Irrigation Metering and Water Use Estimates: A Comparative Analysis, 1999–2007

by Cameron G. Turner • Kate McAfee • Stacy Pandey • Angela Sunley

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Cover photo: Center pivot irrigation in a Texas High Plains cotton field.
Courtesy of the Texas Alliance for Water Conservation.

Edited by Patricia Blanton and Merry Klonower

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Executive Summary

As the single greatest water-consuming sector in Texas, irrigated agriculture uses 9 million acre-feet of water annually on over 6 million acres of crops. Most of that water, 79 percent, is groundwater. However, with dwindling water supplies and frequent droughts, Texas agriculture is faced with the challenge of conserving and managing its water resources. In response to this challenge, the Texas Water Development Board (TWDB) initiated a voluntary irrigation metering program in 1999 as a collaborative effort with groundwater conservation districts and agricultural producers to measure and assess irrigation water use.

The overall goal of the program is to establish how irrigation water use from the state's aquifers is affecting water supply and demand. To accomplish that goal, the program was originally designed to determine the amount of irrigation water pumped within monitor plots to analyze the relationships between irrigation pumping, rainfall, and aquifer levels on a monthly basis. TWDB envisioned that the data from this effort would help regional planning groups and groundwater conservation districts in their planning efforts. In addition, the data was to be incorporated into groundwater availability models so that the models could more accurately assess the state's groundwater supplies.

However, within a few years TWDB and the districts realized that the goals for the program needed to be refocused. Groundwater conservation districts carried the responsibility for collecting the data, and the amount of time required to collect and analyze the monthly data was too much for limited staff resources. In addition, TWDB and the districts encountered inconsistencies in data collection, and the amount of data was not sufficient to be useful for the groundwater availability models.

As a result, TWDB decided to redirect the metering program to gather data to establish irrigation water use by crop type on an annual basis, information that is still useful for planning purposes. TWDB now utilizes this actual irrigation water use data in order to validate and improve calculations of the statewide annual irrigation water use estimates.

This report analyzes the crop-type data collected from 1999 to 2007 in the Panhandle, North Plains, Mesa, Hudspeth, Gateway, Rolling Plains, Coastal Bend, and High Plains groundwater conservation districts and the Lower Neches Valley Authority. Culberson County, Evergreen, and Uvalde County groundwater conservation districts also participated in the program but data analysis is not included for various reasons.

The total metered acreage included in the analysis covers 409,879 acres and represents an average of about 3 percent of the total irrigated acreage of the participating districts. TWDB analyzed 2,218 data points of metered irrigation values and compared them to estimated irrigation values. TWDB also analyzed 1,311 data points from rain gages to compare actual and estimated rainfall.

The aggregated data set for all crops within the participating districts shows that TWDB estimates of irrigation appear to be higher than actual metered values by 2.41 inches per acre. The estimates of aggregated crop water use, which includes both irrigation and rainfall, are also higher than the measured values, by about 4.09 inches (Table E-1)[1].

Table E-1. All crops—weighted averages of metered data and estimates—all districts.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
1999	43	7,939	199,430	4.0	11.13	10.70	33	14.31	23.48	25.43	34.18
2000	47	8,693	199,393	4.4	15.40	11.23	32	22.56	24.22	37.96	35.44
2001	131	23,320	230,931	10.1	12.56	15.15	57	15.48	19.66	28.04	34.81
2002	249	47,820	1,524,903	3.1	15.19	18.16	115	18.44	21.44	33.63	39.60
2003	264	51,074	1,478,324	3.5	12.32	17.82	175	15.69	14.52	28.01	32.33
2004	318	62,040	1,446,968	4.3	14.51	18.02	206	24.25	24.61	38.76	42.63
2005	327	61,430	1,494,121	4.1	12.30	19.08	189	13.78	13.57	26.09	32.65
2006	397	67,737	3,453,259	2.0	16.78	15.05	138	16.80	16.56	33.59	31.61
2007	442	79,826	3,638,462	2.2	17.74	18.45	366	21.03	19.38	38.76	37.83
Averages	246	45,542	1,518,421	3.0	14.83	17.24	146	18.04	19.72	32.87	36.96

All units in inches per acre unless otherwise noted.

The metering sample size of the data analyzed is too small to represent most individual crops in the districts. However, some districts data sets contain statistically valid samples for certain individual crops to draw some conclusions. For example, in the Mesa district, 388 metered values for cotton were analyzed for an average of 6,089 acres, or 11 percent of the 57,149 average cotton acres in the district during the study period. The estimated irrigation was 1.71 inches per acre higher than metered values. With statistically valid data, TWDB can use these differences to consider adjusting irrigation water use estimates to better represent actual water use by producers within a district. For crops in most districts, more data is needed to create these representative samples. Additional metering data points on a continual basis are necessary to validate some of the TWDB crop water use estimates.

Many of the districts reported that the program provided them with irrigation pumping data that either validated or changed their assumptions about irrigation water use estimates in their districts. Most are either continuing to participate in the TWDB voluntary irrigation metering program or continuing their own metering efforts.

1.0 Introduction

As the single greatest water-consuming sector in Texas, irrigated agriculture uses about 9 million acre-feet of water on over 6 million acres of crops, annually. Most of that water, 79 percent, is groundwater. However, with dwindling water supplies and frequent droughts, Texas agriculture is faced with the challenge of conserving and managing its water resources. Droughts in recent years underscore the need to examine irrigation water use, particularly water pumped from aquifers.

The TWDB initiated its voluntary irrigation metering program in 1999. This program is a long-term collaborative effort with groundwater conservation districts and agricultural

[1] Averages for metered and estimated irrigation values are calculated on a weighted average methodology described at the beginning of the Districts' Analysis in Section 4 of this report. Crop water use values are tabulated by adding the weighted average irrigation amounts to the rainfall amounts.

producers to measure and assess irrigation water use at sample sites that represent larger geographic areas. The overall goal of the metering program was to establish how irrigation water use affected water supply and demand. To accomplish that goal, the program was originally designed to determine the amount of irrigation water pumped within monitor plots and to analyze the relationships between irrigation pumping, rainfall, and aquifer levels. Over time, however, the program's design has evolved. It now focuses on the annual crop water use. The data from the program is useful to TWDB for validating irrigation water use estimates, the regional water planning groups for forecasting regional water needs, the groundwater conservation districts for estimating pumpage and managing local water supplies, and the producers for managing irrigation water use.

This report provides an overview of irrigated agriculture in Texas, irrigation metering programs in other states, and objectives of the TWDB metering program. It also analyzes data for the first nine years of the program. The data analysis focuses on comparisons of metered irrigation water use with TWDB county irrigation estimates.

1.1 An overview of irrigation in Texas

According to the U.S. Geological Survey (2000), Texas ranks third in the nation in irrigated land acreage and fifth for irrigation water withdrawals. Irrigation in Texas is used to supplement rainfall, enhance crop yields, and maintain profits to ensure farming operations remain viable in an increasingly competitive global market.

Because of Texas' geographic diversity, the amount of irrigation water used can vary considerably, depending on climatic conditions, soil moisture conditions, available water supply, crop patterns, irrigated acreage, and management practices. Although both surface water and groundwater sources are used for irrigation, the largest share comes from underground aquifers (Figure 1-1). Groundwater is the sole source of irrigation water in the High Plains region of the state.[2] The agricultural areas that rely solely on surface water are the Lower Rio Grande Valley, El Paso County, and the upper portions of the Gulf Coast supplied by the Neches and Trinity rivers. The Winter Garden region of Central Texas uses groundwater with some surface water, and the middle Gulf Coast region, especially in the Colorado River Basin, primarily uses more surface water, with some groundwater.

Methods of irrigation used across the state depend largely on crop and soil types and the water source. In the High Plains region of Texas, sprinkler systems are the dominant method, but flood, furrow, and drip irrigation are also in use, primarily on cotton, corn, grains, soybeans, sorghum, peanuts, and wheat. In the Lower Rio Grande Valley, narrow border flooding, drip, and micro-spray irrigation are used on citrus; flood, furrow, and surge irrigation are used on corn, cotton, sorghum, and sugarcane; and flood and drip irrigation are used for vegetables and melons. In the rice belt along the Gulf Coast, border flooding is the most common method. In the Winter Garden region of Central Texas, vegetables and melons are grown under drip irrigation and drip, surge, sprinkler, and furrow irrigation are used on row crops and pastures.

[2] The "High Plains" region of Texas as used here refers to those counties that are situated over the southern and central High Plains sections of the Ogallala Aquifer.

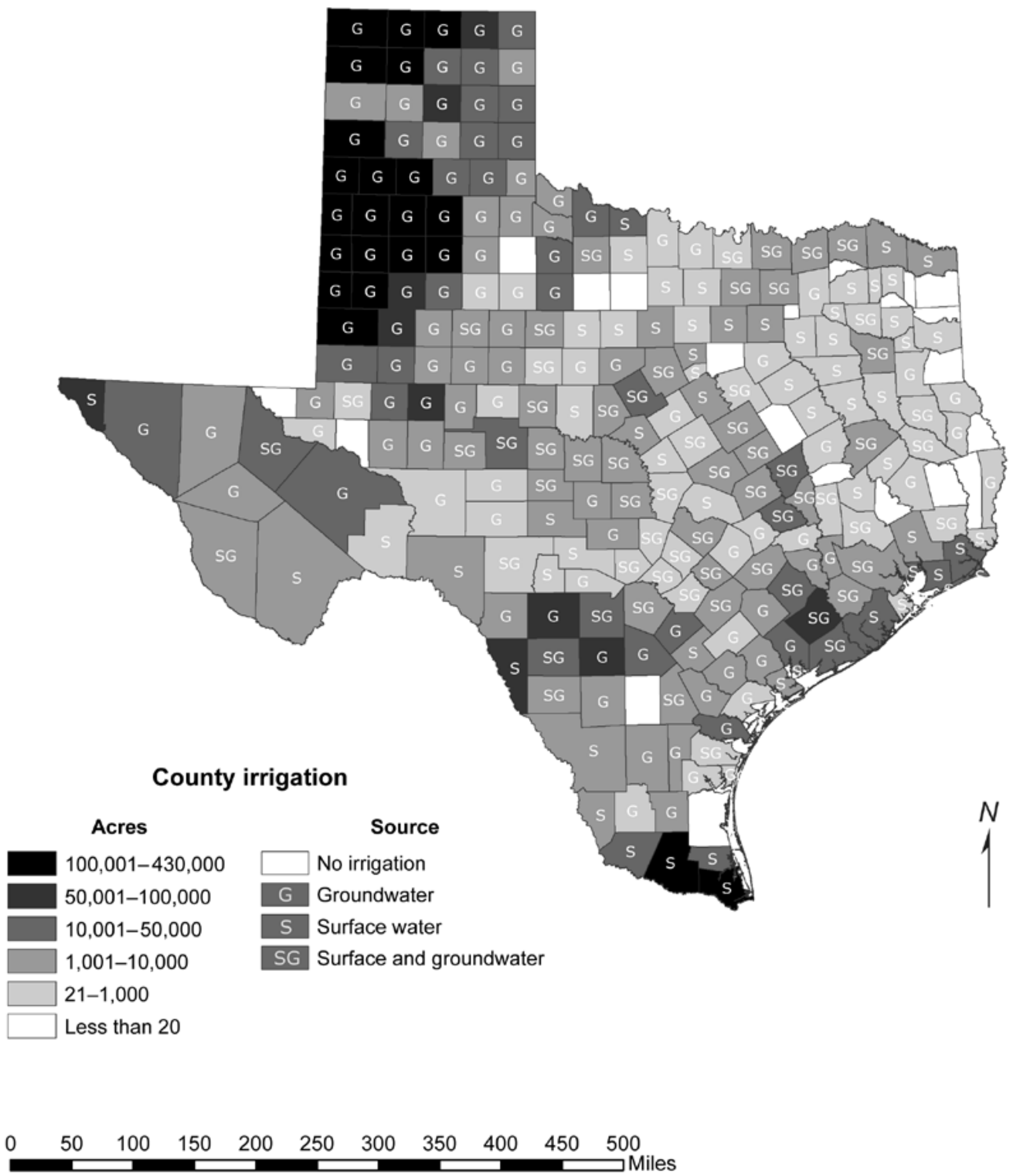

Figure 1-1. **Irrigated acres and water sources.** [3]

[3] Source of county irrigation is either surface water, groundwater, or a partial amount of both from TWDB Irrigation Surveys. Irrigated acreage based on data from the U.S. Department of Agriculture–Farm Service Agency.

1.1.1 How did we get here?

Large-scale irrigation began in Texas with the construction of surface water canals near Del Rio in 1868, and shortly thereafter irrigation development began in the Pecos River area, Lower Rio Grande Valley, and Fort Stockton area (TSHA, 2004). In 1889, Texas had over 18,000 irrigated acres on 623 farms (TWDB, 2001). By 1899, the irrigated acreage rose to 50,000 on 1,325 farms. Rapid development occurred during the early 1900s as more surface water irrigation systems were developed for rice production along the Gulf Coast and for crops in the Lower Rio Grande Valley. By 1909, the irrigated land area was about 451,000 acres. Development slowed between 1910 and 1929, with an addition of only 143,000 irrigated acres during that period.

By 1939, Texas had nearly 895,000 acres of irrigated land. Spurred by new technological developments of gasoline and diesel engines, irrigation development intensified following the end of World War II. According to the 1949 Census of Agriculture, the amount of irrigated land jumped to 3.1 million acres. By 1958, 6.7 million acres were irrigated. These large increases in irrigated acreage were primarily a result of increased pumping of groundwater from the Ogallala Aquifer in the High Plains.

Between 1958 and 2000, the number of statewide irrigation wells tapping into groundwater nearly doubled, from 55,466 to 115,857 (TWDB, 2001) (Figure 1-2). Rapid decline of the water level in the Ogallala Aquifer of 1 foot or more per year was measured during the 1940s, and by the 1950s declines of up to 5 feet per year were occurring (HPUWCD, 2005). During the 1950s, three groundwater conservation districts—the High Plains, Panhandle, and North Plains districts—were created to provide for the conservation, preservation, protection, recharge, and prevention of waste of groundwater stored in the Ogallala Aquifer. These three groundwater conservation districts now manage a large portion of the Ogallala Aquifer, which provides more than 82 percent, or 6 million acre-feet per year, of groundwater for irrigation in Texas[4] (TWDB, 2007).

[4] Other groundwater conservation districts managing groundwater in the Ogallala Aquifer include Garza County, Glasscock, Hemphill, Llano Estacado, Mesa, Sandy Land, South Plains, and Permian Basin.

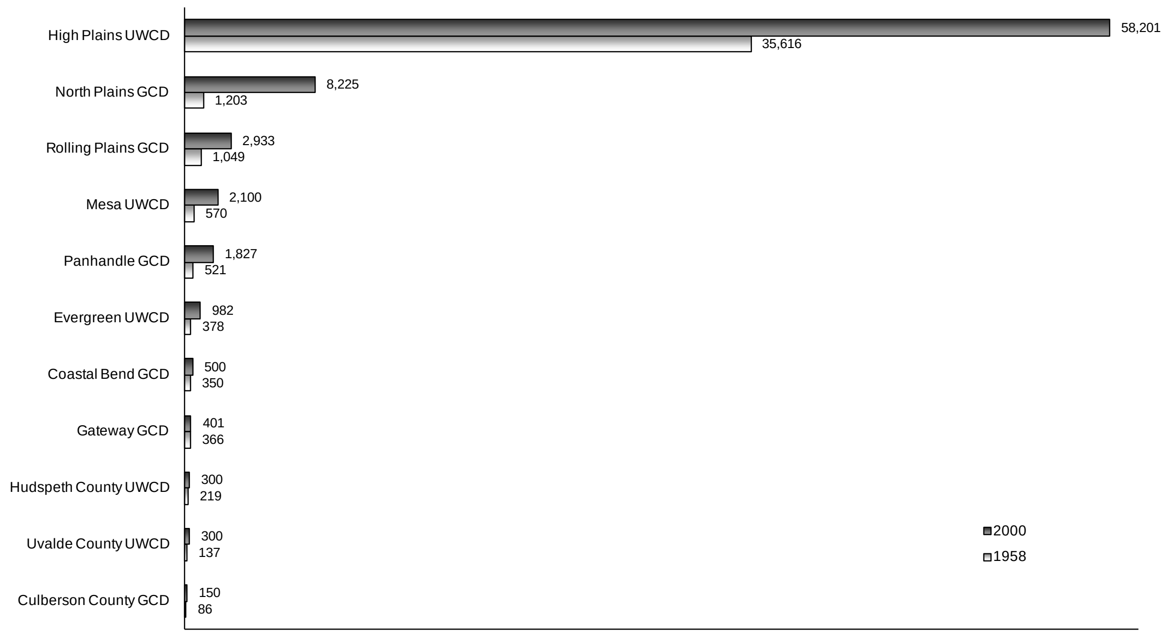

Figure 1-2. Number of irrigation wells between 1958 and 2000 by districts participating in the metering program (TWDB, 2001).

GCD = groundwater conservation district
UWCD = underground water conservation district

Irrigated acreage and irrigation water use in Texas peaked in the 1970s, as did groundwater withdrawal, with 8.6 million acres irrigated in 1974. Over the last 20 years, irrigated acreage has remained relatively steady, with 6.7 million acres in 1984, 6.1 million acres in 1989, and 6.3 million acres in 1994 (Figure 1-3). The 2000 TWDB Irrigation Survey reports 6.4 million irrigated acres, and the TWDB estimate in 2007 was 5.9 million acres.[5]

At the same time that irrigated land in production was peaking in the 1970s, a general trend toward using more efficient irrigation applications was occurring. Irrigation application efficiencies were improving by 20 to 25 percent as producers switched from surface flow to center pivot (sprinkler) application systems. In 1958, 667,558 acres were irrigated with sprinkler irrigation systems statewide. By 1974, that number had increased to over 1.8 million. Center pivot irrigation efficiencies continued to increase with the development in the 1980s of Low Energy Precision Application on center pivots showing efficiencies as high as 95 percent. In 2000, almost one-half of all irrigated acreage in Texas, almost 4 million acres, was irrigated with sprinkler systems. Drip irrigation, which boasts up to 98 percent efficiency, has also been increasingly adopted by producers over the last 25 years. Between 1979 and 2000, acres irrigated under drip systems increased from 19,788 to 76,860 acres in 2000; however, drip irrigation still represents a relatively small percentage of the total.

[5] 2007 estimates of irrigated acreage calculated by TWDB are based on data from the U.S. Department of Agriculture – Farm Service Agency.

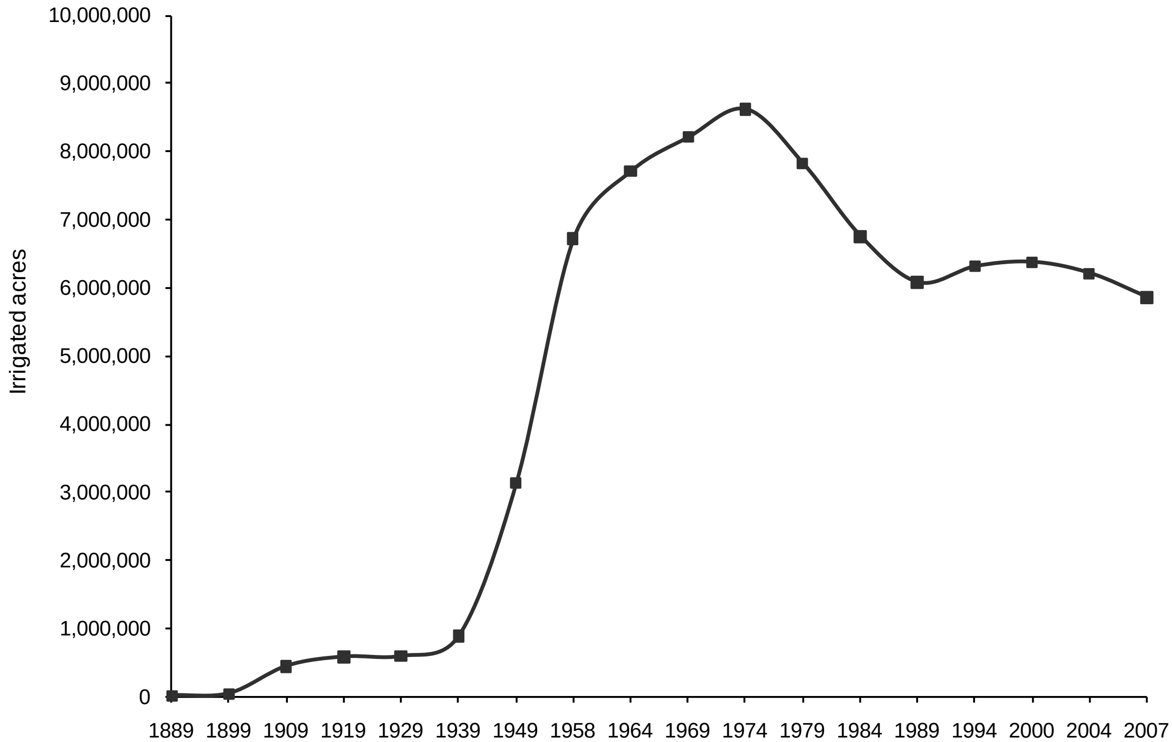

Figure 1-3. Historical irrigated acreage in Texas, 1889–2007 (TWDB, 2001).[6]

Although the history of irrigated land acreage in Texas is traced back to the early 1800s, estimations of statewide irrigation water use in Texas did not begin until the 1950s. The Texas Water Development Board, the USDA-Soil Conservation Service (now Natural Resources Conservation Service), and the Texas State Soil and Water Conservation Board conducted the first detailed, statewide survey of on-farm irrigation water use in Texas in 1958.[7] This collaborative group published surveys every five years thereafter from 1958 to 2000 (Figure 1-4).

Since 2000, TWDB has calculated irrigation water use estimates on an annual basis. Because the calculations are based on estimated crop water use and irrigated acres, the trend line of water use generally follows that of irrigated acres, except where changes in rainfall or crop patterns are significant. TWDB takes into account changes in irrigation water use that are a result of more efficient application equipment, different management practices, or changes in amounts of available water by asking the groundwater conservation districts to provide adjustments to the yearly estimates based on their knowledge of local practices. However, in most cases the adjustments are the result of subjective observation or limited actual measurements and cannot be used to quantify impacts of any specific practices affecting irrigation water use.

[6] Irrigated acreages for 2004 and 2007 taken from TWDB annual irrigation estimates.
[7] The Soil Conservation Service of the U.S. Department of Agriculture is now the Natural Resources Conservation Service.

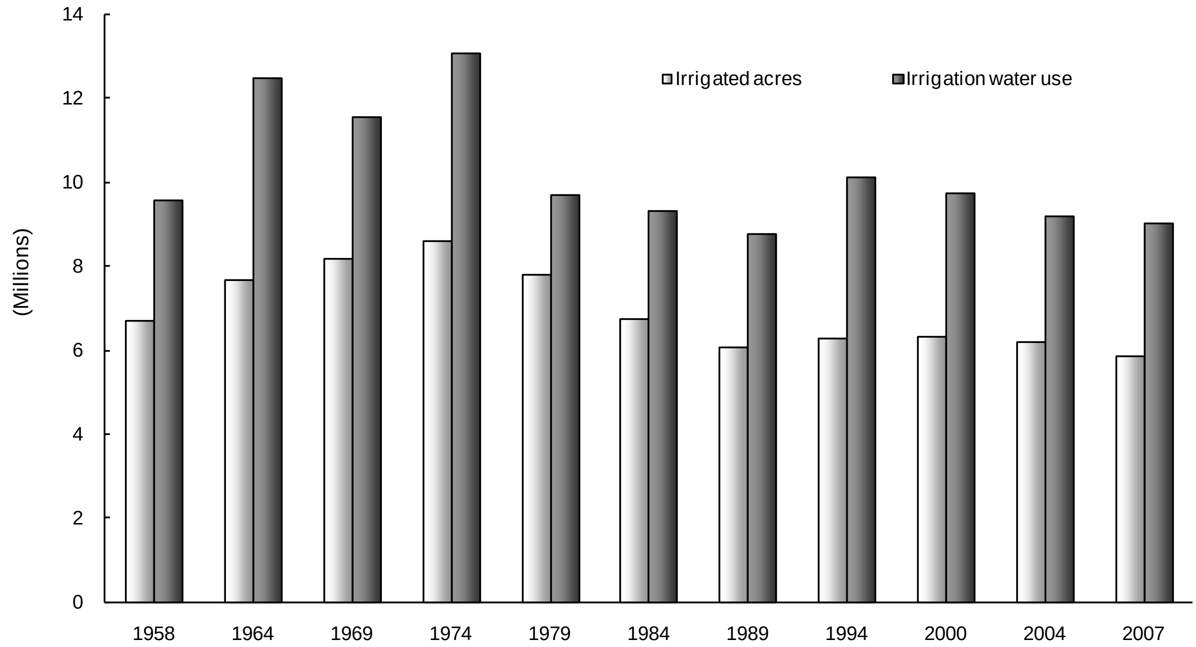

Figure 1-4. Irrigated acres and acre-feet of irrigation water use, 1958–2007 (TWDB, 2001).[8]

1.1.2 Where are we headed in the future?

TWDB projections in the 2007 State Water Plan predict an overall decrease of approximately 1.7 million acre-feet in statewide irrigation water demand over a 50-year planning period (2010–2060). The projected decreases are a result of reduced groundwater supplies, transfers of water rights from agricultural to municipal uses, and expected increases in irrigation efficiency.

By 2060, groundwater supplies are projected to decrease by 32 percent, mainly due to the depletion of the Ogallala Aquifer from irrigation pumping and restricted pumping in the Gulf Coast Aquifer to prevent land subsidence.[9] Irrigated acreage and surface water supplies available to agricultural interests are decreasing as urban development continues to expand onto irrigable land, especially in the Houston-Galveston, El Paso, and San Antonio areas and in the suburbs of smaller cities. In the Lower Rio Grande Valley, large blocks of formerly irrigated land are being converted to urban use, and irrigation water demand is expected to decrease by 16 percent by 2060 as a result of this expansion.

Despite the predicted overall reductions in irrigation demand, several major irrigation regions of the state are predicted to experience an irrigation water deficit in the next 50 years. For example, five counties in the North Plains Groundwater Conservation District have a predicted combined shortage of water for irrigation use of 293,000 acre-feet by 2010. In 2060, that shortage approaches 486,000 acre-feet. Most of the counties in the High Plains Underground Water Conservation District face similar irrigation shortages.

[8] Irrigation water use for 2004 and 2007 taken from TWDB annual irrigation estimates.
[9] Land subsidence occurs when groundwater pumping allows sediments to compress, thus lowering the land surface.

Three counties in this district for instance, Castro, Deaf Smith, and Parmer, will have a projected shortage of over 475,000 acre-feet in 2010 and more than 945,000 acre-feet in 2060. Dawson County (Mesa Underground Water Conservation District) will have a shortage of 95,871 acre-feet in 2010 and 73,240 acre-feet in 2060. Hudspeth County Underground Water Conservation District will experience similar shortages. To a lesser extent, the Rolling Plains Groundwater Conservation District will also grapple with shortages in Knox and Haskell counties (TWDB, 2007).

With predicted shortages of irrigation water supplies, measuring actual irrigation water use in Texas is a valuable tool for future planning and conservation efforts. TWDB, the groundwater conservation districts, and the regional water planning groups need measured water use data to validate estimation methodologies and to understand the effects of conservation efforts, management practices, and declining water supplies on overall irrigation water use. This data will enable these groups to plan more effectively how to sustain irrigated agriculture with limited water supplies.

1.2 Economic importance of irrigated agriculture in Texas

Not only does irrigated agriculture provide us with food, but among its other uses, it also supplies us with clothing, livestock feed, and even fuel. On a global scale "Irrigated land [is], on average, more than twice as productive as rain-fed land" (Stockle, 2001) (Figure 1-5).

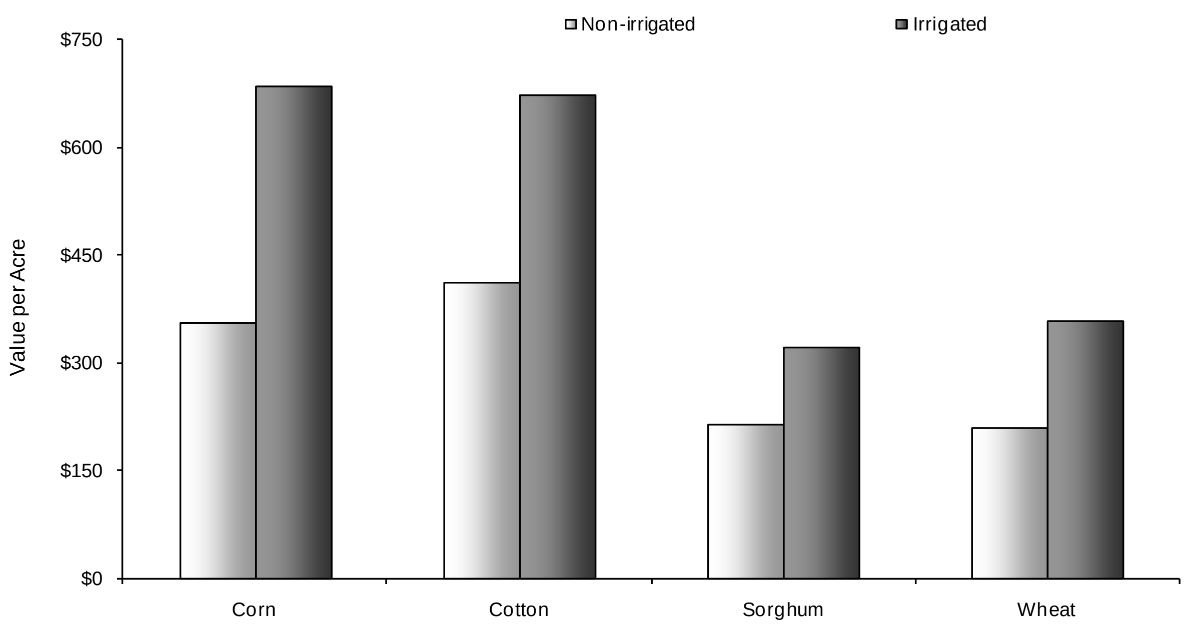

Figure 1-5. Per acre value of common irrigated and non-irrigated crops in Texas, 2007 (NASS, 2009).

1.2.1 What is the impact of agriculture on the economy?

According to the Texas Department of Agriculture (2007), "Each Texas farmer grows enough food and fiber for 129 people in the United States and abroad." Texas' food and fiber industry accounts for 9.5 percent of the gross state product. This industry generates about $73 billion annually, with cash receipts around $19 billion (ERS, 2009) (Table 1-1).

Table 1-1. Top five agriculture commodities, 2007.

	Value of receipts, thousands $	Percent of state total farm receipts	Percent of United States value
1. Cattle and calves	7,630,837	40.8	15.3
2. Cotton	1,923,915	10.3	29.7
3. Greenhouse/nursery	1,511,042	8.1	8.7
4. Dairy products	1,449,723	7.8	4.1
5. Broilers	1,404,552	7.5	6.5
All commodities	18,703,068		6.5

Source: ERS (2009)

Nine percent of all irrigated land in the United States is located in Texas. Twelve of the top 100 agricultural producing counties in the United States are in Texas (NASS, 2004). In 2007, the top five agricultural counties contributed nearly $4.4 billion to the state's economy (Table 1-2), representing about 22 percent of the state's total $20 billion in agricultural sales (ERS, 2009). Table 1-3 shows the value of agricultural exports to the economy of Texas for the year of 2007, as well as a ranking among other states.

Table 1-2. Top five counties in agricultural sales, 2007.

County	Percent of state total receipts	Thousands $
1. Deaf Smith	5.5	1,148,359
2. Castro	4.6	973,352
3. Parmer	4.5	937,661
4. Hartley	3.4	724,508
5. Hansford	2.8	589,799

Source: ERS (2009)

Many rural communities depend on agriculture for continued viability of businesses and infrastructure. The depletion of water resources needed to irrigate crops could be devastating not only for these rural communities, but for Texas as a whole (Segarra, 1999). According to the Texas AgriLife Extension Service (Anderson and Gleaton, 2008), "Farm and farm related employment accounts for 26 percent of jobs in non-metro areas and 13 percent in metro areas."

The drought of 2006 highlighted the economic importance of irrigated agriculture in the state. The cotton crop, coming off a record 8.5 million bale harvest in 2005, yielded 31 percent less in 2006 at 5.8 million bales (NASS, 2008), and most of that drop resulted from cottonseed not germinating due to dry soil conditions early in the season. The lack of forage and hay prompted producers to cull their herds to cut losses (Fannin, 2006).

Table 1-3. Top five agriculture exports, 2007.

	Rank among states	Value, million $
1. Cotton and linters	1	1,824.0
2. Wheat and products	3	529.1
3. Live animals and meat	4	509.0
4. Feed grains and products	7	492.4
5. Feeds and fodders	2	448.1
Overall rank	3	5,198.6

Source: ERS (2009)

1.2.2 How do dryland yields compare to irrigated yields?

In many areas, land previously used to grow irrigated corn and wheat for grain is being turned into dryland. However, the differences in yields between irrigated and non-irrigated lands are significant (Table 1-4) (NASS, 2009). Irrigated crops in Texas generally yield substantially more than their non-irrigated counterparts.

Table 1-4. Irrigated versus non-irrigated yield for common crops in Texas.

Crops	Irrigated acres	Average yield per acre	Non-irrigated acres	Average yield per acre
Corn for grain	950,000	199 bushels	1,020,000	101 bushels
Cotton	1,720,000	1,116 pounds	2,980,000	685 pounds
Sorghum	565,000	88 bushels	1,885,000	59 bushels
Wheat	660,000	56 bushels	3,140,000	33 bushels

Source: NASS (2009)

1.2.3 How do regional water issues affect irrigated agriculture?

The emergence of new markets for irrigated agriculture in the High Plains combined with declining water levels in the Ogallala Aquifer is triggering a shift in the crops producers are planting in that area. Because of regulations in highly populated and environmentally sensitive areas across the country, dairies have begun moving to the Texas High Plains. As a result, producers now have incentives to transition from growing grain crops and supplying feedlots and cattle ranchers to growing alfalfa or silage crops to supply dairy herds.

Almas and others (2006) predicted that dwindling levels in the Ogallala Aquifer will also affect crop patterns for irrigated agriculture in the Texas High Plains (Figure 1-6). They predicted that producers will grow more alfalfa, in addition to transitioning to non-irrigated wheat for cattle grazing.

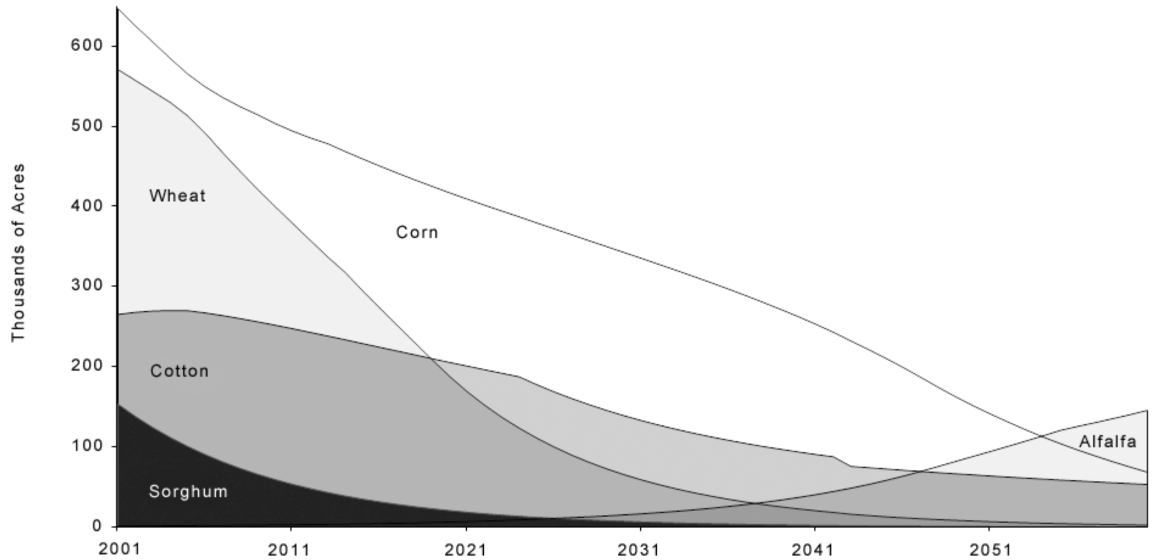

Figure 1-6. Projected estimates of Texas High Plains irrigated acreage (Almas, 2006).

1.2.4 What are the economic impacts on Texas of the growing ethanol market in the United States?

Market demand coupled with strong legislative support resulted in increased spending for research into alternative energy sources and led to rapid development of new ethanol production facilities in some of the US mid-west. At one point, the High Plains region had a predicted six plants proposed (Amosson, 2007).

If this potential development of ethanol is achieved, the influx of ethanol plants will generate an immediate demand for an additional 1.1 billion bushels of corn, or 8 million acres. This volume of corn will largely be shipped in from the Midwest states, but in 2007 many Texas producers were already taking advantage of high corn prices by planting more acres. This shift, however, is largely limited to those producers who have the ability, or rather the water resources, required to grow corn because it is a high water use crop. In the meantime, experts in the industry are working to make the shift to converting ethanol via a cellulosic process, which will allow ethanol to be produced from several crops (Amosson, 2007). Ethanol from corn is currently converted from the starch in the grain. Ethanol from biomass can be converted from the carbohydrates in plant cell walls (cellulose) such as stems, stalks, and leaves of a plant. Crops that produce large tonnage per acre include switchgrass, miscanthus, and sweet sorghum, which can grow up to 20 feet tall and produce up to 2,000 gallons of ethanol per acre, or four times that of corn starch ethanol (Cook, 2007). This would change the focus of production to maximizing biomass per acre instead of grain yields. In time, the market may open up to a number of these alternative crops.

1.2.5 Is irrigated agriculture in Texas sustainable?

Approximately 12 percent of agricultural production in Texas depends heavily on irrigation (Anderson, 2005). However, declining aquifer levels are affecting the amount of irrigated acreage in the state. In several areas overlying the Ogallala Aquifer, pumping has outpaced recharge, and the aquifer has experienced declines by as much as 300 feet in the past 50 years in some regions (TWDB, 2007). As a result, it cannot sustain the amount of irrigation it could in the past. According to Stockle (2001), “Texas has lost 14 percent of its irrigated acreage since 1980 as a result of aquifer depletion.” The loss of irrigation capabilities in these areas affects the production capacity for this arable land and devastates rural economies.

Because the population of Texas is growing at one of the fastest rates in the nation, its agricultural producers face a daunting task—increasing production by improving yields while using less water. The population of Texas is projected to double between the year 2000 (20,851,790) and the year 2060 (45,558,282). Due to this population growth and water shortages, the longevity of irrigated agriculture in some regions of Texas is uncertain. Implementing water conservation technologies and focusing on responsible use is essential to ensuring the continuation of irrigated agriculture and the benefits provided to Texas.

1.3 Importance of metering irrigation water use

Most current research literature refers to the expansion of worldwide populations during the 21st century as key challenge for agriculture with respect to water resources. The growing demand for agricultural products will likely be met by increasing the production on low-yielding acreage, and in some cases, with new or additional irrigation. With agriculture already using more than half of all water supplies, producers will likely have to rethink yields in terms of acre-inches rather than acres, or in “crops per drop” as participants in a U.S. Department of Agriculture Agricultural Water Security Listening Session dubbed the concept (Dobrowolski and others, 2004).

Irrigation metering helps producers better understand the relationships between applied water and production yield in order to manage their irrigation water use more effectively in terms of “crops per drop.” Replogle (2000) stated that “the measurement of applied irrigation water has been and will be one of the major links in efforts to improve irrigation management to achieve the needed efficiency.” According to Rogers and others (1993), “measuring water is the first step” in irrigation management, and “water measurement provides the data for: determining irrigation efficiency, improving water management, monitoring pumping plant performance, detecting well problems, and completing annual water use reports.”

At the national level, the U.S. Department of Agriculture has identified the accurate quantification of agricultural water use as an important research need to ensure future agricultural water security. The department envisions developing a nationwide integrated watershed data and information resource to support effective decision making in water conservation and management (Dobrowolski and others, 2004).

Since the adoption of irrigation metering is fairly new, studies and reports on the actual use of the metering data are scarce. However, the body of literature is growing as recently established programs across the country begin to collect and evaluate data. New agricultural water use estimation models are being developed and tested (and old models are being calibrated) with the actual measurements taken by meters (Marek and others, 2005). Researchers have indicated that initial runs on new water use models yielded better estimations of actual agricultural water use, and in some cases, have shown irrigators actually use less water than the projected estimations (Cummings and others, 2001).

In Texas, the need for accurate accounting of irrigation water use is illustrated by the sheer volume of water use for agricultural purposes: over 9 million acre-feet according to TWDB 2007 irrigation estimates. Several groups have supported the need for improved irrigation metering in Texas. In 2000, a consensus stakeholder group making policy recommendations to the Senate Interim Committee on Natural Resources recommended the following: "Continue and expand the TWDB's grants for conservation equipment purchases program to include an increase in legislative appropriations and conservation related equipment such as meters and data collection equipment" (Wasinger, 2001). Ball and Kelley (2003) recommended that "TWDB should work with irrigation districts, producers, agricultural extension agents, the U.S. Department of Agriculture's Natural Resources Conservation Service and others to increase metering of irrigation water use. Increased metering would provide both a more accurate basis for making water demand projections and, as several studies have shown, help producers reduce water use by ten to twenty percent." The Water Conservation Implementation Task Force recommended volumetric measurement of irrigation water use as a water conservation best management practice,[10] stating that "the cost and the benefits of statewide implementation of this BMP are significant" (TWDB, 2004).[11]

Regarding Texas' current irrigation metering programs in the North Plains and Panhandle regions, Marek and others (2005) concluded, "With recommended improvements to assure a robust data set, the well metering program can be a valuable tool for hydrologic and agricultural water use assessment."

More recently, the regional planning groups have voiced their support for more accurate accounting of irrigation water use. In the 2006 regional water plans, planning groups for regions A, B, E, J, L, and O recommended improving the accuracy of irrigation water use estimates (TWDB, 2007).

It should be noted that the above recommendations emphasize using irrigation metering as a means for better estimates of irrigation water use and to aid local districts in conducting their activities.

[10] A best management practice (BMP) is a generally accepted water conservation measure that is useful, proven, and cost effective.
[11] The 78th Legislature created the Water Conservation Implementation Task Force to review, evaluate, and recommend optimum levels of water use efficiency and conservation for the state. The cost of implementing statewide metering of groundwater is significant due to the large number of existing un-metered irrigation wells, approximately 116,000 statewide.

1.3.1 Who benefits from irrigation metering in Texas?

TWDB and the regional planning groups

TWDB is responsible for providing data to assist regional planning groups in planning for future water supply and demand, which includes irrigation water use estimates. These estimates are used to develop irrigation water demand projections and calibrate irrigation water use in the groundwater availability models. Both the water demand projections and the groundwater availability models provide important planning data for the planning groups. However, the planning groups do not always agree with the TWDB estimates and have expressed concerns over past estimates.

Given the importance of irrigation water use in the state and the potential for conflict over estimates of its use, TWDB works to provide the most accurate irrigation water use estimates possible using the best available science. From 1958 until 2000, TWDB worked cooperatively with the U.S. Department of Agriculture's Natural Resources Conservation Service to provide detailed surveys of irrigation in Texas at five-year intervals and annual on-farm irrigation water use estimates for 1985–2000. Because of funding issues, the Natural Resources Conservation Service has been unable to provide assistance in the form of detailed surveys since 2000, so TWDB is working to develop and refine its own methods for estimating irrigation water use.

TWDB currently uses models based on evapotranspiration for the initial estimates of irrigation water use. (Evapotranspiration is defined as the combined process by which water is transferred from the earth's surface to the atmosphere through evaporation and transpiration.) Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and bodies of water; transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapor through stomata in its leaves. However, predictions based on evapotranspiration can vary greatly from actual irrigation pumpage due to a range of factors, including water availability, water and crop management, crop varieties, climate, salinity, and soils (Allen and others, 2005). Thus, TWDB needs actual irrigation water use data in order to validate and improve calculations of the theoretical irrigation water use estimates.

In 2004, TWDB contracted with the Texas Agricultural Experiment Station[12] to research potential methodologies for estimating irrigation water use statewide. Their recommendations indicated that accurate, measured data on producer diverted or pumped water use by crop type was essential for any realistic estimation using an evapotranspiration methodology (Marek and others, 2004). This type of accurate data, which could be derived from an irrigation metering program, would benefit TWDB and the planning efforts of the regional planning groups.

Groundwater conservation districts

The role of groundwater conservation districts in managing Texas' groundwater resources is significant. In 1997, Senate Bill 1 expressly recognized groundwater conservation districts as the preferred method of groundwater management in Texas.

[12] In 2008 the Texas Agricultural Experiment Station became Texas AgriLife Research.

There are currently 1 pending and 96 confirmed groundwater conservation districts in Texas managing over 8 million acre-feet of groundwater usage annually (TWDB, 2010). Because groundwater conservation districts serve as the managers of the state's groundwater resources, any metering of groundwater withdrawals for irrigation must be administered and coordinated through them. The groundwater pumpage data obtained through TWDB's irrigation metering can provide a valuable management tool for groundwater conservation districts. For example, Mesa Underground Water Conservation District reported that data from the TWDB irrigation metering program was used in developing the district's current groundwater management plan.

Although data on groundwater pumpage for irrigation can be useful to the districts, TWDB is aware of only five districts in the state requiring well metering or pumpage reporting from those wells—the Barton Springs/Edwards Aquifer Conservation District, the Edwards Aquifer Authority, the Harris-Galveston Coastal Subsidence District, the North Plains Groundwater Conservation District, and the Hudspeth County Underground Water Conservation District No. 1.[13] All these districts have significant groundwater use for irrigation except for the Harris-Galveston Coastal Subsidence District where irrigation makes up only 5 percent of total pumpage (HGCSD, 2004).

Like TWDB, the Edwards Aquifer Authority had used an evapotranspiration-based methodology to estimate irrigation withdrawals from the Edwards Aquifer until they implemented their own program requiring meters on all irrigation wells in the aquifer in 1997. Since then, the Edwards Aquifer Authority has used actual pumpage data from their metering program to estimate well discharge and found "that the availability of direct pumpage data has significantly improved their discharge estimating process" (EAA, 2005).

The passage of House Bill 1763 in 2005 resulted in a more regional approach to groundwater management. Groundwater conservation districts within groundwater management areas work in cooperation to adopt desired future conditions of aquifers within the groundwater management area. The Texas Water Development Board is then responsible for developing the managed available groundwater based on the adopted desired future conditions. The desired future conditions and the managed available groundwater are utilized for planning purposes by the regional water planning groups and by groundwater conservation districts for planning and regulatory purposes.

Although the districts clearly can benefit from the data acquired by a metering program, it is important to remember that they may not necessarily need the level of detail on irrigation pumpage that is useful to TWDB for irrigation water use estimates. As a result, the design of the irrigation metering program and its funding must account for the fact that the districts are extending their resources beyond what is needed for their own purposes in collecting and providing data for TWDB needs.[14]

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[13] Requirements vary between districts, and pumping estimation methods based on energy usage can be used in lieu of actual metering in some cases.

[14] The groundwater conservation districts typically only need total pumpage for irrigation purposes, whereas TWDB needs information on crop types, acreage, and other parameters. The additional data required by TWDB and the timing of the data collection can place a burden on limited district staff and funds.

Producers

Irrigation metering is a valuable tool for producers in conserving and managing on-farm water use. Producers in Texas have made significant gains in water use efficiency through installing equipment such as center pivot systems and making physical changes such as laser leveling of fields. For gains in water use efficiency to equate to actual water savings, however, producers must be able to measure irrigation water use. With this information, they will be able to manage irrigation water use more effectively by examining cost-benefit scenarios of best management practices.[15] Metering alone, without implementing irrigation scheduling or other management practices, may provide water savings of 10 to 20 percent as producers become more aware of their water use (Pike, 2003; Fipps and Pope, 2004).

The cost of installing meters on groundwater wells ranges from $600 to $1,000 per meter, but those costs may be quickly offset by savings in energy costs and increases in yields through better irrigation water management (TWDB, 2004). In the TWDB supported irrigation metering program, the meters are paid for with grant funds. Several districts supply producers with summaries of their irrigation water use, thereby providing producers with an incentive for and benefits from participating in the program.

2.0 Metering Programs in Other States

In the context of looking at Texas' voluntary irrigation metering program, it is useful to understand what other states are doing and why. Many states with extensive groundwater resources, including Georgia, Nebraska, Kansas, and Oklahoma, have adopted statewide irrigation metering programs to assist in managing and conserving those resources. In Georgia, for example, measurement of agricultural irrigation withdrawals is now considered to be a prerequisite for providing data for state leaders to make sound state water management policies (GSWCC, 2011). In Kansas, water managers were able to determine from measured water use that current irrigation withdrawal rates would deplete the High Plains Aquifer (of the Ogallala formation) in 25 to 30 years (Huntzinger, 2005). In most of these states, both groundwater and surface water are owned by the state, and water use is permitted through various state agencies. Water volumes are authorized in accordance with need, and producers must manage their allotments effectively to achieve efficient irrigation while maintaining production and reducing costs. In Texas, local groundwater conservation districts are the preferred method of management of the groundwater resource and each district is responsible for the decision on requiring irrigation metering or reporting of pumpage.

2.1 Georgia

Georgia has over 1.5 million acres of irrigated land that is supplied by groundwater and surface water resources. The Georgia Environmental Protection Division permits surface and groundwater usage, including agricultural withdrawals. Until recently, agricultural withdrawals were exempt from water metering, recordkeeping, and reporting. Georgia

[15] A product of the Water Conservation Implementation Task Force, the "Water Conservation Best Management Practices Guide," lists volumetric measurement of irrigation water use as an agricultural best management practice.

lacked a systematic method for calculating agricultural water use and found this to be an issue during negotiations for water allocations between neighboring states. In response to that need, in 1998 the Georgia Environmental Protection Division requested that the Georgia Cooperative Extension Service develop a voluntary, multi-year irrigation metering pilot project to effectively measure irrigation water use so that producers' rights to water were protected. Georgia's goals for the project were to provide accurate data on agricultural water use and to supply water use information to producers to assist them with conservation and continued availability of their water resources.

The Georgia Cooperative Extension Service contracted with Georgia State University to develop a voluntary metering pilot program. The university conducted a survey of producers to define the extent of their knowledge of water meters and to identify barriers to implementing the program. The survey found most producers were not aware of how meters worked or what they might be used for (Morrison and others, 2003). The survey also determined that a cost-share program would be needed for purchasing and installing meters: otherwise widespread voluntary adoption of the program would be hampered by the financial situation of the majority of producers.

For the pilot project, Georgia State University developed a rigorous methodology for sampling the population of irrigators. They selected farms from a statewide pool of well permits that were randomly stratified by county and water source. This initial pool consisted of 2 percent of the total well permits within the state. The second stratification of the sample was to ensure representation of the crop and irrigation practices identified by Georgia Cooperative Extension Service surveys. When a producer declined to participate, another well permit was selected from the same sample stratification to fill the need.

The voluntary program was successful, with 78 percent of the producers agreeing to participate. The Georgia Cooperative Extension Service made multiple monthly visits to the irrigated farms within the study to collect data. The data collection was intensive, and all of the farms were characterized by wells, surface water sources, pumps, irrigation systems, acreage, crops, and farming practices. Field data were entered into a database that had controls to prevent data errors, and an independent quality control officer also worked to ensure data integrity.

The $911,000 start-up funding for the pilot project was provided by the OneGeorgia Authority, which disburses money from the state's settlement with tobacco companies. This money was used to install 177 meters on farms in the southwest region of the state and combined with $1.4 million for the Agricultural Water: Potential Use and Management Program in Georgia (Ag Water PUMPING) contract with the Georgia Environmental Protection Division; $380,000 from the U.S. Department of Agriculture's Cooperative State Research, Education, and Extension Service; and in-kind contributions of $600,000 from the University of Georgia. The total spent in the initial phase was over $2.3 million (Hook and others, 2005).

In 2003, with considerable support from agricultural interests in the state, the Georgia legislature enacted House Bill 579, requiring metering of all permitted agricultural water wells in the state. The Georgia Soil and Water Conservation Commission, a non-regulatory agency, was directed to implement, conduct, and maintain the Agricultural Water Use Measurement Program.

The commission is responsible for installation, maintenance, and data collection for meters on wells that were permitted prior to July 1, 2003, and for maintenance and data collection for meters on wells that are permitted after July 1, 2003 (the producer must purchase the meter and install it). Currently, the commission only collects data on the total volume of annual water use on the acreage covered by a meter when the meter is installed. Individual producers' water use data are protected by law from Open Records Act requests. The commission has implemented telemetry data collection on a random sampling of 1 percent of the meters statewide. About 5,000 meters per year have been installed and by 2009, the program will have 21,000 meters at an estimated cost of $36 million. Funding for this program also comes from the OneGeorgia Authority. The ultimate goal of the program is to generate accurate, useful data on water use by producers (Eigenberg, 2005).

2.2 Nebraska

In Nebraska, water controls have been mandated since the mid-1970s, but Nebraska's irrigation metering program was developed after an interstate water allocation dispute in which Kansas sued Colorado and Nebraska over water rights in the Middle Republican River Watershed. Kansas argued that groundwater overuse in Colorado and Nebraska led to depletion of surface water availability and, therefore, violated the 1943 interstate water compact. Kansas provided extensive data on the correlation between groundwater overuse and the effect on surface water. The suit was appealed to the Supreme Court, but all parties came to a settlement before the case was heard. In the settlement, Colorado and Nebraska agreed to meter all wells and report water use data yearly. Nebraska's natural resources districts for each watershed defined management plans and strict allocation limits for each district in order to ensure adequate water resources were available for Kansas. Nebraska only uses the data to report on actual pumpage, but the state has found the meters useful to their producers by aiding them with water conservation and water use efficiency. They are in the process of developing a program to use the data to estimate irrigation water use for management purposes and state water planning.

2.3 Kansas

Kansas' groundwater usage is managed at the regional level by groundwater management districts. These districts are based on watersheds, and all use within a management area is reported to the applicable groundwater management district. The data are then reported to the Kansas Department of Agriculture, Division of Water Resources. The reporting is mandated by Kansas law K.S.A. 82a-732, which went into effect in 1988; however, data have been collected since 1957. The Department of Water Resources mails out 14,650 water use reports annually and approximately 93 percent are returned before the deadline. Before the reporting requirement was mandated, Kansas averaged a 60 percent return rate.

Kansas' extensive reporting requirements and the standardization of data collection facilitate the validity of the information. Penalties for misreporting and late filing are outlined in Kansas law. The statutes allow the Division of Water Resources to obtain valuable data, which has resulted in an extensive data set more detailed than any other state's program. Irrigation water right holders must report acres, crops, water usage, system types, and well information. The data from this program were invaluable to Kansas during the interstate dispute for water allocations between Colorado and Nebraska.

2.4 Oklahoma

Oklahoma water law is similar to Texas' in that groundwater is treated as the private property of the overlying land owners. The Oklahoma Water Resources Board regulates groundwater permitting by allocating "two acre-feet a year per acre of land in basins where maximum annual yield studies have not yet been completed, and slightly more or less than that amount in basins where studies have determined how much water may be safely withdrawn." (OWRB, 2006). The Oklahoma Water Resources Board is responsible for regulating and enforcing the beneficial use of water resources and has divided the state into 49 stream systems and 46 groundwater basins. Water use estimations are used to determine the allocations for property owners in respect to acreage and crop water use. Irrigation metering became a tool for producers during allocation hearings to justify the amount of water needed. The metering data are also used to make determinations of maximum annual yield for each groundwater basin for the 20-year basin life projections. Historically, only those landowners involved in litigation have been required to meter irrigation use. Data are collected throughout the state, but statewide use of the data has been very limited.

3.0 TWDB's Irrigation Metering Program

The irrigation metering program in Texas differs from most states' in that participation is not mandatory, not a result of legislative action, nor litigation over water allocation rights. Texas law views water ownership differently from most states. Whereas many states own their water, in Texas, the rule of capture applies to groundwater. In essence, the rule of capture gives the property owners legal rights to capture and use the water under their land with only limited restrictions on its use.

During the 1950s, the state legislature gave Texans the ability to create groundwater conservation districts. These districts, in accordance with state legislation or water law, have the authority to monitor groundwater use and create restrictions within their districts. As Texas plans for the future, metering will play an important role in providing accurate data on irrigation water use throughout the state and will aid the groundwater conservation districts and state planners in facilitating management goals (Sanger, 2005). These are important considerations for the long-term viability of the program and in understanding some of the constraints in implementing it.

3.1 In the beginning

In 1998, the Panhandle Regional Water Planning Group (Region A) was working on the first regional water plan for their area, the 2001 Regional Water Plan.[16] During the planning effort, stakeholders expressed concerns about the accuracy of existing groundwater flow models used to assess groundwater supplies. Several studies at the federal, state, and local level had been undertaken to study the region's groundwater supplies; however, issues with aquifer recharge, aquifer stratigraphy, surface/groundwater interaction, and hydrologic boundaries still remained (PWPG, 1998). To address stakeholder concerns, the planning group proposed developing a new model to provide more accurate predictions of groundwater supplies. The Bureau of Economic Geology at The University of Texas at Austin worked with the planning group to develop a new groundwater availability model.

To provide more precise inputs to the new model, the planning group wanted to measure actual irrigation water use. Therefore, as part of the project to develop the new groundwater model, the planning group sought funds from TWDB to establish a long-term program to assess agricultural water use. The intent of the program was to provide data on irrigation pumpage for the new models. For TWDB, the project presented an unprecedented opportunity to obtain measured irrigation water use data for a better understanding of agricultural water use in the region and to improve water supply and demand forecasts critical to the regional water planning process. As a result, the irrigation metering program began as a joint effort between TWDB, the Panhandle Regional Water Planning Group, and two groundwater conservation districts in the Panhandle region—the Panhandle and the North Plains districts.

In December 1998, TWDB provided research and planning grant funds (Senate Bill 1, 75th Session, funds) to the Panhandle Regional Water Planning Group for a proposed scope of work that included upgrading existing groundwater models for the region and establishing the agricultural water use assessment program. The scope of work for the contract called for the planning group to set up metering of irrigation wells in the region, incorporate metering data into a regional groundwater model database, and analyze and assess the data and the effects of irrigation water use on agricultural demands. The planning group subcontracted with the Panhandle Groundwater Conservation District to implement the irrigation metering program in their own district and in the North Plains district.[17]

The program's implementation was designed with two important guidelines:

- The program was administered through a local groundwater conservation district that was responsible for all aspects of collecting and reporting metering data.
- The irrigation metering and data collection were established through voluntary participation of producers in the program.

[16] The Panhandle Water Planning Area was formed pursuant to Senate Bill 1, 75th Session, which requires planning regions of the state to conduct comprehensive water planning. The Panhandle Regional Water Planning Area includes 21 counties in the Texas Panhandle covering over 4,037,760 acres of land area and 139,363 acres (in 2005) of irrigated agriculture.

[17] According to the subcontract between the planning group and the Panhandle Groundwater Conservation District, the district would report the metering data to the Bureau of Economic Geology according to a schedule determined by the Bureau, and the Bureau would incorporate the data into the model.

The irrigation metering program design used 4-square-mile monitor plots rather than individual meters distributed throughout a county. This design focused data collection in small areas of the very large region so that irrigation water use could be associated with groundwater levels in a specific geographic area. Groundwater levels were monitored through existing or newly drilled non-irrigation use wells, and irrigation pumping was metered at existing irrigation wells. The monitor plots were also located near existing potential evapotranspiration (PET) network sites to take advantage of climate and weather data from those sites. Besides water use information, the data collection efforts included information on power use, crop type, and crop yields. The contract called for two years of data collection, during which time the planning group would develop data collection protocols for a longer-term project. According to the contract's proposed scope of work, these data collection efforts would "extend several years into the future until a statistically significant data set [was] achieved."

The funding resulted in the purchase and installation of 149 meters on wells and irrigation systems of voluntary participants in the Panhandle and North Plains districts, using the monitor plot design concept. During this first phase of the project, the Panhandle Groundwater Conservation District took responsibility for all aspects of purchasing and installing meters and collecting data in both districts. The planning group, in conjunction with the Bureau of Economic Geology, was responsible for analyzing data and incorporating the data into the new groundwater model.

3.2 Growth of the program

Encouraged by the potential for obtaining actual data for use in groundwater models and irrigation water use estimates, TWDB pursued expanding the irrigation metering program to other districts.[18] In November 2000, capital equipment purchase funds were awarded to the Mesa Underground Water Conservation District to purchase meters to measure agricultural water use in Dawson County.[19] Though the source of funds for Mesa's metering program was different, the design of the program generally followed the original Panhandle contract. However, because the Mesa district was not located within Region A, Mesa reported data directly to TWDB. TWDB developed some general data collection and reporting protocols, and these were included in the contract with the Mesa district.

By 2001, the Bureau of Economic Geology had completed the development of the groundwater availability model for the northern (Texas) part of the Ogallala Aquifer. Because the irrigation metering program was still in its infancy, timing of the model completion did not allow for incorporation of data from the irrigation metering program for use in the model. In 2001, the Region A Regional Water Plan was also completed, and the original contract for the metering program expired. However, the Panhandle Regional Water Planning Group and TWDB agreed to continue the irrigation metering program and data collection effort. TWDB and the planning group agreed that additional meters and a broader data collection format were needed, including additional sites to

[18] In 2000, TWDB hired a new staff person specifically to manage the irrigation metering program.
[19] Capital equipment purchase funds are appropriated funds that the TWDB can use to purchase equipment in support of agricultural water conservation programs.

provide a more representative sample of irrigation water use and a more comprehensive data set for the long term.

Therefore, TWDB provided additional research and planning grant funding for purchasing more metering equipment in the North Plains and Panhandle districts. The North Plains Groundwater Conservation District took responsibility for the meters in their district. All three districts (including Mesa) signed revised, longer-term contracts with TWDB, obligating them to more detailed protocols, including collecting monthly data during the growing season and providing metering program data directly to TWDB (and the regional water planning groups).

In general, the contracts specified the following conditions:

- All of the water being pumped within the monitor plot had to be completely metered.
- There had to be a minimum of one non-pumping monitor well per monitor plot with known latitude and longitude coordinates.
- Each monitor plot had to have one rain gage.
- The monitor plot had to be at least 4 square miles.
- There had to be a minimum of one monitor plot per county that was a typical representation of the agriculture in that county, when practical.
- Meter readings and monitor well readings had to be collected on a monthly basis during irrigation periods, and precipitation data had to be gathered on a monthly basis.
- Soil type and irrigation method information had to be collected for each meter; irrigated acres and crop type had to be collected on a seasonal basis, and crop status had to be collected at each meter reading date.

Between 2001 and 2003, five additional groundwater conservation districts enrolled in the program, bringing the total to eight (Table 3-1). TWDB purchased the meters for the districts with funds from the capital equipment purchase program.[20] Data collection and reporting protocols varied slightly between the districts based on funding and implementation considerations specific to each district; however, the monitor plot design concept was maintained throughout.

[20] Additional funds for meter purchases were also provided to some of these districts through the Agricultural Water Conservation Grants Program.

Table 3-1. Entities participating in the irrigation metering program, 1999–2007.

District Name	Initial contract year	Funding source	Orginal grant amount $	2007 Metered acres	Total meters
Panhandle Groundw ater Conservation District*	1998	SB1/AEG	111,212	41,913	203
North Plains Groundw ater Conservation District*	1998	SB1	90,522	23,525	66
Mesa Underground Water Conservation District*	2000	CEP/AEG	36,573	16,384	144
Hudspeth County Underground Water Conservation District #1	2002	AEG	25,000	4,380	23
Culberson County Groundw ater Conservation District	2002	CEP	19,990	1,820	28
Gatew ay Groundw ater Conservation District**	2003	CEP	5,508	413	6
Rolling Plains Groundw ater Conservation District	2003	CEP	11,421	401	4
Evergreen Underground Water Conservation District	2003	CEP	8,042	1,550	8
High Plains Underground Water Conservation District #1	2004	AEG	20,000	2,242	15
Coastal Bend Groundw ater Conservation District	2005	AEG	50,000	8,711	55
Low er Neches Valley Authority	2005	AEG	61,000	1,053	23
Uvalde County Underground Water Conservation District***	2006	AEG	86,240	5,297	47
Totals			525,508	107,689	622

* Initial contract re-negotiated in 2001.
** Gateway GCD acreage is from 2004, their initial year of data reporting.
*** Uvalde County UWCD acreage is from 2008, their first year of data reporting.
SB1 = Senate Bill 1
CEP = Capital Equipment Purchase
AEG = Agricultural Equipment Grant

3.3 Evolution of the program and adapting to the realities of implementation

The Panhandle district submitted the first data set to TWDB at the end of the crop year in 2001—a few months after the new contract was signed with the Panhandle district. The data set covered 1999 to 2001.

In 1999, Senate Bill 2, passed by the 77th Legislature, had formalized the groundwater availability modeling program at TWDB by requiring the agency to develop or obtain models for all of the state's aquifers. TWDB's formal groundwater availability modeling program began in the fall of 2000. TWDB subsequently accepted the model developed by the Bureau of Economic Geology for Region A (the northernmost regional water planning area of the state comprised of 21 counties and part or all of five groundwater conservation districts) as the groundwater availability model for the northern part of the Ogallala Aquifer in Texas.[21] During this time, TWDB determined that although site-specific pumping information (such as that gathered at the monitor plots) could be placed into the groundwater availability model, it was a high-effort/low-reward activity. Because there is a tremendous amount of pumping outside the monitor plots, the response of the model to that pumping would dwarf the response to the data from the monitor plots. TWDB decided that information which improves regional estimates of pumping is more appropriate to benefit the models. As a result, data from the irrigation metering program is not included in the models.

During 2001, while TWDB's own formal groundwater availability modeling program was still relatively new, staff in the Conservation Division of TWDB set up a process for receiving and processing the data submitted from the districts as required under the new contracts. TWDB developed a database to store the metering program data and a password-protected, Web-based interface so that the districts could enter metering data and records directly into the TWDB database while maintaining data privacy. Initially, there were some technical difficulties with this interface. It also required duplicative data entry efforts for districts who already stored data in their own separate databases. Most districts opted to submit data in spreadsheets instead.

As TWDB began to receive and work with data from the districts to calculate annual water use by crop type, data issues became apparent in some of the data sets. Some of the issues could have been averted with use of the TWDB-designed database because database controls would have prevented entry of certain types of flawed data (such as consecutive meter readings where the second reading is less than the first) and required entry of other types of data (such as crop acreage). TWDB worked closely with individual districts to resolve some of the data gaps or issues that were recognized but did not make any formal changes to the program or the methods for collecting and submitting

[21] In 2004, this model was updated by the Bureau of Economic Geology in the second round of regional water planning. Specifically, the Bureau of Economic Geology adjusted the elevation of the bottom of the aquifer, recharge, and model parameters at the edge of the aquifer. TWDB subsequently used this model to assist Region A in developing groundwater availability numbers for their 2006 Regional Water Plan.

data. Because the program was still in the early stages, TWDB believed that data problems could be worked out over time.

By 2004 some of the data issues had not been resolved, and this led to TWDB's full review of the program and analysis of the data received from all of the districts. Based on that review and analysis, it was clear that certain aspects of the program had been problematic both for TWDB and for districts and that some of the data received was not appropriate for the type of uses originally anticipated.[22] As a result of these issues, TWDB made several changes to the program. There is no longer a requirement to report aquifer level changes from monitor wells since TWDB does not directly relate this pumpage data with aquifer drawdown, but some districts find this information useful and continue to collect and report data from monitor wells. TWDB now utilizes the irrigation metering data for comparison with irrigation estimates for each major crop within a county.[23] Districts report annual metered irrigation applied to specific crops rather than the previously required monthly meter readings. The districts are now required to calculate inches per acre of metered irrigation applied to each crop instead of TWDB attempting to make these calculations without familiarity of the metered systems.

3.4 Programmatic and data issues

There are many challenges in trying to implement a standardized metering program in highly variable settings. This section identifies some of those challenges and the resulting data issues and gaps that have surfaced over the past five years. This discussion is generalized and issues may not apply to all of the districts in the program or may have been resolved with some districts but not others.

3.4.1 Monitor plot design

The original intent of the monitor plot design was for all of the irrigated acreage in each monitor plot to be 100 percent metered. However, some districts had difficulty implementing 100 percent metering. In some cases, practical considerations, such as producer willingness to participate, prevented the districts from being able to meter all irrigation within a 4-square-mile monitor plot area. Thus, not all of the districts have 100 percent-metered monitored plots, and the sample size is reduced accordingly.

Monitor wells were also part of the original plot design. The objective was to monitor aquifer fluctuations correlated to pumping withdrawals. Although some districts still collect and use this information, TWDB no longer requests districts to report this data. Thus, there is no discussion in this report of the monitor wells and associated data.

[22] In a report to the Panhandle Regional Water Planning Group, Marek and others (2005) provided an assessment of the suitability of irrigation metering program data from the Panhandle and North Plains districts for inclusion in Region A's irrigation water demand model, referred to in their report as the TAMA model. The authors concluded that a modified run for the groundwater availability model for the Ogallala Aquifer was not warranted due to issues with statistical inference and low representation of the data set. For the same reason, the authors did not recommend replacing irrigation water use inputs in the current TAMA model. Their analysis covered data from 2000 to 2003 and did not include other districts in the TWDB metering program.
[23] TWDB methodology for calculating irrigation water use estimates can be found in Appendix B.

The original monitor plot design called for one rain gage in each monitor plot. Although some of the districts have implemented this requirement, others have not. Additionally, the rainfall within a 4-square-mile area, and even on individual fields, can vary greatly. To get a truly accurate picture of crop water use, rainfall may need to be collected at each meter (Cummings and others, 2005). Without more local rainfall data, it is difficult to know how much of the variability in water use might be explained by differences in rainfall.

3.4.2 Data collection

Meter reading frequency

The original design of the program required monthly meter readings. This requirement became unnecessary when TWDB changed the direction of the program from using the data to compare aquifer drawdown with pumpage to using the data to validate irrigation water use estimates. Most of the districts now provide seasonal, quarterly, or yearly meter readings. However, once-a-year readings may not capture acreage or crop type accurately, especially when multiple crops are planted per year. In some cases, a meter could actually roll over twice, so unless this information is being captured, that water use information is lost.

Meter reading and data collection errors

Districts have been responsible for meter installation and calibration. TWDB does not verify meter accuracy, but districts are required to report any differences in flow rates as a result of calibration checks. It is unknown if districts are checking calibration on meters that have been installed for several years.

As a result of manual meter reading and data entry, data errors have occurred in the data. Most districts manually enter metering data into spreadsheets or databases. Errors in data sets from various districts have included transposed meter numbers, extra digits or transposed digits in the readings, meter readings entered for the wrong meter numbers, and transposed month or day on the meter reading date. TWDB detected these errors when calculating the water use (in gallons) from one reading to the next and getting a negative result. However, errors that produce a more subtle difference in water use may never be discovered. Many of the errors that TWDB discovered and brought to the attention of district staff were resolved by referring back to paper records, indicating that many of the errors were actually data entry mistakes. One district, the Mesa Underground Water Conservation District, has been using a personal data assistance device to enter data directly from the field into a spreadsheet, which helps eliminate data entry errors. The spreadsheet also calculates inches per acre automatically so district staff can check for errors right at the meter if the reading looks abnormally high or low.

Another method to minimize data entry error is through forms or parameters set in databases. Most of the districts do not use a database for data entry and storage. Others that are using databases may not be fully using its functionalities to prevent errors, such as creating relationships between tables to prevent duplicate entries.

A solution to eliminate some of the problems associated with manual data entry is attaching a datalogger to the meter. Using the commonly used McCrometer propeller meter for example, attaching a datalogger to the meter (fits directly under the meter read-out panel) data is collected from a pulse that is generated each time the propeller makes a full rotation. From this pulse, total water applied is calculated and stored in the datalogger for later retrieval. However, dataloggers come with their own set of potential technical issues:

- Different meter types can require different dataloggers.
- Technical issues may occur with installation.
- Software issues may occur when downloading the data.
- The data format used by the district may need to be altered to make it compatible with the data format gathered by the datalogger.

Mesa Underground Water Conservation District began a datalogger pilot project in 2006.[24] They hope that it will save them time in the long run but are still struggling with technical issues. For example, they have had to change all of their meter numbers to make the data compatible with the datalogger software. They have also found that several of the meters were not registering water flow after datalogger installation, and they have had issues with error messages while downloading the data.

Accurate acreage

In several of the participating districts, obtaining accurate acreage has been a problem. Most districts have accurate irrigable acreage figures—the amount of area that can be watered under the current irrigation system. However, if only part of a field is watered in a particular season, the district must record the partial acreage at the time the meter is read. In some cases this has not been happening, and the total irrigable acreage, rather than the actual irrigated acreage, has been reported to TWDB. Additionally, when different individuals read meters in different areas of the district, farm acres have been confused with irrigated acres or the acreage under a system has been misunderstood. TWDB developed a metering data collection and reporting worksheet to address this issue, and some of the districts are using the worksheet. TWDB also encourages participating districts to acquire acreage information from the USDA-Farm Service Agency to validate their acreage information; however, discrepancies between actual acreage and Farm Service Agency acreage can also occur. TWDB is unable to confirm whether the districts are using this source of data to cross-reference acreage.

Failed crops

It is imperative for districts to account for failed crops because water use usually stops immediately after the crop has failed (often from a hail storm). In some cases, the water use from fields with failed crops may have been averaged with water use from fields that were harvested, creating an artificially low average, especially when a large area is affected by a natural disaster. Some participating districts report failed acres but do not include water use data; others simply do not make a determination between failed acres

[24] The TWDB purchased 49 dataloggers using capital equipment purchase funds and provided these to the Mesa Underground Water Conservation District for use in the pilot project.

within a crop category. For these reasons of inconsistency in reporting failed acres across the number of entities in the program, analysis of failed crop acreage water use is not included in this report.

3.4.3 Data transfer and storage

Early in the metering program, TWDB created a Web-based application the districts could use to enter data directly into the TWDB database. TWDB designed the application to facilitate data entry and avoid data error issues and expected that the districts would enter information directly from paper records into the online form. TWDB designed the forms in the database to calculate gallons used and inches per acre from monthly meter readings and acreage data. If data were entered through the form, large errors would be obvious by viewing the calculated inches per acre. Additionally, the form was programmed not to accept a value smaller than the previous meter reading for each meter.

However, the large districts have not opted to use the TWDB-designed data entry form for several reasons. A significant issue for the larger districts was the timing of the construction of the TWDB database and the design of the Web-based form. TWDB was developing the form when contracts with the Panhandle, North Plains, and Mesa districts were renegotiated in 2001. For the Panhandle and North Plains districts, the new contract called for submitting data directly to TWDB for the first time. This change came after they had already been collecting metering data for two years and had developed their own methods of collecting and storing data.

In addition to the timing issue, design issues have contributed to the districts' reluctance to use the Web-based form. The larger districts have different data needs from TWDB. The districts collect and maintain certain information that producers may wish to keep confidential (for example, the well owner's name and the location of the meter). The districts also collect data that TWDB does not need but that is important to the district (for example, physical details about the meter installation and location). In the TWDB Web-based form, individual records for each meter must be manually entered in the form. For districts with large numbers of meters, manually entering data for each meter on individual forms has proved to be impractical, especially where districts were already entering producer information into their own databases.

Other issues that may have contributed to some of the districts' reluctance to use the Web-based form included a lack of broadband Internet access in rural areas where district offices are located, concerns about data security, lack of familiarity with Web-based applications, and district interest in maintaining control over data integrity.

TWDB adapted to these issues by accepting data in spreadsheets and hand written worksheets instead of using the Web-based form.[25] TWDB developed a Microsoft Excel spreadsheet data template for the districts to use. By accepting the spreadsheet format, the built-in data quality controls that were features of the TWDB Web-based data entry form have essentially been bypassed. TWDB is in the process of creating a new database to import the data from the spreadsheets into a secure storage location. TWDB anticipates

[25] At the time, TWDB preferred to commit limited financial resources to expanding the number of meters in the field rather than redesigning the database.

that utilization of ArcGIS software will allow managing the irrigation metering data and TWDB irrigation estimates spatially. This goal is to facilitate a geographical comparison of estimates and metered data by crop type within each county.

Each district in the metering program has had a slightly different way of providing data to TWDB, although most of the districts provide raw data to TWDB in the spreadsheet format. TWDB developed a template spreadsheet early in the program that was based on the original monitor plot design and requirements for monthly meter readings. (The template has been modified to meet the current needs of the program.)

The original TWDB template was organized in five separate spreadsheets to obtain the following data from the districts:

- Meter's fixed data: meter number, location, soil type, and irrigation method
- Meter's monthly data: meter readings, date, crop type(s), irrigated acreage, percent acreage of each crop type, and crop status
- Precipitation: rain gage number, location, and rainfall (or snow) amounts
- Monitor well's fixed data: monitor well number, location, and elevation
- Monitor well's monthly data: monitor well readings and date

The revised spreadsheet uses one worksheet to report annual irrigation amounts.[26]

3.4.4 Data analysis

Calculating water use by crop type

Some of the original contracts did not explicitly require calculation of water use by crop type; however, those contracts were amended and do contain this requirement now. All of the districts participating in the irrigation metering program are now calculating water use by crop type, where possible.

Calculating system water use

Many districts have been recording data from meters within systems. A system refers to multiple meters being used to measure the total water use on a particular acreage. Different system types include the following:

- A pivot/row water combination where the pivot is metered and wells are metered to capture row water use
- A pivot that could not be metered due to physical limitations so the wells were metered instead
- One well feeding multiple pivots where the meters are located at the well and some of the pivots, but not all, are metered
- One pivot shifted between two different fields where the pivot may be metered or a well or wells may be metered that feed the pivot.

If meters in the same system are not read on the same day or if one of the meters from that system is not read at all, then the total water use figure is inaccurate. In some cases,

[26] See Appendix A for data reporting worksheets and spreadsheet template.

acreage for the whole system has been reported for each meter, and in other cases acreage has been broken out for different segments of the system. The person calculating system water use must be familiar with the design of the system in order to make the correct calculations. TWDB has requested and obtained detailed system descriptions from most of the districts and has tried to ensure accuracy when calculating system water use.

Split and mixed crops

Regardless of who makes the calculations, there are many crop and irrigation scenarios that make it very difficult to determine irrigation water use by crop type. The most common scenario occurs when one crop follows another crop in the same year; for example, the combination of a summer crop of cotton followed by winter wheat (referred to as a split crop). Most districts report split crops although not all of them read the meters at the time the crop changes, nor do they record separate acreages for each crop. In this scenario, the inches per acre for cotton and wheat cannot be calculated separately.

One resolution to the split crop issue is to read the meters to coincide with pre-watering, planting, and harvesting dates and record acreages for the individual crops. However, this solution would most certainly require that the producers, instead of district personnel, read the meters and record the readings because keeping track of the exact timing of crop changes and irrigating practices for all of the growers in a district would be a monumental challenge. Dataloggers might also be used to get readings at appropriate times of the year, but the timing of the change in crops and the acreage would still need to be manually recorded by the producer.

Another scenario occurs when more than one crop has been grown simultaneously under the same pivot, such as a half circle of peanuts and a half circle of cotton. This mixed-crop scenario is very common and takes on many different forms from year to year depending on market conditions and what types of crops growers have decided will be most favorable in a particular year.

The mixed-crop scenario becomes even more complex with combinations of multiple types of crops (more than two) under one pivot. Combining multiple crops under one pivot is especially common in the vegetable-growing Winter Garden region of south central Texas. The planting and harvesting dates of the different crops under one pivot are highly variable as are acreages of individual crops. In some cases, this is further complicated by the staggering of planting and harvesting of sections or parcels of an individual crop type to take advantage of market prices. In these scenarios, the amount of water that goes to a particular crop cannot be directly measured without the use of directional devices to record when the pivot is watering each individual crop. Even with a directional device, the data collection effort would be very high maintenance. This type of technological approach would require significant additional funding and resources to accommodate the higher level of data gathering and management.

Completely ignoring split and mixed-crop systems in validating county irrigation water use estimates may skew the results and provide an unrealistic assessment of real water use patterns. Omitting these crop scenarios significantly decreases the sample size. The best option for TWDB in these cases may be to look at county averages as a whole rather than trying to separate out water use by crop type.

3.5 Solutions

Over the years, TWDB and the groundwater conservation districts have been working to resolve data and programmatic issues as they are identified. This ongoing work has resulted, for the most part, in more complete and accurate data sets each year. For example, during 2004 TWDB developed a data collection and reporting worksheet to assist some of the smaller districts in obtaining, calculating, and reporting water use data (in inches per acre) in a format appropriate for comparison with TWDB's irrigation water use estimates. The forms are filled out by the producers rather than district personnel. For districts that used the data worksheets, the 2005 data set was improved. TWDB has also been researching methods of addressing specific issues and other solutions, such as the use of telemetry equipment to assist with data collection. In 2005, TWDB purchased approximately 50 dataloggers using capital equipment purchase funds and provided these to the Mesa Underground Water Conservation District to assist with their data collection efforts.

The biggest programmatic change has been in the requirement for monthly data. Although monthly data are ideal, some districts have not been able to keep up with this level of data collection on a long-term basis. TWDB has taken two approaches to adapting to this. The first and simplest option has been to accept annual water use data from the districts. This option still allows for comparison with TWDB estimates that can contribute to improvements in the estimates, but it does not allow for a detailed analysis of water use data. Annual data submittal makes the program more suitable for enrolling a larger number of smaller districts and helping to spread the metering technology to more districts and regions throughout the state. The other option has been to provide additional financial resources to the districts committed to monthly data collection to support or enhance their data collection programs. In 2006, TWDB offered funds for additional meters or data collection to districts through the competitive agricultural water conservation grant program. One district, Mesa Underground Water Conservation District, applied for and was awarded funds to augment their existing metering program. In 2007, funds were awarded to Uvalde County Underground Water Conservation District to implement a metering program. The Panhandle Groundwater Conservation District was awarded additional funds in 2008 and again in 2010 to expand their existing metering program[27]. Also in 2010, Medina County Groundwater Conservation District and Hemphill County Groundwater Conservation District were awarded funds and joined the TWDB irrigation metering program.

3.6 TWDB metering efforts for water conservation

Since 2004, TWDB has provided funding for three additional surface water providers to measure irrigation water, make delivery system improvements, and promote conservation (Table 3-2). These three entities provide water-savings reports, but their contracts do not require crop water use reporting. There were twelve entities that provided crop water use data to the irrigation metering program from 1999 to 2007 (Figure 3-1).

[27] This contract includes funding for more meters and telemetry equipment to improve upon their data set.

Table 3-2. Additional entities with surface water conservation projects.

District name	Program year	Grant amount $	Measurement structures
Cameron County Irrigation District #2	2004	50,000	11
La Feria Irrigation District	2004	20,000	3
Lower Colorado River Authority*	2009	99,219	431
Totals		169,219	445

* TWDB grant funding represents about 10% of this total project cost of upgrading irrigation canals.

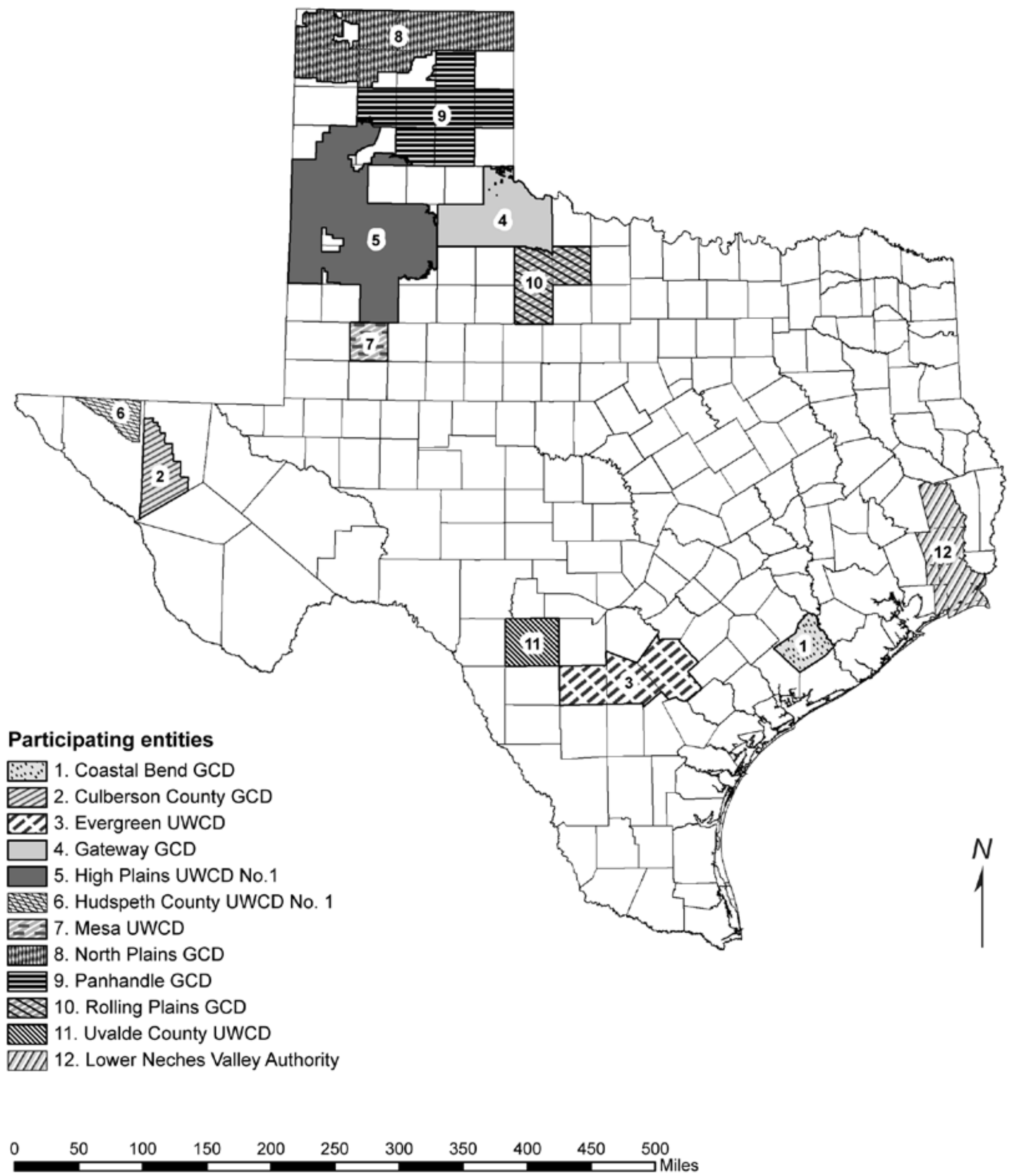

Figure 3-1. Entities participating in the TWDB irrigation metering program, 1999–2007.

4.0 District Data Analysis

Each district summary in this chapter provides a general description of the district's metering program and an evaluation and analysis (where appropriate) of the data provided to TWDB by each of these districts. The focus of the data evaluation and analysis is on the suitability of the data for use in validating the TWDB's irrigation water use estimations.

In the early years of the program, TWDB spent considerable effort calculating gallons used from monthly meter readings and inches per acre by crop type from raw data submitted by the districts. However, in many cases, TWDB encountered issues in making these calculations (as discussed in Section 3), which made the integrity of the calculations questionable. To ensure data integrity for this report, TWDB used the district's own calculations of inches per acre by crop type.[28] District calculations are presented in the data analysis portion of this report. TWDB has created a standardized data reporting format so that all of the districts are encouraged to make these calculations when submitting future data sets.

Each district summary section begins with a "District at a Glance" page that provides relevant information on the agricultural and water use characteristics of the district. A map, showing the location of metered wells in the program, is at the top of those pages. TWDB produced the maps using ESRI ArcMap software and plotted meter locations by latitude and longitude, except for the Panhandle and North Plains districts. Historically, these districts have not provided meter locations due to producer concerns about privacy. Instead, they provide U.S. Geological Survey topographic areas where meters are located. For those two districts, meter locations are denoted by shaded polygons. Meter locations were not available for the Uvalde district or the Lower Neches Valley Authority.

TWDB compiled the agricultural and water use characteristics from the data sources listed below. Where district boundaries dissect a county, the entire county was included in the total for district size, total crop land, and irrigated crop land, except where more precise data were readily available from the district.

The "District at a Glance" pages contain the following information:

Planning region: The regional planning group.

2007 Gross Crop Income: Market value of crops sold. Data are from the National Agricultural Statistics Service—2007 Census of Agriculture (NASS, 2008).

Climate: Climatic zone based on moisture availability.

Average Yearly Rainfall: Average annual rainfall from 1971 to 2000 (TWDB, 2006).

District Size: Total land area within a district. Data are obtained from TWDB ArcGIS shapefiles.

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[28] If a district had not already been submitting their own inches-per-acre calculations, they were asked to provide it for this report.

Total Crop Land: Total crop land in the district for 2007. Data are from the National Agricultural Statistics Service (NASS, 2008).

Irrigated Crop Land: Total irrigated crop land in the district for 2007. TWDB calculates irrigated acreage from USDA-Farm Service Agency acreage data.

Estimated Irrigation Water Use: Estimated irrigation water use for the entire district for 2007. TWDB calculates estimates by using an evapotranspiration-based methodology and input from groundwater conservation districts.

Acres in TWDB Metering Program: Total acres metered from the metering data received from the districts. This number may differ from the acres data in the analysis because data points not suitable for analysis were removed from the data set.

Number of Active Irrigation Wells in Groundwater Conservation District or Underground Water Conservation District: Compiled county totals from the year 2000 irrigation surveys (TWDB, 2001).[29]

Number of Meters in Program: Number of meters in the metering program. TWDB obtained the information from the district's metering data.

Eco-region: Vegetation areas of environmental conditions and natural features (Gould and others, 1960).[30]

Soils: Predominant soil textures within the district (NRCS, 2010).

Crop Types: Crop types monitored in the metering program for all data years. TWDB obtained the information from the district's metering data.

Irrigation methods: Irrigation methods used on acreage in the metering program. TWDB obtained the information from the district's metering data.

4.1 Data analysis methods

The sections for each of the groundwater conservation districts contain the following components:

- Overview of the district
- Unique characteristics of the district's metering program
- Irrigation water use for each crop in the district
- Irrigation water use summary for all crops in the district
- Results and conclusions

[29] In the case of counties where multiple groundwater districts contain portions of a county, the well totals for that county were included with the district totals for the district containing the larger portion of the county (i.e. Potter County well totals are included in the Panhandle Groundwater Conservation District total and not the High Plains Underground Water Conservation District total).

[30] There are differing models of eco-regions developed by numerous individuals. TWDB used the Gould eco-regions similarly used by Texas Parks and Wildlife. State and County map of these eco-regions are available online at http://www.tpwd.texas.gov/publications/pwdpubs/media/pwd_mp_e0100_1070ac_24.pdf.

Although metering data have been collected on a monthly basis for several years of the program, monthly metered irrigation is not analyzed in this report. Only annual irrigation values are included. TWDB performed all data analyses with Microsoft Excel software and used Excel Pivot tables for tabulating descriptive statistics and calculating totals and averages.

For each district, comparisons are made between metered and estimated irrigation values for individual crops and all crops aggregated together. For more accurate inches per acre averages for aggregated data (for multiple years or crop types), weighted averages were calculated instead of using a straight average of inches per acre figures. This was done by first taking each metered inches per acre value and multiplying by associated acreage. Resulting acre-inches applied to that specific crop were totaled within a district. Total acre-inches applied to a crop were then divided by total crop acreage within the district to come up with the average irrigation for each year, and similarly for the entire study-period averages. Irrigation estimates were weighted in a similar manner utilizing district acres and acre-feet totals for individual and all crops each year.

TWDB calculates irrigation estimates on an annual basis based on crop evapotranspiration rates.[31] They are calculated for all relative crop categories within a county on an inches per acre basis. These numbers are compared to previous estimates and adjusted accordingly. Estimates are then mailed to local groundwater conservation districts for comment and review. After taking into consideration their comments, resulting estimates are tallied.[32]

Beyond comparing irrigation amounts, rainfall analysis is included where measured rainfall amounts were available. TWDB rainfall estimates were only compared where rain gages were present. So, within a district for any given year, some crops may have analysis for rainfall where others may not. Analysis of rainfall data is included where appropriate. For most districts, these data are not meter specific but are monitor plot specific. The rainfall values of the monitor plots were associated with individual meters within a monitor plot. To calculate estimated rainfall, estimated values were associated with each individual meter record that had a metered rainfall value. The estimated rainfall was assigned to the record based on the meter's proximity to the closest weather station used by TWDB to calculate crop water use and irrigation estimates. Where a district measured rainfall associated with a meter number but a county name was not given, that rainfall amount was removed from the data. TWDB removed from the data set high outlier values and annual measured rainfall values below 6 inches. This amounted to a resulting data set of 1,311 values, ranging from 6.00 to 39.80 annual measured inches of rainfall.

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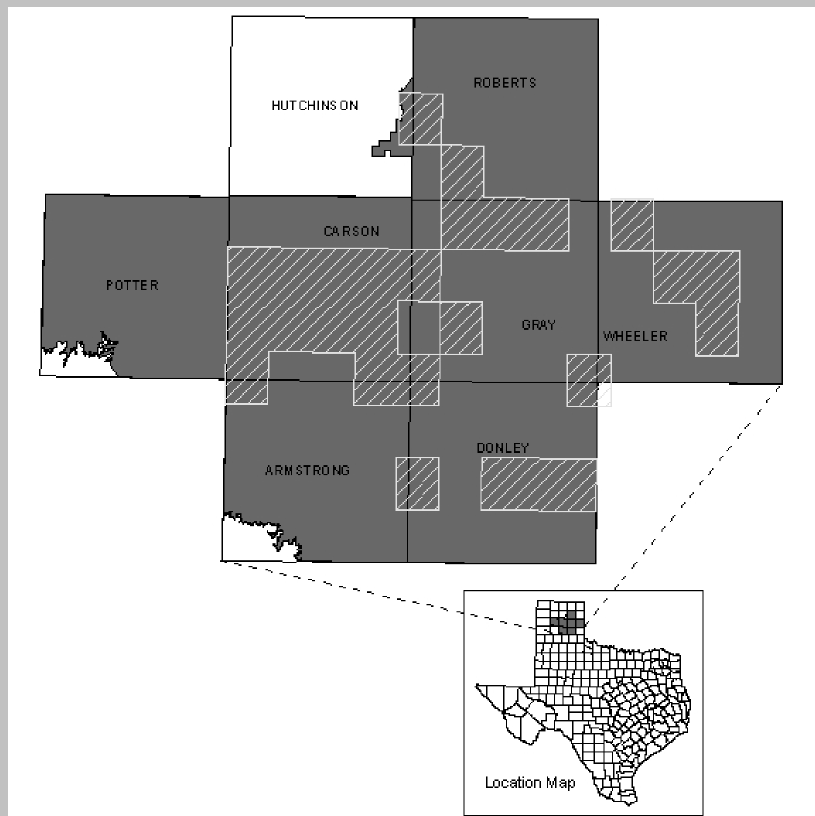
[31] As of 2004 the methodology changed, as documented by internal Work Process Document 1531, "Estimation of Irrigation Water Use," available upon request (Shaw, 2008).
[32] TWDB past years' estimates and historical methodology can be accessed via the web at http://www.twdb.texas.gov/conservation/agriculture/irrigation/

Total crop water use values were computed by adding together irrigation and rainfall totals. Metered crop water use values were calculated by adding together the weighted average metered irrigation plus the average rainfall for each crop. This was compared to the total of TWDB irrigation estimate plus TWDB estimated rainfall. Final comparisons were made between the total crop water use values and evapotranspiration rates (Borelli, Fedler, Gregory, 1998).

4.2 Panhandle Groundwater Conservation District



District at a Glance

Planning Region: *Panhandle (A)*

2007 Gross Crop Income: *$122,067,000*

Climate: *Semi-arid*

Average Yearly Rainfall: *23 inches*

District Size: *4,037,760 acres**

Total Crop Land: *458,500 acres*

Irrigated Crop Land: *141,268 acres*

Irrigation Water Use: *174,193 acre-feet*

Acres in TWDB Metering Program: *28,468 acres*

Number of Active Irrigation Wells in Groundwater Conservation District: *1,827*

Number of Meters in Program: *500**
** Indicates district data*

Eco-region: *High Plains, Rolling Plains*

Soils:
Silty clay loam, Fine sandy loam, Clay loam, Loam, Loamy fine sand, Fine sand

Crop Types:
Corn
Cotton
Grain sorghum
Peanuts
Soybeans
Wheat
Alfalfa, haygrazer
Oats
Black-eyed peas

Irrigation Methods:
Center pivot
Furrow irrigation

TWDB initiated the irrigation metering program with the Panhandle Groundwater Conservation District and the Panhandle Regional Water Planning Group in 1998. The district's willingness to participate and commitment to implementation has been critical to getting the program started. The Panhandle district has formally (according to contractual requirements) provided metering data to TWDB since 2001, but data are also available for 1999 to 2000.

The Panhandle district has the largest number of meters of any district in the program. Between 1999 and 2007, TWDB provided funding for over 200 meters. In 2005, the district began their own cost-share program with producers to provide additional meters. The district now has approximately 500 meters located in producers' fields from which they collect data. Only data for TWDB meters are included in this report; however, TWDB and the district are making plans to exchange data on the additional meters.

The district has 24 monitor plots scattered across seven counties. Because the district has meters located in Collingsworth County, it is also included in the data analysis. Most of the monitor plots in the district are 100 percent metered. The district has about 30 meters that are parts of systems where multiple meters must be read to determine total system water use. The district creates year-end data reports for each producer who is involved in the metering program.

From 1999 through 2004, the district gathered monthly meter readings. In 2005, they switched to three readings a year. District employees read the meters, record readings on paper in the field, and enter the data into the district's database. The district database is queried to generate a raw data file in Excel format for TWDB. This file follows the general format of the TWDB metering data template. The district has been responsive to TWDB in correcting identified data errors, and the resulting data set has generally been of good quality and consistency.

The Panhandle data set is the largest and most diverse of all the districts. Included in the analysis are 1,055 data points from 210,876 acres monitored over the years 1999 to 2007. In 1999, there were 7,939 acres monitored with 43 meters. By 2007, the program expanded to monitor 34,791 acres with 164 meters included in the data set. Irrigation values of less than 1 inch were removed from the data set for the analysis, along with records lacking acreage figures, and a few unusually high outlier values.

All monitor plots have rain gages, and rainfall data are available for all years. Measured rainfall varied significantly within monitor plots. Without latitude and longitude coordinates for rain gages and meters, it was impossible for TWDB to determine which rain gage readings could be associated with nearby meters. Therefore, some meter readings do not have rainfall values associated with them. There is some difficulty in finding a direct relationship between rainfall and irrigation that may lie in the uncertainty and inability to quantify effective rainfall or rainfall that is useful to the crop.

4.2.1 Irrigation Water Use—Individual Crops

In the Panhandle district, mixed crops made up the largest crop type represented in the metering data set at 29.2 percent of the metered values, and unknown or "other" crops were the third largest at 12.8 percent.[33] The metered irrigation values for these "crops" could not be compared to TWDB estimates for individual crops. Of the 1,055 data points included in the analysis, cotton was the most represented individual crop type at 13.2 percent of the metered data points.[34] Corn made up 10.6 percent and wheat made up 8.2 percent. The remaining crops—alfalfa, forage crops, hay-pasture, peanuts, grain sorghum, and soybeans—each represented anywhere from 3 to 6 percent of the data set.

TWDB estimates show that wheat constituted the largest irrigated acreage in the district during the study period, on average 48,172 acres a year, followed by cotton and then corn. Much of the wheat acreage metered in the district was categorized as a mixed crop for the purposes of this analysis because the wheat acreage and water use could not be separated from the other crops grown under the same pivot or system. Corn and cotton acreages were also seen in the combinations.

Alfalfa

Total irrigated alfalfa acreage in the Panhandle district averaged around 5,774 acres a year for the nine-year study period. Close to half of this acreage was located in Donley County, but small acreages of alfalfa were also grown in other counties in the district. Donley County was the only county where alfalfa fields were metered by the district, other than one field in Wheeler County in 2006. The average number of metered alfalfa fields was four, with between two and seven fields metered each year. In some cases, alfalfa was part of a metered multiple crop system, so it was included in the mixed-crop category (unless the system contained forage crops, in which case the alfalfa-forage mix was included in the forage category).

The weighted average metered irrigation for alfalfa for all years (1999–2007) was 19.08 inches per acre and the standard deviation of the 39 metered values was 11.74 inches (Table 4-1). Metered irrigation values for individual fields ranged from 2.40 to 47.04 inches per acre. There were no rainfall data for the metered fields in 2000, 2005, or 2006.

The weighted average estimated irrigation for alfalfa in the district was 22.55 inches per acre, so over the nine-year period the difference in the average metered and estimated values was 3.47 inches per acre (Figure 4-1). In 2005, the estimated value was more than double the metered value, and in 2007 even greater differences existed in these values. In other years, the metered and estimated values differed by less. There are significant differences between measured and estimated rainfall for most years, but the overall averages are only 3.29 inches apart. Total crop water use values also differed significantly in some individual years, yet the nine-year averages were in close agreement.

[33] Metering records that did not include crop type were designated as "other" or "unknown" crops.
[34] One meter was located on a crop of black-eyed peas in 2005. This is included in "all crops" analysis; however, there is no individual analysis for this record. Irrigation applied to the 320 acre crop was 6.12 inches per acre.

Table 4-1. Alfalfa—weighted averages of metered data and estimates—Panhandle district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
1999	3	190	3,036	6.3	24.56	16.37	3	10.77	21.57	35.33	37.94
2000	2	80	5,596	1.4	30.75	21.95	0	na	na	na	na
2001	6	485	5,596	8.7	19.41	21.37	6	17.30	16.61	36.71	37.98
2002	7	555	7,344	7.6	22.29	20.89	3	30.67	20.20	52.95	41.09
2003	6	435	6,576	6.6	23.04	23.23	2	32.95	17.04	55.99	40.27
2004	6	395	6,867	5.8	25.16	20.89	2	20.95	27.27	46.11	48.16
2005	3	270	5,671	4.8	11.79	23.31	0	na	na	na	na
2006	3	375	4,728	7.9	18.76	26.35	0	na	na	na	na
2007	3	494	6,551	7.5	7.04	26.42	3	21.26	11.49	28.31	37.91
Averages	4	364	5,774	6.3	19.08	22.55	2	22.32	19.03	41.40	41.58

na = not available; all units in inches per acre unless otherwise noted.

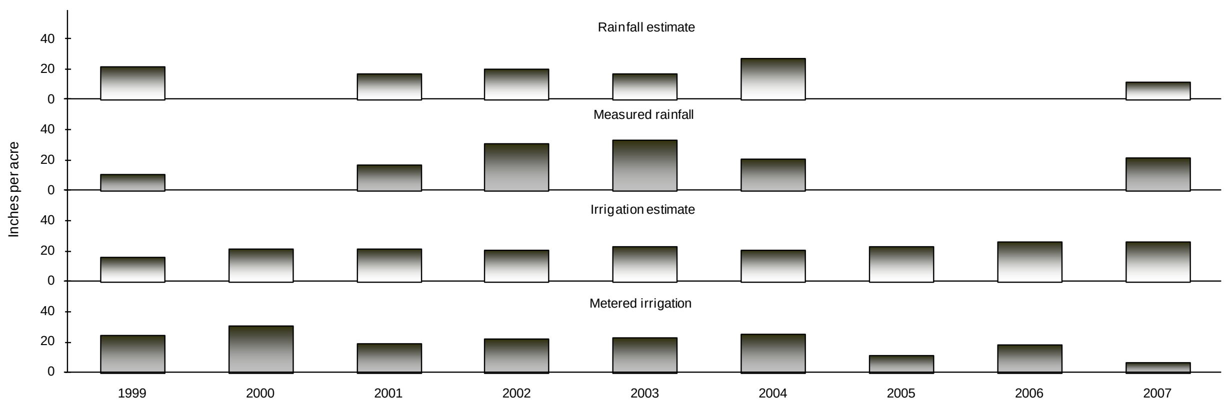


Figure 4-1. Alfalfa metered and estimated irrigation and rainfall for the Panhandle district 1999–2007.

Corn

On average, an estimated 21,555 acres of irrigated corn were grown in the district each year. The district metered an average of 2,521 acres each year, or about 11.7 percent of the total acreage. Corn fields were metered in Carson, Gray, Roberts, and Wheeler counties. The largest acreages of irrigated corn were found in Carson County. For individual years, the district acreage that was metered ranged from 5 to 30 percent, with the largest percentage metered in 2002 and 2003. The average number of metered corn fields was 12, with anywhere between 6 and 30 fields metered each year (Table 4-2). Much of this variation in sample size may be attributed to unreported crop types and corn falling into the mixed-crop category.

The weighted average metered irrigation for corn was 14.44 inches per acre, and the standard deviation was 8.04 inches on the 112 data points analyzed. Metered irrigation values for individual fields ranged from 1.44 to 36.84 inches per acre. The weighted average estimated irrigation for corn was 21.80 inches per acre, so there was a 7.36 inch difference between the average metered and estimated values. For individual years, the differences between the metered and estimated irrigation values ranged from 1.68 inches in 2000 to 12.13 inches in 2005. In all cases, the metered irrigation values were lower than the estimated values (Figure 4-2). The same was true for overall crop water use values for corn. Overall, the measured crop water use values were 10.58 inches lower than estimated values. This is also due to the rainfall values used in the TWDB estimates being higher than the measured rainfall values for all years.

Table 4-2. Corn—weighted averages of metered data and estimates—Panhandle district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
1999	11	2,281	28,373	8.0	14.80	19.56	8	15.05	24.64	29.85	44.20
2000	6	1,266	26,000	4.9	17.61	19.29	5	24.86	25.64	42.47	44.93
2001	7	1,525	19,152	8.0	17.58	24.33	6	18.52	18.68	36.10	43.00
2002	30	6,331	21,589	29.3	14.40	22.15	11	20.10	25.80	34.50	47.95
2003	19	4,342	16,953	25.6	10.80	21.93	11	16.99	18.33	27.79	40.25
2004	11	1,707	16,610	10.3	17.05	22.68	8	22.01	23.08	39.06	45.76
2005	11	1,825	16,382	11.1	10.60	22.73	7	12.00	18.58	22.60	41.31
2006	9	1,764	16,821	10.5	16.80	23.56	5	21.60	22.26	38.40	45.83
2007	8	1,650	32,115	5.1	17.41	22.13	8	19.50	22.64	36.91	44.77
Averages	12	2,521	21,555	11.7	14.44	21.80	8	18.96	22.18	33.40	43.98

All units in inches per acre unless otherwise noted.

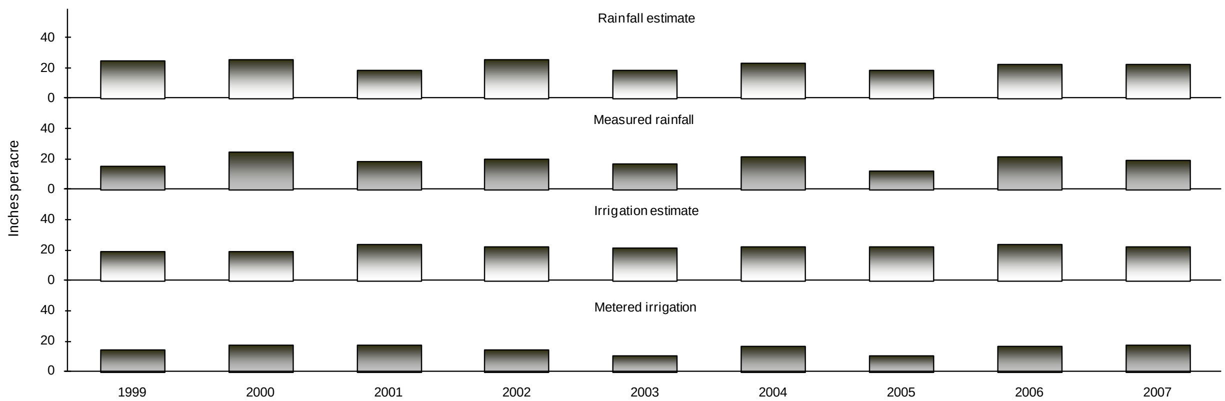


Figure 4-2. Corn metered and estimated irrigation and rainfall for the Panhandle district 1999–2007.

Cotton

Irrigated cotton acreage averaged about 32,900 acres district-wide for the nine-year period. Cotton acreage was metered in all of the counties where monitor plots were located except for Roberts County, where there was very little irrigated cotton. On average, 7.8 percent of the irrigated cotton acreage in the district was metered. The number of fields metered each year ranged from 1 early in the program to 34 in 2004 and averaged 15 (Table 4-3). Additional cotton crops grown in combination with other crops fell into the mixed-crop systems category.

The weighted average metered irrigation for cotton was 9.86 inches per acre, and the standard deviation was 7.15 inches on the 139 metered values. Metered irrigation values ranged from 1.12 to 43.56 inches per acre. The weighted average irrigation estimate for cotton within the district was 15.15 inches. Like corn, the estimates were higher than the average metered values for all years (Figure 4-3). There was a 5.29 inch difference between the metered and estimated nine-year weighted average. The overall estimated crop water use values were 6.97 inches higher than the corresponding measured values.

Table 4-3. Cotton—weighted averages of metered data and estimates—Panhandle district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
1999	1	101	6,000	1.7	6.84	10.13	0	na	na	na	na
2000	2	120	15,418	0.8	8.70	12.93	1	28.00	24.03	36.70	36.96
2001	3	373	17,103	2.2	9.78	12.05	1	11.80	16.61	21.58	28.66
2002	9	1,055	22,002	4.8	9.88	12.03	5	22.90	22.57	32.78	34.60
2003	16	2,497	36,427	6.9	9.35	14.95	8	16.56	19.65	25.91	34.60
2004	34	6,439	42,292	15.2	10.63	15.42	17	18.26	26.38	28.90	41.80
2005	31	5,171	52,438	9.9	6.13	15.77	12	14.26	19.28	20.39	35.04
2006	21	3,032	64,486	4.7	14.23	15.90	4	20.10	18.20	34.33	34.10
2007	22	4,202	39,933	10.5	10.54	17.68	22	18.85	17.57	29.39	35.25
Averages	15	2,554	32,900	7.8	9.86	15.15	8	18.84	20.53	28.71	35.68

na = not available; all units in inches per acre unless otherwise noted.

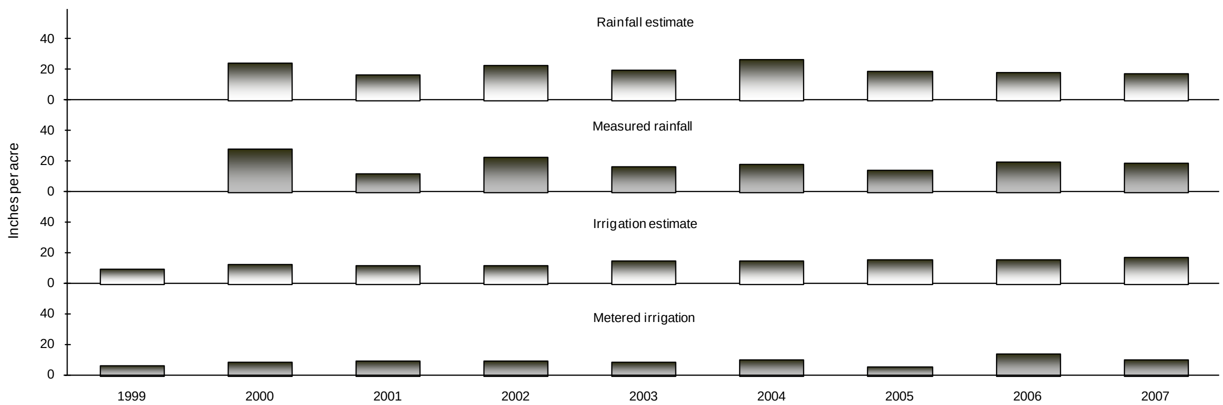


Figure 4-3. Cotton metered and estimated irrigation and rainfall for the Panhandle district, 1999-2007.

Forage crops

The forage crops category is an aggregate of different crops grown for forage. This includes single crops such as haygrazer, as well as forage combinations such as alfalfa and wheat, rye and wheat, alfalfa, and bluestem, and others. Forage crops were metered in Armstrong, Carson, Donley, Gray, Roberts, and Wheeler counties. Over the nine-year period, the average acreage of forage crops grown in the district equated to 6,576. Metered values for this category are compared to TWDB acreage estimates for “forage crops” from Farm Service Agency records. Over the nine-year period, forage crops were metered on an average 976 acres, representing 14.8 percent of irrigated forage crops in the district. The average number of fields metered each year was 7 and ranged from 2 to 15 (Table 4-4).

Owing to the broad range of crop combinations included in the forage crops category, there was the potential for significant differences between metered and estimated values, especially with the alfalfa combinations. The weighted average metered irrigation for forage crops was 12.55 inches per acre, and the standard deviation was 8.73. Metered values ranged from 1.75 to 46.56 inches per acre. The weighted average irrigation estimate was 8.64 inches per acre, resulting in a significant difference of 3.91 inches. Due to systems containing alfalfa-grass combinations, the estimates were less than the metered values for 7 of the 9 years (Figure 4-4). Rainfall data was available for comparison for all years within the forage crops category. Differences between measured rainfall and estimates go back and forth between years. The nine-year averages only differ by 1.14 inches despite the much larger differences in individual years. The overall measured crop water use is higher than the estimated crop water use by 5.05 inches.

Table 4-4. Forage crops—weighted averages of metered data and estimates—Panhandle district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
1999	2	376	12,006	3.1	5.35	4.04	2	12.45	21.57	17.80	25.61
2000	4	546	6,137	8.9	25.43	8.17	4	30.75	24.03	56.18	32.20
2001	8	1,042	6,137	17.0	15.53	6.84	4	20.00	16.61	35.53	23.45
2002	15	2,327	11,975	19.4	10.35	7.18	6	16.67	28.09	27.01	35.27
2003	9	1,365	4,570	29.9	10.70	9.33	6	18.45	18.65	29.15	27.99
2004	6	695	3,937	17.7	18.05	9.21	2	21.70	27.27	39.75	36.48
2005	6	695	2,438	28.5	10.94	15.42	4	16.23	15.27	27.17	30.69
2006	5	849	7,719	11.0	10.28	15.76	3	24.17	9.10	34.45	24.86
2007	5	885	4,263	20.8	11.92	10.99	5	21.97	11.49	33.89	22.48
Averages	7	976	6,576	14.8	12.55	8.64	4	20.26	19.12	32.82	27.77

All units in inches per acre unless otherwise noted.

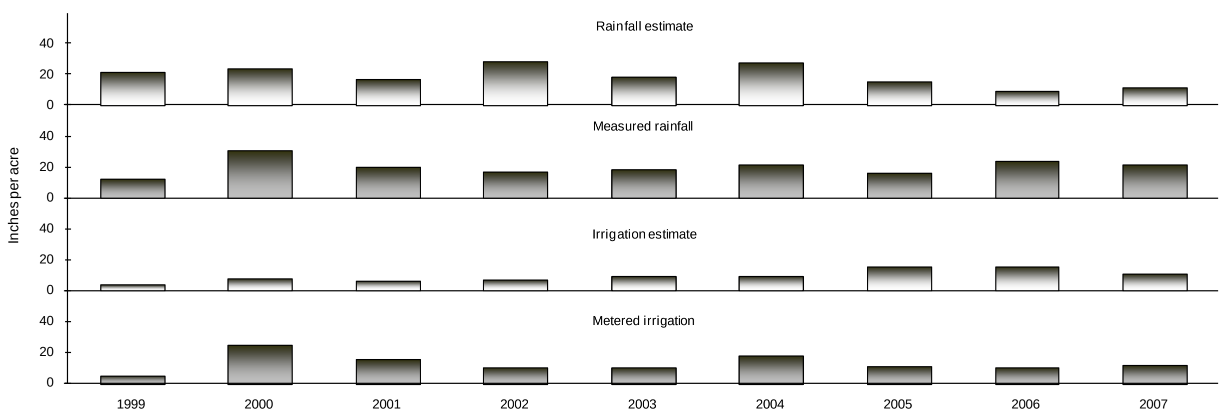


Figure 4-4. Forage crops metered and estimated irrigation and rainfall for the Panhandle district, 1999 through 2007.

Grain sorghum

Irrigated grain sorghum was metered in Armstrong, Carson, Donley, and Gray counties in the Panhandle district. The average of acreage grown across the eight years with metering data included for comparison was about 17,290. The metering data included in this analysis covered an average of 5.4 percent of the district acreage that was metered. In 2002, as much as 20.0 percent of the district acreage was included in the metering analysis. Yet in 2007, less than 1 percent of the district total, 65 acres of grain sorghum was metered. In total, 43 metered values on grain sorghum fields are included over the nine-year study period, ranging from 1 in 2004 and 2007, to 18 in 2002 (Table 4-5). There were no fields included for analysis in 2005. Some of the metered mixed-crop category contained a grain sorghum crop.

In 2004, there was a large difference between the metered and estimated values for grain sorghum (Figure 4-5). The single metered value for 2004 was just over 1 inch per acre. In 2002, when 18 fields were included in the metering analysis, metered irrigation was 2.28 inches lower than estimated irrigation, and the total crop water use values varied by nearly 18 inches due to the differences in measured and estimated rainfall that year. The weighted average metered irrigation for grain sorghum over the 8 years of data included in the analysis was 8.73 inches per acre with a standard deviation of 5.90 inches. Metered values ranged from 1.08 to 23.16 inches per acre. The weighted average estimated irrigation was 12.17 inches per acre, resulting in a 3.44 inch difference between metered and estimated values. Rainfall data was not available for all years. Of those years with reported rainfall amounts, comparisons with estimates resulted in an overall difference of 9 inches. With both the irrigation estimates and rainfall estimates being higher than measured values, the overall crop water use estimates were 12.44 inches higher than the measured crop water use.

Table 4-5. Grain sorghum—weighted averages of metered data and estimates—Panhandle district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
1999	3	247	38,250	0.6	11.86	12.35	2	12.89	25.97	24.74	38.32
2000	4	750	18,942	4.0	12.64	8.73	2	18.75	25.64	31.39	34.37
2001	4	540	15,003	3.6	8.73	10.32	0	na	na	na	na
2002	18	3,602	18,014	20.0	7.83	10.11	8	16.35	32.04	24.18	42.15
2003	9	1,796	13,908	12.9	8.10	15.68	7	23.43	19.17	31.53	34.85
2004	1	160	9,783	1.6	1.08	13.58	0	na	na	na	na
2006	3	322	9,507	3.4	11.87	12.20	1	12.30	27.29	24.17	39.49
2007	1	65	14,915	0.4	22.34	16.09	1	15.00	22.64	37.34	38.73
Averages	5	935	17,290	5.4	8.73	12.17	3	16.45	25.46	25.18	37.62

na = not available; all units in inches per acre unless otherwise noted.

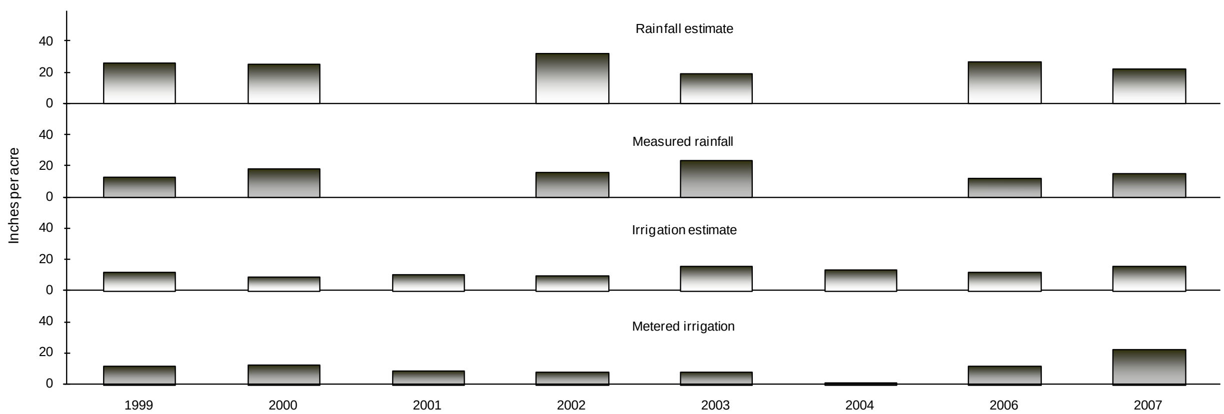


Figure 4-5. Grain sorghum metered and estimated irrigation and rainfall for the Panhandle district 1999–2007.

Hay-pasture

The hay-pasture crop category included records with single crop types labeled as grass, bluestem, and bermuda. Metered values for this category were compared to TWDB estimates for "hay-pasture" from Farm Service Agency records. Relatively small amounts of irrigated grass were grown in four counties in the Panhandle district. On average, 11,430 acres of irrigated hay-pasture were grown during the years with metered data for comparison. Metered data provided a sample of irrigation practices on 12.4 percent of that acreage, averaging about 1,417 acres each year. Hay-pasture acreage was metered in Carson, Donley, Gray, and Wheeler counties. An average of 5 hay-pasture fields were metered each year, ranging from 1 to 7 (Table 4-6).

When averaged over the 8 years with metered values, the weighted average metered and estimated irrigation values were in close agreement at 10.96 and 11.28 inches per acre, respectively. Metered values ranged from 1.68 to 27.84 with a standard deviation of 5.77. For individual years, however, such as 2007, the differences between metered and estimated values were significant with metered values higher some years and estimated values higher in other years. As a result of rainfall estimates being higher than measured rainfall for most years, the overall crop water use differed by 4.96 inches. There were no metered systems in this category in 2000 (Figure 4-6).

Table 4-6. Hay-pasture—weighted averages of metered data and estimates—Panhandle district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
1999	1	60	4,161	1.4	18.72	7.52	0	na	na	na	na
2001	2	622	9,689	6.4	5.18	10.76	0	na	na	na	na
2002	6	2,300	18,678	12.3	15.22	8.35	2	15.50	32.04	30.72	40.39
2003	7	1,947	12,122	16.1	14.10	9.70	4	18.78	19.28	32.87	28.98
2004	7	1,991	12,238	16.3	13.05	10.02	5	20.44	26.51	33.49	36.54
2005	6	1,866	11,591	16.1	8.13	11.18	4	12.58	18.55	20.70	29.73
2006	7	1,991	11,586	17.2	6.72	14.75	4	21.30	22.74	28.02	37.49
2007	5	555	11,379	4.9	5.23	17.54	5	18.62	15.95	23.86	33.49
Averages	5	1,417	11,430	12.4	10.96	11.28	3	17.87	22.51	28.83	33.79

na = not available; all units in inches per acre unless otherwise noted.

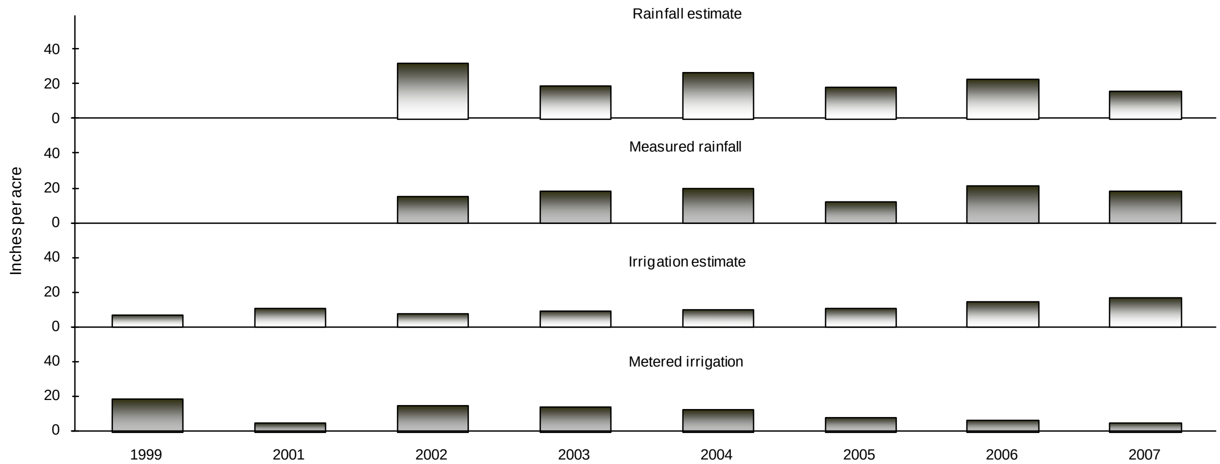


Figure 4-6. Hay-pasture metered and estimated irrigation and rainfall for the Panhandle district 1999–2007.

Peanuts

Irrigated peanut acreage averaged about 18,713 acres district-wide for the nine-year period. Irrigated peanuts were grown and metered in Donley, Gray, and Wheeler counties, as well as in Collingsworth County.[35] Across the district, 4.5 percent of the acreage—on average 836 acres—was metered. A total of 56 peanut fields were metered during the study period, with an average of about 6 (Table 4-7). The number of metered values included for analysis ranged from 1 to 13. Additionally, several of the metered mixed systems included a cotton and peanut combination.

The weighted average metered irrigation for peanuts was 9.54 inches per acre, and the standard deviation was 5.88 inches. Metered values ranged from 2.11 to 31.80 inches per acre. The weighted average estimated irrigation was 19.49 inches per acre (Figure 4-7). Rainfall differences varied in individual years, but were much closer when averaged across the 9 years, differing by only 1.86 inches. The overall metered and estimated total crop water use values differed by 8.08 inches. Judging from the data, it appears many producers in the district may rely upon deficit irrigation on peanuts. More data is necessary to justify doing so, but TWDB should consider possibly making adjustments to irrigation estimates on peanuts in these counties.

[35] Collingsworth County is not located in the Panhandle district; however, several meters are located in the county, and the data is included in the data set and analysis.

Table 4-7. Peanuts—weighted averages of metered data and estimates—Panhandle district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
1999	2	130	29,300	0.4	12.75	15.08	2	13.50	21.57	26.25	36.65
2000	1	70	16,284	0.4	13.80	14.45	1	18.00	24.03	31.80	38.48
2001	8	1,111	15,000	7.4	13.32	23.00	2	18.05	16.61	31.37	39.61
2002	13	1,816	19,700	9.2	9.17	20.00	5	26.78	20.20	35.95	40.20
2003	8	1,072	19,790	5.4	8.38	24.45	4	20.50	17.79	28.88	42.24
2004	10	1,422	20,444	7.0	9.07	24.48	2	22.60	26.64	31.67	51.12
2005	5	729	20,218	3.6	9.48	19.48	4	17.68	15.27	27.16	34.75
2006	4	525	11,800	4.4	9.00	17.19	1	21.60	9.10	30.60	26.29
2007	5	650	15,880	4.1	6.42	17.92	5	20.78	11.49	27.20	29.41
Averages	6	836	18,713	4.5	9.54	19.49	3	19.94	18.08	29.48	37.56

All units in inches per acre unless otherwise noted.

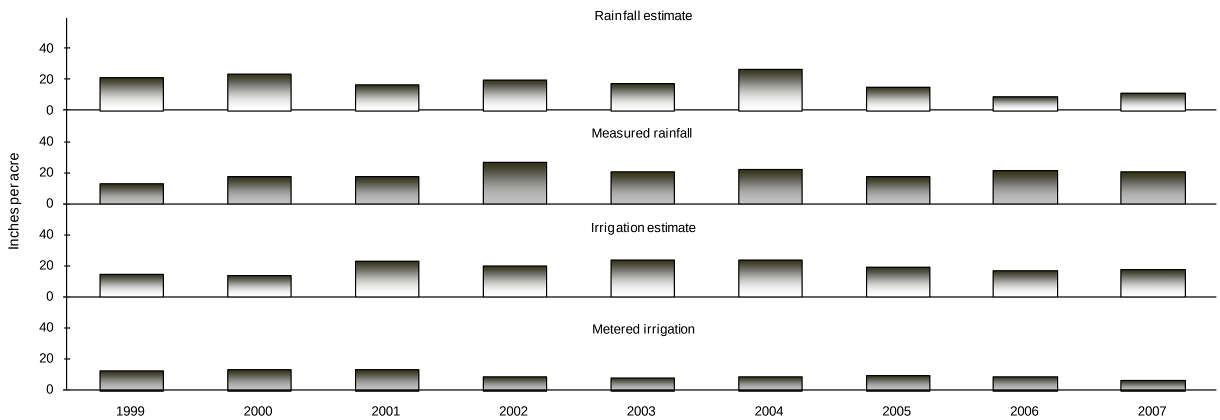


Figure 4-7. Peanuts metered and estimated irrigation and rainfall for the Panhandle district 1999–2007.

Soybeans

Small acreages of irrigated soybeans were metered in Carson, Gray, and Wheeler counties during the study period. Throughout the district, an average of 9,523 acres was grown, and about 9.3 percent of it was metered. There were 34 soybean fields metered, with an average of 5 fields per year, ranging from 1 in 2000 to 10 in 2002 (Table 4-8). Additional fields of soybeans were grown in the mixed-crops category that could not be separated out for inclusion in the analysis of soybeans.

The weighted average metered irrigation was 12.84 inches per acre and the standard deviation was 6.70. Metered values for individual fields ranged from 2.04 to 37.68 inches per acre. The weighted average estimated irrigation was 12.79 inches per acre. There was only 1 rain gage associated with metered soybean crops throughout the 7 years. On average, the rainfall estimates were 7.06 inches greater than the average measured rainfall from this single rain gage. Similarly, as a result, the overall metered and estimated crop water use values differed by 7.01 inches (Figure 4-8). There were no metered fields of soybeans during 2006 or 2007.

Table 4-8. Soybeans—weighted averages of metered data and estimates—Panhandle district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
1999	2	323	16,700	1.9	12.54	12.57	1	8.20	25.97	20.74	38.54
2000	1	198	18,341	1.1	22.20	11.55	0	na	na	na	na
2001	4	541	6,572	8.2	12.54	10.57	1	26.70	16.61	39.24	27.18
2002	10	1,755	12,459	14.1	14.68	10.73	1	14.00	32.04	28.68	42.77
2003	7	1,514	5,107	29.6	11.86	18.72	1	20.80	20.02	32.66	38.74
2004	6	1,066	5,077	21.0	11.37	18.54	1	17.90	27.27	29.27	45.81
2005	4	793	2,407	32.9	10.59	15.80	1	11.60	19.64	22.19	35.44
Averages	5	884	9,523	9.3	12.84	12.79	1	16.53	23.59	29.37	36.38

na = not available; all units in inches per acre unless otherwise noted.

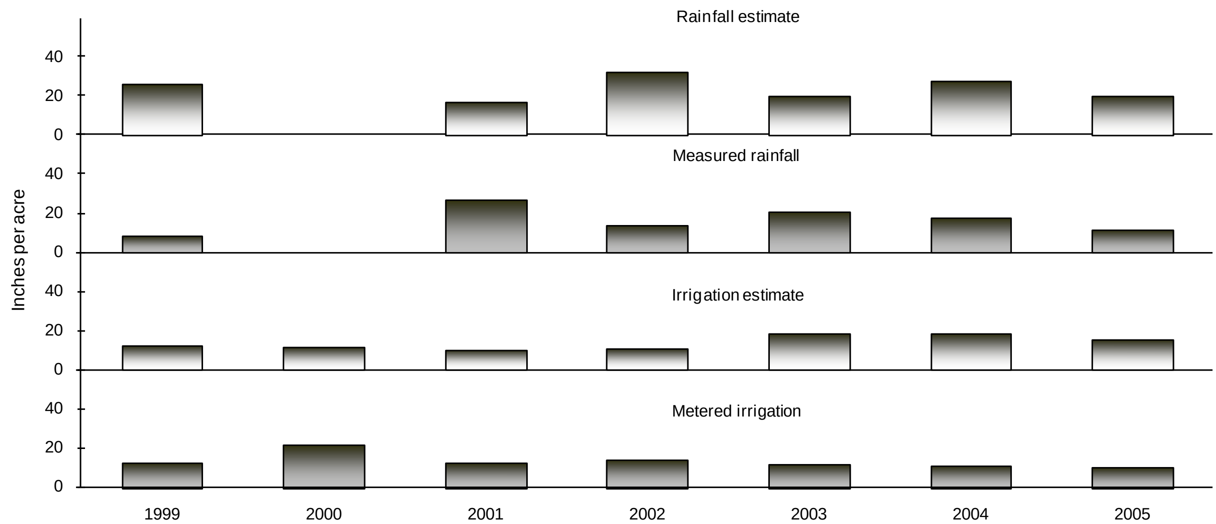


Figure 4-8. Soybeans metered and estimated irrigation and rainfall for the Panhandle district 1999–2007.

Wheat

Annually, an average of 48,172 acres of irrigated wheat was grown in the Panhandle district during the study period. Significant acreage was grown in Carson and Gray counties, and smaller acreages occurred in Armstrong, Roberts, and Wheeler counties. On average, 4.5 percent of the district acreage was metered. A total of 86 wheat fields were metered, ranging from 4 in 2000 to 16 in 2004 and 2007 (Table 4-9). On average, 11 fields were metered each year. Because wheat combination crops were very common, the percentage of wheat acreage in this category was lower than it would otherwise be. A large percentage of the combinations reported contained a wheat crop that cannot be analyzed here.

The weighted average metered and estimated values for irrigation on wheat differed by only 0.07 inches; however, for individual years the values differed by much larger amounts, especially in 2000 and 2005 (Figure 4-9). Metered values in the data set ranged from 1.20 to 32.88 inches per acre, with a standard deviation of 7.42. The weighted average metered irrigation was 8.64 inches per acre and the weighted average estimated value was 8.57 inches per acre. Rainfall estimates were greater than the measured amounts for all years, except for 2000, on average 6.35 inches greater. Total crop water use values differed by 6.27 inches. There were no metered wheat fields in 1999.

Table 4-9. Wheat—weighted averages of metered data and estimates—Panhandle district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
2000	4	501	76,594	0.7	18.46	7.91	3	24.00	20.21	42.46	28.12
2001	14	2,364	50,077	4.7	11.85	5.23	10	11.91	23.59	23.76	28.82
2002	13	1,950	49,128	4.0	9.63	5.88	6	15.90	28.09	25.53	33.97
2003	5	742	67,782	1.1	9.93	8.01	3	12.80	19.03	22.73	27.04
2004	16	3,614	52,470	6.9	6.68	8.59	6	19.40	26.01	26.08	34.60
2005	4	787	42,786	1.8	4.58	12.65	4	11.80	18.55	16.38	31.20
2006	14	3,512	18,354	19.1	7.11	13.53	7	19.43	24.69	26.54	38.22
2007	16	3,926	28,184	13.9	8.71	12.92	16	16.80	22.64	25.51	35.56
Averages	11	2,175	48,172	4.5	8.64	8.57	7	16.50	22.85	25.15	31.42

All units in inches per acre unless otherwise noted.

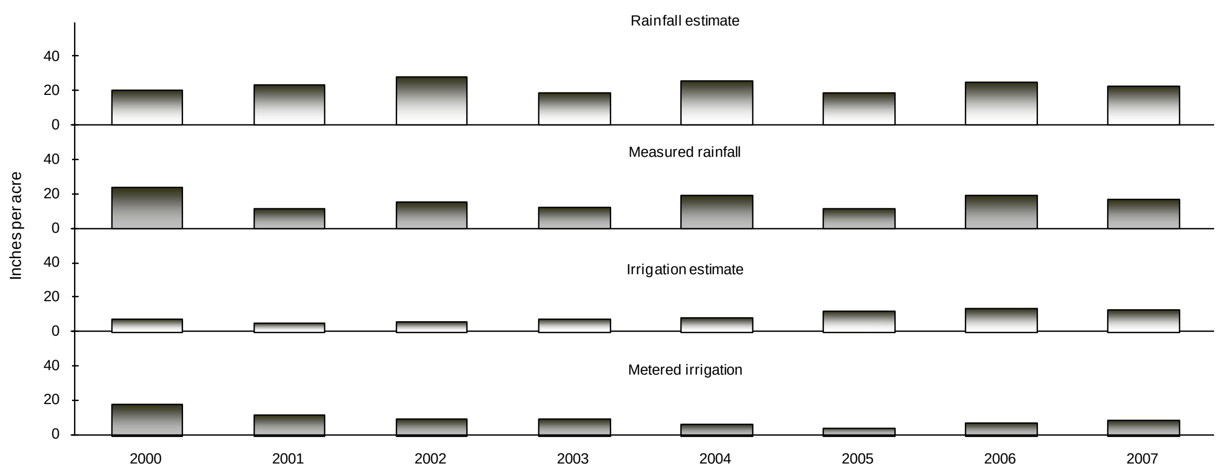


Figure 4-9. Wheat metered and estimated irrigation and rainfall for the Panhandle district 1999–2007.

Mixed crops

Mixed crops included metered fields where one or more crops were grown under the same pivot or row watering system. Combinations of all of the individual crops were seen in this category. For example, a half circle of cotton with a half circle of peanuts or a combination of wheat, corn and cotton may have been grown under one pivot. For these combinations, the district provided acreages for some, but not all, of the individual crops. The metered irrigation could not be calculated for individual crops. For this reason there was no comparison to TWDB irrigation estimates.

On average, about 36 percent of the acreage metered by the district annually was in mixed crops.[36] Mixed crops made up the largest acreage by category in the data set, on average about 8,401 acres. Metered mixed crop acreage was in all counties in the district, as well as in Collingsworth County. A total of 309 fields with mixed crops were metered during the study period. The number of mixed systems each year ranged from 17 to 68, averaging about 34 (Table 4-10). The weighted average metered irrigation for the mixed crops was 11.71 inches per acre. Within the data set, individual metered values ranged from 1.08 inch per acre to 58.24 inches per acre. Weighted averages for each year were somewhat more consistent, differing much less than the 9.07 inch standard deviation implies (Figure 4-10). Rainfall was measured from 198 rain gage totals on mixed crop systems over the nine-year period. Comparisons with rainfall estimates showed a higher estimate value for every year. TWDB and the district should investigate the validity of measured rainfall and rainfall estimates in the region. There is no comparison for total crop water use because TWDB does not calculate irrigation estimates for mixed crops.

Table 4-10. Mixed crops—weighted averages of metered data and estimates—Panhandle district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
1999	18	4,231	na	na	8.85	na	15	15.57	23.26	24.42	na
2000	18	4,322	na	na	13.13	na	13	19.77	25.39	32.90	na
2001	17	3,433	na	na	12.35	na	7	14.26	20.19	26.61	na
2002	32	8,243	na	na	10.02	na	14	20.90	27.36	30.92	na
2003	20	5,232	na	na	11.09	na	9	16.51	19.03	27.60	na
2004	24	6,249	na	na	15.03	na	15	18.15	25.61	33.18	na
2005	52	13,428	na	na	7.25	na	26	14.01	18.21	21.26	na
2006	60	13,735	na	na	12.98	na	31	19.70	21.16	32.68	na
2007	68	16,732	na	na	14.26	na	68	18.49	19.07	32.76	na
Averages	34	8,401	na	na	11.71	na	22	17.48	22.14	29.20	na

na = not available; all units in inches per acre unless otherwise noted.

[36] A district-wide total for mixed crop acreage is unknown. TWDB estimates are compiled from Farm Service Agency crop categories. Crop acreage is reported individually rather than as field totals. In October 2008 a new contract between the Panhandle GCD and TWDB was signed to implement software developed by Net Irrigate, LLC – an irrigation software company specializing in wireless data acquisition and reporting – to attempt to separate the crop water use on individual crops in future mixed crop systems.

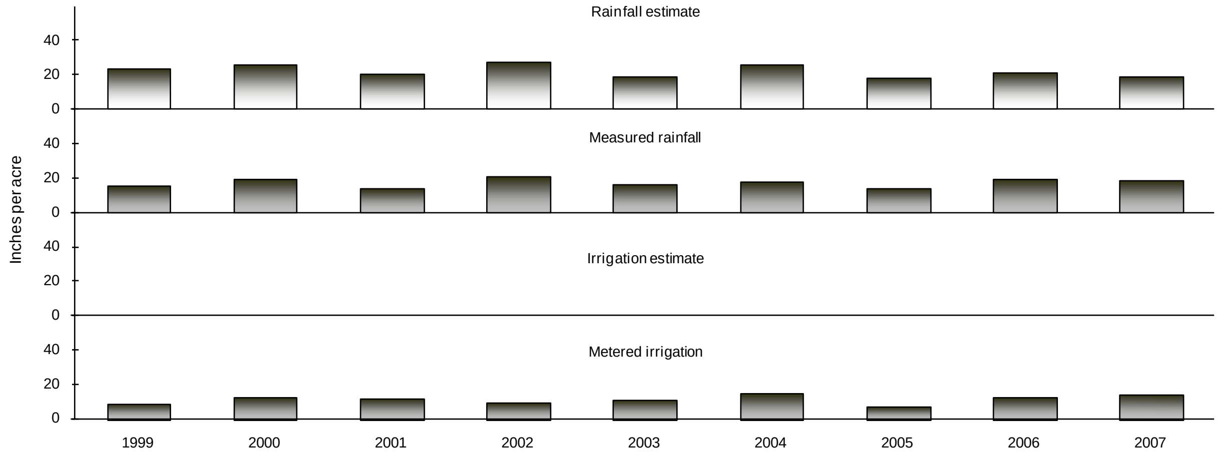


Figure 4-10. Mixed crops metered and estimated irrigation and rainfall for the Panhandle district 1999–2007.

Other crops

For the purposes of this analysis, metering records that did not have a crop type associated with them were designated as "other." On average about 17 metered fields a year had no crop type information; the number of records ranged from 1 to 38 (Table 4-11). In 2001, 2004, and 2007 there were higher numbers of these undesignated records. A total of 135 of the 1,055 records included for analysis covering 27,286 acres over the nine-year study period did not have crop type information. However, in 1999, there were no unknown crops in the data set; in 2005 only one record was without crop type information.

As with the mixed crops, the metered values for unknown crops were not compared to any irrigation estimates (Figure 4-11). Metered values ranged from 1.08 to 59.62 inches per acre. The weighted average metered irrigation for unknown crops was 9.63 inches per acre, with a standard deviation of 8.42. Measured rainfall totals from 94 rain gage values averaged 2.55 inches less than the rainfall estimate. There is no comparison for total crop water use because TWDB does not calculate irrigation estimates for unknown crops.

Table 4-11. Other—weighted averages of metered data and estimates—Panhandle district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
2000	5	840	na	na	15.92	na	3	20.73	20.21	36.66	na
2001	34	8,452	na	na	10.23	na	20	14.69	19.94	24.92	na
2002	5	736	na	na	8.22	na	1	25.00	20.20	33.22	na
2003	13	1,742	na	na	8.09	na	9	14.91	19.36	23.00	na
2004	38	8,574	na	na	8.56	na	26	15.93	26.06	24.50	na
2005	1	125	na	na	9.00	na	1	19.80	15.27	28.80	na
2006	8	1,185	na	na	10.73	na	3	18.83	27.29	29.56	na
2007	31	5,632	na	na	9.87	na	31	17.95	19.94	27.82	na
Averages	17	3,411	na	na	9.63	na	12	18.48	21.03	28.11	na

na = not available; all units in inches per acre unless otherwise noted.

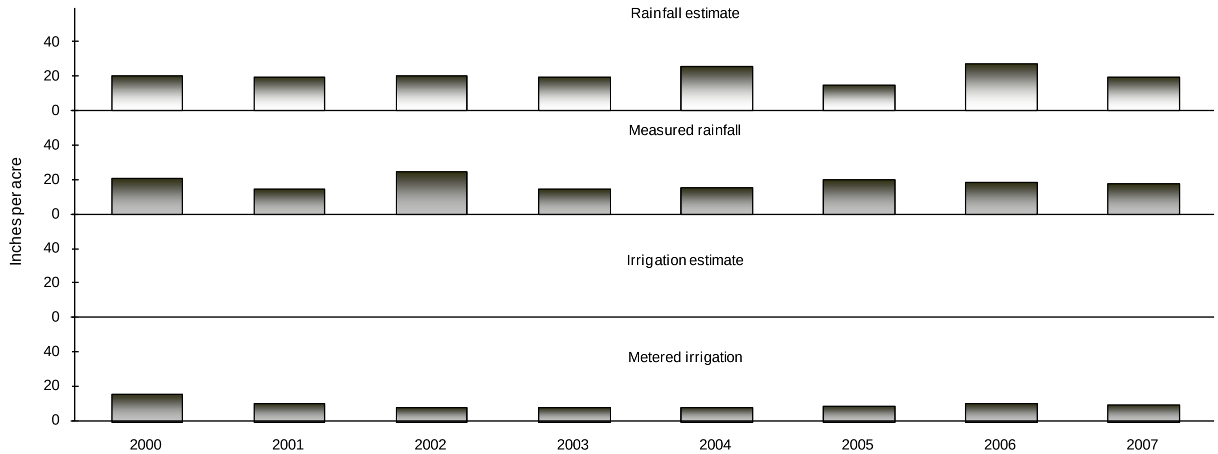


Figure 4-11. Other crops metered and estimated irrigation and rainfall for the Panhandle district 1999–2007.

4.2.2 Irrigation water use—all crops

During the study period, on average 175,959 acres of irrigated crops were grown annually in the Panhandle district. Of this, 13.3 percent, or about 23,431 acres, was metered on average by the district. As many as 203 meters were used in one year, although some data points were removed from the data set. There were over 100 data points removed that had values less than 1 inch of metered irrigation per acre, not representative of an irrigated crop. A few other data points were removed because they were without associated acreage information. An average of 117 systems was analyzed annually. Rainfall data from an average of 69 rain gages were included in the analysis for each year.

Table 4-12. All crops—weighted averages of metered data and estimates—Panhandle district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
1999	43	7,939	199,430	4.0	11.13	10.70	33	14.31	23.48	25.43	34.18
2000	47	8,693	199,393	4.4	15.40	11.23	32	22.56	24.22	37.96	35.44
2001	107	20,488	150,721	13.6	11.84	11.95	57	15.48	19.66	27.31	31.61
2002	158	30,670	188,434	16.3	11.45	11.63	62	20.17	26.63	31.61	38.26
2003	119	22,684	187,719	12.1	10.72	13.93	64	18.11	18.90	28.83	32.83
2004	159	32,312	176,205	18.3	11.23	14.55	84	18.33	25.87	29.56	40.42
2005	124	26,009	171,200	15.2	7.55	15.75	63	14.03	18.10	21.58	33.85
2006	134	27,290	151,332	18.0	11.96	16.43	59	20.05	21.17	32.02	37.61
2007	164	34,791	159,198	21.9	12.19	17.69	164	18.53	18.88	30.72	36.57
Averages	117	23,431	175,959	13.3	11.23	13.60	69	17.95	21.88	29.18	35.48

na = not available; all units in inches per acre unless otherwise noted.

In the early years of the program, TWDB's weighted average irrigation estimates for all crops were lower than the metered irrigation values (Table 4-12). However, in later years, the metered values were lower than the estimates (Figure 4-12). The weighted average metered irrigation for all years was 11.23 inches per acre and the standard deviation was 8.58. Individual metered irrigation values ranged from 1.08 to 59.62 inches per acre. The weighted average estimated irrigation was 13.60 inches per acre. For all years except 2000 the estimated total crop water use values were higher than the measured values.

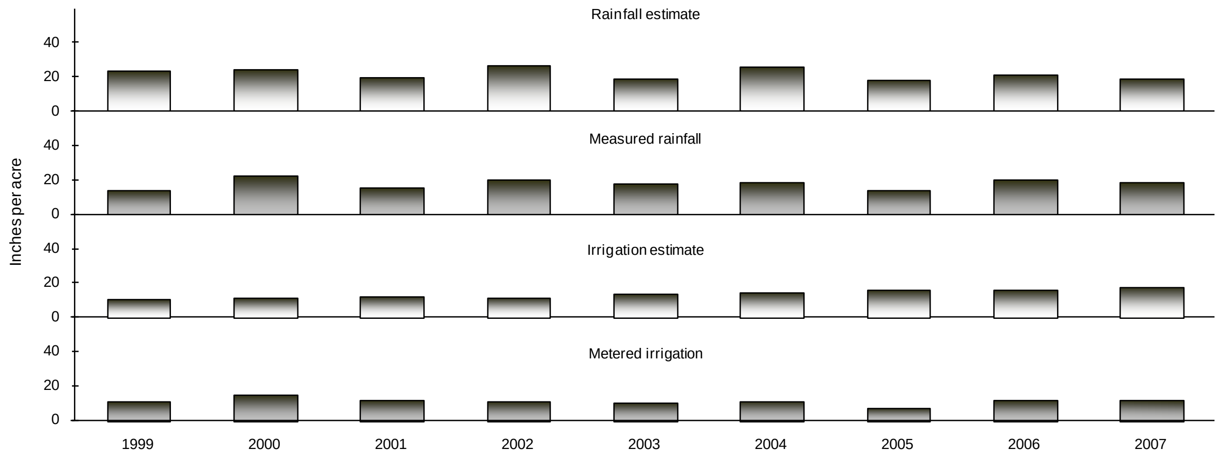


Figure 4-12. All crops metered and estimated irrigation and rainfall for the Panhandle district 1999–2007.

4.2.3 Results and conclusions

The Panhandle district's data set was large and diverse. Data quality was generally good, except there were over 100 data points removed due to very low—less than an inch—water use recorded. The large number of meters found on mixed crops and other crops also diminished the usefulness of the data to TWDB for comparisons with individual crops.

For the metered data for individual crops (excluding the mixed-crop category), the annual sample sizes were too small ($n \leq 50$) to assume that the means were reliably representative of the overall population. Additionally, 25 percent of the Panhandle metering data set contained values between 1 and 6 inches per acre. Although the accuracy of these values was questionable, removing those data points would have significantly compromised the size of the data sets for individual crops.

The aggregated nine-year data set for some individual crops and the annual data set for all crops (1999–2007) provided large enough sample sizes to make some statistical assumptions. For the aggregated data set for all crops, the Panhandle data set has provided a fairly balanced representation of the estimated data set (Table 4-13).

Table 4-13. Nine-year averages of metered and estimated acreages by crop type—Panhandle district.

Crop	Meters	Metered acres	Estimated acres	Percent metered
Alfalfa	39	364	5,774	6.3
Corn	112	2,521	21,555	11.7
Cotton	139	2,554	32,900	7.8
Forage crops	60	976	6,576	14.8
Grain sorghum	43	831	16,248	5.1
Hay-pasture	41	1,259	11,237	11.2
Mixed	309	8,401	na	na
Other	135	3,032	na	na
Peanuts	56	836	18,713	4.5
Soybeans	34	688	7,679	9.0
Vegetables	1	36	523	6.8
Wheat	86	1,933	49,486	3.9
Total	1,055	23,431	175,959	13.3

na = not available

Measured crop water use was calculated by adding metered irrigation and measured rainfall. Likewise, estimated crop water use was calculated by adding TWDB irrigation estimates with TWDB rainfall estimates. Both of these values were compared to crop evapotranspiration rates (Appendix C) for the Panhandle district (Figure 4-13). Based on the metering values analyzed, estimates of annual crop water use for all crops (except for the forage crops category due to alfalfa combinations) in the Panhandle district appeared higher than actual metered crop water use by 6.30 inches per acre on average. Panhandle producers were irrigating below TWDB estimates and below the mean crop consumptive use for most crop types in the region.[37]

[37] Crop evapotranspiration is the mean consumptive crop water use value developed by Borrelli and others (1998).

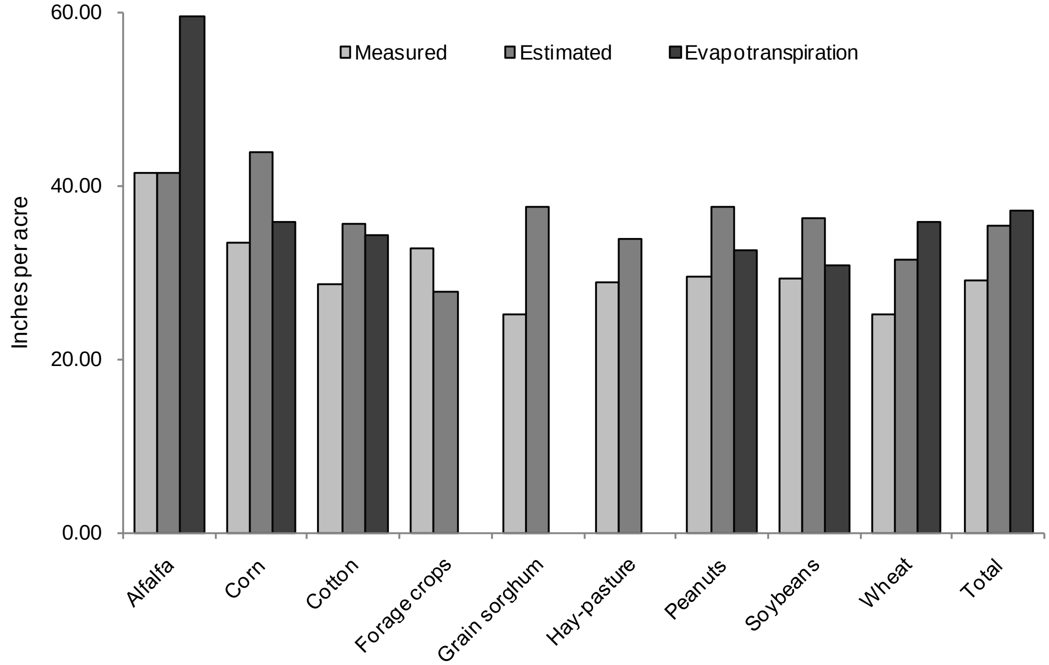
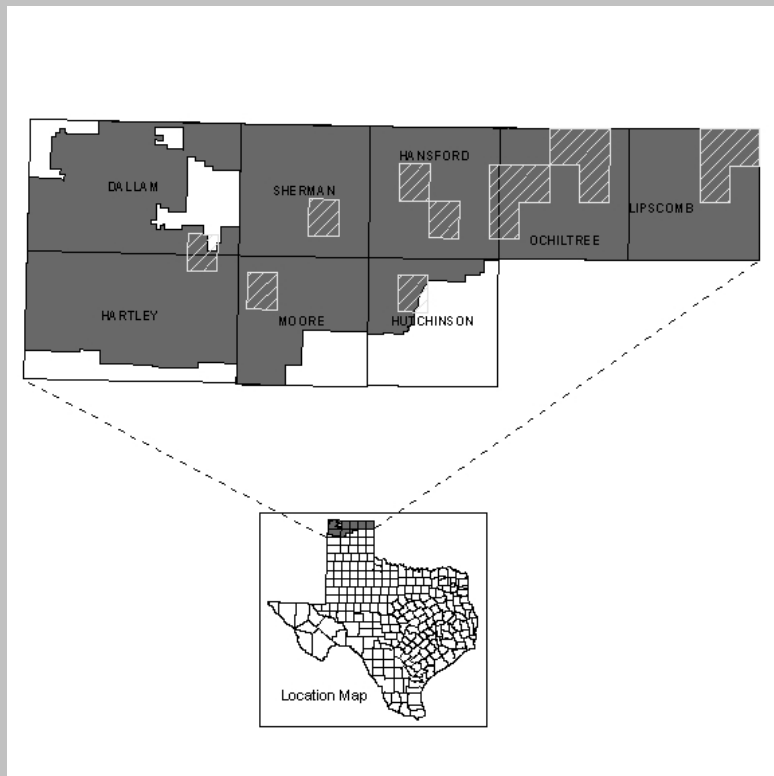


Figure 4-13. Total crop water use values—metered, estimated, and mean consumptive—for individual and all crops for the Panhandle district 1999–2007.

Note: This figure does not include individual crop comparisons for mixed, other, or vegetable crops. The computation of evapotranspiration rates was not available for the categories of forage crops, grain sorghum, or hay-pasture.

The scope of the Panhandle district's metering program is large and ambitious. The district has expressed an interest in and commitment to obtaining accurate data and expanding the metering program. TWDB and the Panhandle district continue to work together to address gaps in the data set and improve the issues of sample size and representation and suitability of the data set for validating TWDB estimates, especially with respect to the large number of records for mixed crops and unknown crops. The district may need to investigate the low water use values to verify accuracy and potentially provide an explanation of what types of irrigation or crop practices are contributing to the low values, if they are in fact accurate. It is not known if failed crops are included in the data set. Inaccurate acreages could also be a cause for low metered values. In the future, the TWDB estimation methodology may need to be revised for counties in the Panhandle district to account for the deficit irrigation (irrigation below mean crop consumptive use) that may be occurring in the district.

4.3 North Plains Groundwater Conservation District



District at a Glance

Planning Region: *Panhandle (A)*

2007 Gross Crop Income: *$607,357,000***

Climate: *Semi-arid*

Average Yearly Rainfall: *19 inches*

District Size: *4,419,200 acres**

Total Crop Land: *1,687,000 acres*

Irrigated Crop Land: *1,122,096 acres*

Irrigation Water Use: *1,245,074 acre-feet**

Acres in TWDB Metering Program: *11,478 acres*

Number of Active Irrigation Wells in Groundwater Conservation District: *8,225*

Number of Meters in Program: *133*

** Indicates district data.*
*** 2007 Gross Crop Income includes all counties except Ochiltree, which was not disclosed by USDA-NASS.*

Eco-region: *High Plains, Rolling Plains*

Soils:
Clay loam, Silty clay loam, Loamy fine sand, Loam, Fine sandy loam

Crop Types:
Alfalfa
Corn
Cotton
Wheat
Oats
Sorghum
Soybeans
Sunflower

Irrigation Methods:

Center pivot
Furrow

The North Plains district helped to initiate the metering program in conjunction with the Panhandle Groundwater Conservation District and the Panhandle Regional Water Planning Group. During the first years of the program, from 1999 to 2001, Panhandle district personnel read meters in the North Plains district. The North Plains district took over this responsibility in 2002.

The North Plains district has a large amount of irrigated crop land—over 1 million acres. The district has 9 monitor plots spread over 8 counties. Not all monitor plots are 100 percent metered. In some counties, such as Moore, there are large contiguous plots that are fully metered, but in other counties, such as Ochiltree, there are only 1 to 2 systems (1 to 4 meters) in the same monitor plot.

District employees read the meters in some counties and rely upon producers to send in information on the rest of the meters. Meters were read monthly during the early years of the program, but the district is now on a yearly data reporting schedule. The district has reported difficulty obtaining accurate irrigated acreage from some producers who read their own meters and send their data to the district. Meter data are collected in the field on paper, transferred to spreadsheets, and sent to TWDB using the metering data template.

The district has about 19 systems in which multiple meters must be read to measure total system water use. The district also has 22 meters on wells where the pivot is metered. TWDB and the district have worked together to consolidate system records to ensure that accurate irrigation water use per acre could be established.

The North Plains data set covers 2002 through 2007.[38] The North Plains district metered an average of 15,973 acres over the six-year period. Consolidation of systems containing multiple metered wells, along with removing systems totaling less than one inch per acre, resulted in 318 data points of annual irrigation water use values for analysis. Two extreme outliers, 96 inches per acre on corn and 77 inches per acre on a mixed crop system, were removed from the data set.

Thirty-eight rain gages are distributed in the monitor plots in Dallam, Hartley, Moore, and Sherman counties where all monitor plots have gages. Rainfall data submitted by the district is associated with monitor plots but not with individual meters. For the analysis, annual rainfall values were assigned to meter readings based on the proximity of the meter to the rain gage within a monitor plot (determined from district maps). Rainfall values were not assigned to meter readings from monitor plots in Lipscomb and Ochiltree counties where there are no gages. After removing values less than 6 annual inches, rainfall values were assigned to 192 data points. There was no rainfall data reported by the district in 2006.

[38] The TWDB has records from 1999 to 2001, but they are not included in the analysis due to concerns over calculating inches per acre by crop type.

4.3.1 Irrigation water use data—individual crops

Corn, sunflowers, wheat, and "mixed" crops were the most prevalent in the data set. Some records did not indicate crop type or were labeled as fallow.[39] Unknown crops and fallow land were aggregated into a category called "other." Additional crops that appeared in the data set included alfalfa, cotton, sorghum, and soybeans. Corn was the most frequently metered crop, with a total of 128 metered values on a six-year average of 5,557 acres, followed by mixed crops with 109 system totals on a six-year average of 6,899 acres, and wheat with 43 readings on a five-year average of 2,242 acres.

Wheat was the most abundant irrigated crop in the district, with corn a close second. TWDB estimates showed that on average about 482,787 acres, or 43 percent of the irrigated acreage in the district, was in wheat. Cornfields made up about 39 percent of the irrigated acreage in the district during the study period. Other crops made up much smaller percentages of the total irrigated acreage. For example, grain sorghum was the third largest irrigated acreage but represented only about 6 percent of the total.

Corn

Total irrigated corn acreage in the district averaged 435,847 acres annually. Of this, an average of 5,557 acres, or just over one percent of the total, was metered each year. Irrigated corn was grown in all counties in the district, but the largest acreage was in Dallam County. However, less than 1 percent of the corn acreage in Dallam County was metered. Hartley, Moore, and Sherman counties also had large amounts of corn acreage. In two of those counties, the percent of acreage metered was slightly higher—3.2 percent in Moore and 2.7 percent in Sherman, yet again less than 1 percent was metered in Hartley County. On average, 21 corn fields were metered each year, with the number ranging from 19 to 33 (Table 4-14).

The weighted average metered irrigation for corn was 18.15 inches per acre, and the standard deviation was 12.77. Metered irrigation values for individual fields ranged from 1.10 to 74.60 inches per acre. The weighted average estimated irrigation was 24.63 inches per acre, and the metered values were lower than TWDB estimates for all years, except 2006 and 2007 (Figure 4-14).[40] In 2003 and 2005, the metered irrigation was less than half of the estimated irrigation. However, in other years it was much closer, especially 2006. Measured rainfall average was 2.39 inches higher than the six-year average rainfall estimate. Total crop water use differed overall by 4.08 inches.

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[39] The North Plains metering data records do not indicate the combination of crop types that make up a mixed crop.

[40] The data from 2007 is suspected to be inaccurate, as TWDB could not confirm the accuracy of the data with the district.

Table 4-14. Corn—weighted averages of metered data and estimates—North Plains district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
2002	19	6,075	451,091	1.3	26.48	28.45	5	12.23	13.93	38.71	42.38
2003	31	8,590	424,456	2.0	11.57	26.41	25	10.66	11.11	22.24	37.52
2004	31	8,575	452,619	1.9	21.69	26.29	30	25.36	17.87	47.05	44.15
2005	33	7,975	400,419	2.0	11.55	24.91	28	13.07	12.07	24.62	36.98
2006	9	1,500	405,886	0.4	21.67	21.66	0	na	na	na	na
2007	5	625	480,614	0.1	54.81	20.20	5	19.66	14.02	74.47	34.23
Averages	21	5,557	435,847	1.3	18.15	24.63	16	16.19	13.80	34.35	38.43

na = not available; all units in inches per acre unless otherwise noted.

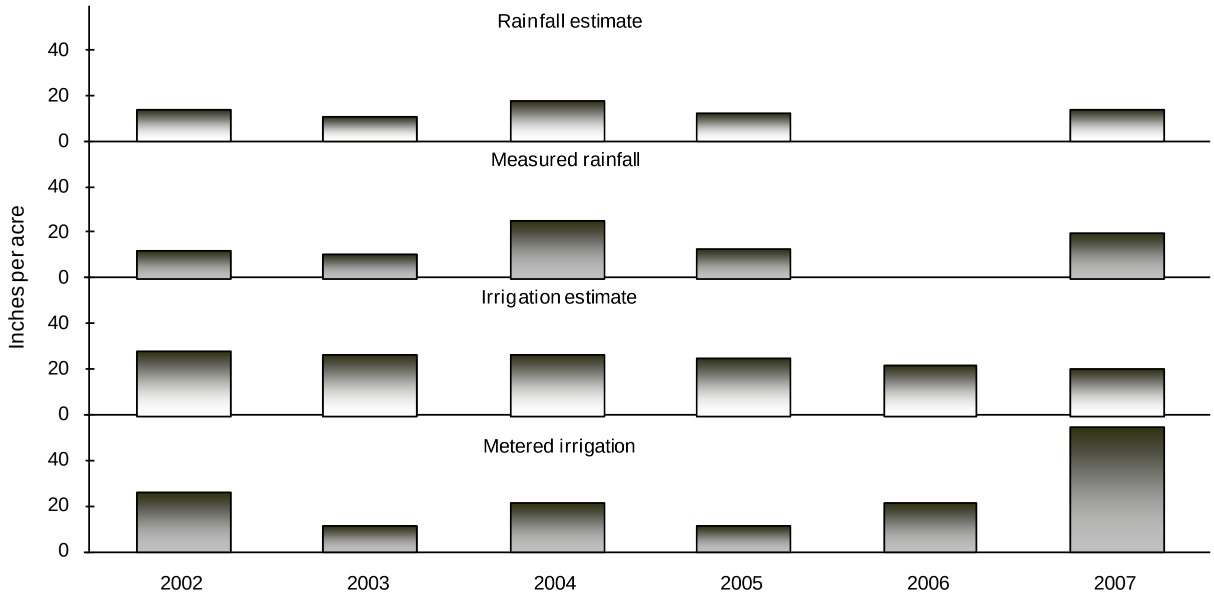


Figure 4-14. Corn metered and estimated irrigation and rainfall for the North Plains district 2002–2007.

Cotton

Cotton is a relatively new crop to growers in the Northern High Plains of Texas. With new cotton gins appearing in the area and producers making investments in new cotton harvesting equipment, there has been a recent growth trend in cotton production in the northern eight counties of the Texas panhandle. In 2002, a little over 2,000 acres were grown in the district, but by 2006, there was over 80,000 acres of cotton in these eight counties.[41]

The district reported 8 metered values over the three-year period from 2005 to 2007 on irrigated cotton fields. The weighted average metered irrigation was 19.36 with a standard deviation of 12.58. The wide range in individual values, from a low of 8.44 to a high of 45.17, demonstrates that producers may not yet be all that familiar with growing

[41] Cotton acreage declined in 2007, because many producers switched back to growing corn that year to capitalize on high corn prices due to market volatility caused in part by the ethanol industry.

cotton and the respective appropriate water use. By comparison, the TWDB weighted estimate based on crop water use requirements for cotton was 14.15 inches per acre. The district reported rainfall totals from three rain gages in 2007, measuring an average of 19.05 inches, almost 5 inches higher than the TWDB rainfall estimate. As a result of these differences, the 2007 and overall average total crop water use measured values were much higher than the estimated crop water use (Table 4-15, Figure 4-15).

Table 4-15. Cotton—weighted averages of metered data and estimates—North Plains district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
2005	1	240	50,455	0.5	8.44	17.45	0	na	na	na	na
2006	4	1,150	81,241	1.4	16.13	13.76	0	na	na	na	na
2007	3	1,000	30,187	3.3	25.69	9.67	3	19.05	14.19	44.74	23.86
Averages	3	797	53,961	1.5	19.36	14.15	1	19.05	14.19	38.41	28.34

na = not available; all units in inches per acre unless otherwise noted.

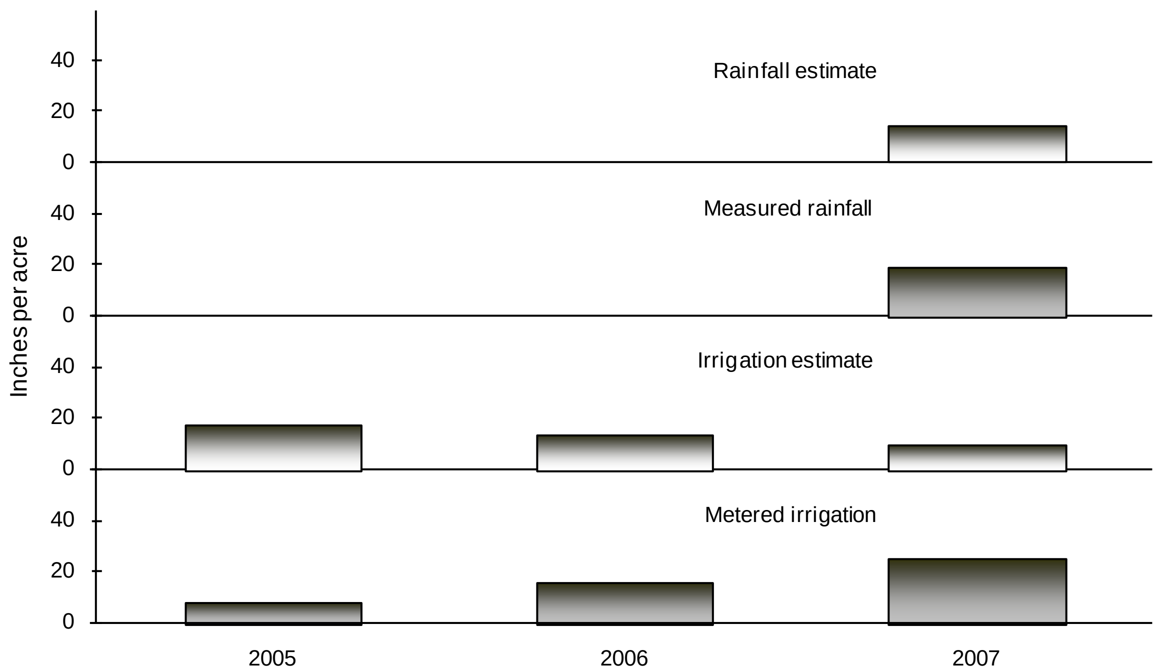


Figure 4-15. Cotton metered and estimated irrigation and rainfall for the North Plains district 2002–2007.

Sunflowers

TWDB irrigation estimates do not contain a specific crop category for sunflowers. In the Farm Service Agency estimates of irrigated acres, sunflowers are included in a larger aggregated category called “other oil crops” that includes other crops such as flax and safflower. For the purposes of this analysis, metered values for sunflowers are compared with the “other oil crops” category.

During the years with metering data for comparison (2004-2006), other oil crops grown in the district averaged 25,387 acres. Metered sunflower fields represented about 2.5

percent of this other oil crops acreage during those years. Sunflowers were metered in Dallam, Hartley, and Ochiltree counties. A total of 11 sunflower fields were metered, so the sample size is very small (Table 4-16).

The weighted average metered irrigation on sunflowers, at 6.42 inches per acre, was significantly lower than the weighted average estimated irrigation for oil crops, which was 17.76 inches per acre. In 2004, metered irrigation on sunflowers was only 3.11 inches, but rainfall was high at 27.05 inches (Figure 4-16). The TWDB rainfall value for 2004 was 17.67 inches. Local differences in rainfall may have contributed to the large differences in the metered and estimated irrigation values. The differences were likely amplified by the small sample size. Individual metered values ranged from 1.48 to 25.61 inches per acre, with a standard deviation of 8.60.

Table 4-16. Sunflowers—weighted averages of metered data and estimates—North Plains district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
2004	4	500	12,507	4.0	3.11	14.01	4	27.05	17.67	30.15	31.68
2005	6	1,265	42,852	3.0	8.17	19.70	5	12.79	14.38	20.96	34.08
2006	1	125	20,803	0.6	1.90	16.02	0	na	na	na	na
Averages	4	630	25,387	2.5	6.42	17.76	3	19.92	16.03	26.34	33.79

na = not available; all units in inches per acre unless otherwise noted.

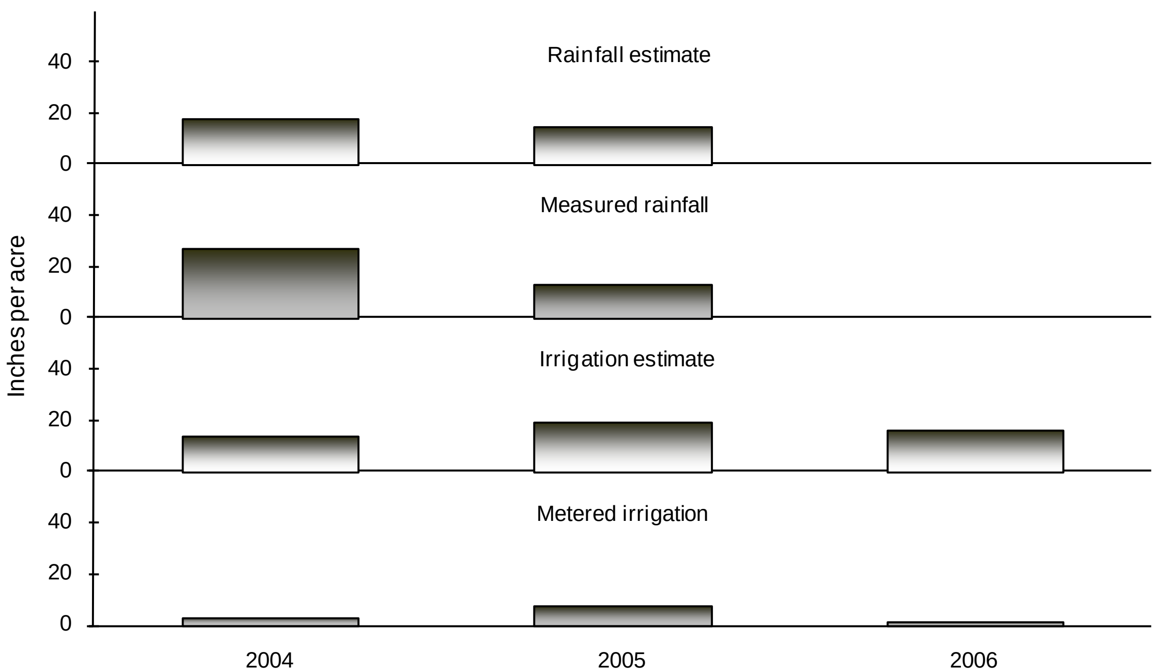


Figure 4-16. Sunflowers metered and estimated irrigation and rainfall for the North Plains district 2004–2006.

Wheat

In the data analyzed an average of 2,242 acres of wheat were metered. This represented less than 1 percent of the overall irrigated wheat acreage in the district, which averaged 478,803 over the five years with metered values available for comparison. A total of 43 wheat fields were metered and ranged from 3 fields in 2002 and 2007 to 16 in 2003, averaging 9 (Table 4-17). There were no metered wheat fields in 2005. The largest irrigated wheat acreages within the district were in Dallam and Hansford counties, each averaging over 104,000 acres during the study period. In these two counties, however, total metered values during this time amounted to a representation of only 2,600 acres. Although a small data set, irrigated wheat acreage was metered in all 8 counties within the district at one point during the study period.

The weighted average metered irrigation was 12.37 inches, and the standard deviation was 8.42. Metered irrigation for individual fields ranged from 1.15 to 35.24 inches. The weighted average estimated irrigation value was 12.91 inches per acre; thus, the metered and estimated values differed by less than one inch overall (Figure 4-17). The measured crop water use values varied significantly from 2003 to 2004 due to rainfall. The measured and estimated crop water use totals were in close agreement in 2003, yet the average crop water use figures show a measured amount 3.77 inches higher than the estimated average crop water use, due in part to the significant differences in measured and estimated rainfall in 2004, but also due to significant differences in metered and estimated irrigation in 2007. There were no rainfall data available for comparison in 2002 or 2006, and in 2005 there were no metered wheat fields.

Table 4-17. Wheat—weighted averages of metered data and estimates—North Plains district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
2002	3	830	582,356	0.1	17.50	13.74	0	na	na	na	na
2003	16	4,073	582,117	0.7	11.60	13.11	10	10.18	9.02	21.77	22.13
2004	13	4,133	554,668	0.7	11.97	13.14	6	27.93	17.79	39.90	30.92
2006	8	1,800	316,530	0.6	10.90	11.82	0	na	na	na	na
2007	3	375	358,343	0.1	20.91	11.89	3	15.27	13.63	36.18	25.52
Averages	9	2,242	478,803	0.5	12.37	12.91	4	17.79	13.48	30.16	26.39

na = not available; all units in inches per acre unless otherwise noted.

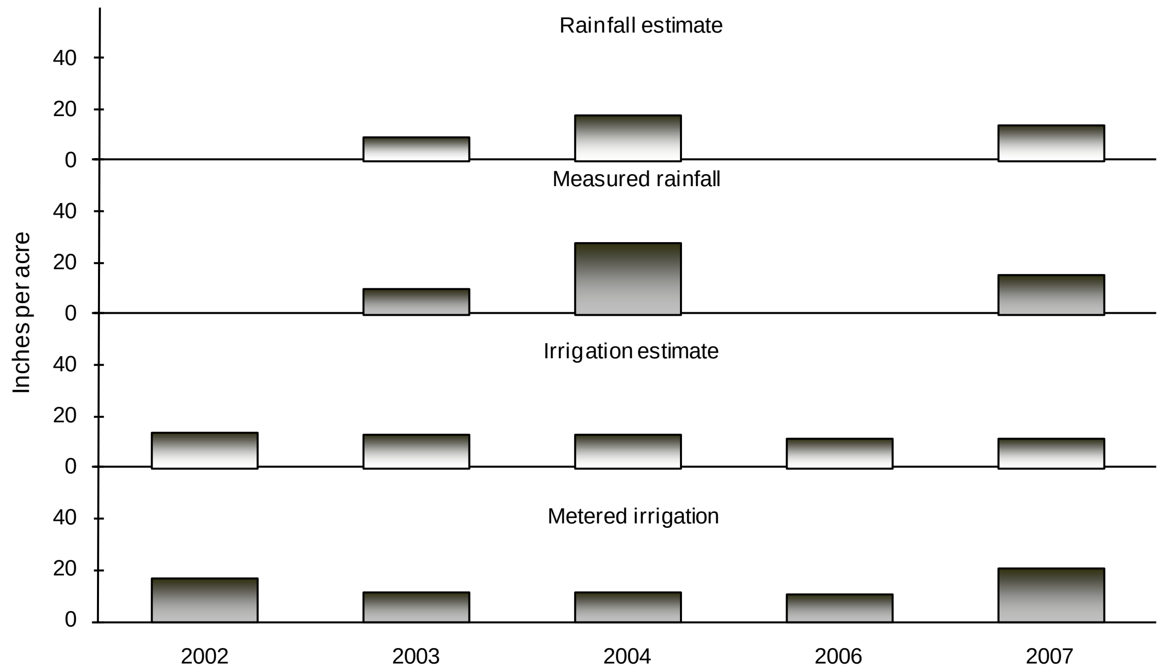


Figure 4-17. Wheat metered and estimated irrigation and rainfall for the North Plains district 2002–2007.

Mixed crops

On average, the district metered about 6,899 acres of mixed crops annually, representing about 43 percent of the metered acreage in the data set. The largest acreages of mixed crops were metered in Moore and Sherman counties. A total of 109 fields with mixed crops were metered during the study period, ranging from 9 in 2002 to 29 in 2007 (Table 4-18). On average, 18 fields of mixed crops were metered each year.

The individual metered irrigation values for mixed crops ranged between 1.00 and 66.25 inches with a standard deviation of 16.26. The weighted average metered irrigation was 20.74 inches per acre. There was no comparison made to irrigation estimates for this data (Figure 4-18). The average metered and estimated rainfall differed by 1.28 inches, with greater disparities in most individual years.

Table 4-18. Mixed crops—weighted averages of metered data and estimates—North Plains district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
2002	9	3,300	na	na	18.95	na	2	9.61	13.93	28.55	na
2003	12	5,135	na	na	11.32	na	9	10.92	12.07	22.23	na
2004	19	7,265	na	na	17.77	na	11	22.20	17.99	39.98	na
2005	20	8,116	na	na	14.91	na	16	13.64	10.34	28.55	na
2006	20	7,375	na	na	16.27	na	0	na	na	na	na
2007	29	10,200	na	na	36.03	na	25	18.36	13.95	54.39	na
Averages	18	6,899	na	na	20.74	na	11	14.94	13.66	35.68	na

na = not available; all units in inches per acre unless otherwise noted.

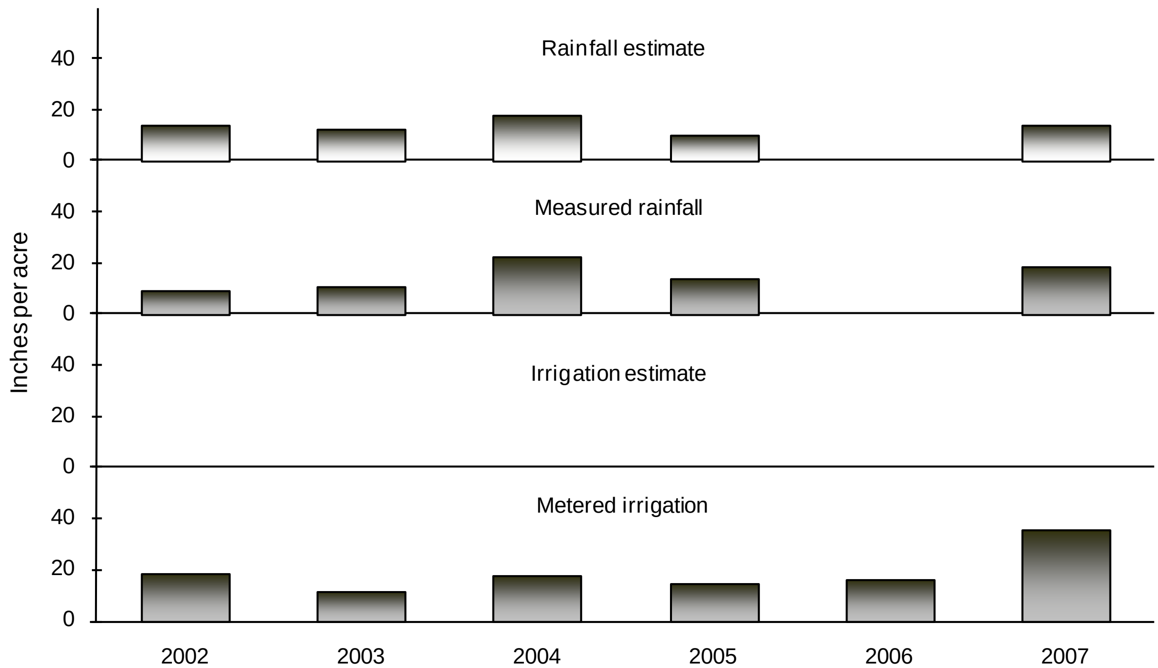


Figure 4-18. Mixed crops metered and estimated irrigation and rainfall for the North Plains district 2002–2007.

4.3.2 Irrigation water use—all crops

The North Plains district metered an average of 15,973 acres each year of the program. This represented about 1.4 percent of the total average estimate of 1,130,417 irrigated acres in the district. Although there were at least 133 meters used in the district, the annual data set for all crops consisted of around 70 data points (because of the arrangements of meters on systems), except for 2002 when there were about half as many meters and only 33 data points. In 2006 and 2007, the district redirected their metering program to focus on the 4 western counties (Dallam, Hartley, Moore, and Sherman) where most of the irrigated acreage is located. This further reduced the number of complete metered systems in the data set to 41 values in 2007.

Table 4-19. All crops—weighted averages of metered data and estimates—North Plains district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
2002	33	10,625	1,257,360	0.8	22.60	19.00	7	11.48	13.93	34.08	32.93
2003	65	19,883	1,206,148	1.6	10.89	18.30	45	10.56	10.87	21.45	29.16
2004	69	20,838	1,191,255	1.7	17.71	18.63	52	25.09	17.87	42.80	36.50
2005	67	20,093	1,122,096	1.8	13.25	19.17	51	13.34	11.84	26.59	31.01
2006	43	12,075	979,431	1.2	16.00	16.68	0	na	na	na	na
2007	41	12,325	1,026,211	1.2	35.42	16.20	37	18.31	13.94	53.72	30.14
Averages	53	15,973	1,130,417	1.4	17.96	18.08	32	15.75	13.69	33.72	31.77

na = not available; all units in inches per acre unless otherwise noted.

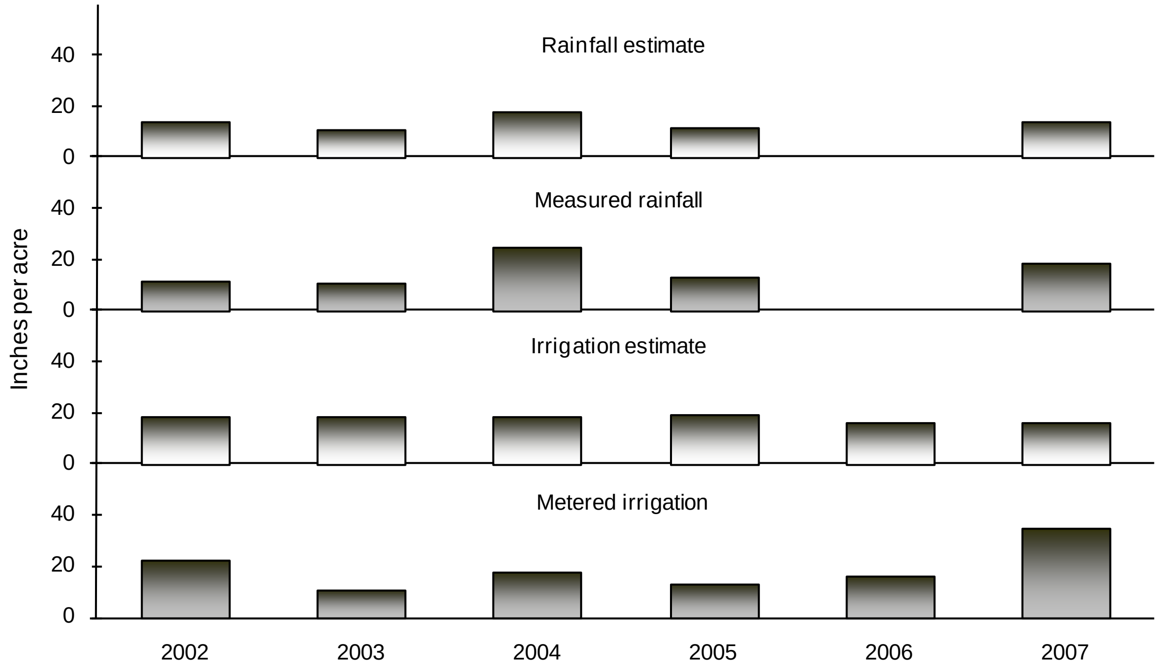


Figure 4-19. All crops metered and estimated irrigation and rainfall for the North Plains district 2002–2007.

The weighted average metered irrigation for all years was 17.96 inches per acre, and the weighted average estimated irrigation was 18.08 inches per acre (Table 4-19). The standard deviation was 13.65. There were significant differences in the annual metered and estimated irrigation values, especially in 2007 (Figure 4-19). Rainfall values were relatively close for all years, except 2004. Crop water use values differed substantially for most individual years, but the overall averages only differed by 1.95 inches.

4.3.3 Results and conclusions

With less that 2 percent of the district's irrigated acreage metered over the study period, the North Plains data set was small relative to the overall size of the district and amount of irrigated acreage in the district (Table 4-20).

Table 4-20. Six-year averages of metered and estimated acreages by crop type—North Plains district.

Crop	Meters	Metered acres	Estimated acres	Percent metered
Alfalfa	4	287	16,263	1.8
Corn	128	5,557	435,847	1.3
Cotton	8	398	30,049	1.3
Grain sorghum	2	74	67,792	0.1
Mixed	109	6,899	na	na
Other	11	495	na	na
Soybeans	2	80	14,554	0.5
Sunflowers	11	315	18,193	1.7
Wheat	43	1,869	482,787	0.4
Total	318	15,973	1,130,417	1.4

na = not available

For the metered data for individual crops, the annual sample sizes were too small to assume that the means reliably represented the overall population. About 16 percent of the data points analyzed had metered irrigation values between 1.0 and 6.0 inches per acre. This seems like a large percentage of low irrigation values that require further field investigation to determine if these values truly represent irrigation practices in the region.

The estimated crop water use and the evapotranspiration rate for corn are in close agreement, with the measured crop water use only slightly lower. On wheat, the estimate is lower than both the measured crop water use and the evapotranspiration rate. This is similarly the case for all crops. (Figure 4-20).[42]

[42] See Appendix C for table with crop evapotranspiration rates used from Borrelli and others.

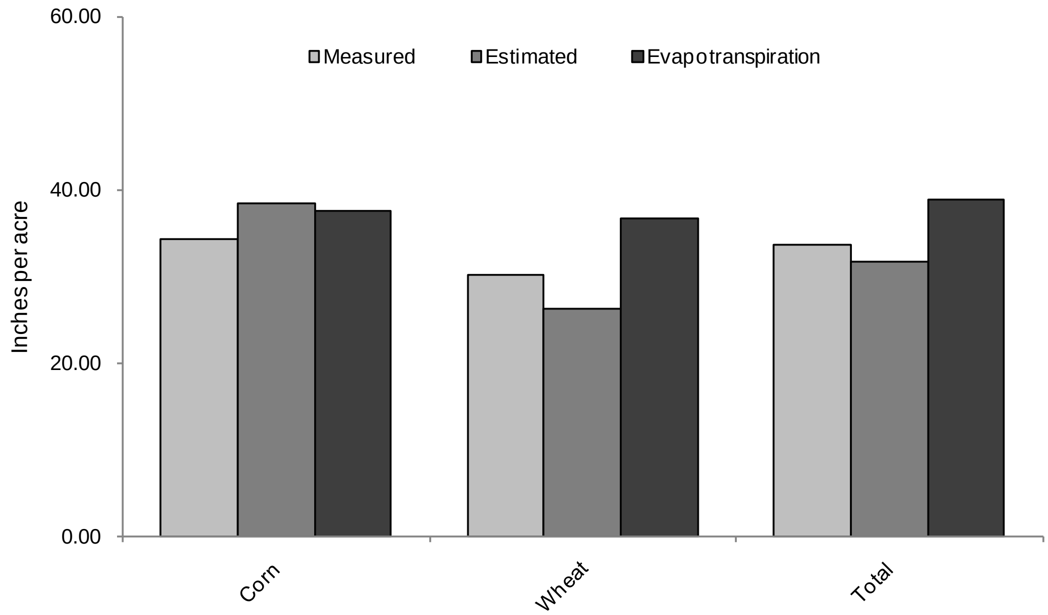
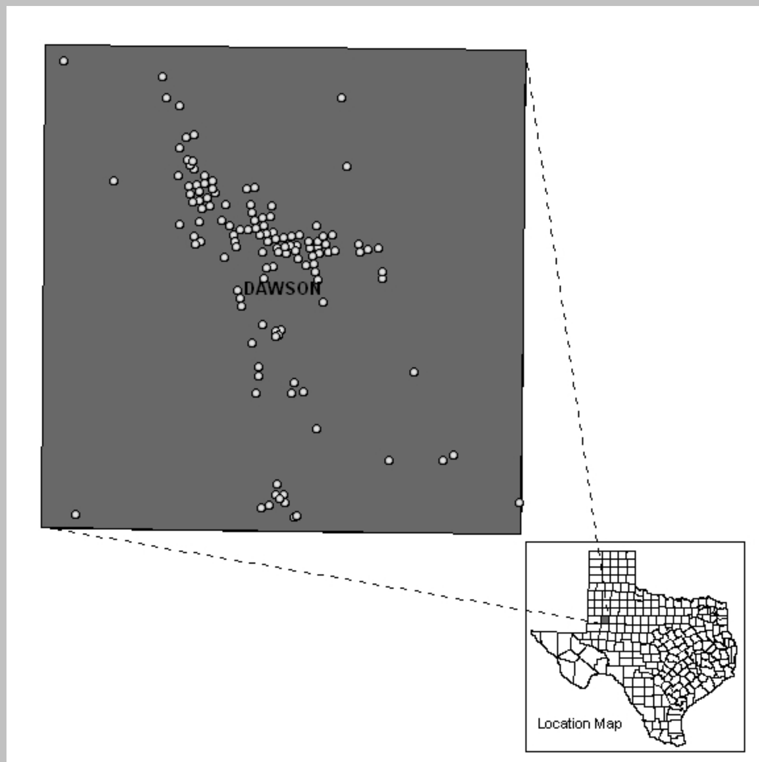


Figure 4-20. Total crop water use values—metered, estimated, and mean consumptive—for individual and all crops for the North Plains district, 2002–2007.

The North Plains district irrigation metering program encountered substantial challenges while attempting to gather and process data for a large amount of irrigated crop acreage spread over a large district. The initial metering installations with metered wells, in addition to metered pivots, contributed to issues with data accuracy. Although the district committed significant resources to the program, the size of the usable data set remained small relative to the amount of irrigated agriculture in the district. The district recently implemented new pumpage reporting requirements for all irrigation wells in the district. This program will meet the district's current needs for data on overall pumpage. In 2009, TWDB and the district modified the existing contract to accommodate changes to the district's focus and in identifying how the well-reporting data might be shared and used to most effectively estimate irrigation water use in the district.

4.4 Mesa Underground Water Conservation District



District at a Glance

Planning Region: *Llano Estacado (O)*

2007 Gross Crop Income: *$108,656,000*

Climate: *Semi-arid*

Average Yearly Rainfall: *18 inches*

District Size: *575,352 acres*

Total Crop Land: *363,339 acres*

Irrigated Crop Land: *72,621 acres*

Irrigation Water Use: *103,102 acre-feet*

Acres in TWDB Metering Program: *16,384 acres*

Number of Active Irrigation Wells in Groundwater Conservation District: *2,100*

Number of Meters in Program: *144*

** Indicates district data*

Eco-region: *High Plains*

Soils:
Fine sandy loam, Loamy fine sand, Sandy clay loam

Crop Types:
Cotton
Peanuts
Wheat
Haygrazer
Sorghum
Alfalfa
Pumpkins, Melons

Irrigation Methods:

Center pivot
Sub-surface drip

Mesa Underground Water Conservation District is a single county district that has fully implemented the monitor plot concept. Dawson County's unique history of irrigation has facilitated the district's metering efforts. In the 1970s, most irrigation wells in Dawson County dried up and irrigation was not possible again until the early 1990s. During the 1990s, new wells were drilled, so many of the earlier abandoned wells remained available to serve as monitor wells. During the original metering program phase, the Mesa district had three monitor plots that were 100 percent metered in 2001. In 2002, TWDB and the district were able to incorporate data from a fourth plot. Rain gages are associated with each of the first three plots, but not the fourth.

Mesa's monitor plots are located a short distance from the district office, facilitating data collection. The district uses an all-terrain motorcycle to access meters, which are all located at the pivots, and a Tungsten E2 personal data assistance device to record meter readings directly in a spreadsheet while in the field. They download this spreadsheet and then import it into a database. Data are collected on the same day (plus or minus two to three days) every month during the summer growing season, but the exact date of the meter reading is not recorded in the district's database. Instead, the district records the month the reading was taken.

The district sends data to TWDB in a spreadsheet but does not use the standard TWDB metering template because their database is set up differently. The district does its own data analysis and calculates gallons used and inches per acre. TWDB and the district work together to import the data into the standard reporting spreadsheet, check for data errors, and standardize the data (that is, crop types). There are usually very few errors, and often, little clarification is needed.

The quality and consistency of data received from the Mesa district has been good throughout their participation. The district has a firm commitment to the program and actively promotes it to producers, collecting and analyzing data and providing water use reports to producers on a monthly basis. According to district staff, producers find the water use reports to be useful and sometimes request information before the district has sent it out. The district continues to apply for grant funds from TWDB to expand their program and integrate new technology, such as dataloggers.

The Mesa data set covers 2001 through 2007, except that rainfall data are not available for 2001. Of the data analyzed, the Mesa district metered an average of 9,800 acres over the seven-year period, with metered acreage increasing each year of the program. This represents almost 13 percent of the average estimated total 79,951 irrigated acres in the district. The data set includes a total of 620 metering records, or an average number of 89 meters included for analysis. Metered water use values less than 1 inch per acre, and those designated as failed crops were removed from the data set. Rainfall values are only available for monitor plots, not for individual meters. For the analysis, rainfall amounts were associated with each meter reading based on the location of the meter within a monitor plot.

4.4.1 Irrigation water use data—individual crops

Alfalfa, cotton, peanuts, and a wheat-cotton combination were the crop types most consistently grown in the metered plots in the Mesa program. Other crops represented more sporadically included grain sorghum and failed cotton, as well as various crop combinations. Cotton was typically the most widely planted irrigated crop in Dawson County, representing about 75 percent of total irrigated acreage (seven-year averages of 57,149 irrigated cotton acres out of the 79,951 total irrigated acres) in the county.

The split wheat-cotton cropping combination presented a challenge for comparing metered irrigation water use with TWDB water use estimates. Most producers in the district plant wheat in the winter as a cover crop to protect against soil erosion and to shelter and/or provide nutrients for the young cotton crop. Winter water use on the wheat crop may vary substantially; however, for the most part, wheat is not harvested as a separate crop.

The Mesa district took monthly readings only during the growing season. Since the Mesa district did not read meters in the winter, it was difficult to distinguish between water use on the winter crop and pre-watering in spring to prepare the soil moisture profile for the summer crop. Even if the Mesa district had taken readings during the winter, it would still have been impractical to assign amounts of water to wheat versus cotton. Wheat remains in the ground throughout the cotton season, although it is usually sprayed and killed just before the cotton is planted. Thus, separate irrigation water use values for cotton and winter wheat could not be calculated. The use of wheat as a cover crop in combination with cotton is a common "no-till" practice in the district that provides topsoil retention and protection for the growing cotton crop. When used in this context, the wheat crop is generally not harvested. So, for the purposes of comparison to the TWDB estimates, the wheat-cotton combination was aggregated with the cotton crop.[43]

Descriptive statistics for individual crops illustrate some of the limitations in using the data to draw conclusions about irrigation water use for individual crops or on individual fields. For crops other than cotton, sample sizes were small, standard deviations ranged from less than 2 to greater than 13 inches, and the range in applied irrigation values often exceeded 20 inches. Given these conditions, the average values might not be representative of the population as a whole or of the average irrigation water use at the county level. However, charts showing annual average values of metered and estimated irrigation, rainfall, and crop water use are useful because they illustrate relationships between the variables.

Alfalfa

Alfalfa had the highest consumptive water use of all the crops in the district. However, alfalfa was only grown on 2 percent of irrigated lands in Dawson County. On average, 1,379 acres of irrigated alfalfa were grown in the district, and 17.6 percent of the total

[43] TWDB reconciled with the Mesa GCD these non-harvested wheat acres that appear in the Farm Service Agency acreage that TWDB uses to make estimates, so aggregating the wheat-cotton combination with cotton is appropriate in this circumstance. The acreage and irrigation water use for wheat was thus deleted for Dawson County in the TWDB irrigation estimates beginning in 2004.

county acreage was metered by the district. Though a sizeable percentage of acreage was metered, there were no more than five fields metered in any single year (Table 4-21).

Table 4-21. Alfalfa—weighted averages of metered data and estimates—Mesa district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
2001	1	120	550	21.8	36.57	21.01	0	na	na	na	na
2002	1	120	1,549	7.7	50.35	21.00	1	16.00	15.59	66.35	36.59
2003	3	257	1,542	16.7	27.86	20.00	3	18.33	12.75	46.20	32.75
2004	5	275	1,630	16.9	27.16	36.00	3	33.33	27.58	60.49	63.58
2005	5	275	1,550	17.7	25.28	36.00	3	15.00	9.61	40.28	45.61
2006	5	276	1,369	20.1	30.04	30.00	3	15.87	11.98	45.92	41.98
2007	5	373	1,464	25.5	14.91	18.85	5	24.65	21.35	39.56	40.20
Averages	4	242	1,379	17.6	27.05	26.73	3	20.53	16.48	47.58	43.21

na = not available; all units in inches per acre unless otherwise noted.

The weighted average metered irrigation for alfalfa was 27.05 inches per acre and the standard deviation was 13.13. The individual values ranged from a minimum of 7.69 inches to a maximum of 58.89. In 2002, the one metered value deviated considerably from the seven-year average. The overall weighted average metered and estimated values differed by less than one inch. The estimated values for 2001 through 2003 were much lower than the weighted average metered values in those three years (Figure 4-21). However, the estimates for 2004 and 2005 were higher than the metered means as a result of TWDB making adjustments to the estimated values in consultation with the district.[44] In 2006, the metered and estimated values were basically identical and remained relatively close in 2007. There was no measured rainfall data for comparison in 2001. For all other years the measured values were higher than the TWDB estimates. As a result of higher measured rainfall primarily, overall measured crop water use average was 4.37 inches higher than the estimated crop water use average.

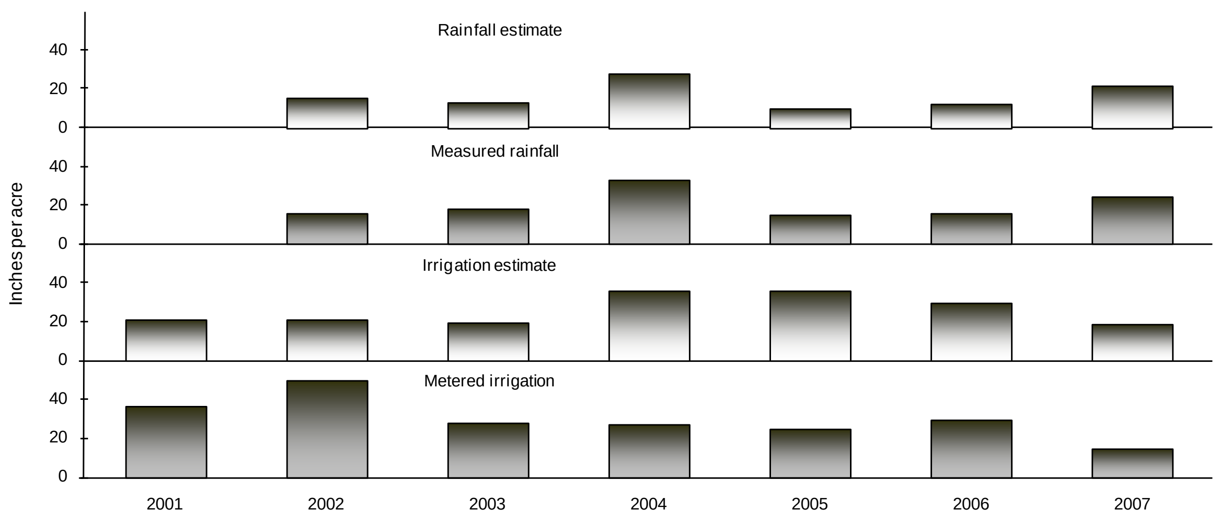


Figure 4-21. Alfalfa metered and estimated irrigation and rainfall for the Mesa district 2001–2007.

[44] In 2004, TWDB began seeking input from the districts on irrigation water use estimates. The Mesa district provided comments to TWDB on the estimates that resulted in TWDB adjusting some estimated values.

Cotton

Cotton acreage averaged 57,149 acres annually and accounted for about 75 percent of all irrigated acreage (75,951 acres) in Dawson County. The metering data for cotton alone represented a relatively small portion of the overall irrigated cotton acreage. However, with the addition of the wheat-cotton combination to the cotton category, the resulting average percentage of cotton metered was 10.7 percent of the county total irrigated cotton acreage. In 2006, there were 10,375 metered acres, or 16.1 percent of the total irrigated cotton acreage, thus providing a representative sample of the largest irrigated crop within the district.

A total of 388 fields with cotton or the wheat-cotton combination were metered during the study period. On average, 55 fields were metered each year with the number of metered fields increasing steadily up to 2006 and then only slightly decreasing in 2007 (Table 4-22). The weighted average metered irrigation for cotton was 16.53 inches per acre and the weighted average estimated irrigation was 18.24 inches per acre. The standard deviation was 7.10, with individual metered values ranging from 3.41 to 43.60 inches per acre. The metered and estimated irrigation values were in very close agreement, except in 2001 (Figure 4-22). Again, there is an obvious drop in the irrigation estimates beginning in 2004, as a result of the aforementioned change in methodology. This change appears to more closely estimate the irrigation practices of producers in the district. The rainfall data shows consistently higher amounts measured than estimated. This resulted in higher measured total crop water use values than estimated.

Table 4-22. Cotton—weighted averages of metered data and estimates—Mesa district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
2001	8	912	56,000	1.6	12.55	22.00	0	na	na	na	na
2002	24	2,596	50,161	5.2	21.85	22.00	19	17.16	15.59	39.01	37.59
2003	41	4,208	54,150	7.8	19.22	21.00	36	16.39	12.75	35.61	33.75
2004	58	6,132	58,110	10.6	17.55	16.00	45	31.18	27.58	48.73	43.58
2005	74	8,562	59,670	14.3	15.23	16.00	45	12.33	9.61	27.57	25.61
2006	94	10,375	64,297	16.1	20.75	21.00	52	14.65	11.98	35.40	32.98
2007	89	9,835	57,652	17.1	10.36	10.23	89	25.34	21.35	35.70	31.58
Averages	55	6,089	57,149	10.7	16.53	18.24	41	19.51	16.48	36.03	34.72

na = not available; all units in inches per acre unless otherwise noted.

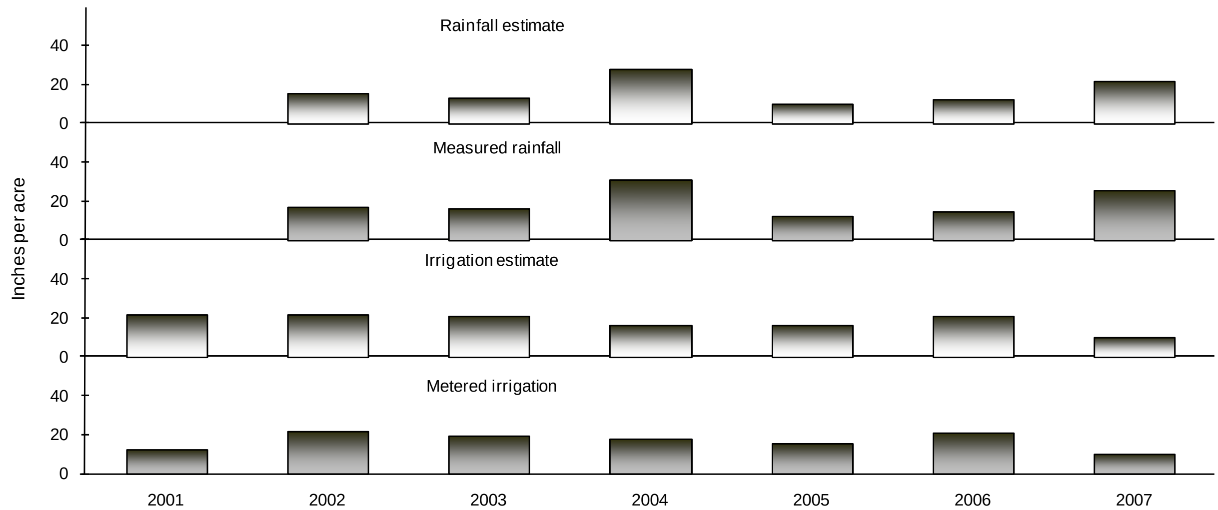


Figure 4-22. Cotton metered and estimated irrigation and rainfall for the Mesa district 2001–2007.

Peanuts

Peanuts accounted for about 13 percent of the irrigated acreage in Dawson County. The district metered a six-year average of 585 acres of peanuts – about 5 percent of the annual average irrigated acreage of 10,747 in the county for those six years. On average, five fields were metered each year, with the number of fields ranging from two to nine (Table 4-23); however, there were no metered peanut fields in 2006.

Table 4-23. Peanuts—weighted averages of metered data and estimates—Mesa district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
2001	9	1,080	14,500	7.4	18.89	23.00	0	na	na	na	na
2002	7	835	14,500	5.8	21.57	21.00	6	17.67	15.59	39.24	36.59
2003	4	244	12,433	2.0	23.33	22.00	2	18.00	12.75	41.33	34.75
2004	2	210	8,280	2.5	13.18	20.00	1	36.00	27.58	49.18	47.58
2005	5	600	9,277	6.5	20.84	20.00	1	10.00	9.61	30.84	29.61
2007	5	540	5,491	9.8	10.85	11.70	5	26.55	21.35	37.40	33.05
Averages	5	585	10,747	5.4	18.59	20.58	3	21.64	17.38	40.24	37.96

na = not available; all units in inches per acre unless otherwise noted.

The weighted average metered irrigation for peanuts for all years was 18.59 inches per acre and the standard deviation was 5.69. Individual metered values ranged from 6.53 to 29.99 inches per acre. The average estimated irrigation was 20.58 inches per acre. Metered irrigation values for peanuts compared favorably with the TWDB estimates except in 2004, where the metered value was 6.82 inches per acre lower than the estimate (Figure 4-23). With 36 inches of rain measured on the peanut fields that year, however, the two peanut producers whose operations were metered in 2004 could afford to cut back on irrigation. Given the annual crop evapotranspiration rate requirement of 34 inches for peanuts, this is plausible (Borrelli, Fedler, & Gregory, 1998). Measured rainfall and rainfall estimates appear to match up fairly well, although differences in 2003 and 2004 may have been amplified due to the small number of rain gages. As with the data in other crops, measured rainfall was greater than the estimates in all years. Total crop water use values were in close agreement for most years, with the exception of 2003 where the measured value was 6.58 inches higher than the estimated value.

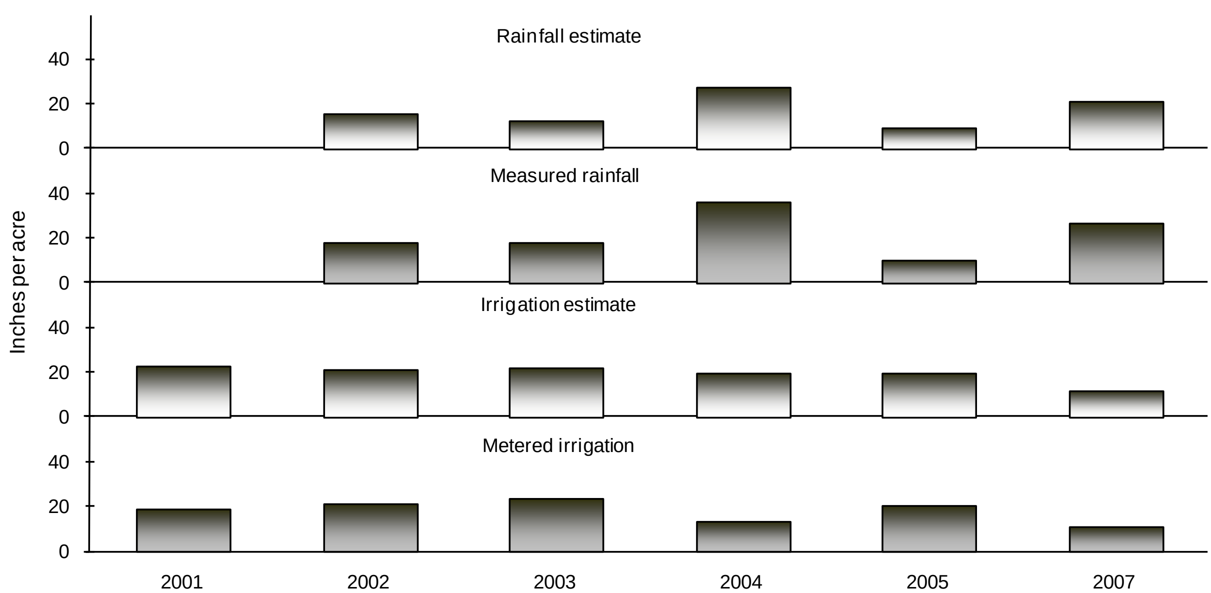


Figure 4-23. Peanuts metered and estimated irrigation and rainfall for the Mesa district 2001–2007.

Mixed crops

A total of 17,887 acres of mixed crops were metered (not including the wheat-cotton combination that was aggregated with the cotton data). There is no comparison to overall estimated acreage for this crop category. The combinations grown in Dawson County included a wheat-cotton combination with peanuts, grain sorghum, or haygrazer as the third crop and a cotton-peanut combination. Mixed crops made up 26 percent of the overall metered acreage in the data set during the study period. There were 150 fields with mixed crops metered during the seven-year period, on average 21 fields per year were in the mixed crop category, with the number of fields ranging from 6 to 38 (Table 4-24). The weighted average metered irrigation for mixed crops was 18.32 inches per acre. The range of metered values for mixed crops was from a low of 5.64 inches per acre to a high of 54.18 inches per acre, with a standard deviation of 6.92 inches per acre. The measured annual rainfall totals were consistently higher than the TWDB rainfall estimates (Figure 4-24). As there is no irrigation estimate for comparison, no comparison to total crop water use can be made.

Table 4-24. Mixed—weighted averages of metered data and estimates—Mesa district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
2001	6	720	na	na	19.66	na	0	na	na	na	na
2002	21	2,514	na	na	20.54	na	18	17.00	15.59	37.54	na
2003	30	3,558	na	na	20.02	na	23	17.13	12.75	37.15	na
2004	19	1,860	na	na	23.65	na	15	31.00	27.58	54.65	na
2005	22	2,642	na	na	18.66	na	17	12.65	9.61	31.31	na
2006	14	1,797	na	na	19.03	na	11	14.84	11.98	33.87	na
2007	38	4,796	na	na	13.19	na	38	25.14	21.35	38.33	na
Averages	21	2,555	na	na	18.32	na	17	19.63	16.48	37.95	na

na = not available; all units in inches per acre unless otherwise noted.

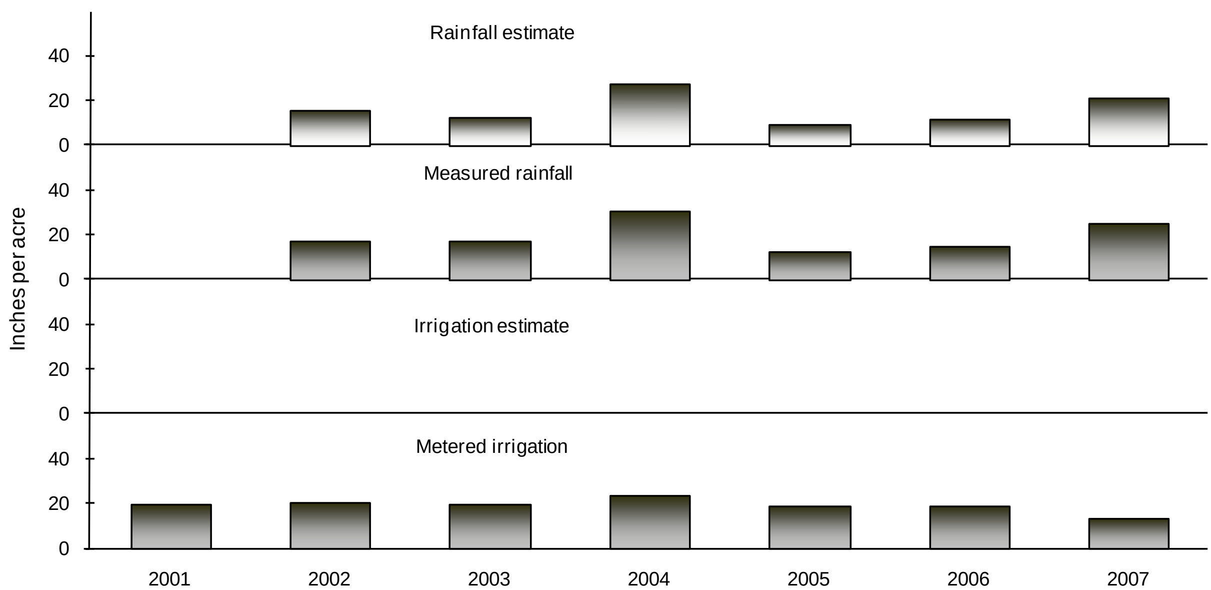


Figure 4-24. Mixed crops metered and estimated irrigation and rainfall for the Mesa district 2001–2007.

4.4.2 Irrigation water use data—all crops

The total irrigated acreage in Dawson County was 75,951 acres. On average, 12.9 percent of that acreage, or 9,800 acres was metered. The number of meters included for analysis ranged from 24 to 144 and averaged 89 (Table 4-25). The weighted average metered irrigation for all years was 17.10 inches per acre, and the standard deviation was 8.03 inches per acre. Metered water use values ranged from 1.03 to 58.89 inches per acre, indicating wide variability in individual irrigation water use. The weighted average estimated irrigation for all crops was 18.25 inches per acre.

Table 4-25. All crops—weighted averages of metered data and estimates—Mesa district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
2001	24	2,832	80,210	3.5	17.79	21.17	0	na	na	na	na
2002	58	6,525	79,109	8.2	20.70	20.29	46	17.17	15.59	37.87	35.88
2003	80	8,507	84,457	10.1	19.93	19.56	66	16.83	12.75	36.76	32.31
2004	84	8,477	71,032	11.9	19.10	16.93	64	31.31	27.58	50.41	44.51
2005	109	12,439	72,206	17.2	16.19	16.95	66	12.50	9.61	28.69	26.56
2006	121	13,438	71,512	18.8	20.29	21.13	68	14.72	11.98	35.00	33.11
2007	144	16,384	73,128	22.4	11.12	11.07	144	25.29	21.35	36.41	32.42
Averages	89	9,800	75,951	12.9	17.10	18.25	65	19.64	16.48	36.74	34.72

na = not available; all units in inches per acre unless otherwise noted.

The seven-year weighted average metered values appear to validate the TWDB estimates, differing by only 1.15 inches per acre overall. The weighted averages of metered and estimated values were consistently close except in 2001 and 2004. The metered irrigation decreased significantly in 2007 in response to an increase in rainfall (Figure 4-25). Measured rainfall data appears to indicate the source of TWDB rainfall estimates may need to be validated, as the district maintains a large number of rain gages and the associated measured amounts were consistently higher than estimates. As a result, the total measured crop water use values were higher than estimated values for all years.

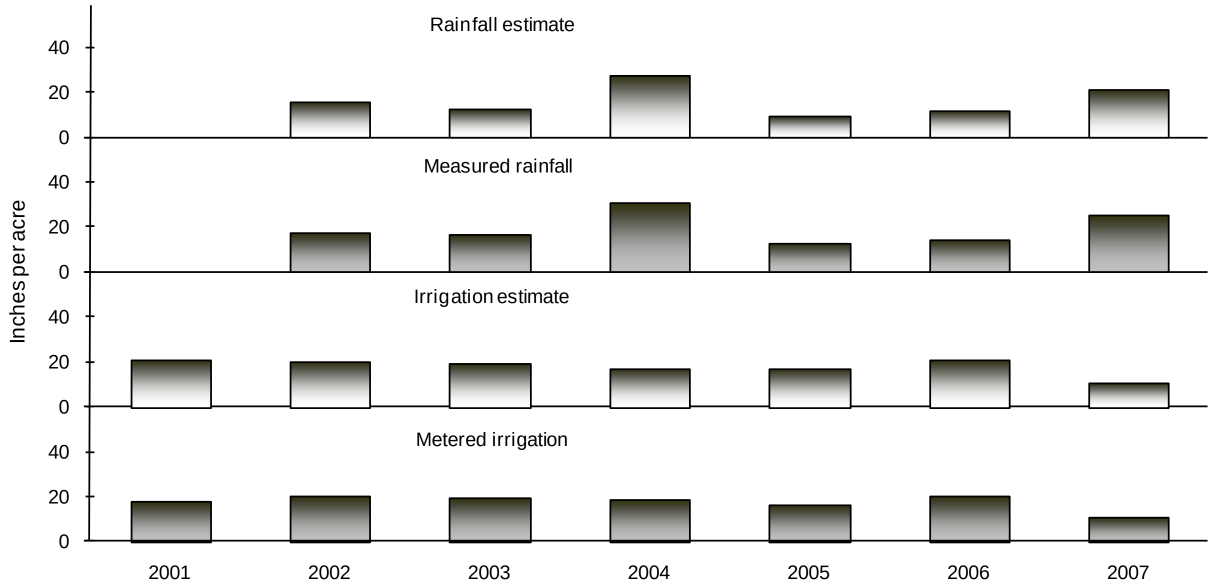


Figure 4-25. All crops metered and estimated irrigation and rainfall for the Mesa district 2001–2007.

4.4.3 Results and conclusions

Mesa's data provides some valuable insight into irrigation water use patterns and practices in Dawson County. Over the seven-year period, the sample size increased and the data set became progressively more useful for comparison to TWDB estimates by both individual crop type and aggregated county level. Combining the cotton crop with the wheat-cotton combination provided more useful data for comparison with the TWDB cotton estimates.

The seven-year data set for individual crops and the annual data set for all crops provided large enough sample sizes to make some statistical assumptions. The crop-type distribution in the Mesa data set provided a fairly balanced representation of the estimated data set, although the metered cotton and peanut acreages could be increased to provide a more representative sample (Table 4-26). Additional investments in new technology could potentially eliminate some of the mixed crops from the data set in the future, further improving the quality of metered irrigation values.

Table 4-26. Seven-year averages of metered and estimated acreages by crop type—Mesa district.

Crop	Meters	Metered acres	Estimated acres	Percent metered
Alfalfa	25	242	1,379	17.6
Cotton	388	6,089	57,149	10.7
Forage crops	3	51	1,569	3.2
Grain sorghum	2	34	2,021	1.7
Hay-pasture	6	107	373	28.7
Mixed	150	2,555	na	na
Other	2	34	na	na
Peanuts	32	501	9,496	5.3
Vegetables	2	11	477	2.4
Wheat	10	175	2,288	7.6
Total	620	9,800	75,951	12.9

na = not available

When comparing crop water use values by incorporating rainfall data with the irrigation values, TWDB estimates were consistently lower than the measured values. However, for the major crop grown in the district, cotton, the measured, estimated, and evapotranspiration values were in very close agreement overall (Figure 4-26).

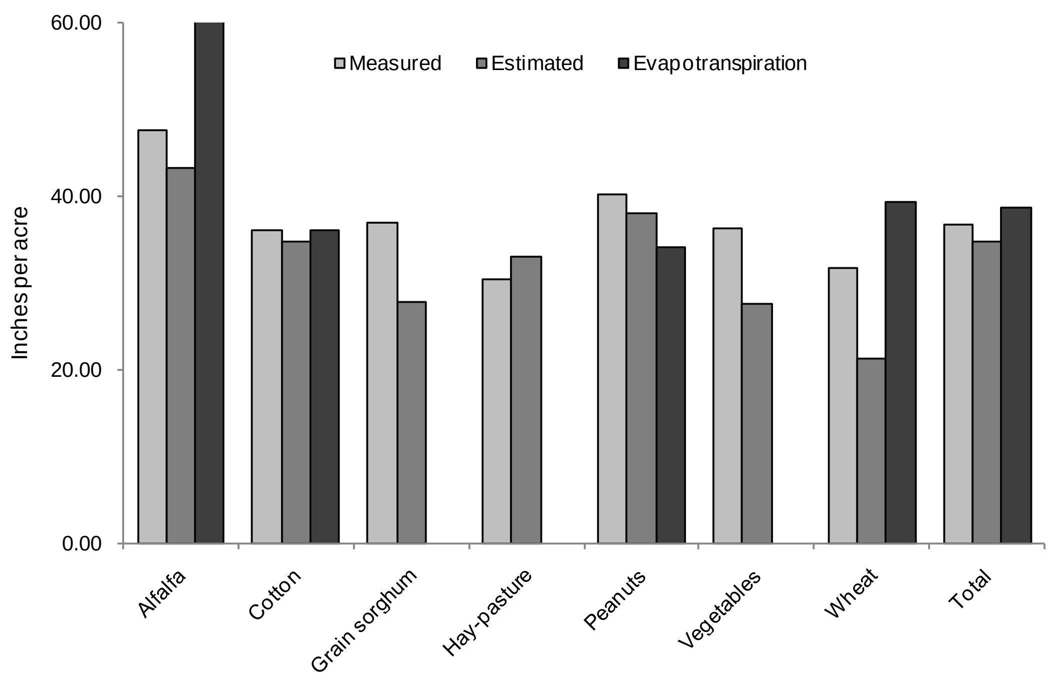
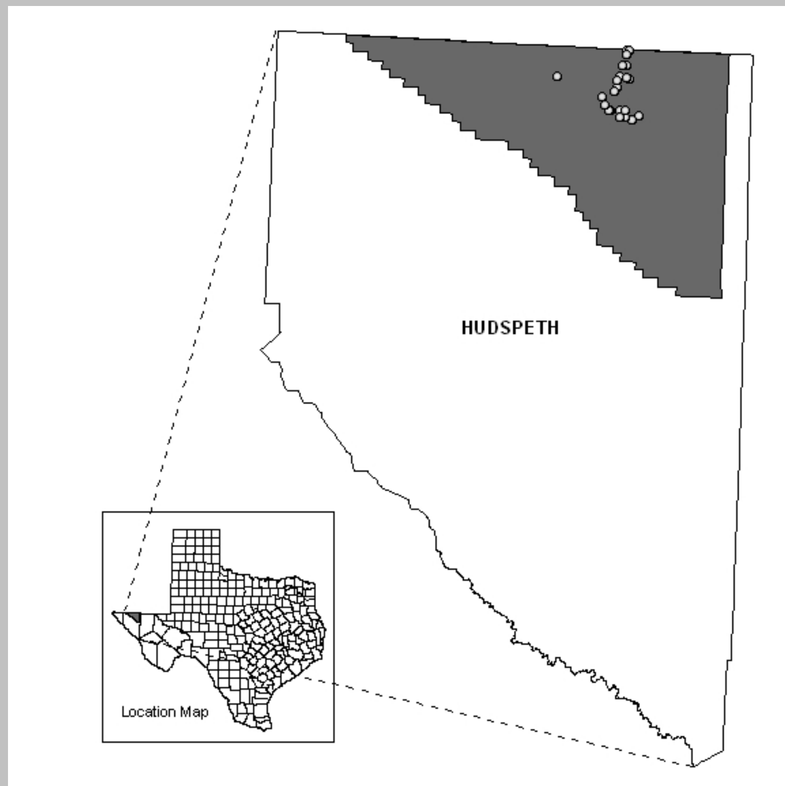


Figure 4-26. Total crop water use values—metered, estimated, and mean consumptive—for individual and all crops for the Mesa district, 2001–2007.

Note: This figure does not include comparisons for the forage, mixed, or other crops. The computation of evapotranspiration rates was not available for the categories of grain sorghum, hay-pasture, or vegetables.

The Mesa Groundwater Conservation District's program is now well established and the data set has improved every year. With minimal enhancements, their irrigation metering program data can provide TWDB with defensible validation for irrigation water use estimates in Dawson County. TWDB should continue working with the district to address gaps in the data set and the issues of sample size and representation where necessary, especially with respect to the large number of metered values on mixed crops. The metered values for all crops combined are consistent with mean consumptive crop water use requirements for the area.

4.5 Hudspeth County Underground Water Conservation District #1



District at a Glance

Planning Region: *Far West Texas (E)*

2007 Gross Crop Income: *$20,170,000*

Climate: *Arid*

Average Yearly Rainfall: *10 inches*

District Size: *572,268 acres*

Total Crop Land: *80,693 acres*

Irrigated Crop Land: *39,339 acres*

Irrigation Water Use: *164,166 acre-feet*

Acres in TWDB Metering Program: *2,825 acres*

Number of Irrigation Wells in Groundwater Conservation District: *300*

Number of Meters in Program: 22

Eco-region: *Trans-Pecos*

Soils:
Fine sandy loam, Loamy fine sand, Clay loam, Fine sand, Gravelly sandy loam, Silty clay, Silty clay loam, Clay

Crop Types:
Alfalfa
Peppers
Grapes

Irrigation Methods:
Center pivot

Hudspeth County Underground Water Conservation District #1 began participating in the metering program in 2002 but had some problems implementing it. The district purchased electronic meters, many of which were faulty. In 2003 the district collected data that included acres and acre-feet of water usage for some of the meters. However, the acreage data were inaccurate and crop-type data were not included. In 2005 the district adopted the TWDB metering data collection and reporting worksheet and provided more accurate and detailed data, including crop type. Data from 2005 through 2007 are discussed and evaluated in this report.

The Hudspeth district is unique because its area does not cover a complete county. However, roughly 75 percent of irrigated agriculture in the county is concentrated around Dell City within the district's geographic boundaries, so county totals are used for this analysis. The remaining irrigated acreage is located in the southwest corner of the county along the Rio Grande Basin. Alfalfa is the largest irrigated acreage in the district, making up about 50 percent of the irrigated cropland. Cotton is second at 35 percent of the total. Vegetables, vineyards, and pastures make up 6 percent, 5 percent and 3 percent, respectively.

From 2005 through 2007 there were 55 metered values included in the data set for analysis. The district metered an average of 3,033 acres over the three years. The largest crop type represented in the data was alfalfa with 9 meters in 2005, 8 meters in 2006, and 15 meters in 2007, on an average of 1,894 acres (Table 4-27). Other metered crops reported were less represented in the data set – cotton for example had only 1 metered value in 2007.

4.5.1 Irrigation water use data—individual crops

Alfalfa

The weighted average metered irrigation for alfalfa was 45.59 inches per acre, which was substantially less than TWDB's weighted average estimate of 62.91 inches per acre (Table 4-27)[45]. Standard deviation for the alfalfa values was 14.17, with a low of 7.94 inches per acre and a high of 65.76 inches per acre.

With the irrigation estimates being significantly higher than the metered values it appears that TWDB should lower irrigation estimates for alfalfa grown in Hudspeth County. The estimates presented here are reflective of comments incorporated from the district on TWDB annual irrigation estimates. Their comments historically have suggested that TWDB should increase irrigation estimates for most all crops, including alfalfa, within the district. The district's metered values do not appear to justify this change however (Figure 4-27).

[45] TWDB sends to the groundwater conservation districts the preliminary irrigation estimates for each county by crop type for their comments and suggestions.

Table 4-27. Alfalfa—weighted averages of metered data and estimates—Hudspeth district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate
2005	9	1,433	20,000	7.2	36.41	60.00
2006	8	1,355	12,822	10.6	43.42	60.00
2007	14	2,765	13,494	20.5	51.42	70.00
Averages	10	1,851	15,439	12.0	45.59	62.91

All units in inches per acre unless otherwise noted.

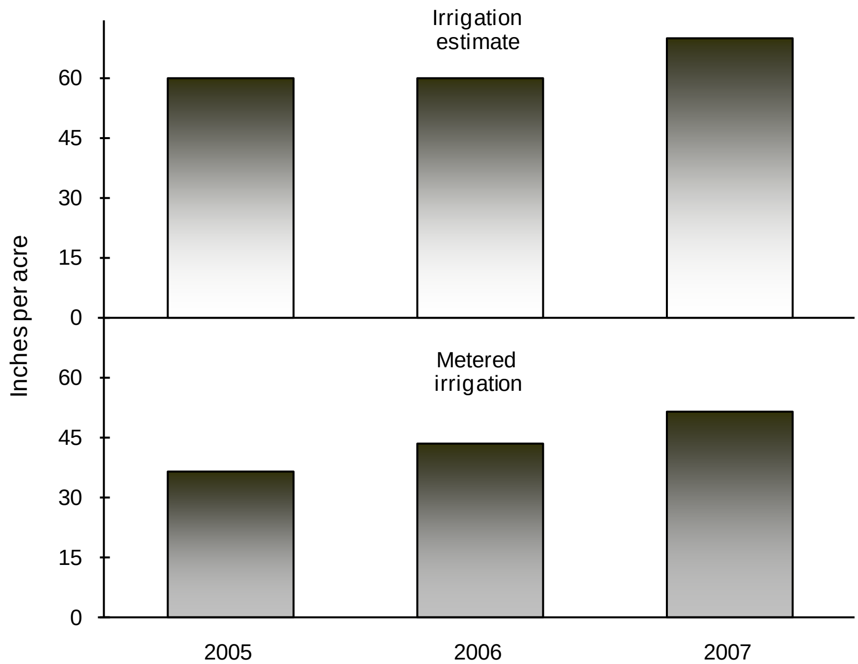


Figure 4-27. Alfalfa metered and estimated irrigation in the Hudspeth district, 2005–2007.

4.5.2 Irrigation water use data—all crops

At the county level, the weighted average metered and estimated irrigation for all crops differed by an average of 10.40 inches per acre (Table 4-28). Standard deviation was 16.87 with a low of 3.84 and a high of 67.22 inches per acre.

Table 4-28. All crops—weighted averages of metered data and estimates—Hudspeth district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate
2005	18	2,314	39,339	5.9	36.56	50.08
2006	14	2,329	25,457	9.1	36.77	49.59
2007	21	4,252	30,804	13.8	48.43	58.60
Averages	18	2,965	31,867	9.3	42.29	52.69

All units in inches per acre unless otherwise noted.

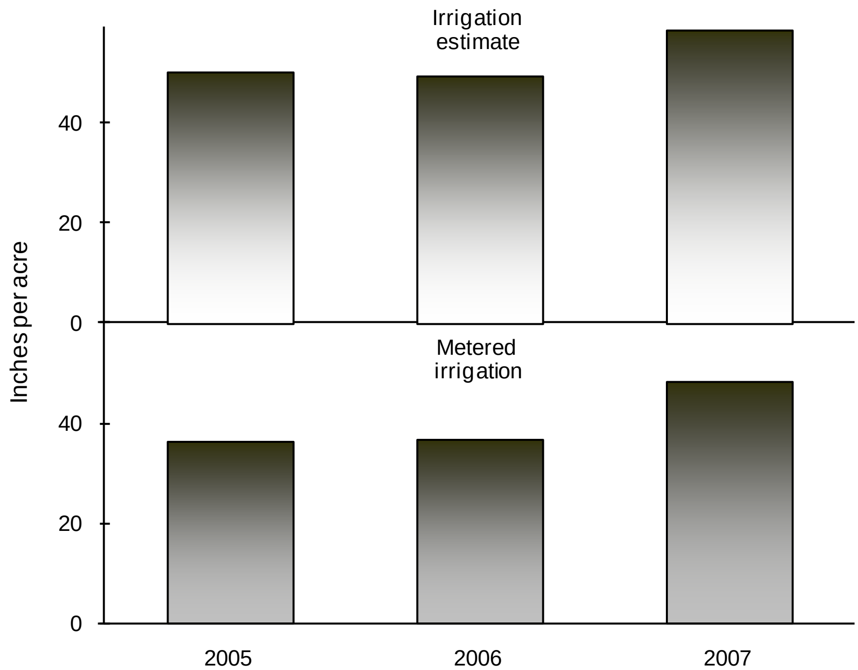


Figure 4-28. All crops metered and estimated irrigation in the Hudspeth district, 2005–2007.

4.5.3 Results and conclusions

The Hudspeth County data set has a good representation of alfalfa irrigation in the district. With 12 percent of the alfalfa acreage being metered, the case may be made that the estimates for alfalfa in Hudspeth County are too high (Table 4-29, Figure 4-29). TWDB and the district need to work together to correct this issue. No conclusions can be made about any other crops due to insufficient representation in the data set. More years of data are needed to further investigate whether irrigation practices on other crops in the district are accounted for in the TWDB estimates. Expanding the program to cover more acreage in the district and include sites with more cotton acreage might prove useful.

Table 4-29. Three-year averages of metered and estimated acreages and irrigation by crop type—Hudspeth district.

Crop	Meters	Metered acres	Estimated acres	Percent metered
Alfalfa	31	1,851	15,439	12.0
Cotton	1	47	11,115	0.4
Hay-pasture	1	85	1,031	8.2
Mixed	17	871	na	na
Other	1	42	na	na
Vegetables	1	23	2,143	1.1
Vineyard	1	47	602	7.8
Total	53	2,965	31,867	9.3

na = not available

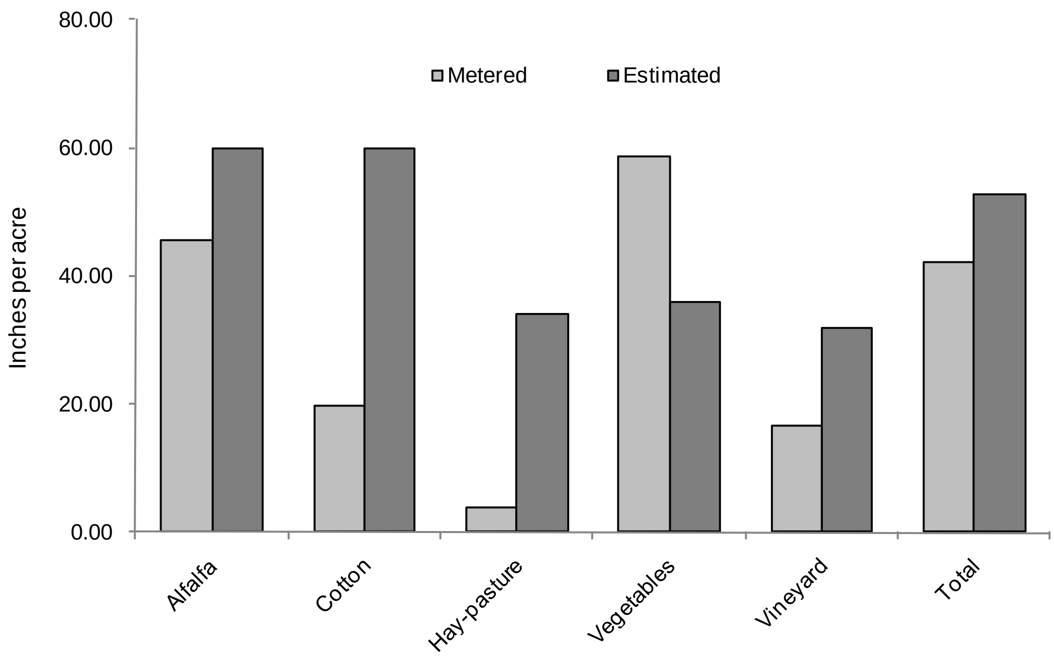
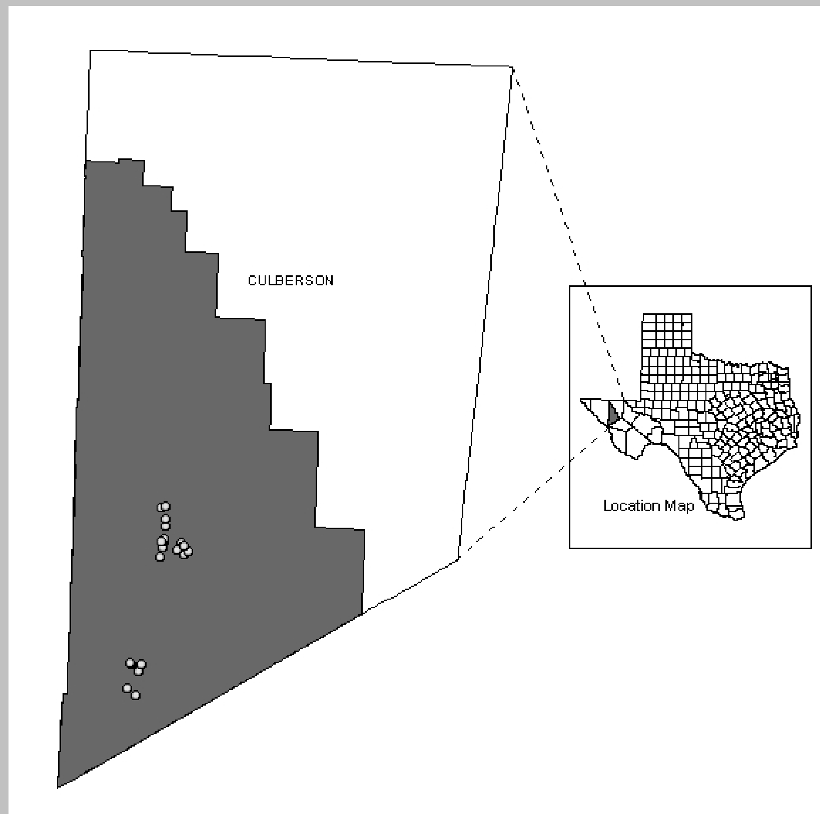


Figure 4-29. Individual crops metered and estimated irrigation in the Hudspeth district, 2005–2007.

4.6 Culberson County Groundwater Conservation District



District at a Glance

Planning Region: *Far West Texas (E)*

2007 Gross Crop Income: *$7,049,000*

Climate: *Arid*

Average Yearly Rainfall: *12 inches*

District Size: *1,103,135 acres*

Total Crop Land: *58,995 acres*

Irrigated Crop Land: *7,100 acres*

Irrigation Water Use: *21,967 acre-feet*

Acres in TWDB Metering Program: *unknown*

Number of Active Irrigation Wells in Groundwater Conservation District: *150*
Number of Meters in Program: *32*

Eco-region: *Trans-Pecos*

Soils: *Clay loam, Gravelly loam, Loam, Silty clay loam*

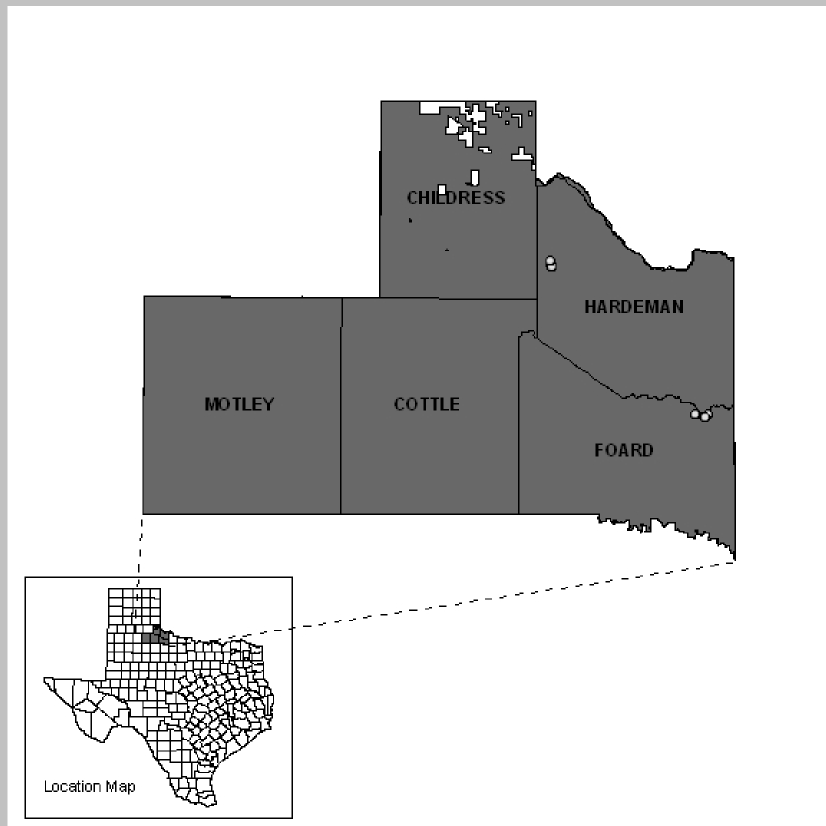
Crop Types:
Alfalfa
Cotton
Corn
Haygrazer
Wheat

Irrigation Methods:
Center pivot
Sub-surface drip

Culberson County Groundwater Conservation District has participated in the irrigation metering program since 2003. This district has 32 meters in two monitor plots. The district initially used the TWDB Web-based data submittal forms but now provides data in Excel spreadsheets, using the TWDB metering data template. TWDB received monthly water usage data from the district for 2003 and yearly data for 2004 through 2007.

The district meters alfalfa, cotton, hay, and wheat and has expressed an interest in expanding its program to include all irrigation wells. Due to concerns within the district, acreage totals for crops were not reported prior to 2008. In 2009, these concerns were quelled and the district began reporting all the desired data fields necessary to compile a data set. Since there is not a complete data set for years 2003 through 2007, analysis for Culberson County is not included in this report.

4.7 Gateway Groundwater Conservation District



Gateway Groundwater Conservation District at a Glance

Planning Region: *Region B*

2007 Gross Crop Income: *$21,355,000**

Climate: *Semi-arid*

Average Yearly Rainfall: *26 inches*

District Size: *2,540,661 acres*

Total Crop Land: *174,752 acres**

Irrigated Crop Land: *9,657 acres**

Irrigation Water Use: *11,560 acre-feet**

Acres in TWDB Metering Program: *373*

Number of Active Irrigation Wells in Groundwater Conservation District: *401**

Number of Meters in Program: *8*

***** *District totals prior to the annexation of Childress, Cottle, and Motley counties.*

Eco-region: *Rolling Plains*

Soils:
Clay loam, Loam, Clay, Loamy fine sand

Crop Types:
Cotton
Alfalfa
Wheat

Irrigation Methods:
Center pivot
Sub-surface drip

The district enrolled in the program in 2003 under the monitoring plot design concept. Over the following years the district experienced problems with the meters due to sand in the produced water. This eventually caused meter failures on all 8 meters in the district. The district, TWDB, and the meter manufacturers tried to resolve this issue, but ultimately, it was more cost effective to nullify the agreement and terminate the contract. Despite this setback, the district has expressed an interest to pursue additional funding to experiment with alternative metering strategies and expand upon their metering program in the future.

There were 2 monitor plots in the district, 1 in the northeast part of Foard County and 1 in west-central Hardeman County.[46] The district had a total of 8 meters, 4 in Foard County and 4 in Hardeman County. The 4 in Foard County were located on 4 wells that pumped into 2 pivot systems, resulting in a total of 6 metered values included for analysis in 2004 and 2005; that was down to 3 in 2006. Each monitor plot had a rain gage and monitor well. Metered irrigation data were available for 2004 through 2006. Rainfall was reported in 2004 and 2005, but not in 2006. An average of 307 acres was monitored by the district over these 3 years.

4.7.1 Irrigation water use data—individual crops

Alfalfa

Each year, one alfalfa field was metered in Foard County. This represents about 3 percent of the average 2,209 acres of alfalfa grown within the district during these three years. The weighted average metered irrigation on alfalfa was 19.22 inches per acre, and the weighted average estimated irrigation was 21.59 inches per acre. The significant differences between individual metered and estimated irrigation values were not apparent when the 3 years were averaged together (Table 4-30, Figure 4-30). The standard deviation was 12.94 inches per acre. Rainfall values were in close agreement. Overall crop water use totals differed by 2.87 inches.

Table 4-30. Alfalfa—weighted averages of metered data and estimates—Gateway district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
2004	1	63	2,138	2.9	8.81	21.72	1	32.00	33.75	40.81	55.47
2005	1	63	2,179	2.9	33.66	20.92	1	21.50	20.71	55.16	41.63
2006	1	60	2,311	2.6	15.00	22.11	0	na	na	na	na
Averages	1	62	2,209	2.8	19.22	21.59	1	26.75	27.23	45.97	48.82

na = not available; all units in inches per acre unless otherwise noted.

[46] The western counties, Childress, Cottle, and Motley were annexed into the district at a later date. In this district's analysis, comparisons were made to estimates that only include Foard and Hardeman counties.

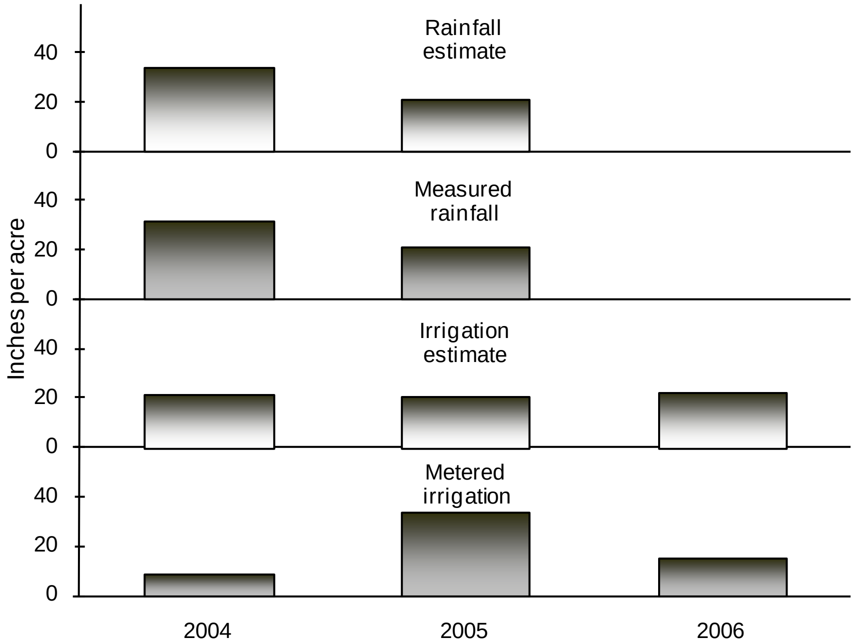


Figure 4-30. Alfalfa metered and estimated irrigation and rainfall for the Gateway district 2004–2006.

Cotton

The district metered four separate cotton plots in 2004 and 2005, and two in 2006. The weighted average metered irrigation was 11.19 inches per acre with a standard deviation of 7.54. Individual metered values ranged from 1.61 to 24.46 inches per acre. The weighted average estimated irrigation was 11.82 inches per acre (Table 4-31, Figure 4-31). Total crop water use totals differed by almost 5 inches due to a similar difference in rainfall totals.

Table 4-31. Cotton—weighted averages of metered data and estimates—Gateway district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
2004	4	230	3,434	6.7	12.91	11.40	4	21.00	33.75	33.91	45.15
2005	4	233	3,195	7.3	12.25	12.12	4	24.90	20.71	37.15	32.83
2006	2	93	2,977	3.1	4.31	12.00	0	na	na	na	na
Averages	3	185	3,202	5.8	11.19	11.82	3	22.95	27.23	34.14	39.05

na = not available; all units in inches per acre unless otherwise noted.

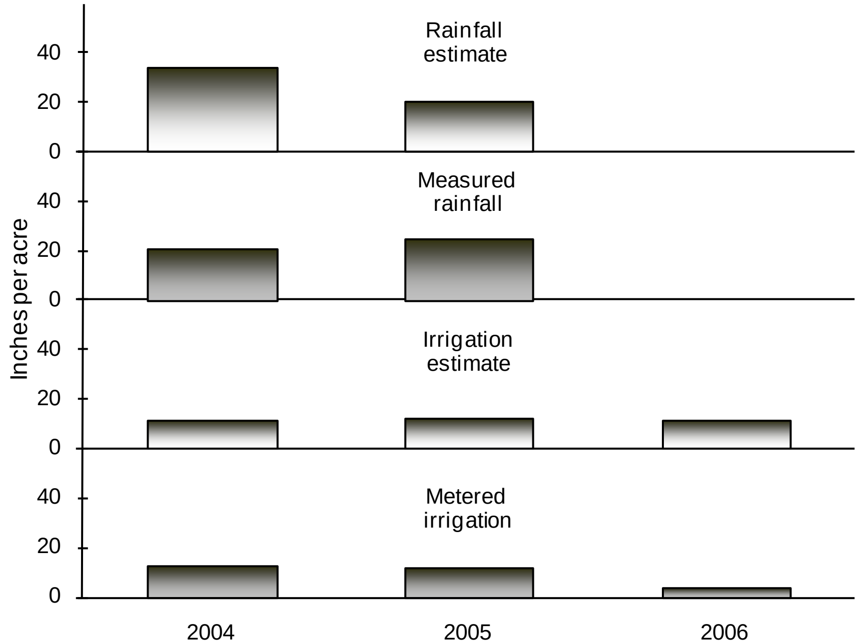


Figure 4-31. Cotton metered and estimated irrigation and rainfall for the Gateway district 2004–2006.

4.7.2 Irrigation water use —all crops

In 2004 the total metered acreage was 413 acres, in 2005 it was 356, and in 2006 it was down to 153 acres. In 2004 the weighted average metered irrigation was 15.21 inches per acre, and weighted average estimated irrigation was 13.85 inches per acre. Similarly, in 2005 the weighted average metered irrigation was 15.89 inches per acre and the weighted average estimated irrigation was 14.46 inches per acre. TWDB estimates closely approximated the applied irrigation for those years prior to the meters beginning to fail, potentially the reason for the resulting lower metered water use in 2006 (Table 4-32, Figure 4-32).

There were greater differences between metered and estimated rainfall data. TWDB rainfall estimates were based on a Chillicothe weather station that provided an estimate of 33.75 inches in 2004 and 20.71 inches in 2005. Averaged across the district, measured rainfall amounts in 2004 differed by 9.08 inches. In 2005 it differed by only 3.06 inches. There was no rainfall data reported in 2006.

Table 4-32. All crops—weighted averages of metered data and estimates—Gateway district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
2004	6	413	8,476	4.9	15.21	13.85	6	24.67	33.75	39.88	47.60
2005	6	356	9,576	3.7	15.89	14.46	6	23.77	20.71	39.66	35.17
2006	3	153	8,611	1.8	8.50	15.82	0	na	na	na	na
Averages	5	307	8,888	3.5	14.36	14.70	4	24.22	27.23	38.58	41.93

na = not available; all units in inches per acre unless otherwise noted.

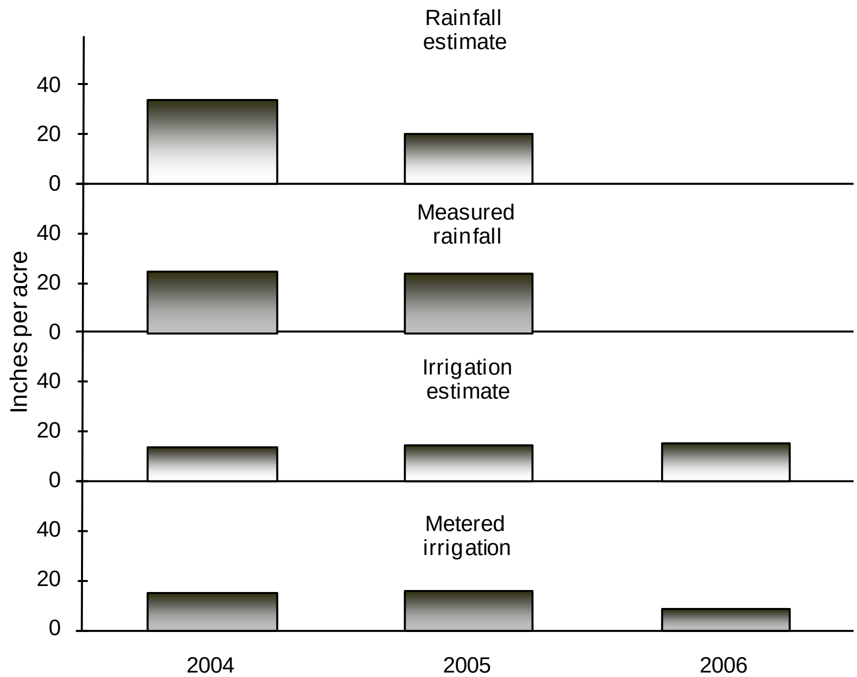


Figure 4-32. All crops metered and estimated irrigation and rainfall for the Gateway district 2004–2006.

4.7.3 Results and conclusions

With only 8 meters in service, the Gateway metering data set was very small (Table 4-33). The data did provide some perspective on irrigation water use for alfalfa and cotton in the Rolling Plains region of the state. The metered amount was closer to the crop evapotranspiration rate for cotton, suggesting the estimated water use may be high; however, more metered data and better rainfall data are necessary to justify changes to the estimation methodology.

Table 4-33. Three-year averages of metered and estimated acreages by crop type—Gateway district.

Crop	Meters	Metered acres	Estimated acres	Percent metered
Alfalfa	3	62	2,209	2.8
Cotton	10	185	3,202	5.8
Mixed	2	60	na	na
Total	15	307	8,888	3.5

na = not available

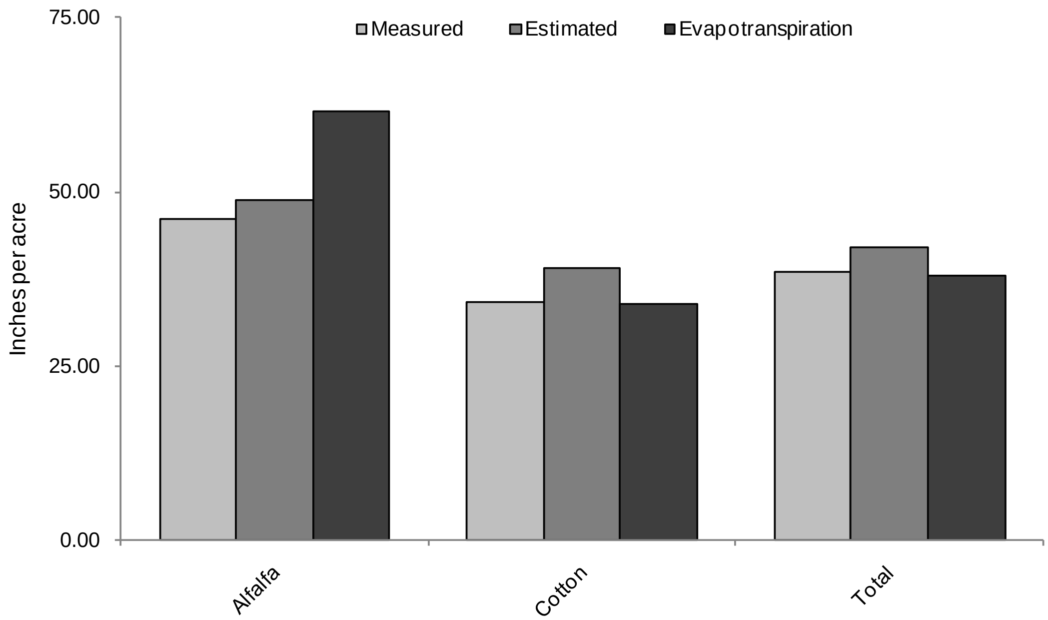
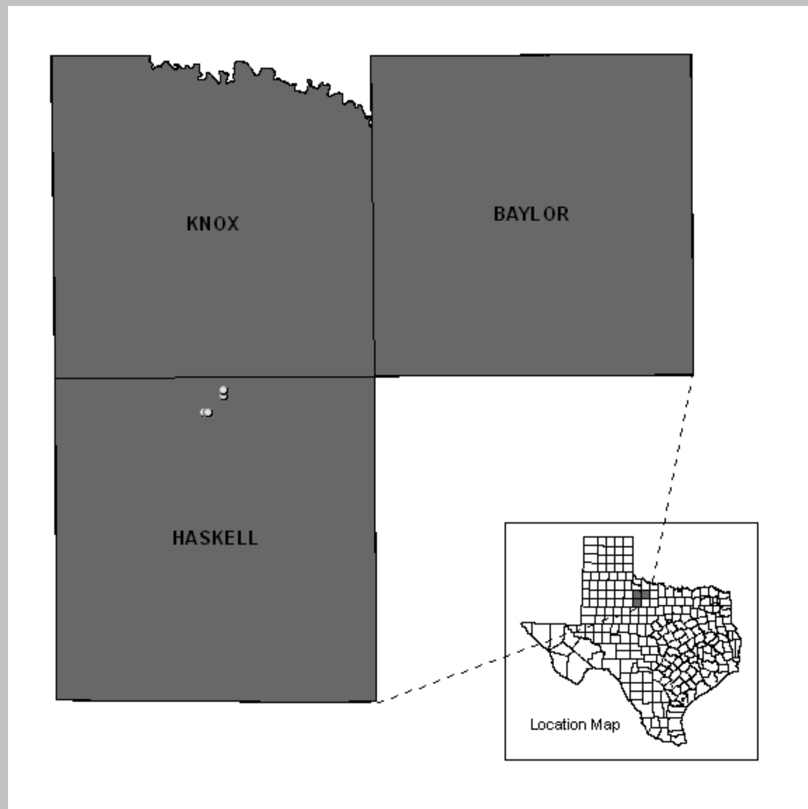


Figure 4-33. **Total crop water use values—metered, estimated, and mean consumptive—for individual and all crops for the Gateway district 2004–2006.**

Based on the limited data set, the TWDB estimates are slightly higher than the metered values for crop consumptive use (Figure 4-33). Expanding the program and adding more meters would be useful in further validating the TWDB estimates. The district expressed an interest and willingness to expand the program, which would likely include other crops grown in the district, such as wheat, grain sorghum, and peanuts. As of 2010, Childress, Cottle, and Motley counties were annexed into the district. With availability of additional funds to purchase more meters, this could open the door for interested producers to join the program who previously did not have the opportunity.

4.8 Rolling Plains Groundwater Conservation District



District at a Glance

Planning Regions: *Brazos (G) and Region B*

2007 Gross Crop Income: *$77,076,000*

Climate: *Semi-arid*

Average Yearly Rainfall: *27 inches*

District Size: *1,702,363 acres*

Total Crop Land: *605,400 acres*

Irrigated Crop Land: *79,732 acres*

Irrigation Water Use: *80,676 acre-feet*

Acres in TWDB Metering Program: *461*

Number of Irrigation Wells in Groundwater Conservation District: *2,933*

Number of Meters in Program: *5*

Eco-region: *Rolling Plains*

Soils:
Clay, Clay loam, Fine sandy loam, Loam, Silty loam

Crop Types:
Cotton
Peanuts

Irrigation Methods:
Center pivot

Rolling Plains Groundwater Conservation District joined the metering program in 2003. The district had one monitor plot located in Haskell County. Two rain gages and 14 monitor wells were located within the monitor plot. The first year of data available for the district was in 2005. The district submitted data from five meters, using both the TWDB metering data template and the data collection and reporting worksheets.

4.8.1 Irrigation water use data—individual crops

Cotton

Approximately 35,228 acres of irrigated cotton were grown in the district over the three-year period. Since the district metered an average of only 174 acres of cotton, or less than 1 percent of the cotton acreage in the district, the sample size was extremely small. The 3-year weighted average metered irrigation on cotton was 13.62 inches, which is in close agreement with the weighted average estimated value of 12.36 inches per acre (Table 4-34, Figure 4-34). Rainfall totals, too, were in close agreement, on average differing by less than 1 inch.

Table 4-34. Cotton—weighted averages of metered data and estimates—Rolling Plains district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
2005	1	121	35,546	0.3	5.59	12.00	1	24.37	20.71	29.96	32.71
2006	2	242	37,681	0.6	21.23	13.00	2	19.74	25.73	40.97	38.73
2007	2	158	32,457	0.5	8.10	12.00	2	22.42	22.89	30.52	34.89
Averages	2	174	35,228	0.5	13.62	12.36	2	22.18	23.11	35.79	35.47

All units in inches per acre unless otherwise noted.

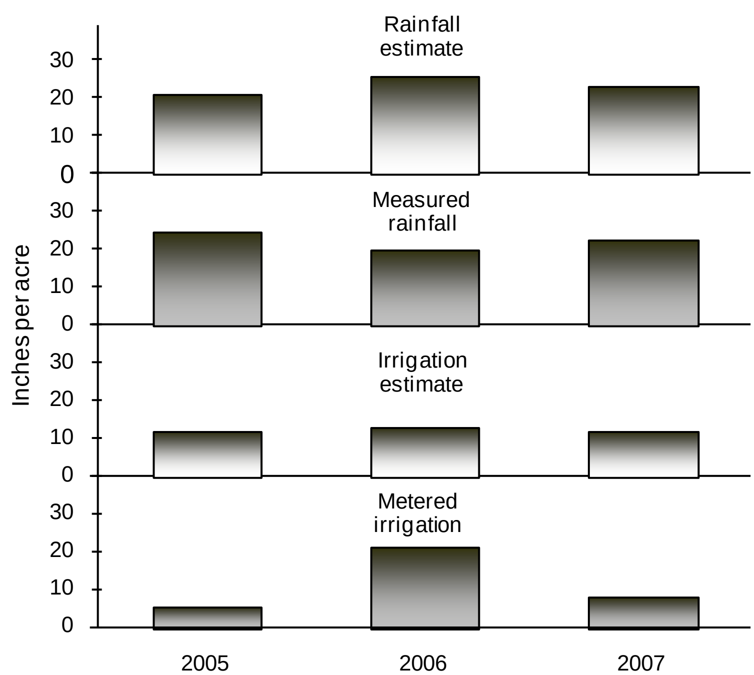


Figure 4-34. Cotton metered and estimated irrigation and rainfall for the Rolling Plains district, 2005–2007.

Peanuts

Peanuts were grown on an average of 9,888 acres of irrigated land in the district during 2005 and 2006, and 98 acres were metered each of those years by the district. The weighted average metered irrigation was 13.02 inches and the weighted average irrigation estimate was 11.41 inches per acre (Table 4-35, Figure 4-35).[47]

Table 4-35. Peanuts—weighted averages of metered data and estimates—Rolling Plains district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
2005	2	98	11,178	0.9	9.72	10.99	2	24.37	20.71	34.09	31.70
2006	2	98	8,597	1.1	16.34	11.97	2	19.74	25.73	36.08	37.70
Averages	2	98	9,888	1.0	13.02	11.41	2	22.06	23.22	35.07	34.63

All units in inches per acre unless otherwise noted.

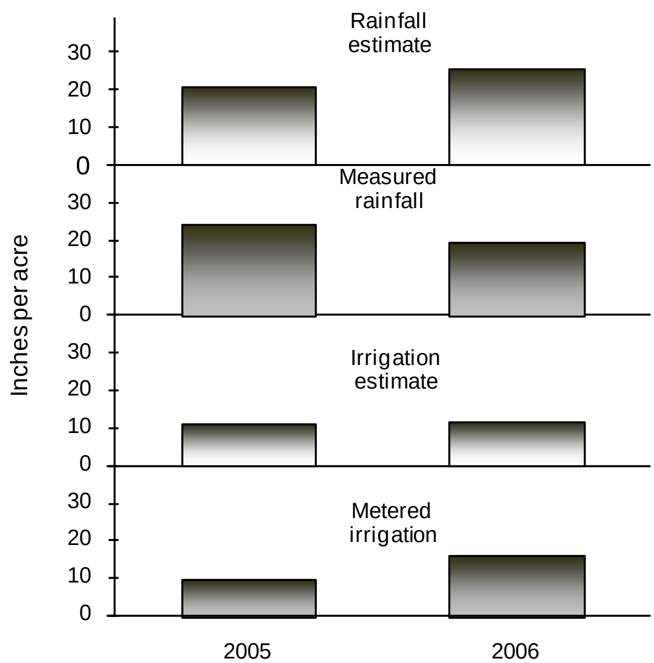


Figure 4-35. Peanuts metered and estimated irrigation and rainfall for the Rolling Plains district, 2005–2006.

4.8.2 Irrigation water use—all crops

All crops metered in the district over the three-year period included cotton, peanuts, and mixed cropping practices. Average metered and estimated irrigation values were in close

[47] TWDB estimates show there were 8,534 acres of irrigated peanuts grown in Knox and Haskell counties in 2007. Rolling Plains GCD did have one meter on a field containing peanuts that year; however, it fell into the mixed crop category. The field was split in two: half in cotton and half in peanuts. Therefore, there were no metered values on peanuts in the dataset for comparison in 2007.

agreement, 11.57 and 11.94, respectively (Table 4-36, Figure 4-36). Rainfall totals were also in close agreement when averaged across the three-year period. Average measured rainfall within the monitor plot was 22.18 inches. TWDB rainfall estimates were based on a station in Munday, located in Knox County. The average TWDB estimated rainfall based on this station was 23.11 inches.

Table 4-36. All crops—weighted averages of metered data and estimates—Rolling Plains district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
2005	3	219	79,704	0.3	7.44	12.15	3	24.37	20.71	31.81	32.86
2006	4	340	78,501	0.4	19.82	12.82	4	19.74	25.73	39.56	38.55
2007	4	401	77,065	0.5	6.83	10.83	4	22.42	22.89	29.25	33.72
Averages	4	320	78,423	0.4	11.57	11.94	4	22.18	23.11	33.75	35.05

All units in inches per acre unless otherwise noted.

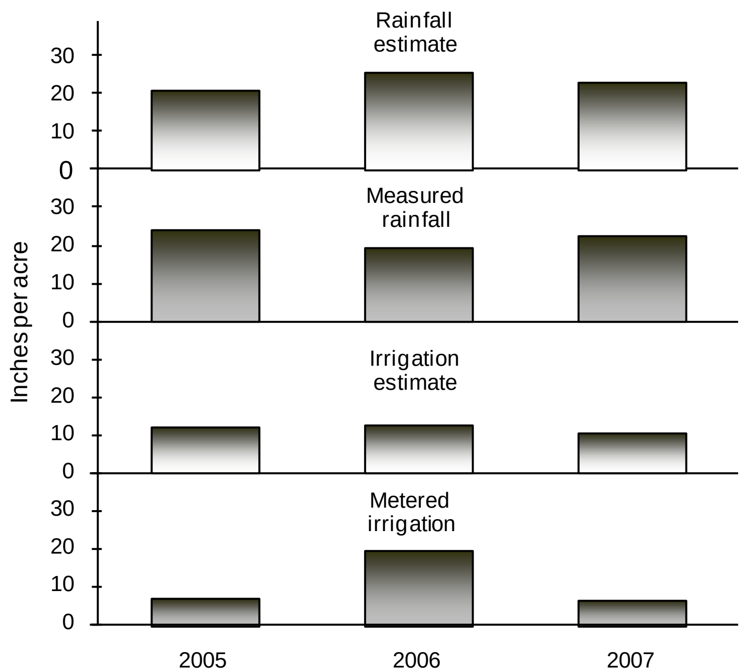


Figure 4-36. All crops metered and estimated irrigation and rainfall for the Rolling Plains district, 2005–2007.

4.8.3 Results and conclusions

The measured crop consumptive use values and TWDB estimated crop consumptive use were in close agreement with the average evapotranspiration requirements for peanuts and cotton. Although based on the limited sample size, little conclusions can be made about the data (Table 4-37). An expanded program that provides more data points could be useful in validating TWDB estimates for crops grown within the Rolling Plains district (Figure 4-37).

Table 4-37. Three-year averages of metered and estimated acreages by crop type—Rolling Plains district.

Crop	Meters	Metered acres	Estimated acres	Percent metered
Cotton	5	174	35,228	0.5
Peanuts	4	65	9,436	0.7
Total	11	320	78,423	0.4

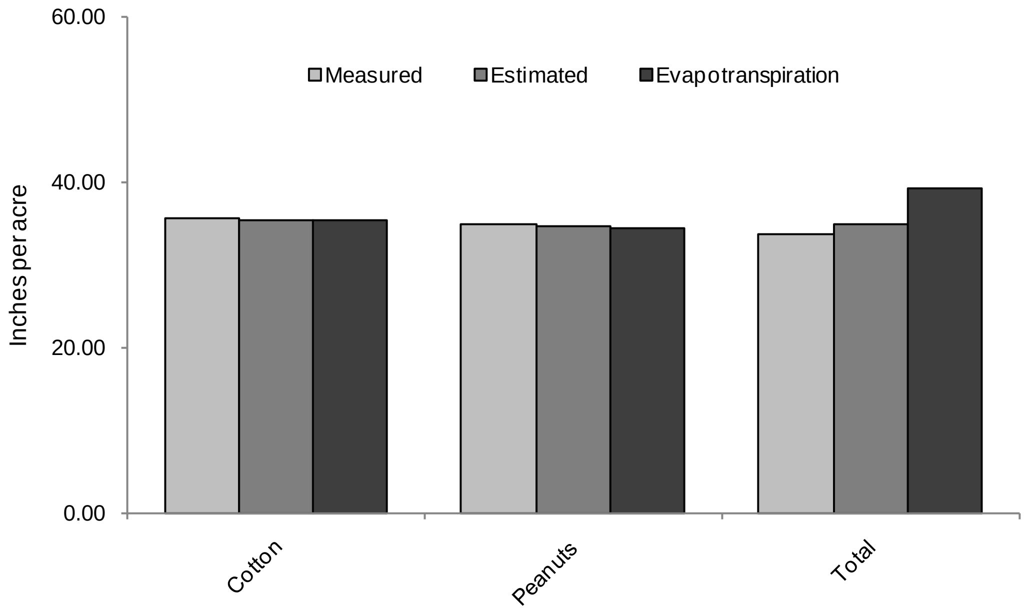
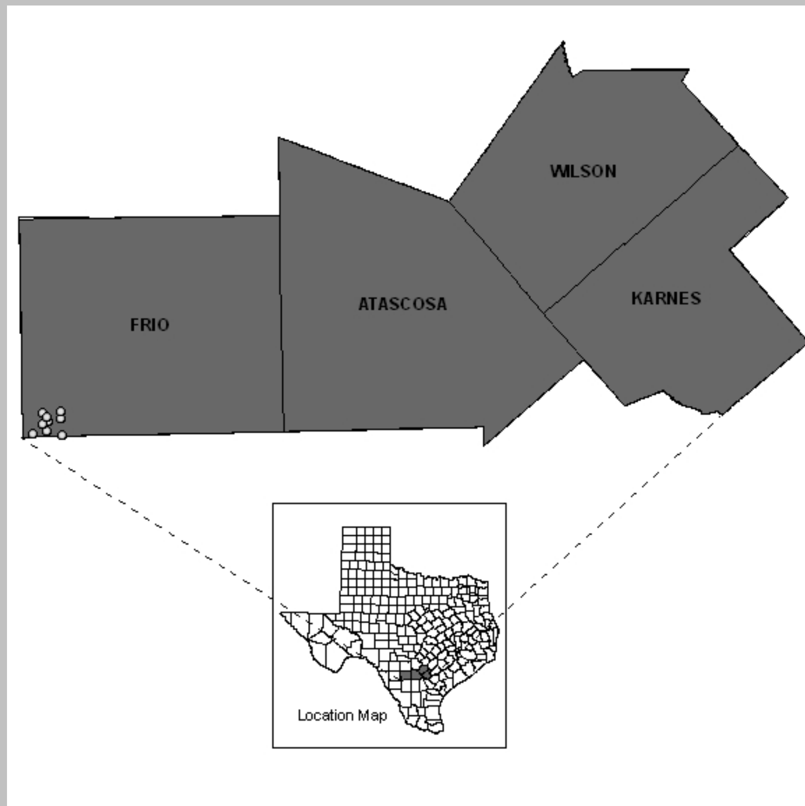


Figure 4-37. Total crop water use values—metered, estimated, and mean consumptive—for individual and all crops in the Rolling Plains district, 2005–2007.

4.9 Evergreen Underground Water Conservation District



District at a Glance

Planning Region: *South Central Texas (L)*

2007 Gross Crop Income: *$82,413,000*

Climate: *Sub-humid*

Average Yearly Rainfall: *28 inches*

District Size: *2,495,010 acres*

Total Crop Land: *161,200 acres*

Irrigated Crop Land: *91,620 acres*

Irrigation Water Use: *74,946 acre-feet*

Acres in TWDB Metering Program: *1,675*

Eco-region: *South Texas Plains, Post Oak Savannah*

Soils:
Fine sand, Clay loam, Very fine sandy loam, Loamy fine sand, Sandy clay loam, Fine sandy loam

Crop Types:
Cotton
Oats, Olives
Peanuts
Potatoes
Sorghum
Vegetables (Deep)—
Beans, Beets, Watermelon
Vegetables (Shallow)—
Onions, Spinach, Cabbage
Wheat

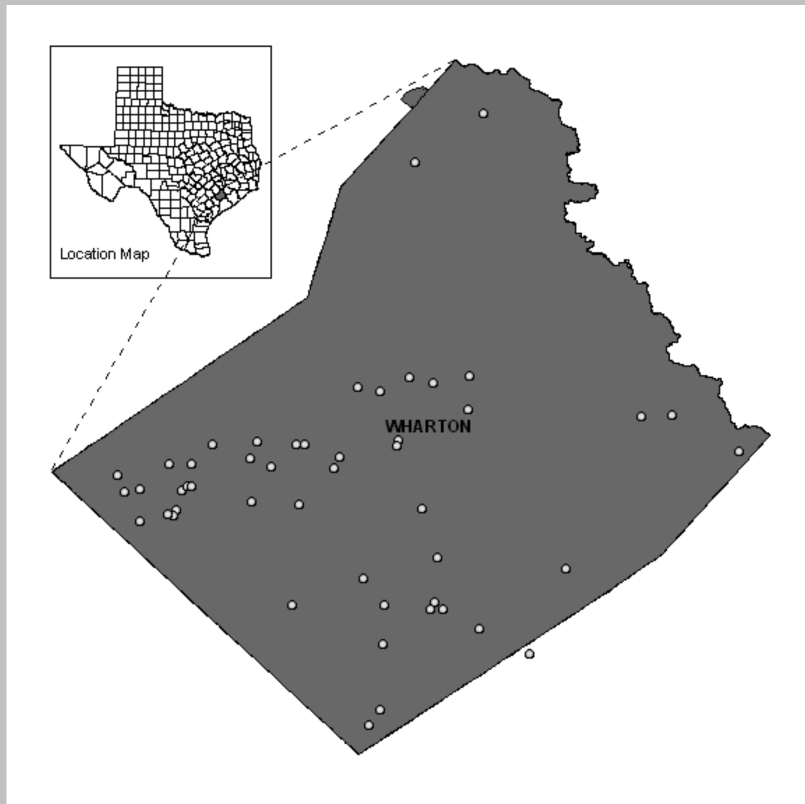
Number of Irrigation Wells in Groundwater Conservation District: *982* **Number of Meters in Program: 9**	**Irrigation Methods:** *Center pivot* *Sub-surface drip* *Side-roll*

Evergreen Underground Water Conservation District joined the metering program in 2003. The Evergreen district had one monitor plot located in southwest Frio County. There were three rain gages and one monitor well in the monitor plot, which was 100 percent metered. The district installed 11 meters on a very complex delivery and points-of-use system because it was an area for which they needed pumpage data. The system consisted of multiple wells supplying several pivot sprinkler systems. Each pivot system had several crops rotating under the pivot throughout the year.

Under this system, there were as many as 12 crops rotating in a single year. One well could feed into several small pivots. There were 15 small pivots, with multiple crops rotating under the same pivot as quickly as every 60 days. Other meters had less crop variation, but most had at least two crops at a time or several crops over multiple seasons. Meter readings were taken once a month, but crops were harvested and planted within the month many times a year. The district had the full cooperation of the producers and communicated directly with them on a regular basis, so acreage was as accurate as possible. However, the acreage was complicated because crops changed so frequently. Attributing an exact acreage to the water use of the multiple crop combination for an entire month was not possible. Obtaining accurate inches per acre per crop for this area would likely require a significant additional investment in meters, dataloggers, telemetry equipment, and pivot directional tracking devices.

The district used the TWDB data template to submit data. To keep up with the constantly changing array of vegetable crops in the monitor plot, the district verified with the producer when various crops were planted or harvested. However, water use by crop type could not be determined. The district is currently not interested in expanding their metering program, primarily due to a lack of resources for the increased workload.

4.10 Coastal Bend Groundwater Conservation District



District at a Glance

Planning Regions: *Lavaca (P) / Lower Colorado (K)*
2007 Gross Crop Income: *$146,003,000*

Climate: *Humid*

Average Yearly Rainfall: *45 inches*

District Size: *698,908 acres*

Total Crop Land: *376,001 acres*

Irrigated Crop Land: *61,717 acres*

Irrigation Water Use: *151,903 acre-feet*

Acres in TWDB Metering Program: *8,711 acres*

Number of Irrigation Wells in Groundwater Conservation District: *500*

Number of Meters in Program: 62

Eco-region: *Gulf Prairies and Marshes*

Soils: *Clay, Fine sandy loam*

Crop Types:
Aquaculture
Corn
Cotton
Hay-pasture
Rice
Soybeans
Turfgrass
Waterfowl

Irrigation Methods:
Border Flood
Center Pivot
Side-roll

Coastal Bend Groundwater Conservation District joined the irrigation metering program in 2005. The district received approval for an application to fund 62 flow meters on a 50 percent cost-share basis. 2006 was the first year of data reporting. There were a total of 92 metered values available for analysis for 2006 and 2007. The district did not report any rainfall data; therefore, total crop water use comparisons are not analyzed.

4.10.1 Irrigation water use data—individual crops

Corn

There were, on average, 8 metered values on 1,239 acres of irrigated corn. This represented about 13.6 percent of the 9,089 acres grown in the district (Table 4-38). Metered irrigation amounts in 2006 were in close agreement. In 2007, however, TWDB estimates attributed 32 inches per acre to irrigated corn in Wharton County (Figure 4-38). Overall, the weighted average metered irrigation was 4.47 inches per acre with a standard deviation of 2.66. Individual values ranged from 1.51 to 12.00 inches per acre.

Table 4-38. Corn—weighted averages of metered data and estimates—Coastal Bend district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate
2006	7	1,079	8,558	12.6	5.27	8.00
2007	9	1,399	9,619	14.5	3.86	32.00
Averages	8	1,239	9,089	13.6	4.47	20.70

All units in inches per acre unless otherwise noted.

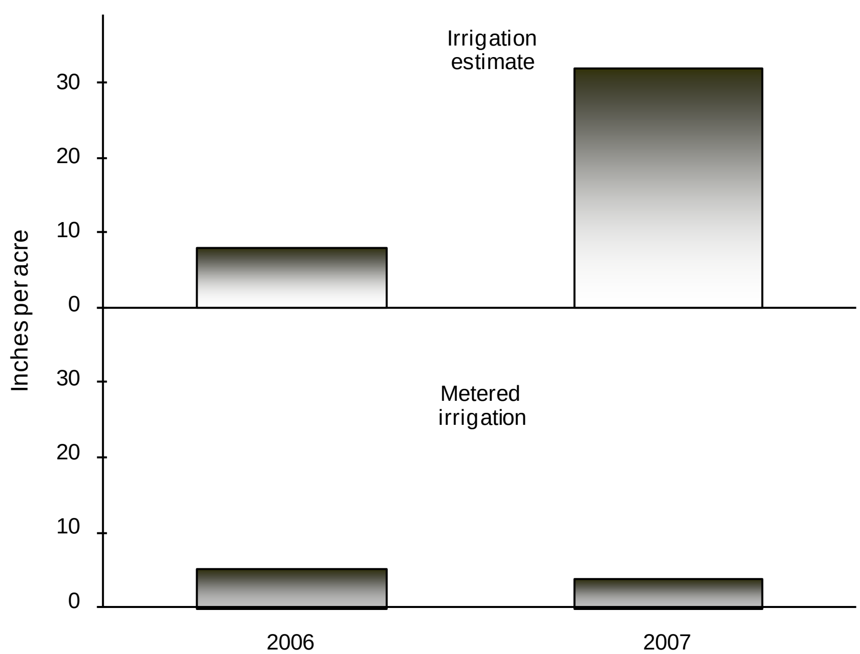


Figure 4-38. Corn metered and estimated irrigation for the Coastal Bend district, 2006–2007.

Cotton

There was an average of 190 acres of cotton metered over the two-year period. This provided a 10 percent representative sample, although there were only 3 total metered values. Metered irrigation was, on average, about half of the estimated irrigation (Table 4-39 and Figure 4-39). Individual values ranged from 2.28 to 6.00 with a standard deviation of 1.87.

Table 4-39. Cotton—weighted averages of metered data and estimates—Coastal Bend district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate
2006	2	180	2,487	7.2	2.55	10.00
2007	1	200	1,293	15.5	6.00	11.00
Averages	2	190	1,890	10.1	4.37	10.34

All units in inches per acre unless otherwise noted.

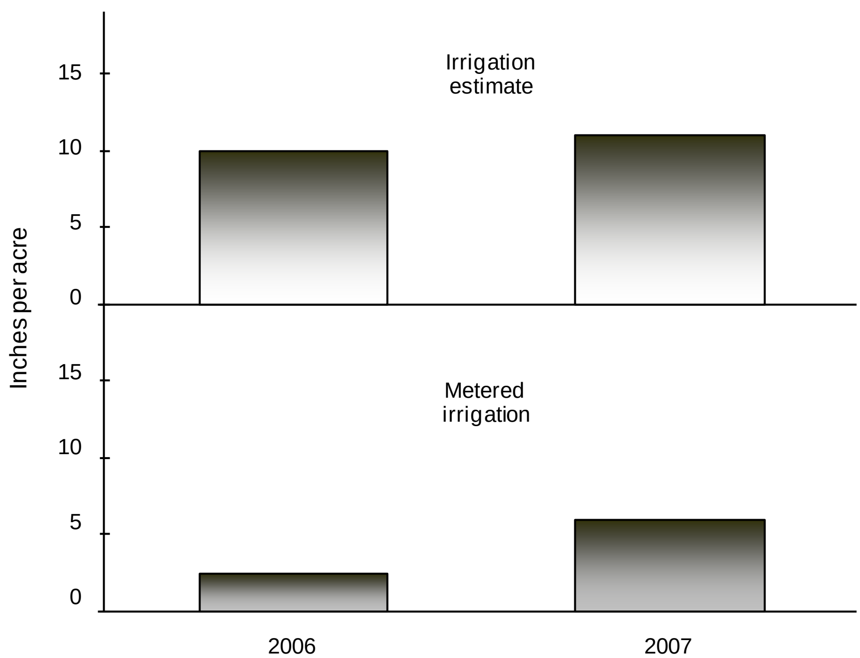


Figure 4-39. Cotton metered and estimated irrigation for the Coastal Bend district, 2006–2007.

Hay-pasture

The district metered an average of 5 percent of the hay-pasture acreage during the two years of 2006 and 2007. Again, like the cotton values, metered values for hay-pasture were 5 inches less than the irrigation estimates (Table 4-40 and Figure 4-40). Individual values ranged from 3.76 to 20.00 with a standard deviation of 5.90.

Table 4-40. Hay-pasture—weighted averages of metered data and estimates—Coastal Bend district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate
2006	3	350	7,298	4.8	7.23	11.00
2007	3	214	2,598	8.2	8.84	18.00
Averages	3	282	4,948	5.7	7.84	12.84

All units in inches per acre unless otherwise noted.

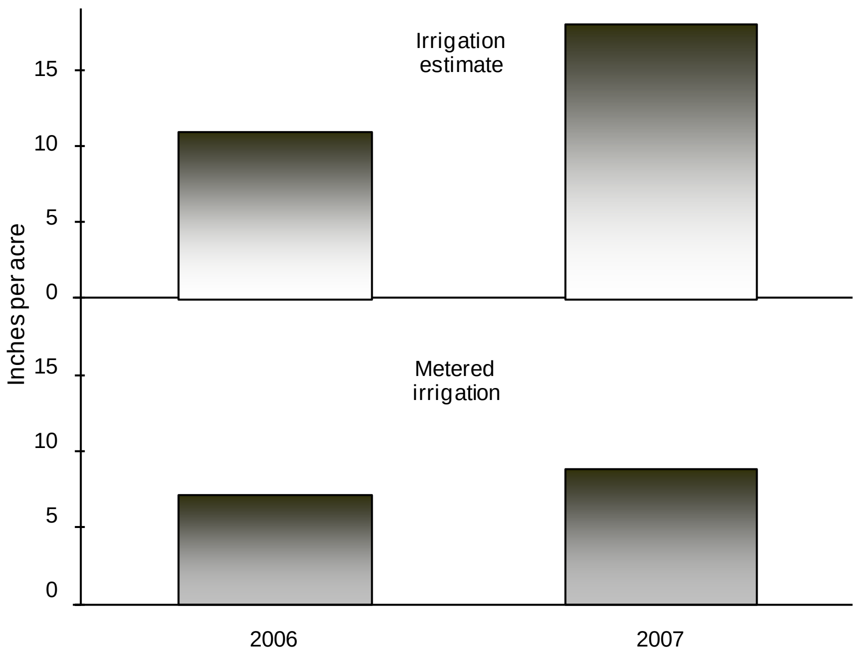


Figure 4-40. Hay-pasture metered and estimated irrigation for the Coastal Bend district, 2006–2007.

Rice

Coastal Bend is a major rice growing region in Texas. Historically, about 20 percent of the statewide acreage has been located in Wharton County. During 2006 and 2007, the district metered a two-year average of 13.5 percent of the rice acreage in the county. Metered irrigation values were only about half the irrigation estimates (Table 4-41 and Figure 4-41). Individual values ranged from 4.19 to 74.29 with a standard deviation of 15.27.

The annual irrigation estimate for rice is affected by the TWDB surface water component of the annual irrigation estimating process. Since 2003, diversion losses in surface water canal delivery systems are included in the irrigation estimate amounts for rice; therefore, it is expected that estimates be somewhat higher than the values metered on-farm.

Table 4-41. Rice—weighted averages of metered data and estimates—Coastal Bend district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate
2006	14	3,127	35,417	8.8	30.71	55.00
2007	23	3,951	17,101	23.1	23.38	63.00
Averages	19	3,539	26,259	13.5	26.62	57.60

All units in inches per acre unless otherwise noted.

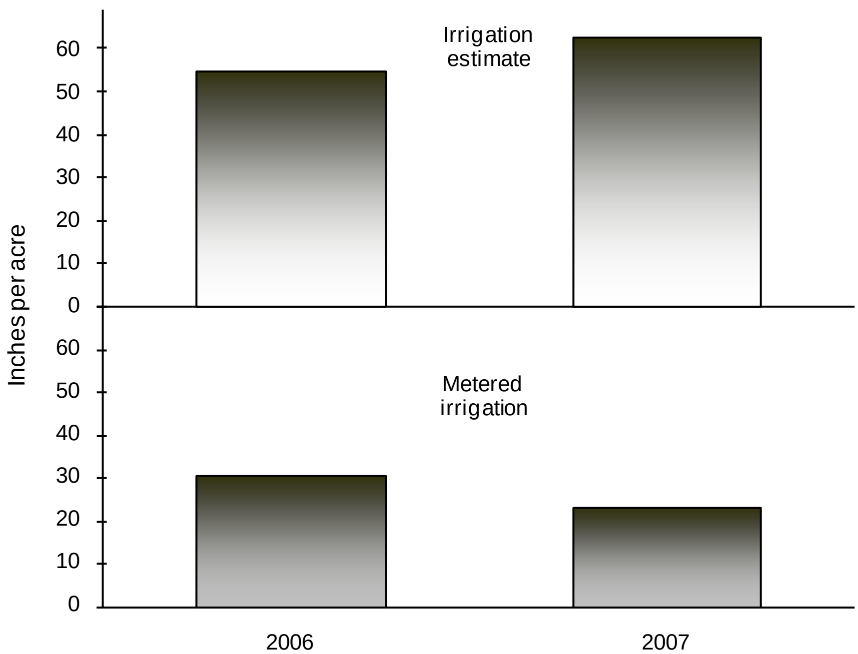


Figure 4-41. Rice metered and estimated irrigation for the Coastal Bend district, 2006–2007.

Turfgrass

The Texas turfgrass industry is deeply rooted in the Coastal Bend region of the state. During 2006 and 2007, the district metered a two-year average of 9.0 percent of the turfgrass acreage in the county. Metered irrigation values were less than half the irrigation estimates (Table 4-42 and Figure 4-42). Individual metered values ranged from 4.65 to 37.55 with a standard deviation of 9.20.

Table 4-42. Turfgrass—weighted averages of metered data and estimates—Coastal Bend district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate
2006	11	883	16,000	5.5	18.62	36.00
2007	14	2,133	17,554	12.2	10.04	20.30
Averages	13	1,508	16,777	9.0	12.55	27.79

All units in inches per acre unless otherwise noted.

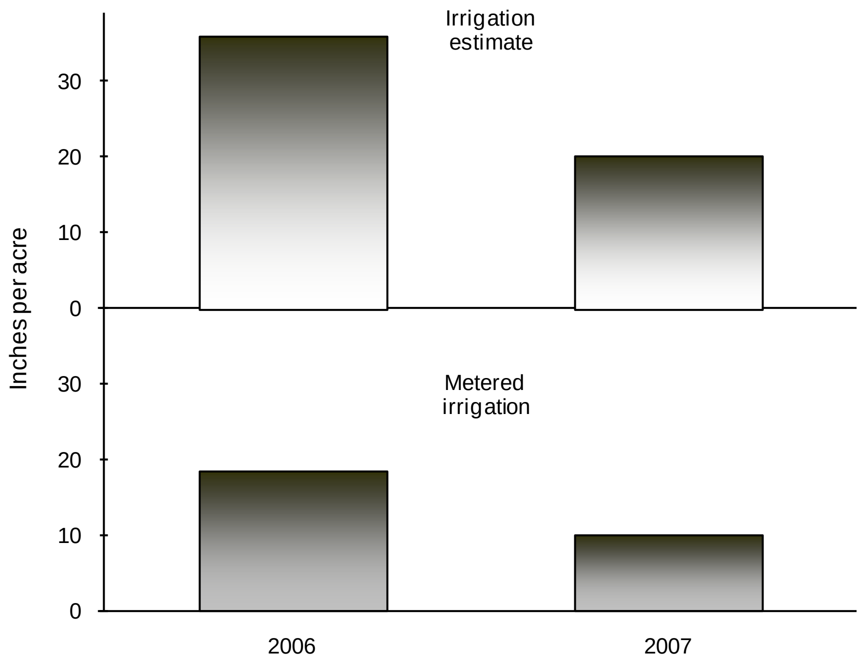


Figure 4-42. Turfgrass metered and estimated irrigation for the Coastal Bend district, 2006–2007.

4.10.2 Irrigation water use—all crops

Coastal Bend personnel provided TWDB with an average of 46 metered values on an average of just over 7,000 acres representing over 11 percent of the average irrigated acreage in the district during the two-year period. Weighted averages of metered irrigation amounted to less than half that of the overall irrigation estimate. Again, this is due, in part, to surface water delivery losses being accounted for in TWDB irrigation estimates for rice acreage (Table 4-43 and Figure 4-43). The individual metered values across all crop categories ranged from 1.51 to 74.29 with a standard deviation of 13.86.

Table 4-43. All crops—weighted averages of metered data and estimates—Coastal Bend district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate
2006	40	5,928	73,787	8.0	20.64	36.97
2007	51	7,962	49,266	16.2	15.39	37.00
Averages	46	6,945	61,527	11.3	17.63	36.98

All units in inches per acre unless otherwise noted.

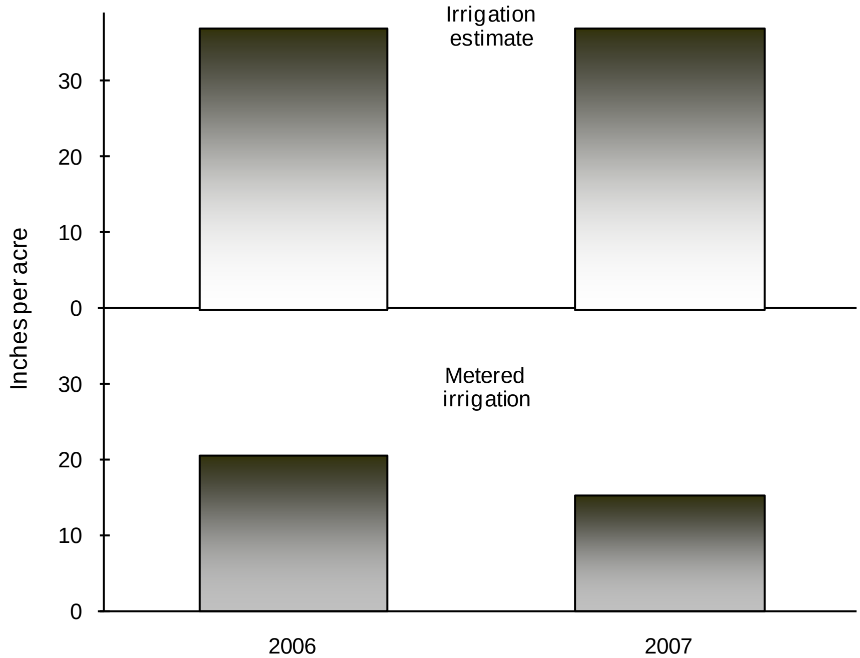


Figure 4-43. All crops metered and estimated irrigation for the Coastal Bend district, 2006–2007.

4.10.3 Results and Conclusions

Over the two year period, Coastal Bend personnel provided TWDB with a total of 91 metered values on an average of almost 7,000 acres representing over 11 percent of the average acreage in the district (Table 4-44). The data set provides a good representative sample of irrigated crops grown within the county.

Table 4-44. Two-year averages of metered and estimated acreages by crop type—Coastal Bend district.

Crop	Meters	Metered acres	Estimated acres	Percent metered
Corn	16	1,239	9,089	13.6
Cotton	3	190	1,890	10.1
Grain sorghum	3	155	938	16.5
Hay-pasture	6	282	4,948	5.7
Rice	37	3,539	26,259	13.5
Soybeans	1	33	1,626	2.0
Turfgrass	25	1,508	16,777	9.0
Total	91	6,945	61,527	11.3

TWDB should investigate the differences in the metered and estimated irrigation amounts (Figure 4-44). It is not known whether or not these metered values fully capture the whole on-farm irrigation water use picture. The Coastal Bend Groundwater Conservation District's focus is clearly on groundwater pumpage; therefore, conjunctive use (surface water and groundwater irrigation) may not be fully represented by the metered irrigation amounts. The Lower Colorado River Authority (LCRA) has taken efforts to improve upon irrigation efficiencies in their service area including land-leveling and canal-lining. TWDB and the Coastal Bend Groundwater Conservation District need to work together to determine if the surface water component of those farms with conjunctive use is being fully captured within the district's metered irrigation data.

As a result of the analysis in this report, in part, TWDB staff is considering revisions to the irrigation estimates process for the crop-year 2010. Proposed changes include calculation of on-farm estimates by crop and possibly adding an additional category, where applicable, to include any surface water delivery losses. This will allow TWDB and regional planners to account for those water losses by county without adjustments to the crop irrigation rates for individual crops. Thus, the resulting on-farm totals of individual crop estimates and overall county totals will be two different values, differing by the approximate amount of surface water delivery loss.[48] Individual crop estimates should then align closer with the district's metered values.

[48] While this water is labeled as "surface water delivery loss" it is important to acknowledge other beneficial uses of the water flowing downstream. Such benefits to the ecosystem include freshwater inflows that improve the health of the bays and estuaries, fisheries, and other wildlife habitat.

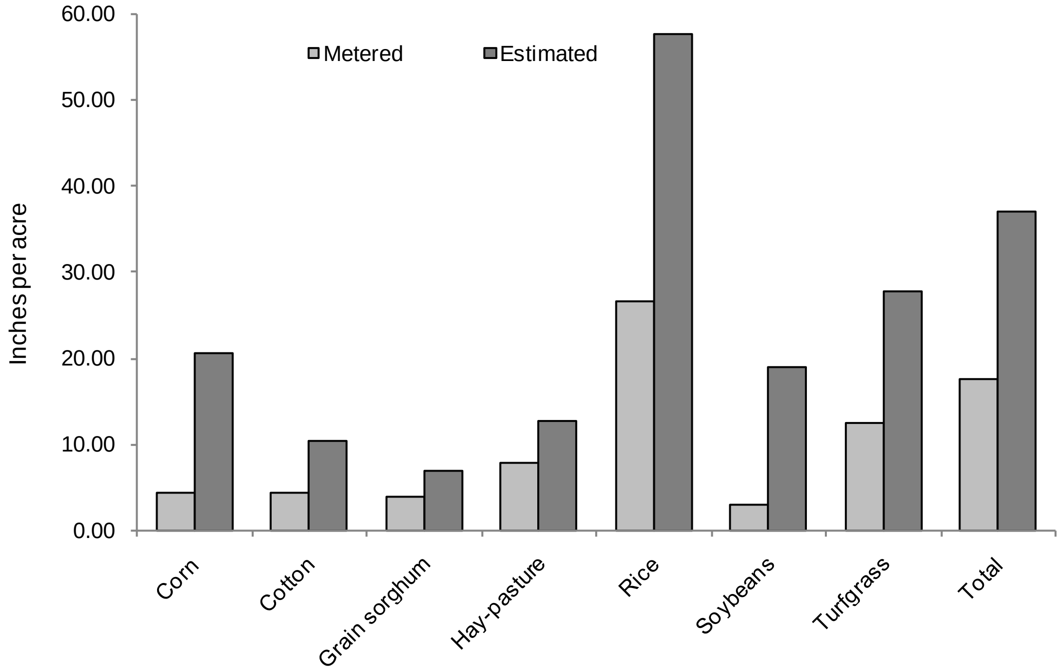
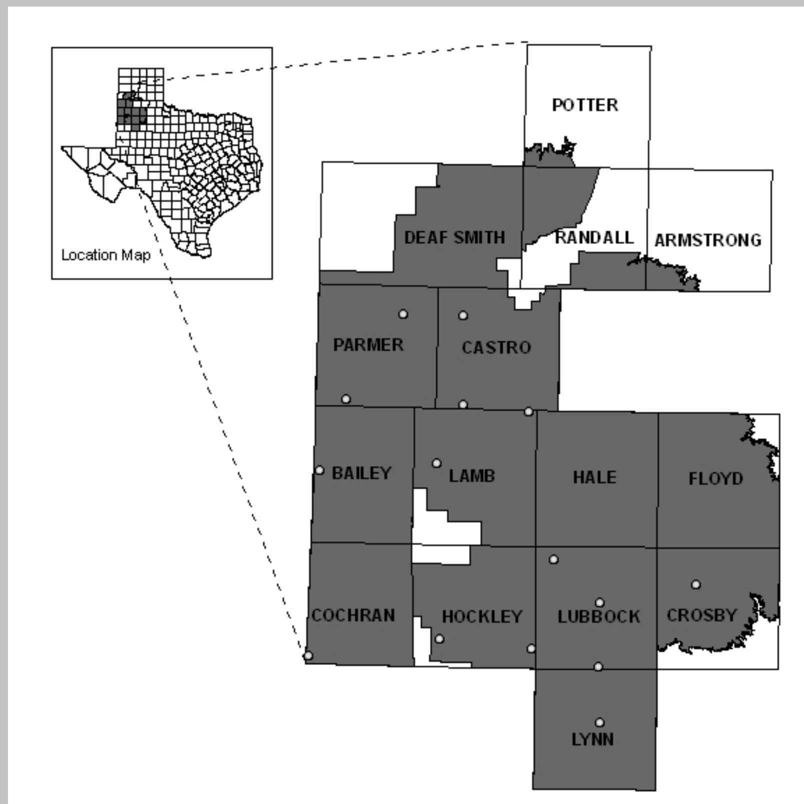


Figure 4-44. Metered and estimated irrigation for individual and all crops in the Coastal Bend district, 2006–2007.

4.11 High Plains Underground Water Conservation District #1



District at a Glance

Planning Regions: *Llano Estacado (O) and Panhandle (A)*

Eco-region: *High Plains*

2007 Gross Crop Income: *$1,011,450,000**

Soils: *Clay loam, Fine sandy loam, Silty clay loam, Loam, Loamy fine sand, Fine sand, Clay*

Climate: *Semi-arid*

Average Yearly Rainfall: *18 inches*

Crop Types:
Cotton
Corn
Grain Sorghum
Peanuts
Wheat

District Size: *6,931,616 acres*

Total Crop Land: *5,454,234 acres*

Irrigated Crop Land: *2,129,974 acres*

Irrigation Water Use: *3,282,861 acre-feet*[49]

Acres in TWDB Metering Program: *~ 2,200*

Number of Irrigation Wells in Groundwater Conservation District: *58,201*

Number of Meters in Program: *15*
** Indicates all county totals. Cochran, Floyd, and Lubbock counties gross crop income not disclosed by USDA-NASS, not included.*

Irrigation Methods:
Center Pivot
Sub-surface Drip
Furrow

The High Plains Underground Water Conservation District #1 joined the program in 2004. The district implemented a monitor plot concept, focusing on acquiring a representative sample with a few metered systems within each county. Annual data reports contained, for each metered system, a detailed report of crops grown, metered irrigation, well pumping rates, yields, and on-site rainfall totals for most systems. This provided a quality sampling of metered data for comparison with TWDB irrigation estimates for counties with data reported.[50]

The first year of data reporting was in 2006. Comparisons to estimates are made for 2006 and 2007. Cotton was the most represented in the data set, accounting for 20 of the total 27 reported values.

4.11.1 Irrigation water use data—individual crops

Corn

The district metered 3 corn systems in 2007 on a total of 480 acres. This represented only about one-tenth of a percent of the 368,969 irrigated corn acres within the district that year. The weighted average of the values were 3.74 inches less than TWDB weighted average estimate. Rainfall from the three related rain gages was significantly lower than the TWDB estimate (Table 4-45 and Figure 4-45). The individual metered values ranged from 17.00 to 19.34 with a standard deviation of 1.21.

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[49] The county-wide acreage and irrigation estimates for Potter and Armstrong counties are not included for comparison with High Plains Underground Water Conservation District #1 data because they were instead used for comparisons with the Panhandle Groundwater Conservation District's metered data as the majority of those two counties lie within the Panhandle Groundwater Conservation District's boundaries.

[50] The High Plains Underground Water Conservation District #1 did not report any data from Hale or Floyd counties as these are more closely monitored by Texas Tech University researchers in the Texas Alliance for Water Conservation project, funded by TWDB. More information available online at: http://www.depts.ttu.edu/TAWC/.

Table 4-45. Corn—weighted averages of metered data and estimates—High Plains district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
2007	3	480	368,969	0.1	18.01	21.75	3	6.60	14.35	24.61	36.10
Averages	3	480	368,969	0.1	18.01	21.75	3	6.60	14.35	24.61	36.10

All units in inches per acre unless otherwise noted.

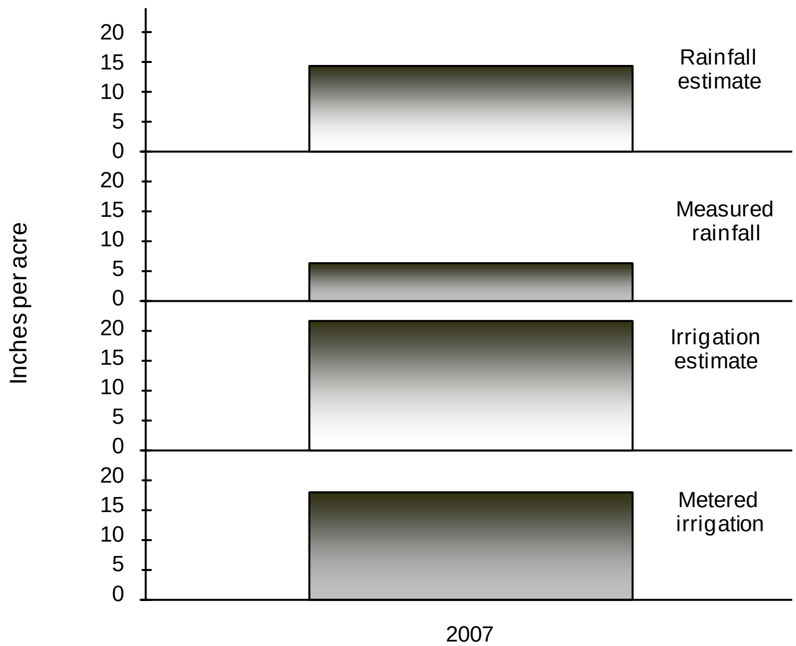


Figure 4-45. Corn metered and estimated irrigation for the High Plains district, 2007.

Cotton

The district metered an average of 10 values over the two-year period covering 1,307 acres representing around one-tenth of a percent of the 1,072,725 irrigated cotton acreage grown within the district. Metered values were both lower and higher than the estimates. Overall, the weighted average value was 11.17 with an estimated value of 13.03 (Table 4-46 and Figure 4-46). Metered values ranged from 3.28 to 20.96 with a standard deviation of 5.11. Cotton is often grown on a deficit irrigation basis in the High Plains district, so it is expected that the overall metered value would be lower than TWDB estimates, which more closely approximate potential evapotranspiration rates and maximum yields.

Rainfall was reported from 14 rain gages, averaging 8.88 inches, significantly less than TWDB estimate of 18.78. Reported rainfall totals are more representative of “effective rainfall” than annual totals.[51]

[51] Effective rainfall is rain that falls between the pre-plant / land preparation time period and harvest season. It is water that is available to the crop for uptake during the growing season.

Table 4-46. Cotton—weighted averages of metered data and estimates—High Plains district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
2006	11	1,503	1,248,745	0.1	14.74	10.03	5	7.50	17.78	22.24	27.81
2007	9	1,112	896,705	0.1	6.34	17.22	9	10.26	19.77	16.59	36.99
Averages	10	1,307	1,072,725	0.1	11.17	13.03	7	8.88	18.78	20.05	31.81

All units in inches per acre unless otherwise noted.

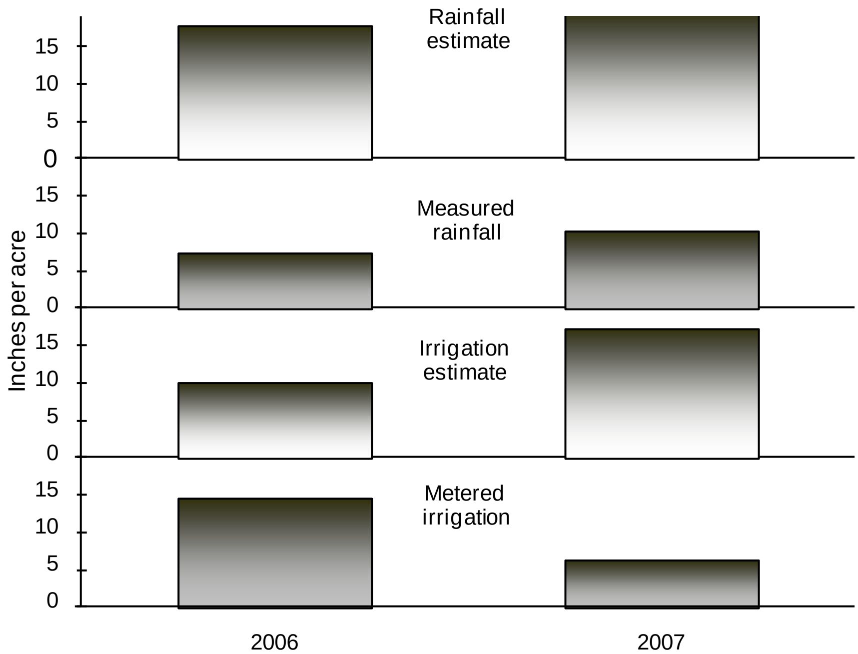


Figure 4-46. Cotton metered and estimated irrigation for the High Plains district, 2006–2007.

4.11.2 Irrigation water use—all crops

During the two years of 2006 and 2007, the district reported data on average of 14 usable metered systems. The aggregated weighted average metered value for all crops was 2.59 inches less than the aggregated estimate (Table 4-47 and Figure 4-47). The individual values ranged from 3.28 to 23.79 with a standard deviation of 5.72. Rainfall totals measured were significantly lower than the TWDB estimates.

Table 4-47. All crops—weighted averages of metered data and estimates—High Plains district.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
2006	13	2,253	1,982,345	0.1	14.14	11.81	7	8.01	16.95	22.15	28.76
2007	14	2,182	2,129,974	0.1	11.18	18.50	14	9.31	18.36	20.49	36.86
Averages	14	2,217	2,056,160	0.1	12.68	15.27	11	8.66	17.66	21.34	32.93

All units in inches per acre unless otherwise noted.

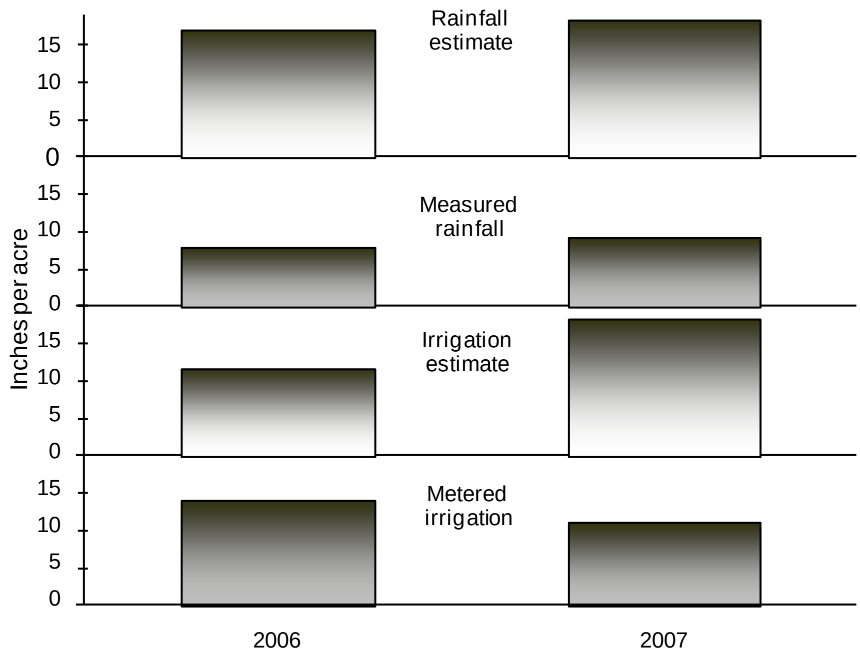


Figure 4-47. All crops metered and estimated irrigation for the High Plains district, 2006–2007.

4.11.3 Results and conclusions

Over the two years included for analysis, the High Plains Underground Water Conservation District #1 provided useful data of 27 metered values with 21 associated rainfall totals. Comparisons to estimates for cotton and corn were possible, but other crops were not well enough represented in the data set (Table 4-48). Additional focus to include metered systems on wheat would be beneficial, as it accounts for about 350,000 acres within the district annually.

Table 4-48. Two-year averages of metered and estimated acreages by crop type—High Plains district.

Crop	Meters	Metered acres	Estimated acres	Percent metered
Corn	3	240	281,410	0.1
Cotton	20	1,307	1,072,725	0.1
Grain sorghum	1	125	166,804	0.1
Mixed	2	375	na	na
Peanuts	1	170	15,212	1.1
Total	27	2,217	2,056,160	0.1

na = not available

Measured crop water use totals were less than estimated values with the exception of the one recorded value on grain sorghum (Figure 4-48). Much of the differences here can be attributed to differences in rainfall, as estimated rainfall values were consistently higher than measured rainfall totals. TWDB uses the nearest weather station data available to calculate annual rainfall totals. On-farm rain gage totals reported by the High Plains Underground Water Conservation District #1 may not be fully representative of annual totals, but instead ("effective") rainfall that was available to the crop during the growing season.

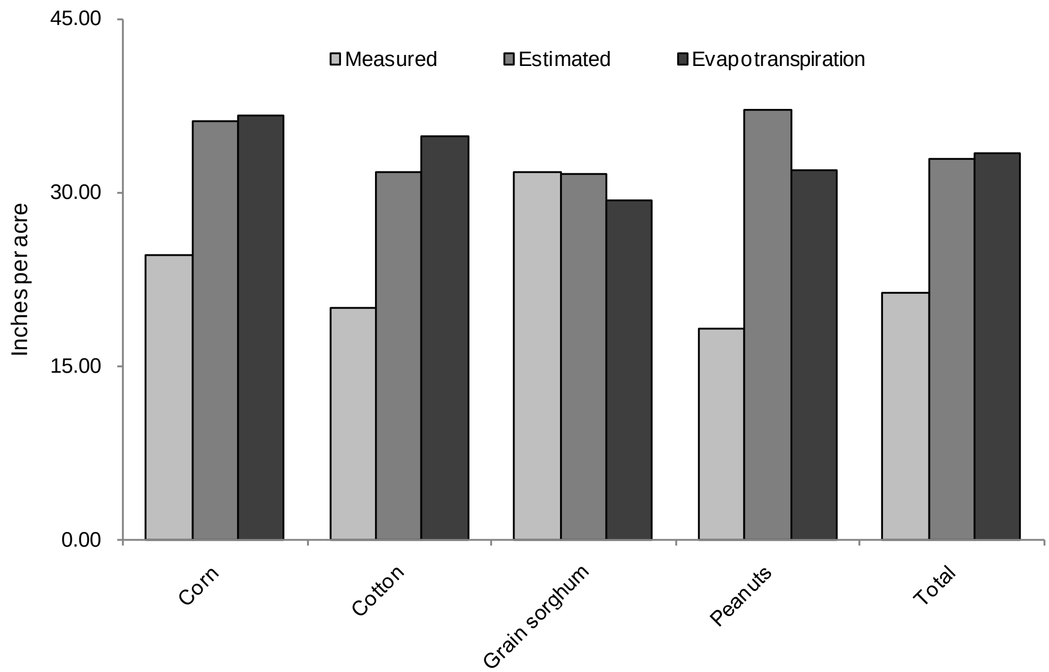
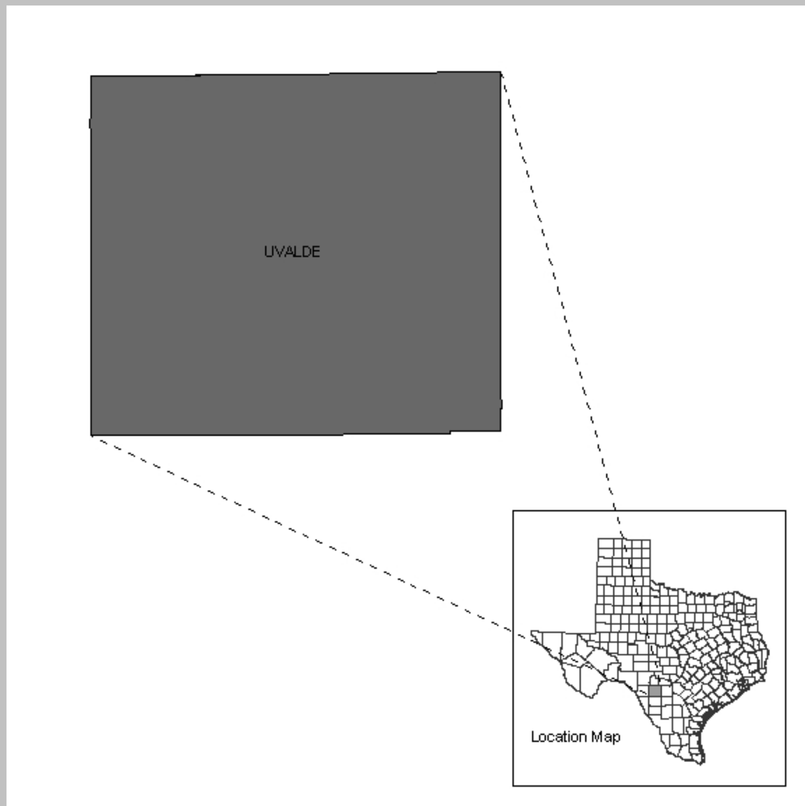


Figure 4-48. Total crop water use values—metered, estimated, and mean consumptive—for individual and all crops for the High Plains district 2006–2007.

The High Plains Underground Water Conservation District #1 participation in the voluntary irrigation metering program has produced only a limited data set. Yet the availability of those numbers for comparison with TWDB estimates is well needed. Irrigated agricultural operations make up the majority of the land use in this area of the state. With projected future water shortages in the region, the district will need to work closely with landowners, producers, researchers, planners, and policymakers to ensure adequate water supplies for citizens, businesses, and farmers of the Southern High Plains of Texas.

4.12 Uvalde County Underground Water Conservation District



District at a Glance

Planning Region: *South Central Texas (L)*

2007 Gross Crop Income: *$31,783,000*

Climate: *Sub-humid, Semi-arid*

Average Yearly Rainfall: *24 inches*

District Size: *997,180 acres*

Total Crop Lane: *131,420 acres*

Irrigated Crop Land: *53,616 acres*

Irrigation Water Use: *37,007 acre-feet*

Acres in TWDB Metering Program: *5,297 acres**

Number of Irrigation Wells in Groundwater Conservation District: *300*

Number of Meters in Program: 42
*District data from first year of reporting, 2008

Eco-region: *Edwards Plateau, South Texas Plains*

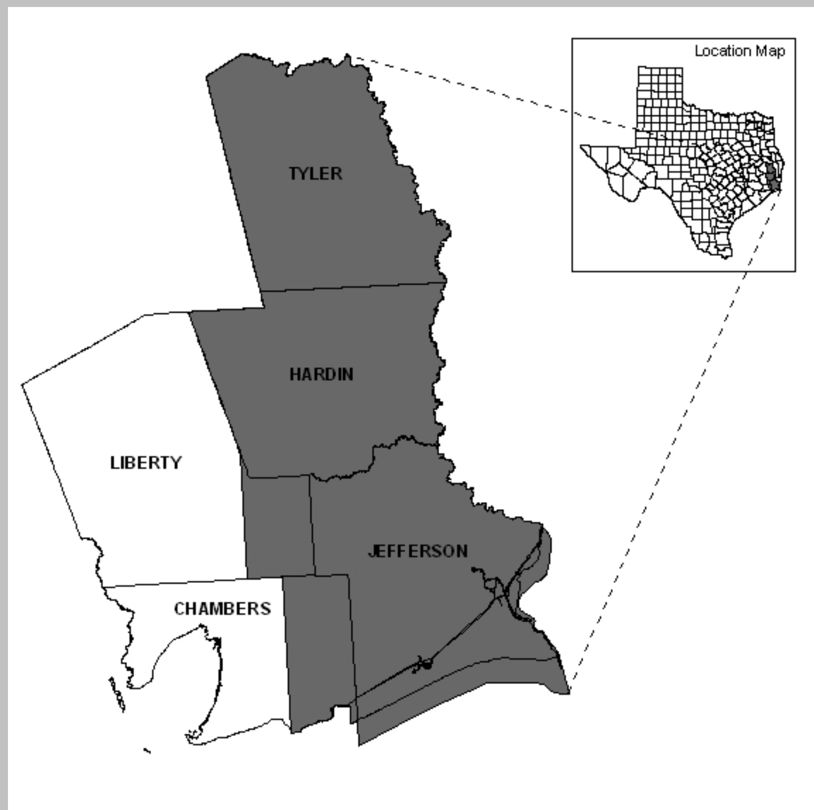
Soils: *Clay, Silty clay loam*

Crop Types: *Bermuda grass, Cabbage, Coastal bermuda, Corn, Cotton, Fescue grass, Grain sorghum, Green Beans, Haygrazer, Hay-pasture, Nursery plants, Oats, Onions, Pecans, Rye-grass, Vegetables**

Irrigation Methods: *Center pivot, Furrow, Linear-move, Side-roll, Surge-flow*

Uvalde County Underground Water Conservation District was added to the metering program in 2007. Their first year of data reporting was not until 2008. For that reason there is no data analysis included in this report.

4.13 Lower Neches Valley Authority



District at a Glance

Planning Regions: *East Texas (I) and Region H*

2007 Gross Crop Income: *$35,535,000*

Climate: *Humid*

Average Yearly Rainfall: *58 inches*

District Size: *2,122,889 acres*

Total Crop Land: *438,683 acres*

Irrigated Crop Land: *32,382 acres*

Irrigation Water Use: *204,089 acre-feet*

Acres in TWDB Metering Program: *2,257 acres*

Number of Irrigation Wells in Groundwater Conservation District: *N/A*
Number of Meters in Program: *24*

Eco-region: *Piney Woods, Gulf Prairies and Marshes*

Soils: *Clay, Very fine sandy Loam, Fine sandy loam, Silty loam, Clay loam, Loamy sand*

Crop Types: *Rice*

Irrigation Methods: *Border Flood*

The Lower Neches Valley Authority (LNVA) joined the TWDB voluntary irrigation metering program in 2005. The first year of data reporting was in 2006. This is the only year included for analysis. The district also reported metering data for 2007; however, all inches per acre values were less than 0.50 inches per acre. The authority confirmed that these numbers were correct and that 2007 was an extremely wet year resulting in many farmers requesting little or no water for irrigation purposes.

4.13.1 Irrigation water use data—individual crops

Rice

The Lower Neches Valley Authority data set contains 24 metered irrigation values on 2,257 acres, representing about 8 percent of the irrigated rice acreage within their five-county area. The weighted average metered irrigation was significantly lower than the TWDB estimate, 20.74 versus 77.54 inches (Table 4-49 and Figure 4-49). The individual metered values ranged from 2.32 to 50.14 with a standard deviation of 11.47.

Table 4-49. Rice—weighted averages of metered data and estimates—Lower Neches Valley Authority.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate
2006	24	2,257	28,001	8.1	20.74	77.54
Averages	24	2,257	28,001	8.1	20.74	77.54

All units in inches per acre unless otherwise noted.

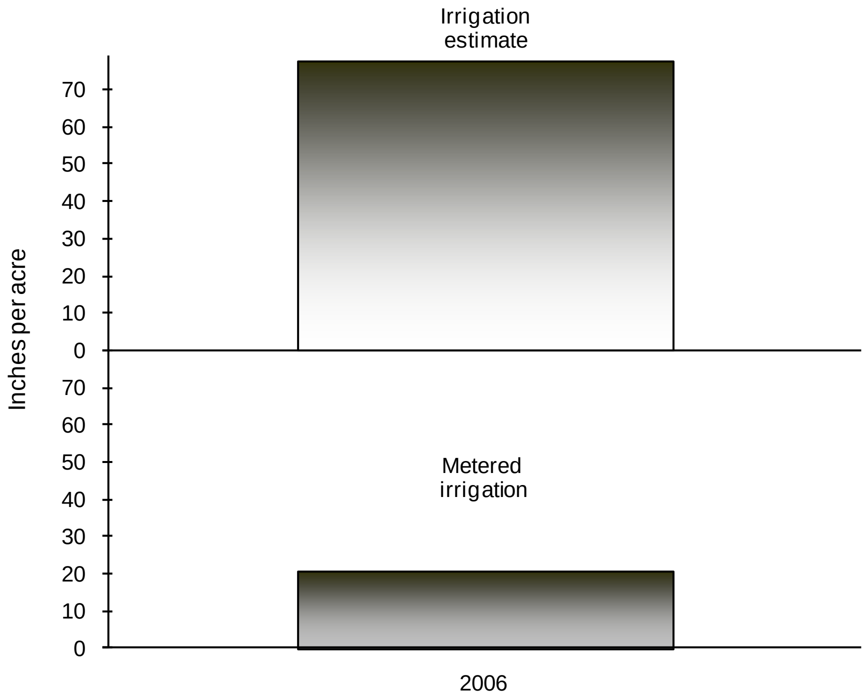


Figure 4-49. Rice metered and estimated irrigation for the Lower Neches Valley Authority, 2006.

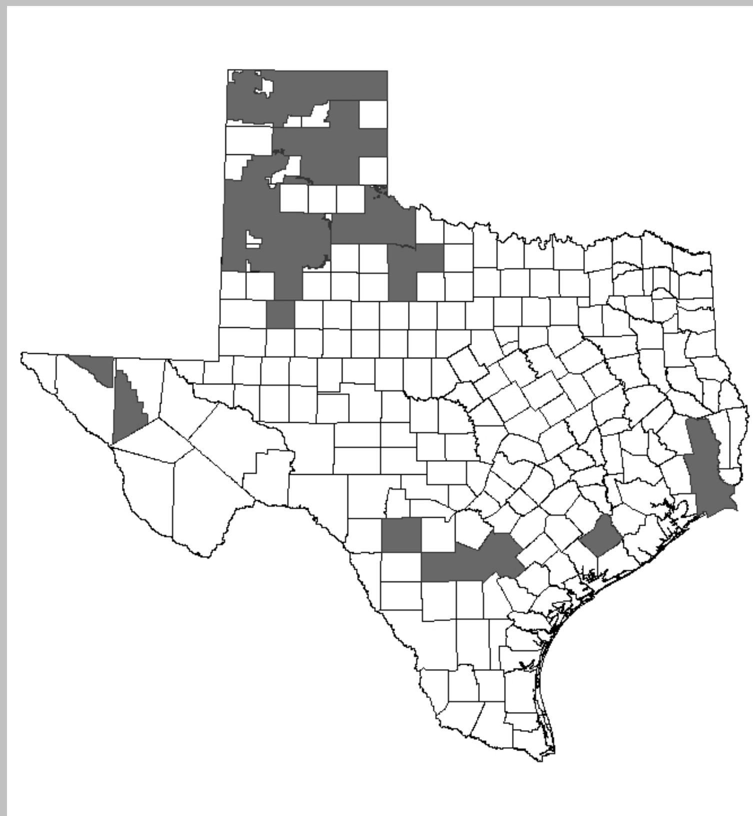
4.13.2 Irrigation water use —all crops

The Lower Neches Valley Authority provided metered data in 2006 for 24 rice fields and no other crops. TWDB estimates show an additional 2,036 acres of other irrigated crops grown within these five counties that year. Rice is the only major crop grown with supplemental irrigation water in the region. Many other crops are grown without the use of irrigation water as this region experiences the highest rainfall totals of anywhere in the state, around 56 inches per year.

4.13.3 Results and conclusions

The data set provides a representative sample of irrigated practices within this rice producing region of the state. Differences in metered values and TWDB estimates are a result of the TWDB surface water calculations, as was previously discussed in the Coastal Bend section of this report.

5.0 All Districts Conclusion



All Districts at a Glance

Planning Regions: *A, B, F, G, H, I, K, L, O, P*

2007 Gross Crop Income: *$2,270,914,000*

Climate: *Arid, Humid, Semi-arid, Sub-Humid*

Average Yearly Rainfall: *28 inches*

Eco-regions: *Gulf Prairies and Marshes, High Plains, Piney Woods, Post Oak Savannah, Rolling Plains, South Texas Plains*

Soils: *Clay, Clay loam, Fine sand, Fine sandy loam, Gravelly sandy loam, Loam, Loamy fine sand, Loamy sand, Sandy clay loam, Silty clay, Silty clay loam, Silty loam, Very fine sandy loam*

Crop Types:
Alfalfa, Aquaculture, Beans, Beets, Black-eyed peas, Cabbage, Corn, Cotton, Grain sorghum, Grapes, Haygrazer, Hay-pasture, Melons, Oats, Olives, Onions, Peanuts, Peppers, Potatoes, Pumpkins, Soybeans, Spinach, Sunflower, Rice,

Turfgrass, Waterfowl, Watermelon, Wheat

District Size: *28,196,342 acres*

Total Crop Land: *9,990,217 acres*

Irrigated Crop Land: *3,841,122 acres*

Irrigation Water Use: *5,551,544 acre-feet*

Acres in TWDB Metering Program: *80,129 acres*

Number of Irrigation Wells in Groundwater Conservation District: *75,919*

Irrigation Methods: *Border Flood, Center pivot, Furrow, Side-roll, Sub-surface drip*

Number of Meters in Program: *907*

The combined data set contained 2,218 usable data points of metered irrigation values from eight groundwater conservation districts–Panhandle, North Plains, Mesa, Hudspeth County, Gateway, Rolling Plains, Coastal Bend, and High Plains; and from the Lower Neches Valley Authority. Over the nine-year period, the metering program has grown in the number of participating entities and metered irrigated acreage. As of 2007, the metering data provided a sample of irrigation practices occurring within these entities boundaries which include more than 3.6 million acres of irrigated crop land (Table 5-1). TWDB estimated total irrigated acreage for the state was 5,861,548 for that year. Based on those numbers, the metering program has successfully grown to represent irrigation practices on roughly 62 percent of the irrigated acreage in the state. However, the data set is still a relatively small sample of that acreage.

Table 5-1. All crops—weighted averages of metered data and estimates—all districts.

Year	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
1999	43	7,939	199,430	4.0	11.13	10.70	33	14.31	23.48	25.43	34.18
2000	47	8,693	199,393	4.4	15.40	11.23	32	22.56	24.22	37.96	35.44
2001	131	23,320	230,931	10.1	12.56	15.15	57	15.48	19.66	28.04	34.81
2002	249	47,820	1,524,903	3.1	15.19	18.16	115	18.44	21.44	33.63	39.60
2003	264	51,074	1,478,324	3.5	12.32	17.82	175	15.69	14.52	28.01	32.33
2004	318	62,040	1,446,968	4.3	14.51	18.02	206	24.25	24.61	38.76	42.63
2005	327	61,430	1,494,121	4.1	12.30	19.08	189	13.78	13.57	26.09	32.65
2006	397	67,737	3,453,259	2.0	16.78	15.05	138	16.80	16.56	33.59	31.61
2007	442	79,826	3,638,462	2.2	17.74	18.45	366	21.03	19.38	38.76	37.83
Averages	246	45,542	1,518,421	3.0	14.83	17.24	146	18.04	19.72	32.87	36.96

All units in inches per acre unless otherwise noted.

The metered irrigation values covered a broad range, with a minimum of 1.00 inch per acre and a maximum of 74.60 inches per acre. As a reflection on this, the standard deviation across the data was 10.98. The program resulted in differences of 2.41 inches per acre between the metered and estimated irrigation weighted averages, 14.83 and

17.24 inches per acre, respectively. The overall nine-year averages of rainfall differed by 1.68 inches.

For individual districts the TWDB estimates were sometimes greater than and sometimes less than the district's metered irrigation for the individual crops data. When all districts were combined, however, the TWDB estimates were consistently higher than the metered weighted averages for the aggregated data set of individual crops with only a few exceptions (Figure 5-1).

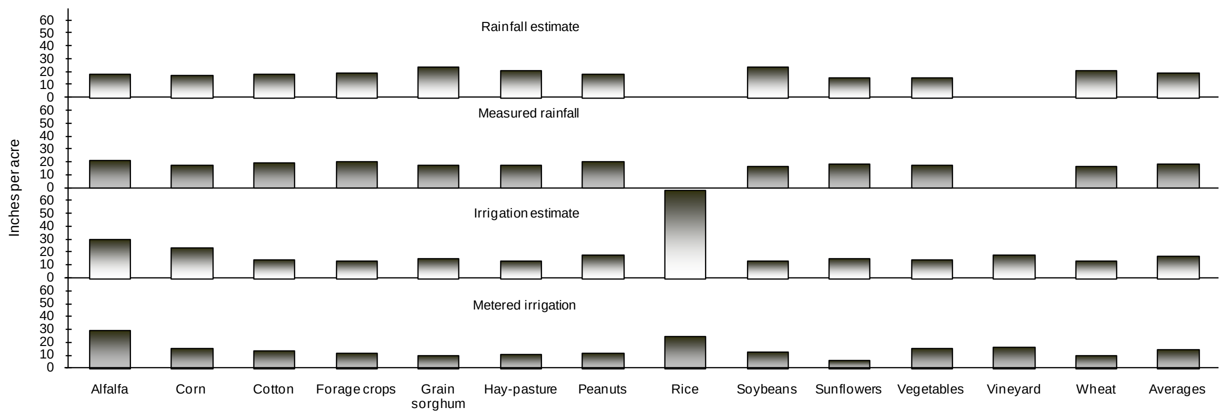


Figure 5-1. Metered and estimated irrigation and rainfall for all crops across all districts, 1999–2007.

Note: Mixed and other crop categories are not included here.

Analyzing the crop water usage on this statewide scale shows the estimates are greater than the metered values for the aggregated data set. The significant number of low metered irrigation values in the data set, however, brings the metered averages down. This presents some concern as to the accuracy of the readings for metered values. Districts must take the initiative to ensure meters are calibrated and properly operating. The TWDB has portable flow meters available to loan, at no cost, to the districts to compare with the readings of each meter. Some districts report they do regularly check meters and are confident they are all properly operating. The TWDB, however, has no way of verifying or enforcing the accuracy of meter readings.[52]

There were 595 metered irrigation values falling under mixed crop systems in the data set. Substantial efforts and cooperation between the districts and TWDB is required to address technology needs to separate this mix of crops into individual crop water use. Less than 2 percent of the districts' corn acreage and less than 1 percent of the wheat acreage was metered. The current sample size of the data set is too small to accurately represent the crop patterns and irrigation practices across these districts (Table 5-2).

[52] Beginning in 2010, TWDB added a new category to the annual request for agricultural water conservation grant applications. This category made funding available for groundwater conservation districts and other political subdivisions of the state to conduct irrigation system audits. One goal of these grants is to verify meter accuracy. Another goal is to identify ways that individual irrigators may be able to improve the efficiency of their irrigation system(s).

Table 5-2. Metered and estimated acreages by crop type—All districts.

Crop	Meters	Metered acres	Estimated acres	Percent of total	Metered irrigation	Irrigation estimate	Rain gages	Measured rainfall	Rainfall estimate	Measured crop water use	Estimated crop water use
Alfalfa	102	12,433	270,307	4.6	30.04	29.84	39	21.54	18.22	51.58	48.06
Corn	259	58,989	3,397,519	1.7	16.15	23.93	165	17.34	17.36	33.49	41.29
Cotton	574	72,212	3,181,432	2.3	14.19	14.31	386	19.78	18.26	33.96	32.56
Forage crops	63	9,135	231,590	3.9	12.19	13.89	36	20.26	19.07	32.45	32.96
Grain sorghum	51	8,726	917,414	1.0	10.12	14.91	24	17.89	24.30	28.01	39.21
Hay-pasture	54	12,900	284,676	4.5	11.00	13.86	26	17.89	20.87	28.88	34.73
Mixed	595	141,873	na	na	15.96	na	392	18.64	18.66	34.61	na
Other	174	33,640	na	na	10.13	na	99	16.61	21.41	26.74	na
Peanuts	93	11,570	317,257	3.6	12.30	18.41	46	20.82	18.07	33.12	36.48
Rice	61	9,335	112,126	8.3	25.20	68.11	0	na	na	na	na
Soybeans	37	6,735	164,998	4.1	12.63	13.69	6	16.53	23.59	29.17	37.28
Sunflowers	11	1,890	132,835	1.4	6.42	15.55	9	19.13	15.84	25.54	31.39
Vegetables	4	468	89,683	0.5	15.86	14.87	2	18.00	15.59	33.86	30.46
Vineyard	1	141	6,221	2.3	16.54	18.11	0	na	na	na	na
Wheat	139	29,832	4,166,395	0.7	9.95	13.08	81	17.08	20.68	27.03	33.75
Averages	148	27,325	1,020,958	2.7	14.83	17.24	87	18.58	19.38	33.41	36.62

na = not available; all units in inches per acre unless otherwise noted.

A more focused effort in metering corn, cotton, and wheat crops is needed to create a representative sample that can validate irrigation estimates. TWDB is currently working with industry experts and district personnel to explore ways to accomplish this. One of the agency's goals is to address the mixed-crop category, which makes up the largest number of metered values and acreage in the data set. Additional efforts by the districts to eliminate unknown crops from their data set could be another approach to achieving this goal.

The metering data are appropriate for determining the total acre-feet of irrigation water pumped for a typical irrigation system. In the High Plains, these systems are generally center pivots that irrigate fixed areas and could be planted to one or more crops. Since the irrigated acreages were reported by the participants, TWDB is able to calculate the seasonal metered water use by individual crops. To validate TWDB water use estimates with the empirical metered water use values, it is essential to expand the data set considerably in order to have enough samples to make it statistically valid. The success and usefulness of data from the program requires that TWDB is provided with accurate water use, acreage, crop information, and the name of the county where meters are located. TWDB is working to evaluate the existing agricultural weather networks and individual station sites in order to improve upon the source of county rainfall estimates and crop evapotranspiration calculations. Districts should also put an emphasis on validating measured rainfall totals and increasing the numbers of automatic rain gages connected to dataloggers. Without accurate local rainfall data, there can be no comparison to calculated crop evapotranspiration rates.

Goals and reasons for participating in the metering program differ by districts. Some require producers to install their meter and take their own meter readings; others take a different approach to their metering efforts, focusing on a smaller more representative sample within each county. This balances the need for a statistically valid sample with a workable and realistic size for data collection. Some groundwater conservation districts could be strained by the enormity of the data collection and data processing workload due to the large geographic distribution of the sites, insufficient personnel or funding, and lack of standardized procedures for data collection and management. TWDB allows flexibility in reporting deadlines with the districts, as many perform their own analysis of the data before reporting to TWDB. This time is crucial to eliminating inaccurate data from the data set and generating their producer reports.

Producer concerns about privacy issues may be a factor with respect to metering site selection, data collection and use, and expansion of the program. TWDB is committed to continually assess producer attitudes about metering to identify specific barriers to their acceptance of the program. TWDB is willing to conduct outreach with producer participants to provide better information on the objectives of the program and how the data is used.

6.0 Acknowledgments

The original vision, inspiration, and tenacity that were necessary to get a program of this magnitude started were provided by Bill Mullican of TWDB and C.E. Williams of the Panhandle Groundwater Conservation District. Much credit goes to Kraig Gallimore who managed and provided technical support for the program before retiring in 2005. Stacy Pandey provided significant technical support to the program in collecting and managing data and resolving issues. Matt Erickson provided technical support with TWDB's metering database. Comer Tuck provided guidance and oversight for the program.

Many thanks go to the producers who have voluntarily offered their operations, time, and effort to participate in the irrigation metering program. Much credit also goes to the staff of the participating groundwater conservation districts who helped launch and maintain their respective programs and have graciously worked with TWDB over the years to provide their data to us, especially C.E. Williams and Amy Crowell at the Panhandle Groundwater Conservation District and Harvey Everhart and Deanya Williams at the Mesa Underground Water Conservation District.

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8.0 Appendices

A. TWDB metering data collection and reporting worksheets

Texas Water Development Board
Irrigation Metering Program

The Irrigation Metering Program is a collaborative effort between irrigators, groundwater conservation districts or river authorities, and the TWDB to measure and record accurate water use data for irrigated agriculture. The attached one page worksheet is intended to provide an easy method for recording metering data and calculating annual inches per acre of irrigation water use. The worksheet should be completed at the end of the irrigation season or by December 31 of each year.

Why is metering important?

- Producers/irrigation managers need to know how much water is applied to a crop. Metering will help in implementing irrigation scheduling and conservation practices. Inches per acre calculations can be used to calculate energy costs on an acre inch basis.
- Groundwater conservation districts need measured water use to get better assessments of actual irrigation pumpage from the aquifer.
- The TWDB uses metered water use data to validate or improve annual county-level irrigation water use estimates and groundwater availability models. More accurate estimates of how much water is used by irrigated agriculture provides a more accurate historical record of use and benefits long range water planning.

Texas Water Development Board
Irrigation Metering Program
Data Collection and Reporting Worksheet

Crop Year ________________[53]

A. **FLOW METER**

Latitude: ______________________________ Longitude: ____________________________

Meter # (serial number)	Begin Register Reading	End Register Reading	Difference (End minus Begin)	Meter Multiplier[54] x 100 or x 1,000

Total Gallons = _____________________[55]

(if meter readings are in acre-feet complete following conversion)

Total Acre Feet	times	325,851	=	Total Gallons
_____________________	*	325,851	=	___________________

B. **CROP & IRRIGATED ACREAGE**[56]

Crop	Acreage

Total Crop Acreage = ____________________[57]

C. **CALCULATE INCHES PER ACRE**

Total Gallons	divided by	27,154	=	Acre Inches
___________	÷	27,154	=	________________
Acre Inches	divided by	Total Crop Acreage	=	Inches per Acre
___________	÷	_________________	=	________________

[53] The year that the crop was irrigated. Winter wheat should be included in the year it is to be harvested.
[54] Some irrigation flow meters (McCrometer for example) have either “00” or “000” just to the right of the readout.
[55] If more than one meter is used (for example, a system utilizing a meter on each of three irrigation wells - as opposed to a single meter on a center pivot drawing from three wells) then add together all of the “Total Gallons” calculation to get a “grand total” that will be used for calculating inches per acre.
[56] Whenever possible, use the same certified crop and acres information provided to the Farm Service Agency (FSA-578).
[57] Only the crop/acreage irrigated through this meter or system.

Name of district or authority:								Data Year:			
Meter number	**County**	**Latitude**	**Longitude**	**Irrigated crop acreage**	**Irrigated crop type**	**Total annual applied water volume**	**Units (in-ac, ac-ft, gal.)**	**Total annual applied inches per acre**	**Irrigation method***	**Measured annual rainfall total**	**Notes and comments**

Template Explanation and Instructions

Meter Number: Serial number for that meter
County: County in which the meter is located
Latitude/Longitude: Enter in degrees and carry out to three decimal places. Example: (Latitude: 30.279 Longitude: -97.739)
Irrigated Crop Acreage: The actual number of acres being irrigated with the system that is metered
Irrigated Crop Type: The crop that is irrigated with the system being metered. If multiple crops are irrigated, show all crops (ex. cotton/wheat)
Total Annual Applied Water Volume: The total amount of water applied on that crop for the year in gallons, acre-inches or acre feet.
1 acre inch = 27, 154 gallons
Inches per Acre = Acre Inches / Crop Acreage
* Irrigation System/Method (optional data, not required)
Pivot=P
Row=R
Drip=D
Side Roll=SR
Other=O (If other, indicate the type in the notes and comments column)
Please enter the name of the district or authority, the data year, and average annual rainfall on the worksheet
Provide a description of the source of rainfall data:

B. Methodology for calculating irrigation estimates.

Texas Water Development Board Irrigation Water Use Estimates

The Texas Water Development Board's (TWDB) irrigation water use estimates from 2003 – 2007 were developed by a different process than the previous annual estimates dating back to the year 1985. During the years from 1985 – 2002, TWDB annual irrigation estimates were made for the on-farm use of irrigation water and did not initially include any distribution losses which may occur in surface water delivery systems. Beginning in 2003, the availability of more comprehensive irrigated acreage data on a statewide basis and better access to surface water use reports available from the Texas Commission on Environmental Quality (TCEQ) led to a change in TWDB methodology for annual irrigation water use. Therefore, a comparison of TWDB irrigation water use estimates from 1985 – 2002 and subsequent years may not be valid in many instances where there are significant uses of surface water. The methodology used in creating the 2003 – 2007 irrigation water use estimates is summarized below:

Irrigated Acreage Data:

1. Comprehensive statewide USDA – Farm Service Agency records of irrigated crop acreage data are obtained and tabulated by county and aggregated into major crop types and serve as the primary source of irrigated acreage data.
2. USDA – Farm Service Agency data includes irrigated acreage identified as Failed Crop Acres. These acres are typically planted crops that receive some irrigation and then fail to reach harvest because of hail, insects, disease, drought, or flood. These irrigated crop acreages are subtracted from the initial total irrigated acreage for that crop and utilized as a special crop type of Failed Acres. Different irrigation water use rates reflective of partial season irrigation are assigned for the aggregated failed crop acres.
3. Some crop types and some counties may not be adequately covered by the USDA – Farm Service Agency acreage data base. In some instances, Texas Agricultural Statistics data, Texas Commission on Environmental Quality data, and local contacts provide information for specific (unique) irrigated crop acreage data.
4. Although it is not agricultural irrigation, many golf courses are self supplied from private groundwater or surface water sources. These uses are not included in the TWDB Municipal Water Use Survey and are actually classified as irrigation use in the Texas Commission on Environmental Quality surface water permit system. Therefore, to the extent possible, these types of golf courses are included in the irrigation use estimates.

Water Use Estimate Process:

1. The TWDB methodology for calculating irrigation water use estimates from 2003 – 2007 in each county begins by using a crop water use based on available weather data and an Evapotranspiration (ET) methodology.
2. After incorporation of responses from local groundwater conservation districts and inclusion of surface water use reports, revised crop water use estimates are developed as appropriate.

3. The annual estimates of irrigation water use are developed to include data for actual conditions as affected by rainfall, availability of groundwater and surface water supplies, and irrigated cropping patterns. This provides a variation from year to year.
4. The value of permitted water use by groundwater conservation districts and the Texas Commission on Environmental Quality surface water rights represent a maximum irrigation use and are not directly utilized in the estimates of annual irrigation water use.

Groundwater Use:

1. Preliminary irrigation county crop/water use data sheets are provided to all known groundwater conservation districts in the state and various other interested entities.
2. TWDB makes numerous revisions to crop water use rates and some acreage data based on responses from the groundwater conservation districts.
3. Available supply of groundwater, rainfall, and the need for irrigation water can make the annual estimates vary widely from year to year.

Surface Water Use:

1. TWDB's irrigation estimates utilizes the annual surface water use reports provided to the Texas Commission on Environmental Quality. Therefore, as utilized, these data already include any transmission and distribution losses that were not included in the On-Farm estimates developed in previous years.
2. The Texas Commission on Environmental Quality Austin Office provides extensive data files for permits not located in a Water Master area, including permit holder information and monthly data. These files are condensed by TWDB into the annual total of diversion use by individual permits in each county and then totaled for each county.
3. There are four locations of offices for the Texas Commission on Environmental Quality Watermaster data files: Concho River, Lower Rio Grande Valley, Middle Rio Grande, and South Texas.
4. When applicable, the Texas Commission on Environmental Quality reported data is reviewed and adjusted to move/transfer some reported use from permit location downstream to where water is actually used (a release from a reservoir for a downstream irrigation district for example).
5. Available surface water supply, rainfall, and need for irrigation water can make the annual reports vary widely from year to year.

Wastewater Use:

1. If wastewater use is included in the Texas Commission on Environmental Quality surface water use report files, it is included as surface water use and an attempt is made to note this on the worksheets.
2. In some instances, TWDB staff is aware that wastewater from a "No Discharge" permit is utilized for irrigated crop production, but is not included in the Texas Commission on Environmental Quality surface water use reports. TWDB staff

separate the total county irrigation water use by source (groundwater, surface water, and wastewater).

C. Crop-evapotranspiration rates

Crop	North Plains Dumas	Childress	High Plains Hereford	Panhandle Average*	Mesa Brownfield	Rolling Plains Guthrie	Gateway Childress	All districts
Alfalfa	59.30	61.40		59.60	63.00	61.70	61.40	61.07
Corn	37.68	33.14	36.68	35.83	36.44	34.72	33.14	35.38
Cotton		33.96	34.86	34.41	36.19	35.42	33.96	34.80
Peanuts		33.18	31.96	32.57	34.09	34.59	33.18	33.26
Sorghum	29.78	32.45	29.31	30.51	32.34	33.35	32.45	31.46
Soybeans	31.34		30.38	30.86	29.97			30.64
Wheat	36.70	33.64	37.33	35.89	39.44	35.55	33.64	36.03
All crops	38.96	37.96	33.42	37.10	38.78	39.22	37.96	37.52

(Borrelli and others, 1998)

Note: Panhandle alfalfa figure calculated by adding monthly evapotranspiration values from maps for Donley County. All other crop evapotranspiration rates for the Panhandle district were calculated by averaging values from Hereford, Dumas, and Childress stations as there are no stations located within the boundaries of the Panhandle district.