A BMP is a conservation measure or series of measures that is useful, proven, cost-effective, and generally accepted among conservation experts.

A Best Management Practices (BMP) Guide was developed for the Texas Water Development Board (2004) as a guideline by the Texas Water Conservation Implementation Task Force to assist regional water planning groups in the development of their conservation programs to meet future water needs. The BMP Guide contains information on estimated costs and water savings of various conservation efforts and was intended for use by both water providers and water users. There are five categories of BMPs for Agricultural Water Users with each category containing several recommended strategies. Appendix A provides details of each BMP.

Five irrigation strategies were previously identified as inapplicable to the Far West Texas region by the FWTWPG and are omitted from this study. They include:

- Furrow Dikes- limited rainfall so little to no value
- Contour Farming- most fields laser leveled so not applicable
- Conversion of Irrigated Farmland to Dryland- not an option for crop production
- Brush Control Management- watershed offers little to no opportunity
- Nursery Production Systems- too small to be a viable alternative.

The Far West Texas Water Plan proposes to use a set of Best Management Practices as a strategy to mitigate water supply shortages during drought. The following synopsis of BMP's is derived from the TWDB's Water Conservation Best Management Practices Guide, Report 362 (2004), the Far West Texas Water Plan (2006) and from other reports and studies. The use of automation and telemetry systems, which was not included in the BMP guide, was added in this analysis.

1. BMP Category – Agricultural Water Use Management

Irrigation scheduling is intended for producers with an adequate supply of water throughout the growing season. It involves scheduling the time and amount of water that is applied to a crop based on the amount of water present in the crop root zone, the amount of water consumed by the crop since the last irrigation, and other considerations. Water savings are difficult to quantify and vary from year to year based on cropping practices, water quality and quantity. It is estimated that 0.3 to 0.5 acre-feet of water per acre may be saved. Costs vary depending upon scheduling method used, number of fields scheduled, type of program and technical assistance. Based upon existing research conducted on surface water delivery through a series of canals, laterals, and on-farm distribution system, irrigation scheduling offers the potential to reduce water deliveries between 10 and 25 percent and more depending upon the capabilities of the individual district and producer (Hamburg, 1980; Gilley et al., 2003).

Volumetric Measurement of Irrigation Water involves the installation of water meters and other methods to measure water (Figure 5). This strategy does not directly conserve water but information garnered may be used to implement other water conserving strategies. Costs vary depending on application.

Figure 5 Groundwater pumping and volumetric measurement of irrigation water.
(courtesy of A. Michelsen)

Crop Residue Management and Conservation Tillage allows for the management of the amount, orientation, and distribution of crop and other plant residue on soil surfaces year-round. This strategy improves the ability of soil to retain moisture and reduces run-off and evaporation. Water savings vary by climate and irrigation method; however, if implemented effectively, irrigations may be reduced by one or more applications. Costs vary depending on the type of field operation used to manage crop residues.

On-Farm Irrigation Audits are used to account for all on-farm irrigation water usage. Opportunities to improve water efficiency may be identified but irrigation audits do not directly conserve water. This provides insight for the farmer which may lead to water savings but in some cases might result in an increase in level of irrigation. Costs vary by audit and range from minimal to significant.

2. BMP Category – Land Management Systems

Land Leveling is applicable to producers who use furrow, border, or basin irrigation methods and is used to increase the uniformity of water applied to an irrigated field. Water savings are difficult to quantify and costs vary but experience suggests success in reducing water applications and/or amount applied per application.

3. BMP Category – On-Farm Water Delivery Systems

Lining of On-Farm Irrigation Ditches involves the installation of a fixed lining impervious material in an existing or newly constructed irrigation field ditch. Three commonly used liners include Ethylene-Propylene-Diene Monomer (EPDM), urethane, and concrete (Figure 6). Water savings involve reduced seepage from the installation of a lining material. Concrete liners are estimated to salvage 80 percent of the original seepage. Costs vary by lining method.

Figure 6 Lined on-farm irrigation ditch in El Paso
(courtesy of Z. Sheng)

Replacement of On-Farm Irrigation Ditches with Pipelines involves replacing open ditches with buried pipeline that is generally 24 inches in diameter or less. PVC Plastic Irrigation Pipe (PIP) and Iron Pipe Size (IPS) PVC are the two most commonly used pipelines. Water savings stem from reduced seepage. Reduced seepage is captured by lining on-farm irrigation distributions systems at a significantly lower cost than installing a pipeline. A pipeline could reduce evaporation losses, but due to the narrow width of on-farm lined ditches, short exposure to the environment and rapid movement of the water, the amount of water lost to evaporation is very small compared to seepage losses. It is estimated that water savings from reduced evaporation are less than 10% of the seepage losses and hence are not considered here. Considering both the cost of installing on-farm pipelines compared to lined ditches and small potential for additional water savings, farmers are reluctant to install on-farm pipelines. Costs vary and depend on pipe diameter, transportation of pipes, trenching, and other site specific considerations.

Low-Pressure Center Pivot Sprinkler Systems can be divided into four categories (Figure 7): Low Pressure Precision Application (LEPA), Low Pressure In-Canopy (LPIC), Low Elevation Spray Application (LESA), and Medium Elevation Spray Application (MESA). Special considerations include a ready water supply and high level of water quality. Water savings vary and are calculated using a water savings equation while investment costs vary from $300 to $500 per acre.

Drip/Micro Irrigation Systems distribute water directly to the plant root zone by means of surface or sub-surface applicators and are typically used to irrigate high value crops. Construction of such a system takes approximately three to six months. Acceptable water quality is vital to the success of this strategy. Water savings vary while implementation and maintenance costs are substantial.

Figure 7 Low pressure linear sprinkler system.
(courtesy of A. Michelsen)

Gated and Flexible Pipe for Water Distribution Systems involves the use of gated aluminum, PVC pipe, or polypipe to distribute water to furrow and border irrigated fields (Figure 8). A steady supply of water is typically needed. Water savings involve reduced seepage rates. Costs vary depending on type of pipe used.

Surge Flow Irrigation for Field Water Distribution applies water intermittently to furrows to create a series of on-off periods of either constant or variable time intervals. A steady supply of water is crucial to the success of this strategy as well as compatible soil types. Water savings vary by soil type but are estimated to be between 10 and 40 percent. Costs vary with surge valves and controllers but are typically between $800 and $2,000 per unit per farm.

Linear Move Sprinkler Irrigation Systems are an adaptation of the center pivot sprinkler systems and are used on fields which are not appropriate for center pivot systems. There are four types of linear move systems: LEPA, LPIC, LESA, and MESA. Implementation requires substantial capital and may take several weeks to months. Water savings vary and are computed using a water savings equation. Costs vary but typically range from $300 to $700 per acre.

Figure 8 Gated pipe water distribution system.
(courtesy of A. Michelsen)

4. BMP Category – Water District Delivery Systems

Lining of District Irrigation Canals involves the installation of a fixed lining impervious material in an existing or newly constructed canal. Three commonly used liners include Ethylene-Propylene-Diene Monomer (EPDM), urethane, and concrete (Figure 9). Water savings involve reduced seepage from the installation of a lining material. Concrete liners are estimated to salvage 80 percent of the original seepage. Costs vary by lining method.

Replacement of District Canals and Lateral Canals with Pipelines involves replacing open canals with buried pipeline that is generally 72 inches in diameter or less. PVC Plastic Irrigation Pipe (PIP) and Reinforced Concrete Pipe (RCP) are the two most commonly used pipelines. Two primary limitations involve cost and water capacity. Water savings stem from reduced seepage. The level of evaporation is small compared to seepage losses. Costs vary and depend on pipe diameter, transportation of pipes, trenching, and other site specific considerations.

Figure 9 Concrete lining along the American Canal Extension in El Paso.
(courtesy of A. Michelsen)

5. BMP Category – Miscellaneous Systems

Tailwater Recovery and Reuse Systems are applicable to any irrigated system in which a significant water quantity runs off the end of the irrigated field (Figure 10). The strategy consists of ditches or pipelines to collect tailwater and deliver it to a storage reservoir or small field pump. The water is then pumped to the upper end of the field and applied with the irrigation water. Water savings from the installation of tailwater reuse systems are highly dependent upon the local water supply (groundwater or surface water) and the current on-farm water management practices of the grower. Water savings will typically vary between 5 and 25 percent of the water applied to the head (upper) end of the field. This may range from a few to several inches (0.5 to 1.5 acre/foot per acre per year). Reservoirs or pump costs range between $35 and $70 per acre per year for pump systems and between $60 and $120 per acre per year for reservoir systems (Gilley et al., 2003 and updated to 2008 costs).

Automation and Telemetry is the use of automatic systems to control irrigation equipment and report water flow rates, weather data, and other information useful to manage and conserve water (Figure 11). There is no direct water savings to be realized and water costs vary by system. Automation and telemetry are critical tools for irrigation district management and control. This suggests opportunities to reduce “spills.”

Regulating Reservoirs are used as storage to offset irrigation water demand and supply. Costs vary depending on land acquisition, construction, maintenance, and capacity. Water savings vary.

Figure 10 Tailwater recovery and reuse system.
(courtesy of A. Michelsen)


Figure 11 Telemetry system in El Paso.
(courtesy of Z. Sheng)

EVALUATION AND ANALYSIS OF PROPOSED IRRIGATION STRATEGIES

Surveys, interviews with local producers, and engineering and economic analyses were all used to evaluate proposed irrigation strategies. Applicability was also based on hydrologic and institutional conditions with special considerations for infrastructure capacities. In addition, input and discussions with managers and farmers played a strong role in how each strategy was considered. Water savings were analyzed while taking into account current practices. The economic costs and benefits of water savings were also analyzed. The following evaluations are organized by BMP within each irrigation district.

1. Strategies for El Paso County Water Improvement District #1

FWT Water Plan recommended conservation strategies, current practices and application potential for EPCWID#1 are shown in Table 11. Five strategies were found to have water savings potential for EPCWID #1: Irrigation Scheduling, Lining of District Canals, Replacement of District Canals with Pipeline, On-Farm Audits, and Regulating Reservoirs. They, along with all other strategies, will be discussed in further detail below. The first column lists the Irrigation Best Management Practice (BMP) while the second column lists each individual strategy. The third column indicates whether the strategy is currently being used in the district and the fourth column indicates if the strategy would be expected to result in additional water savings. The fifth column includes comments and clarifications relative to the status of the stated strategy.

i. Agricultural Water Use Management

The volume of water delivered to a farm or field may be reduced through improved water management practices including *irrigation scheduling*, shifting to crops that use less water and reducing water applications such that the crop will suffer moisture stress. The latter two practices result in reduction of farm income. Agricultural water use management methods include irrigation scheduling, volumetric measurement of irrigation water, crop residue management and conservation tillage, and on-farm irrigation audits. Based on producer and irrigation district interviews and conservation practice survey information from other studies in the region (e.g. Ward, Michelsen and DeMouche, 2007), in El Paso County, irrigation scheduling is widely practiced and is currently being done using soil moisture blocks, probes, and hand feel of soil. Volumetric measurements of irrigation water are already in place for all the surface water delivery. Crop residue management and conservation tillage are not applicable practices due to soil types and current crop mix. Currently on-farm audits are not conducted in El Paso County. Water use management practices, feasibility and estimated additional water savings are discussed and evaluated in detail in the following sections.

In some other locations where irrigation water supplies are not limited, irrigators have tended to over-apply water to prevent crop yield reductions. However, the results of several irrigation scheduling projects have demonstrated that water applications can be reduced and may, in some situations, increase crop yields. Further, in many cases, the application of irrigation scheduling practices has increased the volume of water applied to irrigated crops because many producers have been "under irrigating" their crops. The volume of water applied can also be reduced by

Table 11 Summary of Potential for Proposed Irrigation Conservation Strategies for El Paso County Water Improvement District #1.

Best Management Practice	Irrigation Strategy	Current Practiced	Applicability & Potential for Additional Water Savings	Comments
Agricultural Water Use Management	Irrigation Scheduling	Yes	Small	80% producers already using some form of scheduling
	Volumetric Measurement of Irrigation Water	Yes	Small	Mostly in place
	Crop Residue Management and Conservation Tillage	No	NA	Inapplicable- soil/crop mix
	On-Farm Irrigation Audits	No	Small	Marginal savings, small fields
Land Management Systems	Land Leveling	Yes	No	Adopted, in place
On-Farm Water Delivery Systems	Lining of On-Farm Irrigation Ditches	Yes	Small	Cost prohibitive
	Replacement of On-Farm Ditches with Pipeline	No	No	Cost prohibitive (<1%)
	Low-Pressure Center Pivot Sprinkler Systems	No	NA	System not viable (supply source, water quality, cost)
	Drip/Micro Irrigation Systems	No	NA	System not viable (supply source, water quality, cost)
	Gated/Flexible Pipe (Field Water Distribution)	No	NA	System not viable (supply source, water quality, cost)
	Surge Flow Irrigation (Field Water Distribution)	No	NA	System not viable (supply source, water quality, cost)
	Linear Move Sprinkler Irrigation System	No	NA	System not viable (supply source, water quality, cost)
Water District Delivery Systems	Lining of District Canals/Lateral Canals	Yes	Yes	In place 206 miles
	Replacement of District Canals/Lateral Canals with Pipeline	Yes	Yes	High cost. Potential land and safety benefits
Miscellaneous Systems	Tailwater Recovery and Reuse System	No	Limited	Management issues, cost, little water savings
	Automation and Telemetry	Yes	Yes	Basic telemetry in place, automation needed
	Regulating Reservoirs	No	Yes	2 potential sites under consideration

Source: Interviews, analysis of practices and potential savings, and results from other studies.

shifting to crops that require less water or reduce the water applications to levels that yields are reduced. Using either of these practices will reduce, in all likelihood, the net income to the producer. Thus, they will not be considered in this analysis. The results of applied *irrigation scheduling* studies (Stegman and Ness, 1974; and Heermann et al., 1976) indicated that water balance irrigation scheduling methods could save between 15 and 35 percent of the water normally delivered for those producers pumping groundwater supplies.

The reduction in water delivered through improved water management (*irrigation scheduling*) depends upon a number of factors including the current management practices utilized by the producer. An analysis by Gilley and Supalla (1983) used a reduction of 15% for center-pivot irrigation systems in the Great Plains Region and a reduction of 20% for gated-pipe surface irrigation systems in the same region. These values were obtainable for systems using pumped ground water supplies, and the application day-to-day decisions using the ability to calculate or predict daily values of crop-water evapotranspiration values and a daily soil water balance. Producers using individually managed, pumped water supplies would have the capability to make decisions on a daily basis. Further, those producers using center-pivot systems could interrupt irrigation if a significant rainfall took place. Typically, the costs of obtaining these quantities of water conservation were the increased labor requirements for enhanced management, intensity of the irrigation systems, or the fees charged by irrigation management consultants for water management alone.

It would be expected, that lower values of water conservation would be achievable for producers irrigating from surface water delivery projects, because of reduced water control opportunities and longer anticipation times required for water delivery to the farm. In addition, the costs for this practice are not "covered" by reduced pumping energy costs.

Some form of *irrigation scheduling* has been utilized in El Paso County for several years. An estimated 80 percent of producers use some form of soil moisture monitoring system to assist in determining the next irrigation date. The most common form of soil moisture monitoring is the use of soil-moisture blocks. Across the region, irrigation scheduling practice varies from the limited irrigation scheduling in Hudspeth County to 80% in El Paso County.

Irrigation scheduling practices incorporating climate, crop evapotranspiration and soil water balance models could be incorporated with soil moisture monitoring to enhance the performance of the on-farm utilization of irrigation water. However, the water conservation achieved in the District will not be as large as that potential achieved with producers having direct control of their water supply (ground water). Estimated savings of 5-10% of the water delivered to the farm could be achieved for those producers not currently using irrigation scheduling practices. During drought years, the estimated savings would be even lower since high levels of management and limited water bring about conservation.

Estimated costs are derived from JMLord, Inc. of Fresno, California (Personal communications). This firm provides professional irrigation management services as well as other agronomic and engineering services to the Central Valley and Coachella Valley in California. Current annual costs range between $8.50 to $18.00 per acre. The lower cost is for grains and other crops that only operate for a few months and the higher costs are for drip-irrigation on specialty crops requiring weekly field visits. Small fields located at greater distances would require a higher cost. The cost for irrigation water management under the EQIP program in California and Texas (NRCS, 2008a and 2008b) are listed in Table 12. Estimated costs in the El Paso area, in all likelihood, are at the upper extent of these costs because of the lack of trained professionals currently providing services in the area.

Water meters have been used since 1982 to measure water outtake by individual water-right holders from irrigation canals (EPCWID #1, 2000). Meters are used in open channels and measure water in cubic-feet/second. The meter readings are then put into monthly notices and sent to the water-right holder. The notice details the amount of water delivered to the water-user and serves as a water bill. Individual irrigations are no longer metered but can be re-metered at the request of the water-right holder with water costs calculated on a per acre-inch basis. The water metering system in EPCWID #1 is considered to be effective with little potential for future water savings.

Table 12 Estimated Costs for Irrigation Water Management.

California	
Category	Cost per acre, $
Fields < 10 acres, low-intensity	10
Fields < 10 acres, medium-intensity	35
Fields < 10 acres, high-intensity	50
Fields > 10 acres, low-intensity	5
Fields > 10 acres, medium-intensity	15
Fields > 10 acres, high-intensity	25
http://www.ca.nrcs.usda.gov/programs/eqip/2008/statepriorities2008.htm	
Texas	
Category	Cost per acre, $
Basic, 3 yr incentive	8
Advanced, 3 yr incentive	12
Multiple Inlet, incentive	10
http://www.tx.nrcs.usda.gov/programs/EQIP/08/index.html	

Crop residue management and *conservation tillage* are not currently practiced in the El Paso area and are deemed inapplicable due to soil types and the current crop mix. There is currently no water savings to be expected from these two strategies; however, there is an expected potential increase in wheat production, which may allow the potential for some level of crop residue management system to be implemented in the future. This opportunity is very limited.

Currently, *on-farm irrigation audits* are not conducted in El Paso County. On-farm irrigation audits are applicable to the area but the amount of water saved would depend on whether or not the producer chooses to follow recommendations made by the auditors. If implemented, only marginal water savings may be realized and are very difficult to quantify.

ii. Land Management Systems

Land leveling has been and continues to be practiced by local producers. An estimated 100 percent of local producers within EPCWID #1 have laser-leveled their land in an effort to conserve water and make the production of crops more efficient. An estimated 25 percent of water has been conserved through this strategy. There are little to no additional water savings to be expected as the farmers have adopted use of land leveling as a water-conserving irrigation strategy and as needed, re-level fields.

iii. On-Farm Water Delivery Systems

The lining of on-farm irrigation ditches is a conservation strategy that has been practiced in El Paso County for several years. Currently an estimated 80 percent of on-farm irrigation ditches in EPCWID #1 are concrete-lined. Studies quantifying water conserved by reducing seepage losses at the farm level have yet to be conducted. It is projected that the greatest opportunity to save water from lining ditches is captured in the 80% already lined.

Despite its potential applicability to the region, the strategy of *using pipelines to replace on-farm irrigation ditches* is very limited. An estimated one percent of producers have pipelines to distribute irrigation water on their property. High installation cost, difficulty of maintenance and repairs and frequency or lack thereof are attributed to the strategy's low adoption rate. It is unlikely that producers will replace on-farm lined irrigation ditches with pipeline in the future; consequently, little to no water savings are expected from this strategy.

Pressurized irrigation systems, including low pressure center pivot, drip/micro irrigation, gated and/or flexible pipe, surge flow, and linear move sprinkler systems, are currently not used in the El Paso area. Major obstacles to pressurized systems are water availability, water quality, soil types, crop mixes and filtration costs. A continuous steady flow of water is needed for the pressurized systems to function properly. For these reasons, pressurized irrigation systems are deemed inapplicable to El Paso and are not operationally or economically feasible.

iv. Water District Delivery Systems

The *lining of district canals and lateral canals* as well as the *replacement of district canals and lateral canals with pipeline* are currently being practiced in EPCWID #1. Canal lining of the District delivery system evolves as one of the more effective methods of conserving water. Of significance is the associated investment and annual upkeep. This review is based on studies in the district as well as experiences of South Texas with similar systems.

In 2000, the EPCWID#1 had approximately 256.3 miles of delivery canals where 50.21 were lined with concrete. It is assumed the lined canals are working as planned. This leaves 206.09 miles of eligible canal for lining. An estimated 1.52 miles of lateral canals have already been replaced with pipeline. The district is evaluating expanding the implementation of pipelines.

Studies in the district show that seepage from unlined canals to be from 0.0042 to 0.0132 cubic meters per second per kilometer (Sheng et al. 2003). By converting to English units, this results in a seepage rate between 1.7895 to 5.6242 gallons per second per mile. Using the total unlined canal length of 206.09 miles over the 243 days the canals carry irrigation water indicates seepage losses between 23,766 and 74,692 acre-feet per year. The Texas Water Development Board estimates that 80% of the losses from seepage could be expected to be saved with canal lining or pipeline. Although this region is arid, future water savings with pipelines due to reduced evaporation is very small compared to seepage losses. Further, with stakeholder (farmer) response suggesting little to no interest in on-farm pipelines, they are not considered in this analysis.

Costs of concrete lining for South Texas based on several actual construction projects are listed in Table 13 (Rister, et.al. 2004, 2005[a] , 2005[b] , 2006, 2007 and Sturdivant, et.al. 2005, 2006).

Based on investment costs per mile, the total investment for lining 206.09 miles of canals would be $135,624,119 while costs of installing a pipeline would be $147,635,869. These costs are very similar to the cost estimate for the small canals in the region (King, et al. 2005, King and Maitland 2003). An important aspect of lining canals or installing pipelines is related to annual Operations and Maintenance (O&M) costs. Based on a cost study for South Texas, changes in conventional canal costs including earthen and concrete compared to a pipeline are listed in Table 14. Installation of pipelines results in a reduction in annual O&M costs of $8,106.70 per mile. Therefore, annual savings in O&M costs over the length of canals modified to pipeline is an estimated $1,670,772. Lower pipeline O&M costs are attributable in part to reduced clean-up costs of trash and other debris. By discounting this to a present value at 5.5%, the savings are $24,281,671 thereby reducing the present value of costs for pipeline to $123,354,198. The pipeline cost ranges between $1,652and $5,190 per acre-foot of water conserved. Because the District is considering an adjustment from canals to pipeline, the basis of this analysis is expected costs associated with installation and operation and maintenance of a pipeline. This means a savings on operation and maintenance compared to the current situation.

For comparison, shifting from an earthen canal to lining a canal, there would be the investment of $135,624,119 plus the annual operating and repairs of $9,088. Because operation and maintenance is incurred, the added cost (investment) for lining would range between $1,816 and $5,707 per acre-foot of water saved. In part, because of the difference in O&M costs, canal lining costs are about 10 percent higher than installing and operating a pipeline for the District.

Table 13 Average Total Construction Costs per Mile for Lining and for Pipeline Installation for South Texas, 2002-2004.

Type	Average Initial Construction Costs ($/mile)
Lining (installation) projects	658,082
Pipeline (installation) projects	716,366

Sources: Rister, et.al. 2004, 2005[a], 2005[b], 2006, 2007 and Sturdivant, et.al. 2005, 2006.

Table 14 Annual Operation and Management Associated with 'Canal to Pipeline' Projects in the Texas Lower Rio Grande Valley (2002-2004 Dollars).

		Annual O&M Cost Per Mile ($/mile) for Select Irrigation Districts (basis 2002-2004 dollars) [Going from an old Canal to a new Pipeline]		
ID	Town	(+) new O&M for Pipeline to be incurred with pipeline project ($/mile)	(-) old O&M for Canal to be gotten rid of with pipeline project ($/mile)	Net Change in Annual O&M ($/mile)
HIDCC#1	Harlingen	200.00	1,600.00	(1,400.00)
HCID#1	San Juan	1,246.38	17,014.04	(15,767.66)
HCID#2	Edinburg	1,405.33	18,597.56	(17,192.23)
CCID#2	San Benito	636.06	2,744.29	(2,108.23)
MCWID#1	Eagle Pass	500.00	8,237.00	(7,737.00)
UID	Mission	1,900.74	6,335.81	(4,435.07)
Average		**981.42**	**9,088.12**	**(8,106.70)**

Source: Rister, et.al. 2004, 2005 [a], 2005 [b], 2006, 2007 and Sturdivant, et.al. 2005, 2006.

For the record of drought, the canals carry less water suggesting that there is less lost to seepage. Therefore, the potential savings would be less than that for a normal year. For a conservative estimate, a lower value for potential water savings is selected (approximately 25,000 acre feet). Using a water savings of 25,000 acre feet suggests that the present value of the cost of a pipeline would be approximately $4,900 per acre foot. This value applies to the year(s) of drought of record. Other years would be associated with greater savings and therefore a reduction in cost per acre foot of water. During the drought of record, the value of an acre foot of water would be expected to be more valuable than during a normal year.

Converting the present value of total cost per acre foot of water conserved for pipeline involves amortizing the cost per acre foot across the 30 year life expectancy. Using a discount rate of 5.5% gives an annual cost of $339 per acre foot based on the $4,900 dollars present value total cost. With a greater level of savings the annual costs come down. Taking the expected level of water savings as the average between the low and high suggests an annual average water savings of about 50,000 acre feet. For 50,000 acre feet of annual savings, the present value of cost is $2,467 per acre foot. On an annual average cost basis per acre foot this would be $170. So this analysis estimates that the average annual cost per acre foot saved due to pipeline installation for the year of drought would be $339, compared to $170 for an average. Expected costs associated with canal lining would be an estimated 10 percent greater than for a pipeline when considering operation and maintenance.

With potential water savings and costs established, the value of the saved water is the major point to be considered. Many studies have addressed water value. Many factors come into play including water rights, ability to move water among users, infrastructure and so on. Also, one measure can be costs avoided from having additional (conserved) water such as pumping costs avoided during the drought-of-record, comparative cost of acquiring water from other sources (import of water from other areas), or cost of production of desalinated water for that amount of water conserved. Some alternatives are presented below.

- **Pumping Costs Avoided.** By reducing the seepage of surface water more is available and can be used in place of pumped water. Appendix B presents the procedures for establishing fuel costs for pumping. At the end of the Appendix are energy requirements to pump one acre inch from alternative depths. For example from 300 feet it requires 41.8 kwh and at $0.12 per kwh cost is $5.02 per acre inch. On an acre foot basis then the cost would be $60.25, certainly less than the cost to line or install pipelines. But this does not represent the value of the water in production of agriculture crops.

- **Agriculture Value.** In a study by Ward and Michelsen (2002), they review water use for a hypothetical farm producing cotton. The bottom line of their study was that irrigation water in agriculture has an average value per acre foot between $76 and $92, still significantly less than the cost of lining.

- **Municipal Value.** Certainly the urban community can afford to pay significantly more than agriculture to assure water for the people. Particularly in times of drought, marginal units of water can be traded for very large sums. However, the goal here is to get some basis for what the city would pay for water. There is a contract between EPCWID#1 and EPWU which allows the city to purchase "surplus" water. The price in 2007-8 was approximately $300 per acre foot for one time delivery. This contract price has an escalator clause meaning over time the price rises.

- **Benefit/Cost.** Reviewing the cost per acre foot for installing pipelines for distribution canals suggests an average annual cost range from $170 to $339 per acre foot. In the case of agriculture, the costs exceed the expected value in production of crops. However, for municipal uses where the contract price is $300 per acre foot, there may be a net value during the record of drought. The key is the amount of water conserved from lining/pipelines. If indeed the water savings are 50,000 acre feet annually then there is a positive net of $130 per acre foot. However, if the savings in water are nearer the 25,000 acre feet level, then costs exceed value even in municipal use.

v. Miscellaneous Systems

According to the EPCWID #1, there is little to no *tailwater recovery and reuse systems* in El Paso County. Any tailwater that is collected is sent to the HCCRD #1 for use on agricultural lands in Hudspeth County. Discussion with district personnel and producers indicate that there is little tailwater within this district with limited loss from the bottom of the fields. Further, any losses from the district become the water supply to Hudspeth County.

Examples of tailwater runoff values from irrigated fields within surface water delivery projects are given in Table 15.

Table 15 Tailwater Runoff from Surface Irrigated Fields Supplied by Surface Water Delivery Districts.

Crop	Tailwater % of delivery	**Average**
Alfalfa	14-18	15
Cotton	6-26	16
Vegetables		
Onion	25-37	33
Lettuce	25-30	28
Melons	17-37	27
Bermuda Grass	14-30	20
Sugar Beets	15-28	22
Overall Average	**15-24**	**19**

Source: Sources for this data include Boyle Engineering; 1990; Hamburg, 1980; Oster, et al. 1986; Gilley, et al., 2003; and O'Halloran, 1990.
Note: The variation between individual irrigations on the same field can be quite large, by a factor between 20-100%, depending upon the management practices and "control" of the irrigation water. Data from national studies by the Bureau of Reclamation indicated runoff values less than 5% and greater than 40% with a national average of 15.1%.

Based upon studies from previous research, typical annual costs for tailwater systems range between \$39 and \$69 per acre per year for pump systems, and between \$76 and \$154 per acre per year for reservoir systems (Gilley et al., 2003 and updated to 2008 costs). Examples are shown in Table 16.

Table 16 Cost Estimate for a Typical Pump Tailwater Reuse System for Various Field Systems.

Field area (acres)	Capital Costs (\$/acre)	O+M cost (\$/acre)	**Total Cost (\$/acre)**
73	56.13	9.83	**69**
145	35.98	5.60	**45**
290	31.85	3.82	**39**

Note: Total costs included capital costs (pump, pump pipe, motor, etc.), maintenance cost, operating cost, and agronomic benefits. The average cost over all crops and field sizes, was \$60.38 (updated to July 2008 costs).
Source: Gilley, et al. (2003) Cost Values were updated to July 2008 using the U.S. Bureau of Reclamation (2008) cost trends <http://www.usbr.gov/pmts/estimate/cost_trend.html> July 1998 to July 2008 → 1.498

Using an estimated 7.5% water savings from the installation of tailwater reuse systems, over 33% of the irrigated lands in the district (Table 17) would result in an approximate water savings of 6,300 acre feet in a “full water” year and a savings of 1,700 acre feet in a drought year. The cost for this conserved water would be approximately $185 per acre foot in a normal year and $529 per acre foot in a drought year (Table 18). From a regional perspective the fact that Hudspeth County is dependant on return flow, spills and such from El Paso County dramatically conflicts and any evaluation of water savings.

Automation and telemetry have been used by the EPCWID #1 for several years and have improved the water delivery system for the District. Automated gates have been installed at several turnouts and headgates; however, little additional water savings are projected from the expanded use of automation and telemetry.

Several small potential *regulating reservoirs* can be found in El Paso County, and could be used for the purposes of diverting and/or storing water. For example, the area known as the Socorro ponds have potential to capture stormwater flow several times a year. Each pond is approximately 400 acres by 10 feet. Stormwater flows and operational spills could also be sent to Ascarate Lake. Also, with the help of a pumping station, water quality could be expected to improve as the lake acts as a storage reservoir. Other studies are in progress for these two sites.

Assumptions used for EPCWID#1’s water conservation and costs for selected BMP strategies are summarized in Table 17. Water savings and cost estimates under both drought and full supply conditions are shown in Table 18.

A note on how EPCWID#1 water conservation impacts HCCRD#1. Both EPCWID #1 and HCCRD #1 receive surface water via the Rio Grande. HCCRD #1 irrigation water supply is a function of drainage, return flows, and spills from EPCWID #1. This suggests water conservation in EPCWID #1 essentially reduces available water to HCCRD #1, complicating an analysis of irrigation water conservation options as both districts are interrelated.

Table 17 Water Conservation Assumptions for EPCWID #1.

BMP Strategy	Description
Irrigation scheduling under normal supply	10% conservation, over 20% of the land area
Irrigation scheduling under drought	5% conservation, over 20% of the land area
Cost is $12/acre based upon EQIP values for Far West Texas (NRCS, 2008b)	
Tailwater reuse under normal supply	7.5% conservation, over 33% of the land area
Tailwater reuse under drought	3% conservation over, over 33% of the land area
Cost is $69/acre. (Gilley, et al., 2003)	

Table 18 Summary of Water Savings and Cost Estimates for EPCWID #1.

BMP Strategy	Water Savings (af)		Annual Cost ($)		Unit Cost ($/af)	
	Drought	Full	Drought	Full	Drought	Full
Scheduling	1,740	5,070	96,000	122,400	**55.17**	**24.14**
Pipelines for District Canals*	25,000	50,000	8,487,434	8,487,434	**339**	**170**
Tailwater Reuse	1,723	6,274	910,800	1,161,270	**529**	**185**

*Present value of annual cost including capital cost and annual operating and maintenance (discount rate of 5.5% over 30 year life expectancy), using 206 miles of canals.

2. Strategies for Hudspeth County Conservation and Reclamation District #1

The FWT Water Plan recommended conservation strategies, current practices and application potential for HCCRD#1 are shown in Table 19. The first column lists the Irrigation Best Management Practice (BMP) while the second column lists each individual strategy. The third column indicates whether the strategy is currently being used in the district and the fourth column indicates if the strategy would be expected to result in additional water savings. The fifth column includes comments and clarifications relative to the status of the stated strategy.

Little opportunity for water savings were identified within the HCCRD #1. Major obstacles impeding implementation of water conservation strategies include a stochastic water supply dependent upon return flows from the EPCWID #1, water quality, crop mixes, and soil types. Each strategy is discussed below.

i. Agricultural Water Use Management

Some producers in the District schedule irrigation events. Therefore, *irrigation scheduling* practices, if utilized across the district, would result in some small water savings. However, producers in Hudspeth are more vulnerable to water availability because water deliveries are return flow dependent and tend to irrigate when water is available. There is no water savings expected during drought.

As described earlier, the opportunities for water conservation through utilization of irrigation scheduling practices within HCCRD #1 are quite limited. Nevertheless, it is anticipated that the practice could result in some conservation in normal water supply years if utilized by more users. Using an estimated 5% reduction through irrigation scheduling over 50% of the irrigated area (Table 20) would result in a savings of approximately 1,275 acre-feet in a normal year at a cost of $63/acre-foot (Table 21).

Water metering is practiced by the HCCRD #1, with each water turnout being metered. Individual irrigations are no longer metered but can be re-metered at the request of the producer. Little additional water savings are possible since the strategy is already in practice.

HCCRD#1 does not practice *crop residue management* or *conservation tillage* due to the current crop mix and soil types; however, this strategy is applicable to the area with a potential for minimum tillage programs. Only minimal water savings are expected from this strategy.

The HCCRD #1 does not conduct *on-farm irrigation audits*. Opportunities for very limited improved water use efficiency and water savings may be identified from the implementation of on-farm audits, but are not projected to be cost effective. Expected water savings are difficult to quantify.

ii. Land Management Systems

An estimated 100 percent of local producers within HCCRD #1 have laser-leveled their land in an effort to conserve water and make the production of crops more efficient. Water conserved through land leveling is difficult to quantify. No additional water savings are expected to be made from the continued use of land leveling as a conservation strategy because it is in place.

iii. On-Farm Water Delivery Systems

The *lining of on-farm irrigation ditches* has been practiced in HCCRD #1 for some time. An estimated 100 percent of on-farm irrigation ditches in the HCCRD #1 are concrete-lined. Studies quantifying water conserved by reducing seepage losses at the farm level have yet to be conducted. For this study it is not relevant since the practice has already been adopted.

The replacement of on-farm irrigation ditches with pipeline is not currently practiced in HCCRD #1. Implementation of this strategy may result in some water savings from reduce seepage of unlined ditches. Studies quantifying water conserved by reducing seepage losses at the farm level have yet to be conducted. The issue is one of significant costs and highly variable timing of supply. Hence, it is not considered to be cost effective.

Pressurized irrigation systems, including low pressure center pivot, drip/micro irrigation, gated and/or flexible pipe, surge flow, and linear move sprinkler systems, are currently not used in the HCCRD #1. Major obstacles to pressurized systems are water availability, water quality, soil types, crop mixes and filtration costs. A continuous steady flow of water is also needed for the pressurized systems to function properly. For these reasons, pressurized irrigation systems are deemed inapplicable to the HCCRD #1 and are not economically feasible.

Table 19 Hudspeth County Conservation and Reclamation District #1 Summary of Proposed Irrigation Conservation Strategies.

Best Management Practice	Irrigation Strategy	Currently Practiced	Applicability & Potential for Additional Water Savings	Comments
Agricultural Water Use Management	Irrigation Scheduling	No	Limited	Return flow dependent
	Volumetric Measurement of Irrigation Water	Yes	No	In place of turnouts
	Crop Residue Management and Conservation Tillage	No	NA	Not applicable crops or soils
	On-Farm Irrigation Audits	No	Small	Marginal savings, small field
Land Management Systems	Land Leveling	Yes	No	Adopted
On-Farm Water Delivery Systems	Lining of On-Farm Irrigation Ditches	Yes	No	Adopted
	Replacement of On-Farm Ditches with Pipeline	No	No	Cost prohibitive
	Low-Pressure Center Pivot Sprinkler Systems	No	NA	System operation not viable
	Drip/Micro Irrigation Systems	No	NA	System operation not viable
	Gated/Flexible Pipe (Field Water Distribution)	No	NA	System operation not viable
	Surge Flow Irrigation (Field Water Distribution)	No	NA	System operation not viable
	Linear Move Sprinkler Irrigation System	No	NA	System operation not viable
Water District Delivery Systems	Lining of District Canals/Lateral Canals	No	Yes	Cost prohibitive
	Replacement of District Canals/Lateral Canals with Pipeline	No	Yes	Cost prohibitive
Miscellaneous Systems	Tailwater Recovery and Reuse System	No	Small	Limited volume, costly
	Automation and Telemetry	Yes	Small	Basic telemetry in place automation needed
	Regulating Reservoirs	Yes	Yes	3 in place additional site under study

Source: Interviews, analysis of practices and potential savings, results from other studies.

iv. Water District Delivery Systems

Despite the anticipated water savings from *lining district canals and lateral canals* in EPCWID #1, as well as the *replacement of district canals and lateral canals with pipeline*, these two strategies not considered viable alternatives for implementation in the HCCRD #1.

Hudspeth County is dependent upon return flows and river flow below El Paso County. There is only irrigation water demand and no local urban or municipal demand. Although the seepage rates will not be the same as in El Paso County, the analysis for El Paso County serves as an excellent proxy for Hudspeth County. Since Hudspeth County is only agricultural irrigation then based on costs for lining or installing pipelines of over $170 per acre foot, it is concluded that the value of the water in irrigation would be significantly less. Therefore, it is not economically feasible for Hudspeth County to engage in lining or pipeline installation.

v. Miscellaneous Systems

Currently, there is no *tailwater recovery and reuse system* in place for the HCCRD #1. Most of the irrigations result in little or no runoff. Assuming modest volumes of runoff (5% in normal years and 3% in drought years shown in Table 20), results in only 1,225 acre-feet in normal years at a cost of $364 per acre-foot (Table 21). Accordingly, there is little opportunity for water conservation with tailwater reuse system in the HCCRD #1. Irrigations yield little to no tailwater, making a tailwater recovery system futile and ineffective.

The HCCRD #1 does use *telemetry* and has improved water delivery. Limited additional water savings are projected from automation as well as cost prohibited.

Three *regulating reservoirs* are in operation under the HCCRD #1. The reservoirs cannot capture water but can regulate the flow. The reservoirs are doing their job with little opportunity for further enhancement.

Due to HCCRD #1's water supply being dependent on what comes from EPCWID #1, irrigation water is erratic and variable in quality and timing, placing the farmers in a "use it or lose it" situation. If the water becomes available, the only choice is to apply irrigation with little to no regard to audits, moisture blocks or other management strategies.

Assumptions used for HCCRD#1**'s** water conservation and costs for selected BMP strategies are summarized in Table 20. Water savings and cost estimates under both drought and full supply conditions are shown in Table 21.

Table 20 Water Conservation Assumptions for HCCRD#1.

BMP Strategy	Description
Irrigation scheduling under normal supply	10% conservation, over 20% of the land area
Irrigation scheduling under drought	5% conservation, over 20% of the land area
Cost is $12/acre based upon EQIP values for Far West Texas (NRCS, 2008b)	
Tailwater reuse under normal supply	5% conservation, over 33% of the land area
Tailwater reuse under drought	0% conservation over, over 33% of the land area
Cost is $69/acre (Gilley, et al., 2003)	

Table 21 Summery of Water Savings and Cost Estimates for HCCRD#1.

BMP Strategy	Water Savings (af)		Annual Cost ($)		Unit Cost ($/af)	
	Drought	Full	Drought	Full	Drought	Full
Scheduling	0	1,275	38,400	80,700	NA	63.29
Tailwater Reuse	0	1,275	220,800	464,025	NA	364

3. Strategies for Hudspeth County Underground Water Conservation District #1

FWT Water Plan recommended conservation strategies, current practices and application potential for Hudspeth County Underground Water Conservation District #1 are summarized in Table 22. The first column lists the Irrigation Best Management Practices (BMP) while the second column lists each individual irrigation strategy. The third column indicates whether the strategy is currently being used in the district and the fourth column indicates if the strategy would be expected to result in additional water savings. The fifth column includes comments and clarifications relative to the status of the stated strategy.

Several strategies were identified as having water savings potential for the HCUWCD #1: irrigation scheduling, on-farm ditch replacement with pipeline, the use of gated pipe, and an improved tailwater recovery and reuse system. Each strategy is discussed in further detail below.

i. Agricultural Water Use Management

Irrigation scheduling using soil moisture measuring equipment is not widely practiced in the HCUWCD #1. Current scheduling is based on knowledge and experience with crop growth patterns, such as irrigating chile more frequently during establishment, reducing irrigation in late spring to encourage deeper root system growth, and then regular irrigations during the remaining production season. Implementation of soil moisture measurement practices with center-pivot irrigation systems, primarily used for alfalfa production, could result in potential water

Table 22 Hudspeth County Underground Water Conservation District #1 Summary of Proposed Irrigation Conservation Strategies.

Best Management Practice	Irrigation Strategy	Currently Practiced	Applicability & Potential for Additional Water Savings	Comments
Agricultural Water Use Management	Irrigation Scheduling	No	Yes	Irrigation scheduling could reduce pumping
	Volumetric Measurement of Irrigation Water	Yes	No	Adopted
	Crop Residue Management and Conservation Tillage	Yes	No	No till practiced
	On-Farm Irrigation Audits	No	Small	Part of metering and scheduling
Land Management Systems	Land Leveling	Yes	Done	Surface field leveled, not needed for pivot
On-Farm Water Delivery Systems	Lining of On-Farm Irrigation Ditches	Yes	Small	Adopted (NA for non flood irrigation)
	Replacement of On-Farm Ditches with Pipeline	Yes	Small	5% remaining, cost prohibitive
	Low-Pressure Center Pivot Sprinkler Systems	Yes	No	Adopted
	Drip/Micro Irrigation Systems	No	Small	Cost, Water quality, selected crops
	Gated/Flexible Pipe (Field Water Distribution)	Yes	Small	Limited for surface irrigation not already in gated pipe
	Surge Flow Irrigation (Field Water Distribution)	No	NA	No gain with alfalfa (no furrow)
	Linear Move Sprinkler Irrigation System	Yes	Small	No saving over pivot, could increase irrigated acreage
Water District Delivery Systems	Lining of District Canals/Lateral Canals	No	NA	No district canals
	Replacement of District Canals/Lateral Canals with Pipeline	No	NA	No district canals
Miscellaneous Systems	Tailwater Recovery and Reuse System	Yes	Small	Could apply to remaining surface water acres
	Automation and Telemetry	NA	NA	Individual wells. GW level is monitored.
	Regulating Reservoirs	NA	NA	Aquifer is a underground reservoir

Source: Interviews, analysis of practices and potential savings, results from other studies.

conservation. Estimated savings ranges between 5% and 15% of the water pumped. Costs for the services are similar to those indicted in the EPCWID #1 analysis with some slight reductions because of the concentration of irrigation systems and the irrigated area under each system. Water conservation for surface irrigated fields is estimated to range between 10% and 20% of the water pumped. Costs are similar as those listed for the EPCWID #1 and were taken from California experiences. Cost per acre is expected to range from $10 to $20 per acre.

In addition to the water savings resulting from the incorporation of irrigation scheduling practices, the producers will have a cost reduction resulting from a lower volume of water pumped. The magnitude of this economic savings depends upon the volume of water saved and the energy used to pump the water. Calculations provided in Appendix B indicate a fixed costs savings between $3.40 and $6.50 per acre-inch ($40.80 and $78.00) per acre-foot. These savings will often be more then the "irrigation scheduling" costs, thus providing addition incentive to improve irrigation management practices (Gilley and Supalla, 1983).

The *volumetric measurements of irrigation water* and *conservation tillage* are practiced within the HCUWCD #1. Each groundwater well is equipped with its own meter that aids producers in gauging the amount of water that is being pumped from the Bone Spring-Victorio Peak Aquifer. This strategy is being used so there is no opportunity to expand.

On-farm irrigation audits are not practiced in the HCUWCD #1. Opportunities for improved water use efficiency and water savings may be identified from the implementation of on-farm audits. Expected water savings are difficult to quantify. This strategy is not deemed to be a significant water conservation option.

ii. Land Management Systems

Land leveling is in place for furrow irrigated crops. There is little to no opportunity for expansion or added water savings.

iii. On-Farm Water Delivery Systems

Existing on-farm irrigation ditches have already been concrete-lined. The *replacement of on-farm irrigation ditches with pipeline* is applicable to the Dell City area and would result in marginal water savings but the cost is prohibitive. An estimated 5 percent of remaining ditches can be replaced with pipeline but again the cost outweighs the benefits. With irrigation wells there is not a need for a large set of ditches and canals.

Low-pressure center pivot sprinkler systems, *gated/flexible pipe,* and *linear move sprinkler irrigation systems* are currently in use in the HCUWCD #1, demonstrating their applicability to the area. Estimated water savings from these systems would be the quantity of water saved from reduction of seepage loss from the head ditch on the field. Costs include the installation of the pressurized systems. PVC pipe is used on pivot systems due to the region's water quality. Three different brands of center pivot systems are used in the region; all three can be classified under the LESA and/or MESA systems. The linear move sprinkler system used in the region can be classified as a LESA system. Water savings from moving from surface irrigation to linear move systems would be the improvements in "irrigation efficiency" between the two systems. However, with laser-leveled and mostly flood irrigated alfalfa, very little improvement in water use efficiency is projected.

Drip/micro irrigation systems are not applicable to the HCUWCD #1 due to the water quality and the types of crops grown; therefore, no water savings are expected from drip/micro irrigation systems. *Surge flow irrigation* could be used but small fields and growing alfalfa limited any potential water savings. No water savings are expected for this strategy.

iv. Water District Delivery Systems

The HCUWCD #1 manages the production of groundwater from the Bone-Spring Victorio Peak Aquifer and manages wells within its jurisdiction. It is not charged with delivering irrigation water to individual producers because there are wells scattered across the landscape. Therefore, the suggested strategies of *lining district canals and lateral canals* and the *replacement of district canals and lateral canals with pipeline* are inapplicable to the HCUWCD #1. No water savings are anticipated from this BMP.

v. Miscellaneous Systems

The HCUWCD #1 currently has tailwater recovery and reuse systems on a substantial portion of their irrigated farms. The installation of similar systems on the remaining irrigated fields may yield an estimated 7.5 to 15% water savings in irrigated water pumped on these farms (Table 23). The actual water savings that would be the amount of water currently lost to tailwater runoff which is highly variable depending upon several of irrigation management factors. Furthermore, some farms collect tailwater from the upper fields being irrigated first and use this water to irrigate lower fields, suggesting the strategy is already used. Lacking field data from this location, one could estimate the amount of tailwater runoff from other similar surface-water supplied irrigation districts and those from other areas served by pumped groundwater.

Historical studies conducted by Gilley and Supalla, 1983 (and others) have found improvements in irrigation system performance between 10 and 25 percent through incorporation of a tailwater runoff reuse system. The amount of surface tailwater runoff from crops similar to those found in the district and cost for tailwater reuse systems are provided in Table 15 and Table 16

Estimated costs for water conservation using tailwater recovery systems are between $104 and $329 per acre-foot (Table 24) using the cost values listed in Table 16. However, there will be an energy savings (and corresponding cost benefit) from reduced water pumping as the total volume of water pumped will be reduced by the volume of water “re-circulated” by the tailwater recovery system. This savings ($) depends upon the pumping lift required from the groundwater levels to the soil surface, the pipe friction losses from the well to the irrigated field, the volume of water saved, the pump efficiency, and the energy cost. The values will be grower dependent. Approximate values would range between $3.40 and $6.50 per acre-inch ($40.80 and $78.00) as shown in Appendix B.

Table 23 Water Conservation Assumptions for HCUWCD #1.

BMP Strategy	Description
Center Pivots/Sprinklers	
Irrigation scheduling under normal supply	10% conservation over all the area irrigated by center pivots (75% of total area)
Irrigation scheduling under drought	5% conservation over all the area irrigated by center pivots
Cost $12 per acre includes associated energy savings from reduced water pumping.	
Surface Irrigation	
Irrigation scheduling under normal supply	15% conservation over all the area with surface irrigation (25% of the total area)
Irrigation scheduling under drought	7.5% conservation over all the area with surface irrigation
Tailwater reuse under normal supply	15% conservation over 50% of the surface irrigation area
Tailwater reuse under drought	7.5% conservation over 50% of the surface irrigation area
Cost $69 per acre includes associated energy savings from reduced water pumping. Gilley, et al. (2003).	

Table 24 Summary of Water Savings and Cost Estimates for HCUWC#1.

BMP Strategy	Water Savings (af)		Annual Cost ($)		Unit Cost ($/af)	
	Drought	Full	Drought	Full	Drought	Full
Scheduling						
Pivot/sprinkler	2,357	7,453	202,920	202,920	**83**	**27**
Surface irrigation	1,178	3,726	67,650	37,650	**57**	**18**
Tailwater Reuse						
Surface irrigation	589	1,863	194,063	194,063	**329**	**104**

Depending upon the local condition and the current irrigation management practices of the grower, the installation of tailwater water recovery system might actually result in an economic benefit. The energy savings from reduced water pumping could be more than the cost of installing a tailwater recovery system. For systems with pumping lifts greater than 150-200 feet, the installation of a tailwater recovery system had positive economic benefits (Gilley and Supalla, 1983).

Some *automation and telemetry* is used in the pumping of water from the Bone Spring-Victorio Peak Aquifer and in the use of center pivot and linear move irrigation systems. No additional water savings are projected from additional adoption of automation and telemetry.

Assumptions used for HCCWC#1's water conservation and costs for selected BMP strategies are summarized Table 23. Water savings and cost estimates under both drought and full supply conditions are shown in Table 24. In addition, energy savings from reduced pumping can offset the cost for implementing BMP strategies as listed in Table 25.

Table 25 Reduced Pumping Costs for HCUWCD #1 under Alternative Strategies.

BMP Strategy	Unit Cost ($/af)	
	Drought	Full
Scheduling		
Pivots/Sprinkler	**54**	**54**
Surface irrigation	**40**	**40**
Tailwater Reuse		
Surface irrigation	**40**	**40**

Represents avoided pumping cost.

SUMMARY

This report evaluates the applicability, water savings potential, implementation feasibility and cost effectiveness of irrigated agriculture water conservation practices in Far West Texas during both drought and full water supply conditions. Agricultural, hydrologic, engineering, economic, and institutional conditions were identified and examined for three irrigation districts in El Paso and Hudspeth Counties. These three irrigation districts, the El Paso County Water Improvement District #1, the Hudspeth County Conservation and Reclamation District #1, and the Hudspeth County Underground Water Conservation District #1 account for 90% of total irrigated agricultural acreage in Far West Texas. The evaluation incorporated interviews and discussion with irrigation district managers and farmers, findings from other studies, and engineering, hydrologic, economic and institutional analyses. Factors considered included water sources, use, timing, water quality, cropping patterns, irrigation practices, delivery systems, technological alternatives, market conditions and operational constraints.

Seventeen water conservation strategies were evaluated for each of the irrigation districts. In addition to the seventeen irrigation conservation strategies evaluated, five other irrigation strategies had previously been identified by the FWTWPG as inapplicable to the Far West Texas region and were omitted from the analysis. They are: Furrow Dikes, Conversion of Irrigated Farmland to Dryland, and Brush Control Management and Production Systems, which are classified as Land Management Systems, and Nursery Production Systems, which is classified as a Miscellaneous BMP.

Applicability of a number of the strategies is closely related to the water source (surface water or ground water), delivery system (gravity flow or pump/pressurized systems) and water quality. EPCWID#1 and HCCRD#1 primarily rely on surface water with gravity flow delivery systems. HCUWCD#1 is using all ground water with the majority of delivery through pressurized systems compatible with sprinkler systems. Elevated salinity is a factor in all of the districts.

The potential water savings for both drought and full supply years, by strategy and irrigation district, are summarized in Table 26 for those strategies estimated to have water saving potential. The three districts total potential water savings during drought and full supply years are estimated to be 32,587 and 76,926 acre-feet. However, it is important to note that the cost of the most effective strategy, Pipeline/Lining of District Canals, exceeds the value of water in agricultural production. If all of these strategies were implemented, the water conserved would satisfy less than 25% of the projected unmet agricultural water demand in 2060 during drought-of-record conditions. Summaries of conservation strategy potential for each of the districts follow.

1. Strategies for El Paso County Water Improvement District #1

Three strategies were found to have viable water savings potential for producers and the EPCWID #1 (Table 18 and Table 26). Irrigation Scheduling was estimated to have a 5-10% rate of water savings, during non-drought years, for water delivered to the farm for those producers currently not using some form of irrigation scheduling. Estimated annual costs range between $24 and $55 per acre-foot with annual water savings between 1,700 and 5,000 acre-feet.

Table 26 Summary of Potential Water Savings for Three Districts, acre-feet per year.

BMP strategy	EPCWID#1		HCCRD#1		HCUWCD#1	
	Drought	Full	Drought	Full	Drought	Full
Scheduling (subtotal)	**1,740**	**5,070**	**0**	**1,275**	**3,535**	**11,179**
Pivot/Sprinkler	**-**	**-**	-	-	2,357	7,453
Surface irrigation	**-**	**-**	-	-	1,178	3,726
Pipeline/Lining District Canals	**25,000**	**50,000**	-	-	NA	NA
Tailwater Reuse	**1,723**	**6,274**	**0**	**1,275**	**589**	**1,863**
Total	**28,463**	**61,344**	**0**	**2,550**	**4,124**	**13,032**

Data from Table 18 for EPCWID#1, Table 21 for HCCRD#1, and Table 24 for HCUWCD#1.

Estimated annual costs for installation of tailwater reuse systems range between $185 and $529 per acre-foot with water savings between 1,700 and 6,300 acre-feet. Water savings from lining District canals and laterals, as well as the Replacement of District Canals with Pipelines, was estimated at a reduction of 80% of seepage losses.

The average annual cost for a pipeline was estimated at $170 to $339 per acre foot (and 10 percent higher for lining of canals), higher than the value in irrigated agriculture. When adding in the value for avoided pumping costs and municipal value, it is a cost-effective BMP. It should be noted that implementation of a large scale canal lining project will reduce or eliminate a large component of recharge to the underlying aquifer system. The District is currently evaluating the expansion of canal lining and pipeline implementation. Therefore if implemented, this could affect groundwater availability and water supply strategies that rely upon these groundwater resources and these would need to be reevaluated in future regional water plans.

Several suggested strategies have already been completed in the area and the potential for water savings have already been realized. These strategies include the Volumetric Measurement of Irrigation Water, Land Leveling, Lining of On-Farm Irrigation Ditches, and Automation and Telemetry. All pressurized systems were considered inapplicable to the study area due to water quality, the pre-dominate use of surface water, gravity flow irrigation methods, and the water delivery system. Other strategies deemed inapplicable to the study area included Crop Residue Management and Conservation Tillage, Regulating Reservoirs, and Tailwater Recovery and Reuse Systems.

2. Strategies for Hudspeth County Conservation and Reclamation District #1

Results for the analysis of HCCRD #1 were similar to the results from EPCWID #1; however, since water availability is dependent on return flows from the EPCWID #1, water savings are more difficult to quantify. Irrigation Scheduling and Tailwater Reuse were found to have potential for future water savings (Table 21 and Table 26). Maximum annual water savings ranged between 0 and 1,300 acre-feet with annual costs between $63 and $364 per acre-foot.

Strategies that have already been completed in the HCCRD #1, thus resulting in no new water savings, include the Volumetric Measurement of Irrigation Water, Land Leveling, Lining of On-Farm Irrigation Ditches, and Automation and Telemetry. All pressurized systems were considered inapplicable to the study area due to water quality, the pre-dominate use of surface water, gravity flow irrigation methods, and the water delivery system. Other strategies deemed inapplicable to the study area included Crop Residue Management and Conservation Tillage and Regulating Reservoirs.

3. Strategies for Hudspeth County Underground Water Conservation District #1

Results from analyzing the groundwater district in this study revealed that there are potential opportunities for water savings from Irrigation Scheduling, the expanded use of Linear Move Sprinkler Irrigation Systems, and improvements to current Tailwater Recover and Reuse Systems (Table 24 and Table 26). Estimated savings from Irrigation Scheduling were between 7% and 15% of water pumped with costs ranging between $18 and $83 per acre-foot. Additional savings are possible from reduced pumping costs (Table 25). By improving current tailwater recovery and reuse systems, between 10-15% water savings are expected with costs ranging between $104 and $329 per acre-foot.

Suggested strategies that have already been implemented in the Dell City area and therefore have already realized potential water savings include the Volumetric Measurement of Irrigation Water, Crop Residue Management and Conservation Tillage, Land Leveling, Lining of On-Farm Irrigation Ditches, Low Pressure Center Pivot Sprinkler Systems, the use of Gated/Flexible Pipe for field water distribution, and the regulating of the aquifer.

Strategies deemed inapplicable due to water quality and crop mix include Drip/Micro Irrigation Systems and Surge Flow Irrigation. Since there is not a District canal system, then the Lining of District Canals, the Replacement of District Canals with Pipeline, and Automation and Telemetry are not relevant.

RECOMMENDATIONS

The overall conclusion of this analysis is that very limited opportunities exist for significant additional water conservation in Far West Texas irrigated agriculture. The primary reasons can be summarized by: the most effective conservation practices have already been implemented and associated water savings realized throughout the region; reduced water quality and the physical nature of gravity flow delivery limit or prohibit implementation of higher efficiency pressurized irrigation systems; increased water use efficiency upstream has the net effect of reducing water supplies and production of downstream irrigators; and, water conservation implementation costs for a number of practices exceed the agricultural value and benefits of any water saved.

The three recommended practices with potential to save water are pipeline/lining of irrigation district canals in the El Paso County Water Improvement District No. 1, irrigation scheduling for all three districts and tailwater reuse for all three districts. In nearly all cases, these practices have been adopted to a large extent if applicable, further emphasizing the very limited opportunities for additional conservation.

While the greatest water savings would come from pipeline/lining of irrigation district canals, the cost exceeds most agricultural water values. If the main objective is to conserve water then additional funding from other sources such as the TWDB, City of El Paso or U.S. Bureau of Reclamation is recommended.

It should also be noted that pipeline/lining canals will reduce or eliminate recharge to the underlying aquifers in those areas. This will affect groundwater availability for future water supplies and integrated water resources management strategies for the region. Therefore, additional study is recommended on the impacts on groundwater availability of pipeline/lining irrigation district canals so that future management strategies can account for changes in water supply conditions.

This study's conclusion that there are very limited opportunities for significant additional water conservation has important implications, not just to the Far West Texas Water Plan but also to other Regional Water Plans. It is clear that additional agricultural conservation, even including the practices that are not economically feasible, will not satisfy projected unmet agricultural water demand in Far West Texas. The implementation of water conservation Best Management Practices in irrigated agriculture is also identified as a strategy to satisfy unmet demand for water during drought in 11 of the other 16 Texas State Water Planning Regions. While water resource and irrigated agricultural conditions in Far West Texas are unique, there are also some similarities with other regions in Texas that have limited water supplies and competition for available water resources. Therefore, in other State Water Planning Regions where Texas Water Development Board, Water Conservation Best Management Practices Guide, practices have been identified to satisfy unmet water demand, it is recommended Region specific assessment of the applicability and effectiveness of conservation strategies be conducted.

Overall, there are no silver bullets for agricultural water conservation in Far West Texas short of taking irrigated land out of production when water supplies are limited.

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Appendix A: Texas Water Development Board's Best Management Practices

Table A-1. Texas Water Development Board's Best Management Practice: Agricultural Water Use Management Systems

BMP	Strategy	Applicability	Description	Schedule	Scope	Water Savings	Cost Considerations
Agricultural Water Use Management	**Irrigation Scheduling**	For producers who have access to adequate quantities of irrigation water at required times; applicable to nursery/floral irrigation systems with adequate water supply and delivery systems; used to determine when to irrigate a crop	Scheduling time and amount of water applied to a crop based on amount of water present in the crop root zone, amount of water consumed by the crop since the last irrigation, and other considerations; direct measurement methods and soil water balance equations	Anytime during crop production; usually established before 1st crop irrigation	Must be able to balance both the demand by the crop for water and the amount of labor and water supply available; balance cost of irrigation with risk of reducing crop yield and/or quality if water is delayed	Difficult to quantify; varies from year to year; influenced by climatic variation, cropping practices, water quality, water quantity; estimated savings of 0.3 to 0.5 af per acre	Varies depending on method of scheduling used, number of fields scheduled, type of program, and cost of technical assistance
	Volumetric Measurement of Irrigation water	Agricultural irrigation systems and producers that irrigate	Provides information needed to assess performance of irrigation system and better manage crops; direct methods (meters, ultrasonic, weirs, flumes, velocity); indirect methods (energy used, water pressure, design specifications	Installation time of meters vary	Methods vary from site to site; simple to complex	Does not directly conserve water; information can be used to implement voluntary conservation measures	Varies from application to application; impeller meter installations (4 to 15 in) cost $600-$1,000 per meter; installation of a large open channel flow meter, tens of thousands of dollars
	Crop Residue Mgmt and Conservation Tillage	For irrigated crops and most producers using irrigation water; conservation tillage applicable to both irrigated and dryland farming	Includes no till, strip till, mulch tillage, and ridge till; allows for the management of the amount, orientation, and distribution of crop and other plant residue on soil surface year-round; Improves ability of soil to retain moisture, reduces amount of run-off, and evaporation	May be practiced continuously throughout crop sequence or as part of a residue management system with other tillage methods	Crop residue in furrows may impede water flow & cause problems with irrigation uniformity and application efficiency; may be more appropriate with some types of irrigation systems than others (works well with low-pressure center pivot & subsurface drip irrigation)	Varies by climate and irrigation method; may allow farmer to conserve 1 or more irrigation applications per year from increased soil moisture (0.25 to 0.5 acre feet per acre); reduction in soil moisture loss during irrigation season, an additional 0.5 acre-foot per acre	Varies depending on type of field operation used to manage crop residues; some conservation tillage programs may be less expensive than conventional tillage

Source: Texas Water Development Board, Best Management Practices Guide, 2004

Table A-2. Texas Water Development Board's Best Management Practice: Land Management Systems

BMP	Strategy	Applicability	Description	Schedule	Scope	Water Savings	Cost Considerations
Land Management Systems	**On-Farm Irrigation Audits**	For producers who currently use on-farm irrigation	Method for accounting for all water usage for on-farm irrigation; can identify opportunities to improve water efficiency; may increase energy savings and reduce chemical costs; includes measurements of water entering farm or withdrawn from an aquifer	Audits must be completed in a timely manner; recommendations should be implemented within the first normal budget cycle following the conclusion of the audits	Water users with one or several farms should conduct a water audit following guidelines listed in the BMP guide	Does not directly conserve water; information can be used to implement other BMPs	Varies from audit to audit; costs may be minimal to significant depending on the extent of the audit
	Furrow Dikes	Used to reduce water runoff from row crops; intended for use by producers that plant row crops	Small earthen dams formed periodically between furrow ridges; reduce runoff from soil surface and increase rain and water infiltration; can be used on gently sloping land in arid and semiarid areas	Typically installed in non-wheel traffic rows when crop bedding is prepared and is reinstalled or maintained as necessary during growing season	Installed using a tractor-drawn implement; can be used in conjunction with a conventional or conservation tillage practice	Difficult to quantify; depends on when dikes are installed, amount of rainfall, rainfall intensity, infiltration rate of soil, slope of furrow, and application rate of the sprinkler system; quantity of runoff in crop field without dikes is equal to 12% of the gross quantity of water applied using sprinkler irrigation; quantity of water saved varies from field to field, season to season; conservative estimates are 3 in/season or 0.25 acre-feet per acre	Cost for purchasing/constructing a furrow dike implement ranges from less than $2,000 to several thousand; cost estimates per crop season per acre range from $5 to $30 per acre
	Land Leveling	For producers who use furrow, border, or basin irrigating	Used to increase uniformity of water applied to an irrigated field; mechanized grading of agricultural land based on a topographic survey; usually done using a laser	Large-scale land shaping: typical to newly irrigated land or land that has never been graded; land-level or floating of a field: prior to preparation of seed beds or borders; time to level dependent on size of land grading equipment and quantity and distance that soil must be moved	Used on mildly sloping land; contour farming used to farm modest slopes; terrace farming used for steeply sloping land; used by producers using surface methods (furrow, border, basin) to irrigate their fields; can improve drainage of non-irrigated fields	Difficult to quantify	Cost for new irrigation fields: based on soil type, cut to fill ratio, and total number of cubic years that must be cut, $50-$400; touch-up leveling based on a "per acre" or "per hour" rate; less than $40/acre; commonly $25/acre; cost per yard of cut: from $1 to$2.00 per cubic year, depending on diesel costs

Source: Texas Water Development Board, Best Management Practices Guide, 2004

Table A-2 (continued). Texas Water Development Board's Best Management Practice: Land Management Systems

BMP	Strategy	Applicability	Description	Schedule	Scope	Water Savings	Cost Considerations
Land Management Systems	**Contour Farming**	For use where crops are irrigated on moderately sloping lands	The practice of tillage, planting, and other farming operations performed on or near the contour of the field slope; most effective on slopes between 2 and 10%	Implemented at the time the field is being prepared for farming	Must determine min and max row grade, ridge height, slope lengths, and stable outlets; considerations include obstruction removal and changes in field boundaries and shape	Varies from site to site; depends on how the field was previously farmed and irrigated	Minimal cost when compared with conventional row preparation; primary cost/acre is for field layout and surveying of contours; secondary costs for small row lengths and ends of fields; cost for surveying varies from $1.00 to $3.00 per acre
	Conversion of Supplemental Irrigated Farmland to Dry-land Farmland	For producers who currently use ground or surface water as a supplement to rainfall to irrigate lands located in areas where crops can be produced without irrigating	Dry-land farming produces crops using precipitation as the source of soil moisture; crop yields for dry-land farming vary from year to year; permanent pasture is the most common type of dry-land farming	Can be implemented at the beginning of the crop growing season on a field by field basis	Can be used with other BMPs to improve water efficiency of dry-land farming	Can be estimated based on historical water use records for crop type and location	Requires complex economic and climate analysis; dryland farming can be significantly less costly than irrigated farming; must also consider possibility of a reduced crop yield
	Brush Control Management	For use by producers in riparian areas or on upland areas where sufficient rainfall or water exists; intended for use with government cost-share programs	Includes the removal, reduction, or manipulation of non-herbaceous plants by mechanical methods, chemical treatment, biological methods, prescribed burning, or a combination of methods	Typically multi-year in scope to achieve initial removal levels; requires follow-up treatments every 3 to 5 years; can be scheduled over several years to reduce costs of the project	Typically applicable to non-irrigated land in areas with sufficient rainfall, as determined by feasibility studies	Requires expert analysis; expected water yields for various levels of control/mgmt of brush in upland areas range from 0.34 to 0.55 acre-feet/yr per acre (net); estimated annual amount of water salvaged from salt cedar control/mgmt in riparian areas along Pecos River is 5 to 8 acre-feet per acre treated	Present values of total upland brush control costs per acre: from $35.57 to $203.17 for a period of 10 years (TAMU); cost of "added water": between $14.83 and $35.41 per acre-foot for the same time period; county average costs range from$150 to $200; (Salt cedar program on Pecos using aerial application: $183 to $189 per acre; resulting cost of salvaged water of $7.90 to $8.22 per acre-foot for a 3-yr treatment

Source: Texas Water Development Board, Best Management Practices Guide, 2004

Table A-3. Texas Water Development Board's Best Management Practice: On-Farm Water Delivery Systems

BMP	Strategy	Applicability	Description	Schedule	Scope	Water Savings	Cost Considerations
On-Farm Water Delivery Systems	**Lining of On-Farm Irrigation Ditches**	For producers that use open channels to convey irrigation water to fields	Accomplished by installing a fixed lining of impervious material in an existing or newly constructed irrigation field ditch; commonly used liners: Ethylene-Propylene-Diene Monomer (EPDM), urethane, and concrete; Concrete - most expensive; reinforce concrete liners - most durability buy may have largest seepage rate; urethane - low seepage but uses hazardous chemicals during installation	Time required to line a farm irrigation ditch depends on size of cross-sectional perimeter of the ditch, amount of work needed to prepare the ditch for lining, type of liner used; EPDM - usually easiest and quickest to install	Replacement of on-farm ditches is an alternative to lining the ditch; small ditches are typically candidates for replacement	Seepage rate can be estimated by conducting a ponding test with a typical section of the ditch prior to lining (calculated as af/mi/da); EPDM liner - minimal or no seepage; concrete liner - seepage depends on how liner is constructed and amount of water that seeps through cracks and expansion joints; conservative estimates: concrete liner salvages 80% of the original seepage	Installed EPDM liner: $0.85/square foot; Installed urethane: $1.43/square foot; concrete linings: from $2.50 to $3.50/square foot; each liner has different life expectancy, thus providing the need for a present-value analysis of costs
	Replacement of On-Farm Irrigation Ditches with Pipelines	Applicable to irrigated farms that use an open ditch to convey irrigation water; an alternative to ditch-lining (pipelines generally used to replace ditches with less than 2,000 gpm capacity)	Replacement of ditches with buried pipeline and appurtenances to convey water from the source to irrigated field; generally 24 inches in diameter (or less); 8 in-15 in are common; most use either PVC Plastic Irrigation Pipe (PIP) or Iron Pipe Size (IPS) PVC pipe	Time required to replace open ditch with buried PVC pipeline varies (site conditions, depth of trench, size of pipe, number of outlets, equipment); typical installation time: 100 ft/da to over 500 ft/da for a 6-12 in diameter pipeline; installed during winter or early spring	Two main limitations: cost and capacity; decision to line ditch or replace it with a pipeline is based on how much water is conveyed in the ditch	Seepage rate can be estimated by conducting a ponding test with a typical section of the ditch replacement (calculated as af/mi/da); replacement of ditch with a buried PVC pipeline would result in minimal or no seepage	Cost dependent on pipe diameter and distance between pipe factory and installation site; PIP 80 psi PVC pipe with 15 in diameter costs about $5 delivered to most of Texas; pipeline design, site prep, trenching, bedding materials, backfill, compaction, and finch work are site and project specific
	Low Pressure Center Pivot Sprinkler Irrigation System	Applicable to both arid and humid locations, most soil types, and land with flat to modest slopes; can be used for irrigating a wide variety of crops	4 types: Low Pressure Precision Application (LEPA), Low Pressure In-Canopy (LPIC), Low Elevation Spray Application (LESA), and Medium Elevation Spray Application (MESA); care must be taken to match water application rates to soil intake rates to minimize runoff	Installation of new center pivot on land previously using surface irrigation can take several weeks to months at a significant cost; implementation should be completed within one growing season of commencement of BMP to achieve max. water efficiency benefit	LEPA systems require installation of additional conservation practices (farming in a circle, use of furrow dikes)	Varies; must apply water savings equation; equation variables: annual amount of water pumped or delivered, application efficiency of non-BMP sprinkler system, and application efficiency of BMP sprinkler system	Typically $300 to $500 per acre

Source: Texas Water Development Board, Best Management Practices Guide, 2004

Table A-3 (continued). Texas Water Development Board's Best Management Practice: On-Farm Water Delivery Systems

BMP	Strategy	Applicability	Description	Schedule	Scope	Water Savings	Cost Considerations
On-Farm Water Delivery Systems	**Drip/Micro Irrigation System**	For producers of crops which have been proven to be irrigable using drip or micro-irrigation; water supply of sufficient quality to make drip/micro irrigation feasible should be available	Provides for distribution of water directly to plant root zone by means of surface or sub-surface applicators; 3 types: Micro-Spray or Bubblers, Sub-Surface (buried) Drip, Orchard Surface Drip or Microspray Irrigation; typically used on high-value crops	Typical design and constructions takes approximately 3 to 6 months for large fields; typically takes one year from planning to system operation	Amount of dissolved salts, suspended solids, and particulate in irrigation water must be tested to determine feasibility; maintenance and monitoring required to maintain system	Varies; depends on many parameters; primary reason for conversion: crop yield and quality rather than water use reduction	Typically the most capital expensive; installation costs for sub-surface range from $800 to $1,200 per acre; operation and maintenance costs vary depending on crop value and water quality
	Gated and Flexible Pipe for Field Water Distribution Systems	Applicable to producers that currently use unlined ditches to distribute water to furrow or border irrigated fields	Aka polypipe; used to convey and distribute water to furrow/border irrigated fields; gated pipe - made of aluminum or PVC; ranges in diameter from 6-12 in and lengths 20-30 ft; ports/gates installed in side of pipe at 20, 30, 36, or 40 in intervals; flexible pipe available in 12-21 in diameters in roll lengths of 1,320 ft.	Often implemented simultaneously with ditch replacement; can be implemented in one to two days if water delivery system is applicable to gated or flexible pipe	Pipe is laid out after the rows or borders are prepared; removed after the last irrigation of the season; gated pipe has long life cycle (10-40 yrs); Flexible pipe typically used 1-2 seasons; both are easy to install and remove; typically connected to a buried pipe via a pipeline riser with a hydrant	Water savings can be estimated by determining previous seepage from unlined ditch; water saved by increasing application efficiency is usually greater than water saved from reducing amount of water lost to seepage	Cost for a 12-in diameter PVC gated pipe: from $2-$2.50 per foot; flexible pipe ranges from $0.15-$0.20 per foot; it takes about 34 feet of gated or flexible pipe per acre for a field length of 1,300 feet with row spacing of 36 inches
	Surge Flow Irrigation for Field Water Distribution Systems	For producers that currently use gated or flexible pipe and who have soil types that swell and reduce infiltration rates in response to irrigation	Applies water intermittently to furrows, creating a series of on-off periods of either constant or variable time intervals; applicable to fields with medium soils; limited applicability to fields with heavy clay soils or light sandy soil	Can be implemented in one-two days if water delivery system is adaptable to gated or flexible pipe	Surge flow valves have a 5-15 yr life cycle; commonly used with gated pipe rather than flexible pipe	Water savings estimated to be between 10 and 40%; dependent on soil type and timing of operations; differences in soil texture and field slope have significant impact on actual water savings	Surge valve with an automated controller: from $800-$2,000 depending on size of valve and controller options
	Linear Move Sprinkler Irrigation Systems	Applicable to both arid and humid locations, most soil types, and land with flat to minimal slope; can be used to produce a wide variety of crops	Adaptation of the center pivot sprinkler; for use on fields not suited for center pivot systems (shape or elevation changes); composed of a series of towers that suspend the irrigation system; move laterally in direction of rows; 4 types: Low Energy Precision Application (LEPA), Low Pressure In-Canopy (LPIC), Low Elevation Spray Application (LESA), & Medium Elevation Spray Application (MESA)	Installation of a new system can take several weeks to months; implementation should be completed within one growing season of commencement of BMP to achieve max. water efficiency benefit	An agricultural water user with multiple fields can implement the Linear Move System on each field in different years or growing seasons, if timing cost-effective	Varies; must apply water savings equation; equation variables: annual amount of water pumped or delivered, application efficiency of non-BMP sprinkler system, and application efficiency of BMP sprinkler system	Purchase and installation of linear move system is typically $300 to $700 per acre

Source: Texas Water Development Board, Best Management Practices Guide, 2004

Table A-4. Texas Water Development Board's Best Management Practice: Water District Delivery Systems

BMP	Strategy	Applicability	Description	Schedule	Scope	Water Savings	Cost Considerations
Water District Delivery Systems	**Lining of District Irrigation Canals**	Applicable to any district	Accomplished by installing a fixed lining of impervious material in an existing or newly constructed irrigation canal or lateral canal; commonly used liners: Ethylene-Propylene-Diene Monomer (EPDM), urethane, and concrete	Time required to line a canal depends on size of cross-sectional perimeter of the canal, amount of work needed to prepare the canal for lining, type of liner used; specific steps required to implement this BMP depend on the type of canal liner used and the existing conditions of the canal to be lined	Each type of liner has its advantages and disadvantages; EPDM should not be used in locations subject to large animal or other traffic that might tear the liner	Seepage rate can be estimated by conducting a ponding test with a typical section of the ditch prior to lining (calculated as af/mi/da); EPDM liner - minimal or no seepage; concrete liner - seepage depends on how liner is constructed and amount of water that seeps through cracks and expansion joints; conservative estimates: concrete liner salvages 80% of the original seepage	Installed EPDM liner: \$0.85/square foot; installed urethane: \$1.43/square foot; concrete linings: from \$2.50 to \$3.50/square foot; each liner has different life expectancy, thus providing the need for a present-value analysis of costs
	Replacement of District Canals and Lateral Canals with Pipelines	Applicable to districts that use open canals and lateral canals to convey irrigation water; alternative to lining canals	The replacement of district canals and lateral canals with buried pipeline and appurtenances to convey water from source to fields; can be used to replace most types of small canals or lateral canals; district pipelines are generally 72 (or less) inches in diameter (12-48 inches most common); most use PVC plastic Irrigation Pipe (PIP) or Reinforced Concrete Pipe (RCP) with gasketed joints	Installation requires design and field engineering; replacement time varies depending on site conditions and pipe used; typically done during winter or early spring	2 primary limitations: cost and capacity; decision to line canal or replace it with a pipeline is based on how much water is conveyed in the ditch	Seepage rate can be estimated by conducting a ponding test with a typical section of the canal to be replaced (calculated as af/mi/da); replacement of canal with a buried PVC pipeline would result in minimal or no seepage	Cost is dependent on pipe diameter and distance between pipe factory and installation site; because of heavy weight and transportation costs of reinforced concrete, its usually manufactured in area of use; PIP 80 psi PVC pipe with 24 in diameter costs about \$15 to \$21 delivered to most parts of Texas; pipeline design, site prep, trenching, bedding materials, backfill, compaction, and finch work are site and project specific

Source: Texas Water Development Board, Best Management Practices Guide, 2004

Table A-5. Texas Water Development Board's Best Management Practice: Miscellaneous Systems

BMP	Strategy	Applicability	Description	Schedule	Scope	Water Savings	Cost Considerations
Miscellaneous Systems	**Tailwater Recovery and Reuse System**	Applicable to any irrigated agricultural system in which significant quantity of water, as a result of method, runs off the end of the irrigated field; typically implemented by producers that use flood or furrow irrigation	Consists of ditches or pipelines to collect tailwater and deliver water to a storage reservoir; includes pumping and pipeline system that conveys water for reuse	Construction and installation of a tailwater system varies from several days to over a month	Common limitation: the availability of land for construction of the storage reservoir such that the tailwater can be conveyed to the reservoir by gravity; secondary concerns: water quality and disease problems	Direct and indirect measurements of the volume of water captured and reused by the system can be used to determine annual volume of water saved; amount of runoff varies; not uncommon for runoff to be 15% or greater of gross volume applied to the field; typical tailwater systems reuse 0.5 to 1.5 acre-feet per acre of irrigated crop per year	Construction costs vary significantly from site to site and with land costs; cost to construct small storage reservoir (assuming water user owns land) ranges from $800 to $2,000 per acre-foot; construction of the tailwater collection system varies from little cost to as much as $15 per foot of installed pipe; cost of pump-back system is also significant and typically costs several thousands of dollars
	Nursery Production Systems	Applicable to irrigation of nursery crops	Systems includes the following practices: Irrigation System Design and Management, Plant Media and Management,	Implementation time depends on the size and extent of the nursery operation and which conservation practices are to be implemented; less than one week to several months	Applicability of each practice must be customized for the specific requirements of each system	Water savings are site specific; dependent on amount of water used by existing system and currently implemented conservation practices	Cost-effectiveness requires analysis for each nursery production system; cost ranges from minimal to significant

Source: Texas Water Development Board, Best Management Practices Guide, 2004

Appendix B: Development of Pumping Energy Requirements

Following is a development of techniques, which can be used to calculate the pumping energy requirements for many different types of irrigation systems that are operating under variable conditions.

CONTINUNITY EQUATION

$$Qt = 452.5\, dA \qquad \text{(B-1)}$$

where Q = Total system flow rate (gallons per minute)
t = operating time (hours)
d = the average gross irrigation depth (inches)
A = the irrigated area (acres)

POWER EQUATION

$$POWER = QH/(3960E) \qquad \text{(B-2)}$$

where Power = the BRAKE power required (brake horsepower)
Q = Total system flow rate (gallons per minute)
H = the total dynamic head required (feet of water)
H = L + 2.31 * P
L = Dynamic pumping lift (feet)
P = pressure requirement (pounds per square inch or psi)
E = pump efficiency (decimal)

Combining equations (B-1) and (B-2) results in the following

$$POWER = QH\,/\,(3960E) = 452.5\frac{d}{t}AH\,/\,(3960E)$$

$$POWER = 0.1143\,\frac{d}{t}\frac{A}{E}H$$

and

$$BRAKE\_ENERGY = POWER * TIME = 0.1143\, dAH\,/\,E \qquad \text{(B-3)}$$

ALSO this can be expressed as FUEL UNITS by dividing equation (3) by a conversion factor, which accounts for the efficiency of the POWER UNIT. Accordingly,

$$FUEL = 0.1143 dAH\,/\,(EKR) \qquad \text{(B-4)}$$

Where K is a conversion unit that accounts for the efficiency of the power plant (Table B-1) and R is the rating of the pumping system (decimal). R is the ratio of the fuel requirements of a "standard rated pumping plant" divided by the pumping plant actual fuel requirements. The value of R typically ranges between 0.76 and 0.95 and should be close to 1.0 for properly designed "new" pumping plants.

Table B-1. K values for different fuel types

PUMPING PLANT FUEL	VALUE OF K IN EQUATION B-4 brake horsepower-hours/unit of fuel
Diesel	14.89 bhp/gallon
Gasoline	10.21 bhp/gallon
Propane	9.18 bhp/gallon
Natural Gas	88.9bhp/1,000 cubic feet
Electricity	1.216 bhp/kwh

EXAMPLE 1 --- Diesel powered units

Diesel pumping plant operating a sprinkler irrigation system with a pressure requirement of 70 psi, total pumping lift (well drawdown of 120 feet plus an elevation change of 20 feet). The total gross irrigation depth is 20 inches, the irrigated area is 127 acres and the system flow rate is 750 gallons per minute. Assume a pump efficiency of 75%. Calculate the annual fuel requirements (gallons).

SOLUTION

$$POWER = QH\ /\ (3960E) = 750 * (120 + 20 + 2.31 * 70)\ /\ (3960 * 0.75)$$

$$POWER = 750 * (140 + 161.7)\ /\ 2970$$

POWER = 76.19 horsepower (called brake horsepower)

Annual hours of operation (use continuity—Equation B-1)

$$Qt = 452.5\ dA$$

*TIME(t) =452.5*20*127/750 = 1532.5 hours*

Thus

*ENERGY (brake horsepower hours) = POWER * TIME = 76.19 * 1532.5 = 116,761 bhp-hrs*

FUEL = Energy (kWh)/ factor in Table B-1 = 116,761/ 14.89 = 7,842 gallons

Alternate Solution --- use Equation (B-4)

$$FUEL = 0.1143 dAH\ /\ (EKR)$$

*FUEL = 0.1143 * 20 * 127 * 301.7/ (0.75 *14.89 *1.0) = 7,843 gallons*

EXAMPLE 2 --- Electrical powered units

Electrical pumping plant operating a sprinkler irrigation system with a pressure requirement of 70 psi, total pumping lift (well drawdown of 120 feet plus an elevation change of 20 feet). The total gross irrigation depth is 20 inches, the irrigated area is 127 acres and the system flow rate is 750 gallons per minute. Assume a pump efficiency of 75%. Calculate the annual fuel requirements (gallons).

SOLUTION

$$POWER = QH\ /\ (3960E) = 750 * (120 + 20 + 2.31 * 70)\ /\ (3960 * 0.75)$$

$$POWER = 750 * (140 + 161.7)\ /\ 2970$$

POWER = 76.19 horsepower (called brake horsepower)

Annual hours of operation (use continuity—Equation B-1)

$$Qt = 452.5\ dA$$

*TIME (t) =452.5*20*127/750 = 1532.5 hours*

Thus

*ENERGY (brake horsepower hours) = POWER * TIME = 76.19 * 1532.5 = 116,761 bhp-hrs*

FUEL = Energy (kWh)/ factor in Table B-1 = 116,761/ 1.216 = 96,021 kWh

Alternate Solution --- use Equation (B-4)

$$FUEL = 0.1143 dAH\ /\ (EKR)$$

*FUEL = 0.1143 * 20 * 127 * 301.7/ (0.75 *1.216 *1.0) = 96,042 kWh*

****

Assumptions:

1. Electrical Power with a performance rating of 0.9 (older units)
2. Pump efficiency of 0.75 (75 percent), average unit

$$FUEL = 0.1143 dAH\ /\ (EKR)$$

The fuel needed for an one-inch irrigation over an acre of land can be derived as following (Table B-2),

FUEL per acre-inch (pumped)

$$= 0.1143 dAH\ /\ (EKR) = 0.11432H\ /\ (EKR) = 0.11432H\ /\ (0.75 * 1.216 * 0.9) = 0.139279H$$

Table B-2. Summary of power requirements and costs

Total Head	Electricity Required	Power Cost (electricity = $0.12 per kWh)
Feet	kWh/acre-inch	$/acre-inch
100	13.9	1.67
200	27.8	3.35
300	41.8	5.02
400	55.7	6.68