Senate Bill 2 – Region A Task 3 Memorandum on Water Supply Analysis

Final Task 3 Water Planning Report

prepared by

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Executive Summary

In 1998, the Agricultural Water Conservation Program of the Texas Water Development Board (TWDB) entered into a long-term water metering and reporting contract with several Texas Panhandle groundwater conservation districts to obtain irrigation pumping records from selected wells on a routine basis. The purpose of this effort was the assessment of hydrologic impacts by the agency and to provide well data as it relates to current water planning efforts. It was also hoped that an assessment of the water pumped by crop could also be calculated later from the well metering records.

Analysis of the water meter datasets from three years of records from two groundwater districts indicated a disparity in reporting format, data continuity, and sufficient readings which made it difficult to assign well records to specific acreages and to determine the water applied per crop. These variations limited the original intent of the project analysis particularly from a statistical viewpoint and more so in the earlier years of the records. Using the limited assignable data, comparisons with the theoretical crop water use values modeled by the Texas A&M-Amarillo (TAMA) model indicated general overall agreement. Thus, no changes in established theoretical values are recommended from these metered data sets at this time. Consequently, as good agreement was made to the theoretical values, no changes to the regional GAM model are warranted at this time.

Conclusions reached from the rainfall analysis indicate a lack of temporal rainfall data associated with the individual meter recordings in the datasets. Very little rainfall data collected could be compared with the respective crop growing seasons to indicate definitive trends in water use which could be supported. Furthermore, influences other than gross rainfall was known to occur some years (ag. energy costs), affecting the amount of irrigation that producers could afford to apply to field crops.

Several problems related to the temporal recordings of the meter data have been identified. These temporal problems, as provided to the water team, limited both interpretation and extrapolation of the data for addressing the objectives of the study. The water team was late in the evaluation of the data phase for this study and as a result there was not sufficient time nor opportunity to make the necessary corrections to improve the data collection, interpretation and extrapolation. It should be indicated that significant differences exist in the datasets gathered from the two groundwater districts.

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It is recognized from the data reviewed that the Panhandle Groundwater Conservation District is dedicated to the metering effort and this commitment is reflected in the improvement and evolving completeness of their respective database. The North Plains Groundwater Conservation District has, since this program was initiated, amended their Rules to require ALL water users to report total water production from each property (section or pooled unit) within the district beginning in 2006 and report the production by January 30, 2007 and report previous year production by January 30th each year thereafter. Because of the staff requirements related to this Rule change, the district has not been as committed to the data interpretation required by this project.

It is recommended that identified improvements in the computerized record keeping program be implemented. Furthermore, it is recommended that additional financial support be provided to the groundwater districts to implement recommendations discussed in this report regarding meter and rainfall monitoring operations, partitioning, crop acreages and types and data format standardization which will require additional personnel and travel resources. If these investments are not made, the well metering program will not achieve its potential. However, 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.

Background

In 1998, in the Senate Bill 1 (SB1) planning effort, the water team located at the Texas A&M University System's Agricultural Research and Extension Center at Amarillo, Texas developed a new irrigation demand model (TAMA) that provided improved estimates for Region A as compared to the previous survey method used. It was estimated that the agricultural sector utilized 92 percent of all water use in Region A. Irrigated crop use accounted for 89 percent of the total, while livestock production used three percent. The magnitude of water use in agriculture makes the accurate water use assessment of this sector critical for future water planning within Region A. Under Senate Bill 2 (SB2), these estimates were revised (reduced) in several Panhandle counties and were adjusted for probable and realistic trends in irrigation practices, adoption rates, and technological advances. In addition, anticipated livestock increases over time were deducted from the available irrigation capacities.

According to Sanger (2005), "As Texas faces challenges in meeting the water needs of its growing population, water regulators and water users are exploring every available tool to efficiently manage and conserve water." One method of measuring this finite resource of water is through the Agricultural Water Conservation Program developed by the Texas Water Development Board (TWDB). Political subdivisions such as a groundwater district were awarded grants to purchase and install water meters with the requirement that water use would be monitored for ten years. One objective of the program is to utilize the data improvements in regional and statewide water planning efforts.

Political subdivisions such as the North Plains Groundwater Conservation District have also developed a list of approved water meter manufactures. Many water managers also require the water meter to be calibrated to meet the American Water Works Association's accuracy for actual flow (Sanger, 2005). Maintenance of water meters is a key element in assuring that valid data is being gathered. In addition, a metering program is only as effective as the accurate and representative data that is collected. This requirement indicates that a verification program may be required to be implemented for quality assurance and quality control purposes along with other logical operational pattern and application assessments, if feasible, and beneficial use of the data is to be realized.

Objectives

The overall objective of this analysis was to improve water supply estimates for Region A, if possible, from the recorded data collected in the well metering program conducted by the water districts. The specific objectives of this study were to:

1. Compare actual water use to theoretical demands developed for the Panhandle Region A.
2. Identify metered water used by irrigation system, crop, and soil type.

3. Evaluate precipitation records with metered pumping use and assess the changes in pumping as rainfall changes.
4. Adjust theoretical demands as indicated by the evaluation of the real-time data, if warranted.
5. Extrapolate findings throughout the region to generate irrigation production input to the Ogallala GAM model to assess groundwater availability.
6. Identify potential problems in data and data collection to sustain the use of the data from the on-going metering program. Prepare a task memorandum describing the findings of this study and recommendations for development of future irrigation water needs.

This analysis does not address the hydrological aspects of the recorded data which is to be evaluated by the TWDB personnel. This analysis of the metering program dealt with only the temporal pumping aspects of the effort.

Methodology, Analysis, and Results

Well metering databases were obtained from the North Plains Groundwater Conservation District of Dumas and the Panhandle Groundwater Conservation District headquartered in Panhandle located in Region A. The meter data sets were analyzed as a unit with no particular unit singled out in the analysis. Several Texas A&M project staff personnel were used during the effort to sort, manipulate and interpret the metered records. Some assistance with metering personnel of both water districts was conducted and appreciated. Difficulties were generally experienced in the analysis of metered records regarding continuity and integrity of the data in attempting to assess water application and utilization. Application and utilization in this report are defined as that being attributable to a particular irrigation system, acreage and crop during the appropriate crop growing season. This accounting was required for comparisons with the data requirements of the TAMU-Amarillo model (Marek et al., 2000), hereafter referred to as the TAMA model, used in projecting irrigation demand in Region A and subsequently in the GAM model.

Comparison of discernable and attributable metered data against the theoretical demands computed by the recently developed, evapotranspiration (ET) based irrigation model for Region A was done. The model computes county water use based on crop categories and their respective growing seasons. The eight major crop categories used were corn, cotton, hay, pasture and other grasses, peanuts, sorghum, soybeans, and wheat. The number of months for a crop season was as follows: four months for corn, five months for cotton, seven months for hay, and pasture and other grasses, six months for peanuts, five months for sorghum, five months for soybeans, and 8.5 months for wheat. The specific timelines for the growing seasons can be found in Table A-4. The TAMA model, for the specific years of comparison contained evapotranspiration (ET) demand data, Farm Service Agency (FSA) acreages and quadrangle or North Plains Evapotranspiration network (NPET) (Elliott et al., 2000) rainfall as recorded and proportioned throughout the respective Region A counties. The years of metered data for study comparison (the earlier years of the metering program) were selected to coincide with the partitioned crop acreages available from the FSA used in the TAMA model. Seasonal crop water use data from the meter readings were needed to compare against the temporal periods of the respective crops used in the TAMA model.

While some meter records were straightforward, many challenges were realized in analyzing the datasets. Unusually high, sometimes unrealistic, water application values were often derived from the data, both temporally and for seasonal values. These values were discarded from consideration. Many temporal problems were noted from the records resulting from either non-readings, reading errors or problems due to possibly meter drag, stoppage or other mechanical malfunctions. A typical example (not exhibited) demonstrating such missing data was no water being pumped for several months on crops known to be water sensitive during the time period and then unrealistic amounts being recorded for the next reading. These types of omissions were obvious to detect, as the associated hydraulic conductivities and horsepower requirements were unrealistic, if the readings were assumed valid.

Another type example classified as an ”error” was when a particular reading from one well recorded in the dataset indicated water from the well was used to irrigate corn, wheat and hay with designated percentages, respectively, of the total water pumped being allocated to those crops. Total water applied for the crop group from the well records was 8.40 inches over a June to December period, which is appreciably low for any one of the crops individually for this time period, much less for the group. Lack of application level per crop renders the data virtually unattributable due to the unknown degree (percentage of ET) of producer irrigated practice of applying reduced quantities (i.e. irrigation) per crop and is compounded by the known fact that the water use requirement curve (crop ET) in the region of each of these crops varies seasonally and overlaps for the group. No feasible partitioning of the water pumped per crop could be determined from many of these type designated acreages within the records from both databases. Although recognized in field practice, a classification of “mixed” crops could not be attributed accordingly for comparison purposes with the theoretical model. Other unrealistically low meter values were also observed throughout the database records in that seasonal application through center pivot irrigation systems were unusually small, suggesting that the well (and associated readings) was either part of a non-metered well system or identified only as part of a system attributable to manifolded wells for irrigation within a field, whether by surface or center pivot. Furthermore, meter readings that were designated between crops had inadequate, discernable recorded readings with respect to partitioning of water applied per crop per acreage per unit time. This missing information is required for a valid and representative comparison of water pumped with respect to the various crops in the TAMA model, which was a major objective of the analysis.

An example of an attributable meter record that was comparable to a theoretical crop irrigation value must include a similar meter record to that of a crop’s growing season as defined in Table A-4. For instance, grain sorghum had a specified growing of May 15 through October 15. If the meter record had irrigation meter readings that were designated solely to grain sorghum for a similar period of May through October and the acreage of that record was designated for that same time period, the record was assessed as being attributable and subsequently included for comparison purposes. However, if a wheat crop was irrigated during the later part of the grain sorghum season (September and October), the meter record was determined non-attributable because the amount of irrigation of the respective grain sorghum and wheat crops could not be partitioned accordingly. In this case, both the grain sorghum and wheat associated meter reading records were not considered for comparison. Similarly, wheat that was watered early in a corn growing season would not be included as it could not be partitioned either accordingly.

Explicitly, the example below illustrates an attributable metering record that appears reasonable with regards to crop production (the county designation is not displayed for identification purposes regarding the example):

Year	**County**	**Crop**	**Irrigated Crop Acreage**	**Irrigation, acre-inches**	**Irrigation applied in/ac**
2000	XXXX	milo	41	671	16.37

The following reduced records illustrate unattributable metering records that were determined inappropriate for comparison purposes and not included in the analysis:

Year	**County**	**Crop**	**Irrigated Crop Acreage**	**Irrigation, acre-inches**	**Irrigation applied in/ac**
2000	XXXX	soybeans and sunflowers	?	4,677	?
2000	XXXX	Peanuts & Cotton& Wheat	60ac 60ac 60ac	6,804	? each crop
2001	XXXX	Corn	514	70,660	137.5
2001	XXXX	unknown	125	2,338	18.71
2002	XXXX	Peanuts	125	748	5.98

In year 2000, there was virtually no designated or attributed crop acreage in the metered records and this lack of required data accounts for the singular value in Tables 4 and 7.

For a truly one-to-one comparison with the theoretical values of the TAMA model and again considering the previous grain sorghum example, the rainfall that occurred during the grain sorghum season associated with meter readings was needed. In the TAMA computations, rainfall intensity was also considered and effective rainfall estimated. This rainfall data was not correspondingly available in the meter record datasets for the respective crops and seasons, as analyzed. This implies that a TAMA crop irrigation value per acre (as reduced by the effective rainfall and seasonal soil moisture use over the growing season) was being compared to the metered crop irrigation value per acre (as affected by site rainfall and a seasonal soil moisture quantity). As a result, a comparison using only the limited, attributable irrigation values per acre per crop per county was conducted. During the analysis, it became apparent that there was a significant amount of the counties that did not have attributable meter readings and these represented a large portion of the region's irrigated area, it was determined that the objective of comparison was not going to be adequately completed and representative on a regional basis. It should be noted that once this recognition occurred not every record may have been included in the analysis, although a consummate attempt by the analysis team was made to include as many of the records as logically possible.

Objective 1: Compare actual water use to theoretical demands developed for the Panhandle Region A.

The overall theoretical irrigation demand estimates per county for year 2000 computed using the TAMA irrigation demand model are presented in Table 1. Table 1 was computed with year 2000 FSA acreage data, 2000 ET values proportioned on a county basis obtained from North Plains Evapotranspiration (NPET) network and rainfall. Similarly, Tables 2 and 3 include the annualized county crop water use values for years 2001 and 2002. Generally, these are the years utilized for comparison against the well meter records within this report. The tables include an average irrigated crop water use per county and average Region A value per crop. (The total Region A county water use figures for year 2000 in this report differ slightly from those previously provided in the Senate Bill 2 revision report due to the fact that the wheat acreages as provided by the FSA for the year 2000 in this analysis do not include graze-out wheat (non-harvested but irrigated) in the wheat category.) The years of 2001 and 2002 were similarly void of the FSA graze-out wheat acreages in the computations. The choice was made to use these provided values for consistency across years of the study. The estimated annual total irrigation demands per county are included in the appendix (Tables A-1 through A-3).

It is recognized that rainfall throughout a given region is generally highly variable. Originally, several sources of rainfall data were considered for use in the theoretical analysis. Since the TAMA model specifically uses effective rainfall along with soil moisture as an offset to compute the amount of irrigation demand, the use of the rainfall values against irrigation demand is correlated accordingly. These comparisons within the model are predominantly predetermined with the only variations being the computed annual ET demand and rainfall variation. Use of quadrangle rainfall data for the study period were considered as it provides a more average representation within the counties and the region, but in this objective a more site-specific type evaluation was needed than that provided from a quadrangle basis. Thus, the NPET rainfall dataset was used in the TAMA model runs.

The well meter records reviewed yielded the number of wells that could be attributable to a specific crop category per season and given year. Tables 4 through 6 include the number of metered wells that potentially could provide reasonable production levels considering rainfall and nominal soil moisture levels and production season for a given crop within the region. The number of attributable records increased as with the years of operation in the metering program.

The seasonal crop water use values that were derived (measured) from the metering datasets are included in Tables 7 through 9. While limited, an illustration of the crop comparison of water applied is presented in Figure 1. From the visual comparison, the data reflects that the metered values generally agree with the theoretical values for the major production crops within the region. The county differences between the theoretical and attributable metered values per crop are included in Tables 10 and 12. The average, actual differences regarding the respective crops is plotted in Figure 2.

Region A Counties	Corn	Cotton	Hay	Pasture & Other	Peanut	Sorg.	Soyb.	Wheat	Avg.
Armstrong	19.29	-	-	-	-	10.58	25.12	8.92	15.98
Carson	17.82	15.59	30.83	29.83	-	10.28	18.11	9.05	18.79
Childress	-	15.59	30.83	29.83	31.83	10.28	-	9.05	21.24
Collingsworth	19.29	13.54	-	37.70	23.71	10.58	-	5.06	18.31
Dallam	19.34	20.35	36.72	35.72	-	16.62	23.64	15.23	23.94
Donley	17.36	12.44	32.36	31.36	25.09	8.99	13.68	7.04	18.54
Gray	18.23	15.12	31.03	30.03	-	10.38	17.52	8.05	18.62
Hall	-	15.04	33.28	32.28	28.35	11.54	-	11.40	21.98
Hansford	24.93	-	38.77	37.77	-	14.75	23.12	15.65	25.83
Hartley	23.82	21.07	38.26	37.26	-	16.36	24.36	14.78	25.13
Hemphill	-	-	31.41	-	-	10.52	-	6.05	15.99
Hutchinson	25.32	-	39.35	38.35	-	13.03	20.18	16.02	25.38
Lipscomb	19.09	-	31.48	30.48	-	10.55	16.07	4.69	18.73
Moore	26.77	20.94	36.70	35.70	-	15.74	24.37	13.39	24.80
Ochiltree	23.98	-	36.88	35.88	-	14.33	21.85	16.15	24.84
Oldham	-	22.75	-	43.47	-	17.12	-	16.73	25.02
Potter	27.31	22.75	44.47	43.47	-	17.12	25.83	16.73	28.24
Randall	27.31	22.75	44.47	43.47	-	17.12	25.83	16.73	28.24
Roberts	22.49	-	35.98	34.98	-	13.16	21.35	13.32	23.55
Sherman	25.39	21.71	42.18	41.18	-	16.62	25.10	16.11	26.90
Wheeler	17.99	15.41	30.91	29.91	31.28	10.32	17.87	8.65	20.29
Average	22.10	18.22	35.88	35.72	28.05	13.14	21.50	11.85	-

Table 1. Year 2000 Region A county theoretical crop water use values, inches.

Region A Counties	Corn	Cotton	Hay	Pasture & Other	Peanut	Sorgh.	Soyb.	Wheat	Avg.
Armstrong	17.27	14.92	39.25	-	-	5.93	6.79	9.33	15.58
Carson	17.80	14.07	35.66	34.66	-	7.30	6.85	5.08	17.35
Childress	-	14.07	35.66	34.66	15.08	7.30	6.85	5.08	16.96
Collingsworth	20.76	11.87	38.83	-	16.45	8.31	-	7.60	17.30
Dallam	23.93	17.17	38.79	37.79	-	12.48	12.32	12.56	22.15
Donley	-	14.46	38.61	37.61	17.28	10.09	9.80	8.54	19.48
Gray	18.51	-	36.44	35.44	-	7.56	7.39	5.70	18.51
Hall	-	13.33	39.14	38.14	17.01	8.91	-	8.44	20.83
Hansford	20.94	-	38.81	37.81	-	8.85	9.18	13.25	21.47
Hartley	21.79	16.68	38.25	37.25	-	10.69	10.71	14.09	21.35
Hemphill	-	-	38.02	-	-	8.06	8.48	8.12	15.67
Hutchinson	19.65	-	36.77	35.77	-	7.75	7.86	13.74	20.26
Lipscomb	20.31	-	38.34	37.34	-	8.16	8.70	7.22	20.01
Moore	18.86	14.75	35.06	34.06	-	8.24	8.39	11.67	18.72
Ochiltree	22.23	-	40.89	39.89	-	9.97	10.53	9.05	22.09
Oldham	-	19.65	-	42.71	-	12.17	-	12.63	21.79
Potter	23.67	19.65	43.71	-	-	12.17	12.27	12.63	20.68
Randall	23.67	19.65	43.71	42.71	-	12.17	-	12.63	25.76
Roberts	19.85	-	-	36.73	-	8.32	8.38	8.74	16.40
Sherman	22.92	18.06	41.30	40.30	-	11.31	11.36	12.90	22.59
Wheeler	-	13.87	35.96	-	15.21	7.41	7.06	5.32	14.14
Average	20.81	15.87	38.59	37.68	16.21	9.20	9.00	9.73	-

Table 2. Year 2001 Region A county theoretical crop water use values, inches.

Region A Counties	Corn	Cotton	Hay	Pasture & Other	Peanut	Sorgh.	Soyb.	Wheat	Avg.
Armstrong	16.94	10.02	33.04	-	-	10.64	9.69	15.62	15.99
Carson	15.70	5.74	22.22	21.22	-	6.47	5.39	15.38	13.16
Childress	-	5.74	-	21.22	15.78	6.47	-	15.38	12.92
Collingsworth	-	9.56	27.28	26.28	16.29	9.96	-	13.07	17.08
Dallam	26.31	-	37.25	36.25	-	15.21	13.19	21.77	25.00
Donley	18.90	10.20	34.44	33.44	18.44	10.66	10.12	14.84	18.88
Gray	16.04	6.68	23.48	22.48	-	7.33	6.18	14.81	13.86
Hall	-	10.99	29.57	28.57	18.37	11.44	-	14.65	18.93
Hansford	20.57	-	35.42	34.42	-	12.78	11.31	19.74	22.37
Hartley	23.74	13.36	35.54	34.54	-	13.97	12.43	20.38	21.99
Hemphill	-	-	26.00	-	-	9.07	7.79	14.32	14.30
Hutchinson	22.07	-	36.69	35.69	-	13.50	12.18	19.95	23.35
Lipscomb	16.75	-	26.51	25.51	-	9.42	8.11	12.93	16.54
Moore	21.51	12.54	32.89	31.89	-	13.03	11.83	17.10	20.11
Ochiltree	19.07	-	34.15	33.15	-	12.07	10.44	18.71	21.27
Oldham	-	-	-	36.44	-	13.46	-	22.69	24.20
Potter	23.06	12.71	37.44	-	-	13.46	-	16.63	20.66
Randall	23.06	12.71	37.44	36.44	-	13.46	12.15	22.69	22.57
Roberts	18.74	-	-	29.72	-	10.56	9.23	18.00	17.25
Sherman	23.51	-	37.26	36.26	-	13.81	12.36	21.98	24.20
Wheeler	15.84	6.12	22.72	21.72	15.83	6.81	5.71	15.16	13.74
Average	20.11	9.70	31.63	30.29	16.94	11.12	9.88	17.42	-

Table 3. Year 2002 Region A county theoretical crop water use values, inches.

Region A Counties	Corn	Cotton	Hay	Pasture & Other	Peanut	Sorgh.	Soyb.	Wheat	Total
Armstrong	-	-	-	-	-	-	-	-	-
Carson	-	-	-	-	-	1	-	-	1
Childress	-	-	-	-	-	-	-	-	-
Collingsworth	-	-	-	-	-	-	-	-	-
Dallam	-	-	-	-	-	-	-	-	-
Donley	-	-	-	-	-	-	-	-	-
Gray	-	-	-	-	-	-	-	-	-
Hall	-	-	-	-	-	-	-	-	-
Hansford	-	-	-	-	-	-	-	-	-
Hartley	-	-	-	-	-	-	-	-	-
Hemphill	-	-	-	-	-	-	-	-	-
Hutchinson	-	-	-	-	-	-	-	-	-
Lipscomb	-	-	-	-	-	-	-	-	-
Moore	-	-	-	-	-	-	-	-	-
Ochiltree	-	-	-	-	-	-	-	-	-
Oldham	-	-	-	-	-	-	-	-	-
Potter	-	-	-	-	-	-	-	-	-
Randall	-	-	-	-	-	-	-	-	-
Roberts	-	-	-	-	-	-	-	-	-
Sherman	-	-	-	-	-	-	-	-	-
Wheeler	-	-	-	-	-	-	-	-	-
Total	-	-	-	-	-	1	-	-	1

Table 4. Number of attributable meter records by crop in database, 2000.

Region A County	Corn	Cotton	Hay	Pasture & Other	Peanut	Sorgh.	Soyb.	Wheat	Total
Armstrong	-	-	-	-	-	-	-	3	3
Carson	2	1	-	1	-	4	3	7	18
Childress	-	-	-	-	-	-	-	-	-
Collingsworth	-	-	-	1	2	-	-	-	3
Dallam	-	-	-	-	-	-	-	-	-
Donley	-	1	6	2	4	-	-	-	13
Gray	1	-	-	-	-	-	-	4	5
Hall	-	-	-	-	-	-	-	-	-
Hansford	-	-	-	-	-	-	-	-	-
Hartley	-	-	-	-	-	-	-	-	-
Hemphill	-	-	-	-	-	-	-	-	-
Hutchinson	-	-	-	-	-	-	-	-	-
Lipscomb	-	-	-	-	-	-	-	-	-
Moore	-	-	-	-	-	-	-	-	-
Ochiltree	-	-	-	-	-	-	-	-	-
Oldham	-	-	-	-	-	-	-	-	-
Potter	-	-	-	-	-	-	-	-	-
Randall	-	-	-	-	-	-	-	-	-
Roberts	-	-	-	-	-	-	-	-	-
Sherman	1	-	-	-	-	-	-	-	1
Wheeler	-	1	-	2	1	-	1	-	5
Total	4	3	6	6	7	4	4	14	48

Table 5. Number of attributable meter records by crop in database, 2001.

Region A Counties	Corn	Cotton	Hay	Pasture & Other	Peanut	Sorgh.	Soyb.	Wheat	Total
Armstrong	-	-	-	3	-	2	-	-	5
Carson	17	3	-	7	-	12	10	6	55
Childress	-	-	-	-	-	-	-	-	-
Collingsworth	-	-	-	1	2	-	-	-	3
Dallam	-	-	-	-	-	-	-	-	-
Donley	-	-	7	1	6	-	-	-	14
Gray	2	-	-	2	-	2	-	4	10
Hall	-	-	-	-	-	-	-	-	-
Hansford	-	-	-	-	-	-	-	-	-
Hartley	3	-	-	-	-	-	-	-	3
Hemphill	-	-	-	-	-	-	-	-	-
Hutchinson		-	-	-	-	-	-	-	-
Lipscomb	-	-	-	-	-	-	-	-	-
Moore	11	-	-	-	-	-	-	-	11
Ochiltree	-	-	-	-	-	-	1	-	1
Oldham	-	-	-	-	-	-	-	-	-
Potter	-	-	-	-	-	-	-	-	-
Randall	-	-	-	-	-	-	-	-	-
Roberts	3	-	-	1	-	-	-	-	4
Sherman	3	-	1	-	-	-	-	-	4
Wheeler	2	5	-	-	5	-	-	2	14
Total	41	8	8	15	13	16	11	12	124

Table 6. Number of attributable meter records by crop in database, 2002.

Region A Counties	Corn	Cotton	Hay	Pasture & Other	Peanut	Sorgh.	Soyb.	Wheat	Avg.
Armstrong	-	-	-	-	-	-	-	-	-
Carson	-	-	-	-	-	16.37	-	-	16.37
Childress	-	-	-	-	-	-	-	-	-
Collingsworth	-	-	-	-	-	-	-	-	-
Dallam	-	-	-	-	-	-	-	-	-
Donley	-	-	-	-	-	-	-	-	-
Gray	-	-	-	-	-	-	-	-	-
Hall	-	-	-	-	-	-	-	-	-
Hansford	-	-	-	-	-	-	-	-	-
Hartley	-	-	-	-	-	-	-	-	-
Hemphill	-	-	-	-	-	-	-	-	-
Hutchinson	-	-	-	-	-	-	-	-	-
Lipscomb	-	-	-	-	-	-	-	-	-
Moore	-	-	-	-	-	-	-	-	-
Ochiltree	-	-	-	-	-	-	-	-	-
Oldham	-	-	-	-	-	-	-	-	-
Potter	-	-	-	-	-	-	-	-	-
Randall	-	-	-	-	-	-	-	-	-
Roberts	-	-	-	-	-	-	-	-	-
Sherman	-	-	-	-	-	-	-	-	-
Wheeler	-	-	-	-	-	-	-	-	-
Average	-	-	-	-	-	16.37	-	-	-

Table 7. Region A 2000 average county measured crop water use values, inches.

Region A Counties	Corn	Cotton	Hay	Pasture & Other	Peanut	Sorgh.	Soyb.	Wheat	Avg.
Armstrong	-	-	-	-	-	-	-	6.45	6.45
Carson	25.62	5.61	-	4.46	-	9.9	7.86	16.85	11.72
Childress	-	-	-	-	-	-	-	-	-
Collingsworth	-	-	-	8.33	11.08	-	-	-	9.71
Dallam	-	-	-	-	-	-	-	-	-
Donley	-	15.31	23.75	3.79	14.77	-	-	-	14.41
Gray	18.12	-	-	-	-	-	-	2.19	10.16
Hall	-	-	-	-	-	-	-	-	-
Hansford	-	-	-	-	-	-	-	-	-
Hartley	-	-	-	-	-	-	-	-	-
Hemphill	-	-	-	-	-	-	-	-	-
Hutchinson	-	-	-	-	-	-	-	-	-
Lipscomb	-	-	-	-	-	-	-	-	-
Moore	-	-	-	-	-	-	-	-	-
Ochiltree	-	-	-	-	-	-	-	-	-
Oldham	-	-	-	-	-	-	-	-	-
Potter	-	-	-	-	-	-	-	-	-
Randall	-	-	-	-	-	-	-	-	-
Roberts	-	-	-	-	-	-	-	-	-
Sherman	19.48	-	-	-	-	-	-	-	19.48
Wheeler	-	8.26	-	16.9	8.47	-	27.76	-	15.35
Average	21.07	9.73	23.75	8.37	11.44	9.90	17.81	8.50	-

Table 8. Region A 2001 average county measured crop water use values, inches.

Region A Counties	Corn	Cotton	Hay	Pasture & Other	Peanut	Sorgh.	Soyb.	Wheat	Avg.
Armstrong	-	-	-	9.06	-	5.39	-	-	7.23
Carson	20.56	7.95	-	12.65	-	7.68	15.16	8.02	11.72
Childress	-	-	-	-	-	-	-	-	-
Collingsworth	-	-	-	14.45	19.44	-	-	-	16.95
Dallam	-	-	-	-	-	-	-	-	-
Donley	-	-	24.27	7.04	8.4	-	-	-	13.24
Gray	21.76	-	-	1.87		7.26	-	4.35	8.81
Hall	-	-	-	-	-	-	-	-	-
Hansford	-	-	-	-	-	-	-	-	-
Hartley	29.18	-	-	-	-	-	-	-	29.18
Hemphill	-	-	-	-	-	-	-	-	-
Hutchinson	-	-	-	-	-	-	-	-	-
Lipscomb	-	-	-	-	-	-	-	-	-
Moore	12.31	-	-	-	-	-	-	-	12.31
Ochiltree	-	-	-	-	-	-	31.38	-	31.38
Oldham	-	-	-	-	-	-	-	-	-
Potter	-	-	-	-	-	-	-	-	-
Randall	-	-	-	-	-	-	-	-	-
Roberts	29.44	-		24.08	-	-	-	-	26.76
Sherman	13.91	-	11.83	-	-	-	-	-	12.87
Wheeler	21.96	8.27	-	-	8.62	-	-	13.32	13.04
Average	21.06	8.11	18.05	11.53	12.15	6.78	23.27	8.56	-

Table 9. Region A 2002 average county measured crop water use values, inches.

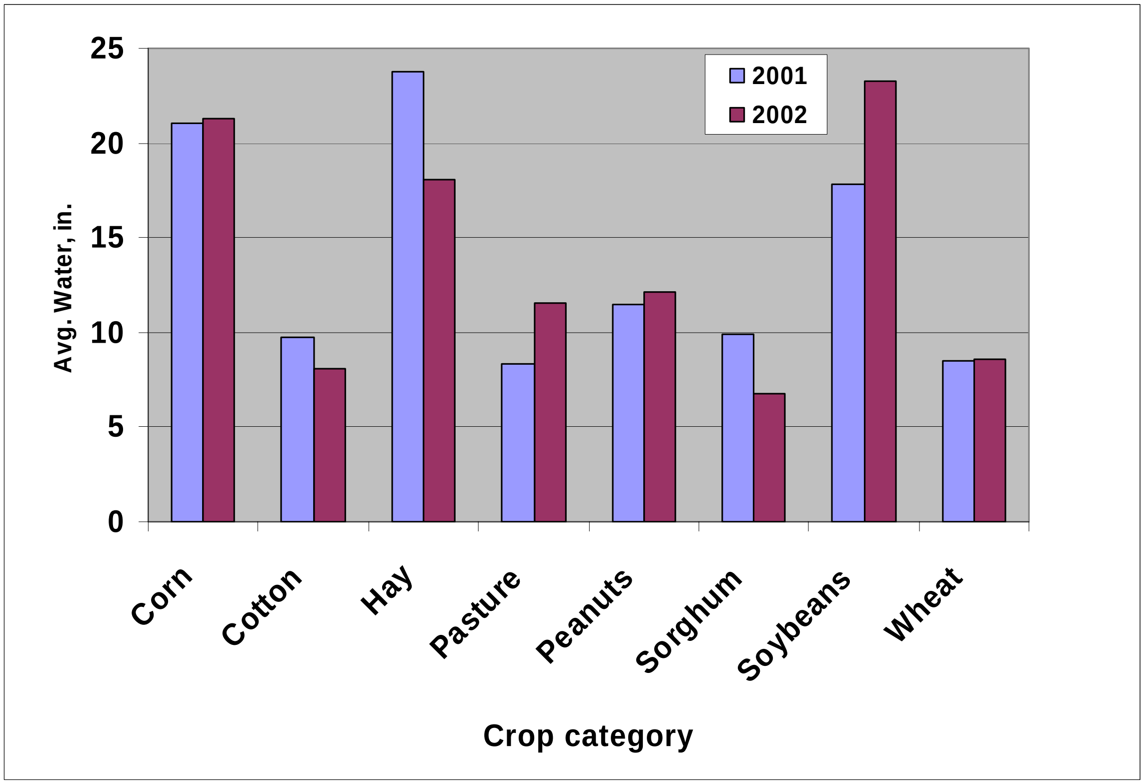

Figure 1. Average metered irrigation water quantity (inches per acre) attributed per crop category in 2001 and 2002.

Region A Counties	Corn	Cotton	Hay	Pasture & Other	Peanut	Sorgh.	Soyb.	Wheat	Avg.
Armstrong	-	-	-	-	-	-	-	-	-
Carson	-	-	-	-	-	-6.09	-	-	-6.09
Childress	-	-	-	-	-	-	-	-	-
Collingsworth	-	-	-	-	-	-	-	-	-
Dallam	-	-	-	-	-	-	-	-	-
Donley	-	-	-	-	-	-	-	-	-
Gray	-	-	-	-	-	-	-	-	-
Hall	-	-	-	-	-	-	-	-	-
Hansford	-	-	-	-	-	-	-	-	-
Hartley	-	-	-	-	-	-	-	-	-
Hemphill	-	-	-	-	-	-	-	-	-
Hutchinson	-	-	-	-	-	-	-	-	-
Lipscomb	-	-	-	-	-	-	-	-	-
Moore	-	-	-	-	-	-	-	-	-
Ochiltree	-	-	-	-	-	-	-	-	-
Oldham	-	-	-	-	-	-	-	-	-
Potter	-	-	-	-	-	-	-	-	-
Randall	-	-	-	-	-	-	-	-	-
Roberts	-	-	-	-	-	-	-	-	-
Sherman	-	-	-	-	-	-	-	-	-
Wheeler	-	-	-	-	-	-	-	-	-
Average	-	-	-	-	-	-6.09	-	-	-

Table 10. Region A 2000 county crop water use value differences, inches.

Region A Counties	Corn	Cotton	Hay	Pasture & Other	Peanut	Sorgh.	Soyb.	Wheat	Avg.
Armstrong	-	-	-	-	-	-	-	2.88	2.88
Carson	-7.82	8.46	-	30.20	-	-2.60	-1.01	-11.77	2.58
Childress	-	-	-	-	-	-	-	-	-
Collingsworth	-	-	-	-8.33	5.37	-	-	-	-1.48
Dallam	-	-	-	-	-	-	-	-	-
Donley	-	-0.85	14.86	33.82	2.51	-	-	-	12.59
Gray	0.39	-	-	-	-	-	-	3.51	1.95
Hall	-	-	-	-	-	-	-	-	-
Hansford	-	-	-	-	-	-	-	-	-
Hartley	-	-	-	-	-	-	-	-	-
Hemphill	-	-	-	-	-	-	-	-	-
Hutchinson	-	-	-	-	-	-	-	-	-
Lipscomb	-	-	-	-	-	-	-	-	-
Moore	-	-	-	-	-	-	-	-	-
Ochiltree	-	-	-	-	-	-	-	-	-
Oldham	-	-	-	-	-	-	-	-	-
Potter	-	-	-	-	-	-	-	-	-
Randall	-	-	-	-	-	-	-	-	-
Roberts	-	-	-	-	-	-	-	-	-
Sherman	3.44	-	-	-	-	-	-	-	3.44
Wheeler	-	5.61	-	-16.90	6.74	-	-20.70	-	-6.31
Average	-1.33	4.40	14.86	9.70	4.87	-2.60	-10.85	-1.80	-

Table 11. Region A 2001 county crop water use value differences, inches.

Region A Counties	Corn	Cotton	Hay	Pasture & Other	Pean.	Sorg.	Soyb.	Wheat	Avg.
Armstrong	-	-	-	-9.06	-	5.25	-	-	-1.90
Carson	-4.86	-2.21	-	8.57	-	-1.21	-9.77	7.36	-0.07
Childress	-	-	-	-	-	-	-	-	-
Collingsworth	-	-	-	11.83	-3.15	-	-	-	4.34
Dallam	-	-	-	-	-	-	-	-	-
Donley	-	-	10.17	26.40	10.04	-	-	-	15.54
Gray	-5.72	-	-	20.61	-	0.07	-	10.46	6.35
Hall	-	-	-	-	-	-	-	-	-
Hansford	-	-	-	-	-	-	-	-	-
Hartley	-5.44	-	-	-	-	-	-	-	-5.44
Hemphill	-	-	-	-	-	-	-	-	-
Hutchinson	-	-	-	-	-	-	-	-	-
Lipscomb	-	-	-	-	-	-	-	-	-
Moore	9.20	-	-	-	-	-	-	-	9.20
Ochiltree	-	-	-	-	-	-	-20.94	-	-20.94
Oldham	-	-	-	-	-	-	-	-	-
Potter	-	-	-	-	-	-	-	-	-
Randall	-	-	-	-	-	-	-	-	-
Roberts	-10.70	-	-	5.64	-	-	-	-	-2.53
Sherman	9.60	-	25.43	-	-	-	-	-	17.52
Wheeler	-6.12	-2.15	-	-	7.21	-	-	1.84	0.19
Average	-1.76	-2.18	17.80	10.67	4.70	1.37	-15.35	6.55	-

Table 12. Region A 2002 county crop water use value differences, inches.

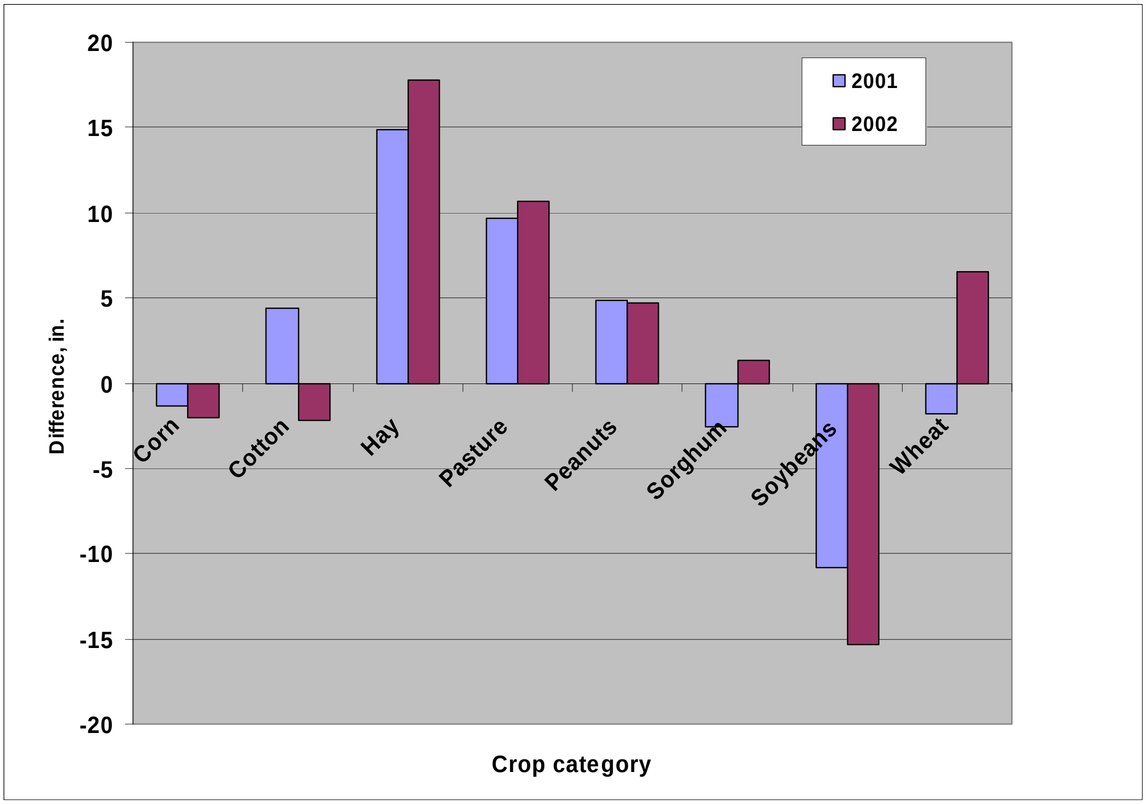

Figure 2. Average difference (inches) of the theoretical minus metered irrigation water quantities per crop category in 2001 and 2002.

Results – Objective 1.

It can easily be deduced that the metering program was in its early stages from Table 4. It can be viewed from Tables 5 and 6 that both implementation and monitoring of the number of crop attributable wells within Region A increased over the study period. It is also apparent that the amount of meter data by crop is limited throughout much of the major crop producing counties of the region. Certainly, the acreage attributable by the number of metered well records reviewed even in the last study year is relatively small in comparison to the acreage of production in the counties and the region as a whole. This lack of representation limits the inferences that can be gathered from the overall regional metered database and significantly impacts an accurate comparison (for changes) with the TAMA model estimates. This is especially a concern when delineated on a county level basis considering the range of irrigation practices and system operations that are experienced in the field.

Comparisons of differences between the theoretical values and the well metered data were made and shown in Tables 10 through 12 and overall crop averages are illustrated in Figure 2. The comparisons indicate a generally nominal variation in average values between the theoretical and metered values. The term difference in this analysis is defined as that of the theoretical (TAMA value) minus the metered value for the crop of interest. Larger differences exhibited in the tables were interpreted to be the result of only applying minimal to marginal irrigation levels as compared to a higher average percent of ET applied within the TAMA model runs. (In the TAMA model, these percentages were obtained from more detailed TCE demonstration data than gathered through the metering program.) This lower ET application type deviation was indicated by a positive value difference. This is particularly exhibited in the pasture category in Figure 2 for both of the latter years. The cases generally regarding average metered values for corn and soybeans indicated that either the grower factors (amount of crop ET applied to full ET required) used in the TAMA model were too low, that the water metered values were representative of watering beyond the crop ET requirements (in the case of soybeans) or pumpage was not attributed properly to the respective crops. Given the limited representation of metered well data per crop per county, especially in the more heavily irrigated counties, future attention to county meter representation and more detailed record collection is warranted before adjustments should be made to the TAMA model estimates. It is recognized by the authors that meter location was determined initially by producers that would allow water meters to be installed in their irrigation systems. Efforts should be made in the future, however, to install meters in the needed, representative heavier counties of irrigation and over a range of representative producers and irrigation practices.

Objective 2. Identify metered water use by irrigation system, crop, and soil type.

The data required for comparisons against the theoretical estimates of the model regarding crop type for most of this objective were separated out in the previous section in Tables 7 through 9. The compiled values regarding water use against soil type were substantially more discernable from one of the district's records. The results from both of the data sets are presented in Table 13. As viewed, the standard deviation is significantly large categorically and this indicates that little definitive inference can be generally made from the data records regarding irrigation amount applied to soil type.

Soil Type	Year									
	1999		2000		2001		2002		2003	
	Avg Water Use	σ	Avg Water Use	σ	Avg Water Use	σ	Avg Water Use	σ	Avg Water Use	σ
Silty Clay Loam	13.40	-	16.37	-	5.42	18.83	11.99	8.93	9.17	6.85
Clay Loam	-	-	-	-	11.44	11.43	12.84	15.22	10.83	9.61
Fine Sandy Loam	-	-	-	-	14.84	9.90	16.56	12.39	16.56	9.16
Loamy Fine	-	-	-	-	16.80	5.32	10.49	5.32	10.55	5.71
Fine Sand	-	-	-	-	-	-	10.37	4.23	10.09	3.77

σ=standard deviation.

Table 13. Average metered water use value (inches) and standard deviation per soil type classification from 1999-2003.

Irrigation Type	Year			
	2000	2001	2002	2003
Pivot	-	17.44	14.75	11.71
Surface	16.37	8.86	8.00	8.39
Side roll	-	3.99	2.03	10.37
Drip	-	-	-	-

Table 14. Averaged metered water use values attributed to system type.

Results – Objective 2.

The fact that the majority of discernable data was obtained from center pivot systems is not surprising. Pivots are typically dedicated to a well or group of manifolded wells for producers within the region. This is opposed to a well or group of wells seasonably being "stretched" over numerous surface irrigated fields or acreages. Center pivots are increasingly becoming the system of choice in terms of application efficiency, operability and labor requirements from the producer standpoint. In essence, there is little drip irrigation in the region and none of it is apparently monitored. The relative importance and representation of surface irrigation in the region continues to decrease as producers move to more efficient irrigation systems.

The average water applied by irrigation system in the region from the databases for the years 2000 through 2003 is presented in Figure 3. In year 2002, there was a marked decline in water pumped for center pivot systems, which is not the trend generally observed over time in the field within the region. Natural gas prices increased dramatically in 2002 resulting in producers typically reducing irrigation pumpage to contain operating costs (Guerrero et al., 2005). This possibly explains the reduced application in the latter years of the plot, with the exception of the sideroll system.

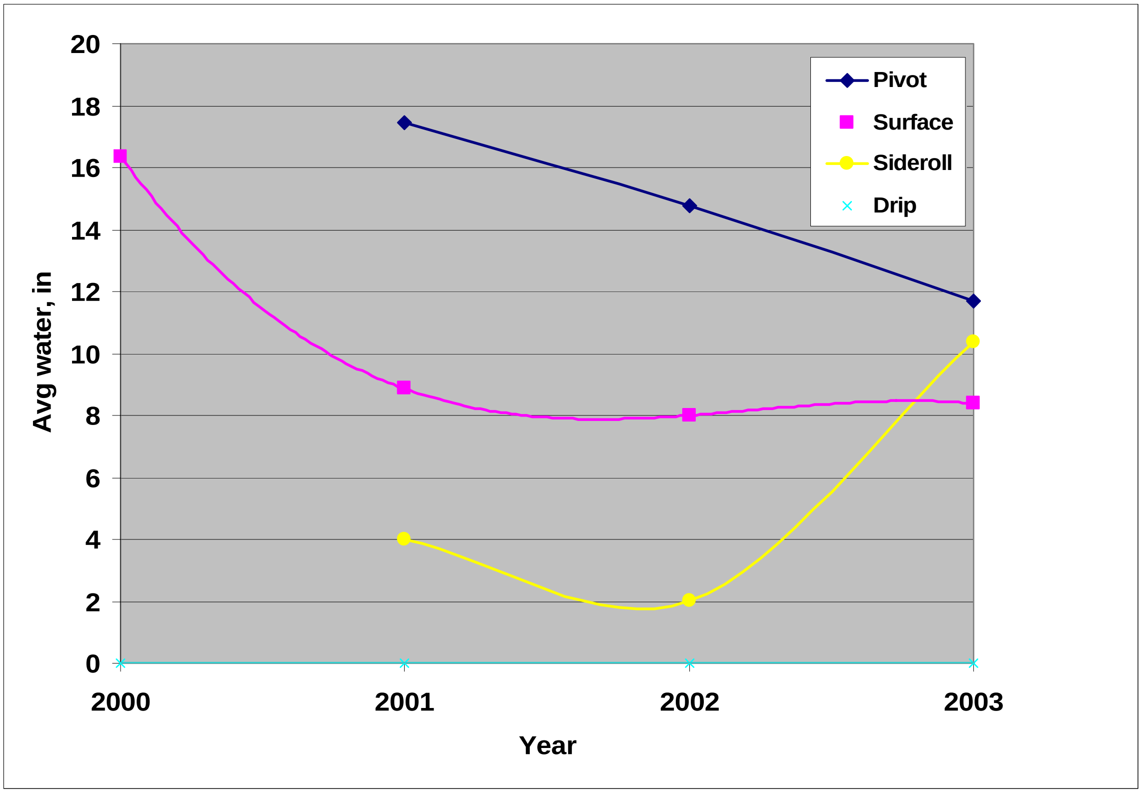

Figure 3. Average water metered (inches) by irrigation system and trend lines for years 2000 through 2003.

The average water applied from the data studied did not directly support the theory that the sandier soils used more water than the heavier clay soils on a seasonal basis. Although water application in 2001 conformed to this notion, improved management could be a possibility as to why the 2002 and 2003 water applied averages on the finer soils were in the same range of use with the clay loam soils. The water applied by soil type going from the heavier to the lighter (finer) soils is illustrated in Figure 4.

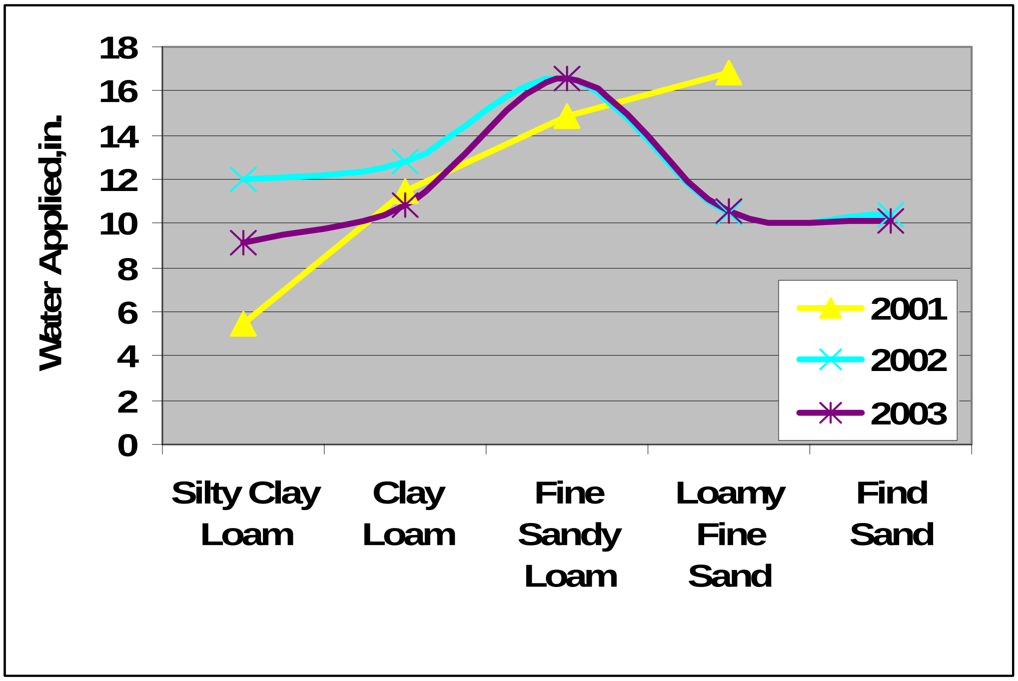

Figure 4. Average water metered (inches) for the soils of the database shown for years 2001 through 2003.

Objective 3. Evaluate precipitation records with metered pumping use and assess the changes in pumping as rainfall changes.

This objective of the study dealt with examining the relationship between rainfall and the amount of metered irrigation applied. Conventional wisdom would indicate that as rainfall increases, expected irrigation should on average be reduced. However, several factors impact the conventional relationship in practice including effective rainfall (affected by intensity and amount), rainfall distribution (throughout the respective seasonal and recorded periods), natural gas pricing, commodity prices, and irrigated production levels of the respective crops targeted by the irrigator. (The latter is known as the grower or pumpage factor in the TAMA model.) These factors have a significant impact on the level of irrigation application and are usually limited on the "upside" by well production capacity.

An average rainfall value recorded per crop per county was needed for this analysis from the metering records to do a representative comparison with the gross (not effective) rainfall values used in the TAMA model for the study years. Metered record periods were not sufficiently delineated in the databases and did not coincide with seasonal rainfall periods of the respective crops used in the TAMA model. This could be due to a limitation of resources to adequately check rainfall gauges on a routine basis. In Table A-4, the seasonal dates used in the effective rainfall (ER) period computations are provided and it should be noted that they differ from the growing season periods used in the theoretical crop ET computations. This is due to the fact that rainfall occurring near the end of a season does not always contribute to crop production. The NPET gross rainfall values along with irrigation requirements per county are presented for each crop category in the appendix. (Tables A-5 through A-12)

Results – Objective 3.

The average rainfall values recorded per crop per county from the metering records were not able to be adequately compiled for direct comparison given the degree of difference between the recorded rainfall dates of the databases and the crop seasonal periods used in the TAMA model. For example, plotting the county NPET rainfall values versus irrigation applied for corn over the study years conformed to conventional expectations that irrigation decreases as rainfall increases, Figure 5. As discussed previously, this relationship was expected with only the degree of slope and scatter among the counties in the plot being determined by the actual ET and rainfall values. The outlier (the observation point on the lower left) in the plot was due to an abnormally dry year for Dallam County in year 2000. Deleting the single point, the slope of the relationship increases by 25 percent. In either case, the expected relationship is observed. Such was not the case for the metered data since other impacts affect the relationship as mentioned earlier.

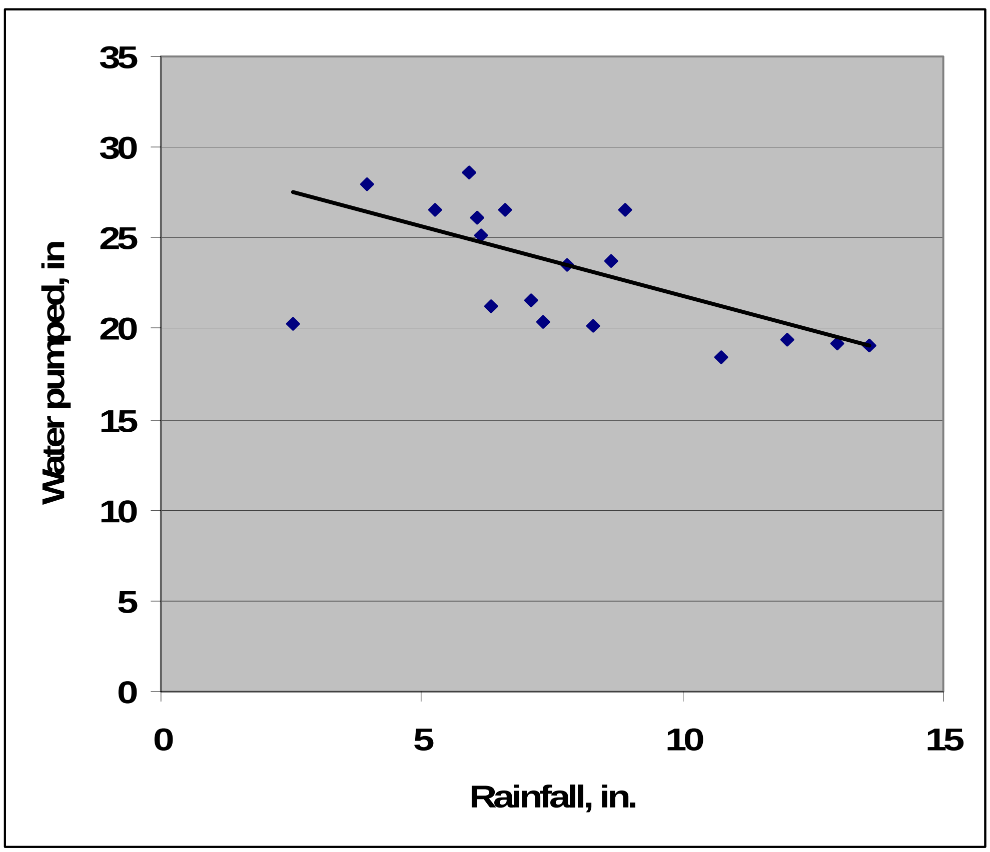

Figure 5. NPET irrigation to rainfall relationship of the TAMA model for corn in 2000 study year.

Plotting of the pumped meter reading data against all gross rainfall received from the records for all years, including 2003 is presented in Figure 6. There is no apparent relationship between rainfall and water pumped observed in the plot. Statistically, this was confirmed through regression analysis. Separating the yearly variation of water pumpage to rainfall for the years of 2001 through 2003 is illustrated in Figures 7 through 9. While conventional thinking indicates that the two parameters would be well correlated, the other factors mentioned earlier must account for the non-relational variation within plots of the data. This could be especially true during the driest of the years, 2002, when escalating natural gas prices were realized and reduced pumpage was practiced for cost containment; whereas, typically this situation would be addressed with increased pumpage or to the point of maximum allowable capacity. The relationship of rainfall and water pumped in individual years is confounding in Figures 7 through 9. In 2001, this relationship acts opposite of what would be intuitive, while in 2002, it plots as expected and more neutral than anticipated. Given that these plots encompass multiple crops and practices per year, much of the dispersion of the data is expected. This is realized in the low coefficients of determination of the regression lines. No definitive trend can be concluded based on the 2003 data. (Year 2003 data was also analyzed for this objective since FSA acreage was not involved.)

While it possibly would be best to separate the data out by crop category versus year, the problem still exists regarding seasonal to recorded rainfall timeframes and the small sample size per respective county.

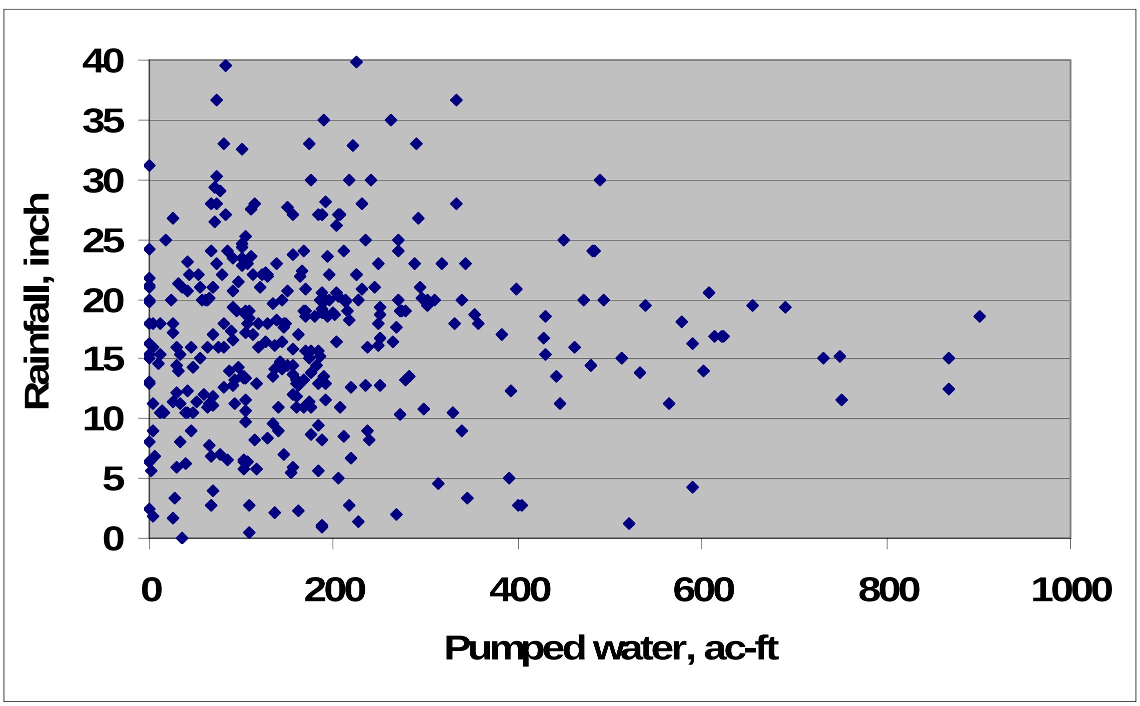

Figure 6. Plot of gross rainfall versus water pumped for the years of 1999-2003. (Majority of data is from latter years.)

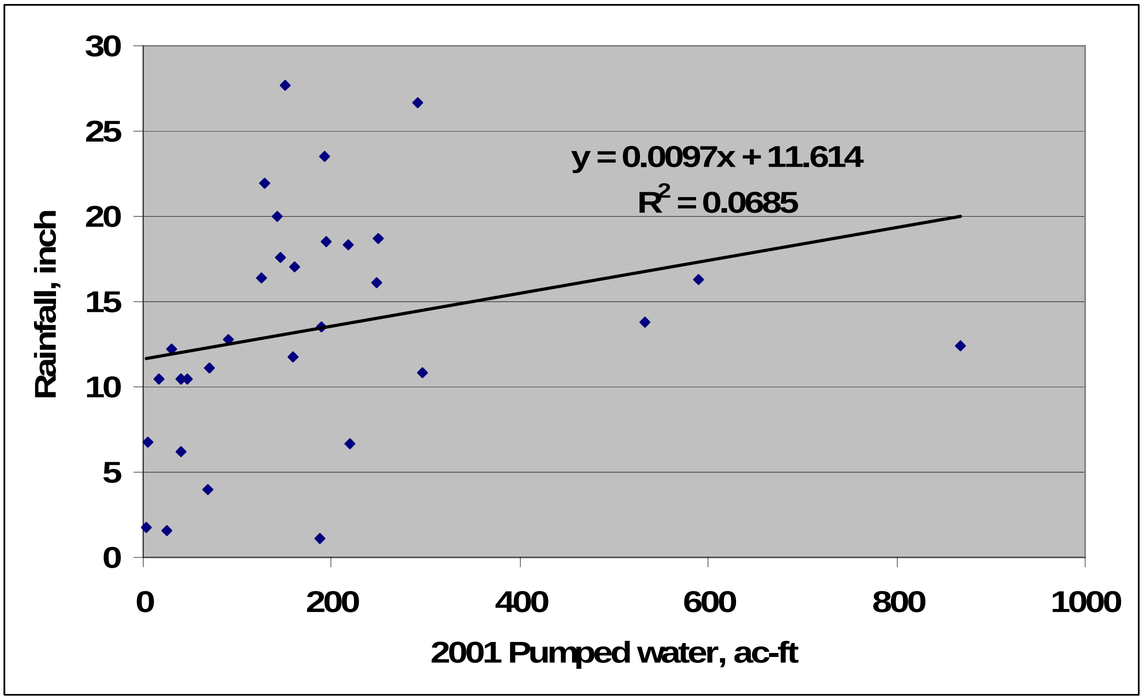

Figure 7. Plot of gross rainfall versus water pumped for the 2001 year.

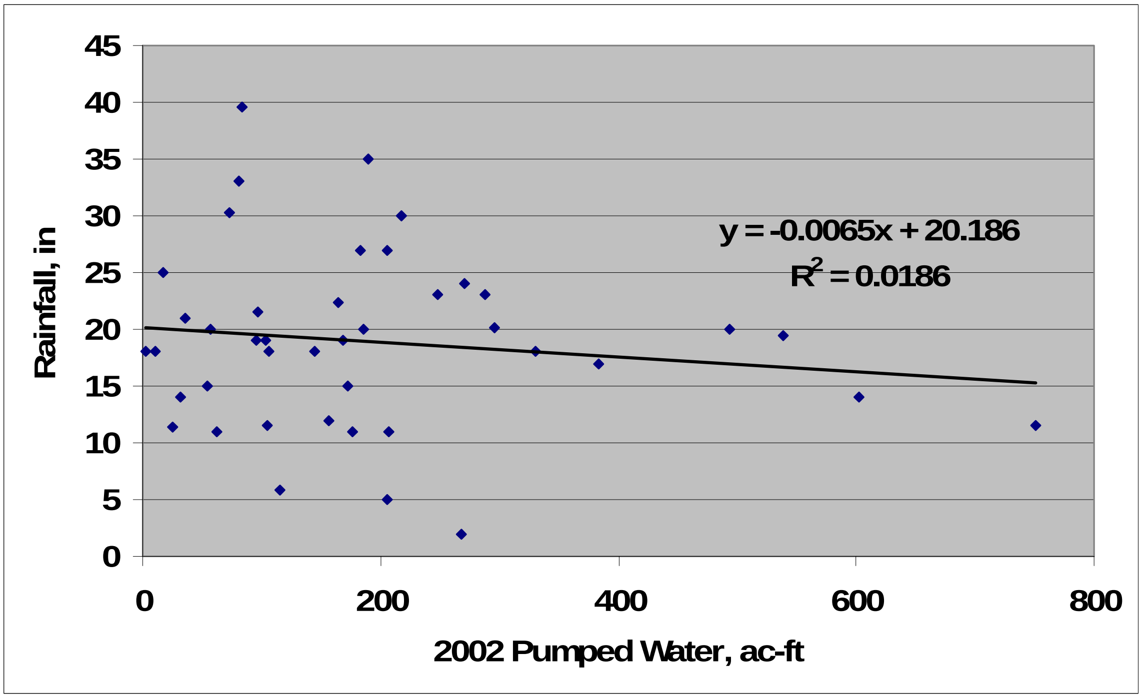

Figure 8. Plot of gross rainfall versus water pumped for the 2002 year.

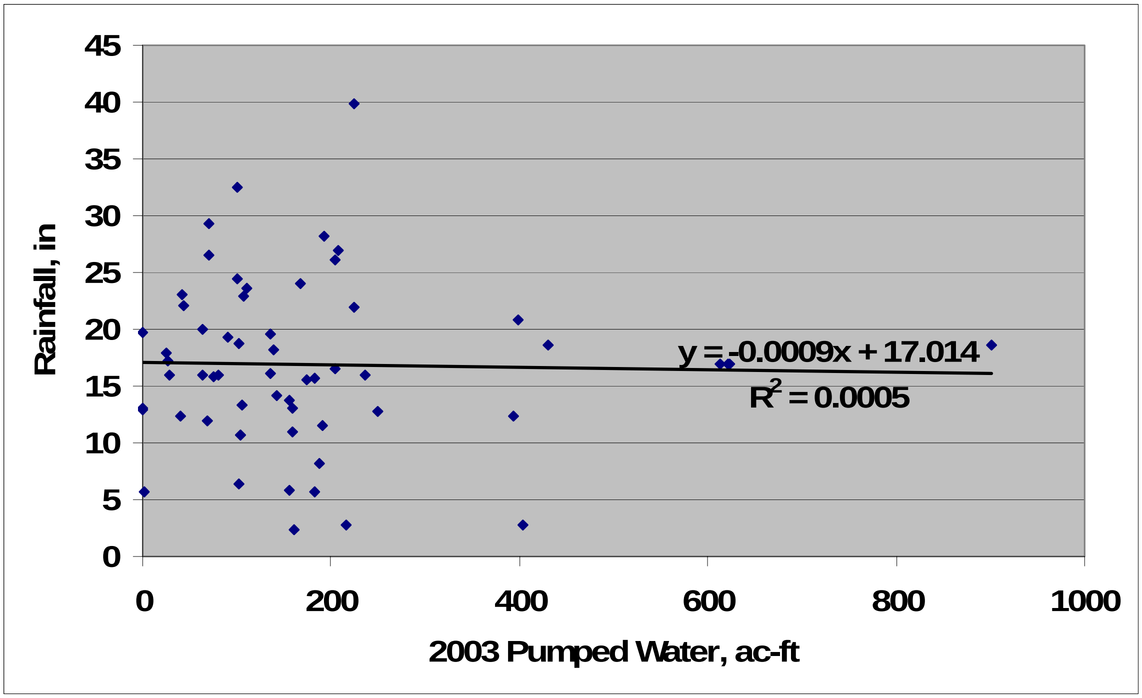

Figure 9. Plot of gross rainfall versus water pumped for the 2003 year.

Plots of selected irrigation systems rainfall versus total metered values are included in the Appendix. Data problems occurred in this analysis, as in other objective sections, as data deduced from the databases indicated that the number of wells per year per same system varied. For instance, only one well could be attributed in one year and four wells were attributed for the years prior and after that year for the same system. Thus, a median value of the multiple well values in a system was line plotted against the yearly rainfall data in the plots to represent a more uniform analytical approach. The median was selected over a mean value of multiple wells to lessen the influence of a variant value among the group. Plotting the pumped total of the system wells comparatively would result in a much biased assessment that represents more so the number of attributable wells in a system per year rather than a mean or median output well value of the system group. Even plotting in the median manner, there is no apparent conclusion that can be gathered from the data as the pumpage values were known to be influenced by the relatively high natural gas costs occurring during the growing season of 2002 and part of 2003.

Objective 4. Adjust theoretical demands as indicated by the evaluation of the real-time data, if warranted.

Data for this objective is presented in the tables in objective one regarding the differences of the theoretical versus the metered values. Currently, the metering data does not have the statistical representation needed to justify replacing the multi-year grower factors and application data obtained through the more detailed TCE Agri-Partner program and used in the TAMA model. Due to the low county sample representation, especially in the heavier irrigated counties, and statistical inference issues previously mentioned, no changes in the theoretical values are recommended or warranted from the data analyzed at this time. The adequacy of representation and attribute shortfall will be discussed in the recommendations section.

Objective 5. Extrapolate findings throughout the region to generate irrigation production input to the Ogallala GAM model to assess groundwater availability.

The purpose of this objective was to adjust the theoretical values based on the metered well data and extrapolate those changes throughout the region through a modification of the TAMA model and discuss the resultant differences in county and regional water use. Subsequently, the intent was to infer what impact this would have on any potential counties that were shown to be forecasted to incur a shortfall in supply before the 50 year horizon of the GAM model run. Due to the relatively low representation for the entire region and associated statistical inference issues of the data sets previously mentioned, no valid, definite extrapolations can be realistically suggested at this time. Therefore, no modified GAM model run is warranted.

Objective 6. Identify potential problems in data and data collection to sustain the use of the data from the on-going metering program and provide recommendations.

It is understood by the authors that the original intent of the contracted metering program was primarily for hydrologic purposes and the water districts were not under contract to obtain all of the needed data to fully assess the objectives of this study. Nonetheless, it is understood that the districts took it upon themselves in differing manners to acquire some of the data that was utilized for evaluation of the objectives.

Several of the problems related to the temporal recordings of the meter data have been mentioned in the previous sections. These temporal problems, as provided to the water team, limited both interpretation and extrapolation of the data for addressing the objectives of this study. It should be indicated that significant differences exist in the datasets gathered from the two groundwater districts. It is recognized from the data reviewed that the Panhandle Groundwater Conservation District is dedicated to the metering effort and this commitment is reflected in the improvement and evolving completeness of their respective database. The North Plains Groundwater Conservation District has, since this program was initiated, amended their Rules to require ALL water users to report total water production from each property (section or pooled unit) within the district beginning in 2006 and report the production by January 30, 2007 and report previous year production by January 30th each year thereafter. Because of the staff requirements related to this Rule change, the district has not been as committed to the data interpretation required by this project. It is strongly recommended that data collected hereafter be standardized and more inclusive in terms of application and temporal data, including timely rain gauge readings at the respective meter site. The recording format needs to be mutually agreed upon with all metering participants based on perceived informational needs of future water planning. This data could then also be readily used for both modeling and producer irrigation practice evaluation. The latter purpose brings up a significant concern regarding confidentiality of producer data. Every effort should be made to assure that the data, interpretations and assessments are not used against the producer or other users entrusted with the data. Rather, the producer or cooperator should be assured that data evaluations will be used to assist the producer in improving his/her irrigation operations through efficiency or cost cutting efforts. Any legal issue of dissemination or divulgence of individual parties' data should be appropriately addressed and resolved accordingly prior to acquisition.

Temporal data from meter readings that is directly attributed to the particular crops used in the TAMA model (typical of conventional seasons throughout the region) are needed from an agricultural irrigation assessment view. Mixed crop acreages and manifolded systems need to be partitioned with definitive water and crop attribution per metered reading. If this cannot be accomplished, these metered fields should be abandoned for use in future water planning and evaluations such as those in this study and meters focused on fields that can be solely attributed or partitioned accordingly. It is also recommended that a statistically significant number of meters be monitored to produce representative data regarding particular crops that are being grown within a respective county. This is especially relevant and desired in the most heavily irrigated counties of the region as these inputs typically influence the model estimates proportionately.

It is recommended that data acquisition be conducted on a biweekly interval or less. Data should include water use, field acreage, irrigation type, crop attribution, rainfall, soil type, and soil partitioning data per given irrigated area when such conditions exist. At a minimum, soil moisture conditions should be assessed at the beginning and end of each respective crop season. Rainfall gauges need to be of the type that is oil filled to reduce evaporation losses between readings. The rain gage readings need to also coincide with crop growing seasons at a minimum. A bi-weekly assessment is required to compute any minimal type effectiveness rainfall measure as used in the TAMA model. While not directly required for the metering assessments, logging of planting dates, crop growth stages and cropping conditions is encouraged and can be of value in assessing crop ET representation. This data could be used to effectively assess correlation with the crop ET requirements as used within the TAMA model. Seasonally, this data should be checked to ensure its accuracy and appropriateness with respect to the well(s) or well systems being monitored.

Metered data collected should be based on a statistically significant percentage of the FSA acreage within the county. This data should be representative of the number of system types, distribution of progressive and less progressive producers, cultural practices, and crop types within the county. This address probably differs in intent from the original meter location arrangement where just more progressive producers were willing to allow meters to be located within their operations.

In addition, new technologies such as an automated system of remote accessing and telemetry relaying meter data to improve efficiency in data collection and potentially reduce overall costs should be investigated, encouraged, and potentially cost-shared. An automated system could prevent or at least assist in the detection of many of the non-readings and temporal problems that were encountered in the current database. The development of a customized computer program to analyze records as they are read or recorded could also assist in detecting meter problems much sooner than having to do it manually or at the respective seasons end. Transmission and downloading periods could possibly be monitored on a weekly or less (possibly daily) basis using automated technologies. Costs to adequately implement the data acquisition system for the suggested data requirements, whether automated or manual will entail additional field personnel, vehicles, vehicle maintenance, fuel costs, computers, software, data analysis, and office space. Unless a tipping rain gage system is integrated into the transmission system at the site, frequent field trips will still be necessary throughout the study region. Regardless, adequate resources should be made available for the program and these should be cost shared adequately or totally if the data is desired and valued by the state.

A summary of the recommended data compilations and suggested frequency of acquisition for water metered related data in the future is compiled in the following table:

Data Item	Minimum Acquisition Frequency-time interval	Desired Acquisition Frequency-time interval
Date	Per reading	Same
Well ID	Bi-weekly	Twice weekly
Meter reading	Bi-weekly, crop & acreage attributed	Twice weekly, crop & acreage attributed
Multiplier	Annually noted/as meter changed	Seasonally noted/as meter changed
Correction factor	Annually noted/as meter changed	Seasonally noted/as meter changed
County	Annually noted	Same
Field acreage	Seasonally, if dedicated crop; otherwise , per reading	Same
System type per meter reading	Seasonally, if dedicated; otherwise, per reading	Same
Crop attribution	Seasonally, if dedicated; otherwise, per reading	Same
Soil Type & Code(s) plus soil type partitioning per irrigated area, if applicable	Annual declaration w/ seasonal record	Seasonally tag with crop
Rainfall	Bi-weekly	Twice weekly
Soil moisture	Seasonally (initial and ending)	Bi-weekly
Crop planting date, as applicable	Seasonally noted	Same
Crop growth stages	Bi-weekly	Twice weekly
Cropping conditions	Monthly	Weekly
Harvest Date	Seasonally noted	Same

Table 15. Summary data and frequency recommendations of future water metering efforts.

Lastly, the groundwater districts are to be acknowledged for their initial efforts to compile individual water meter use data for beneficial producer purposes. Despite the early deficiencies and current limitations encountered in this analysis, continuation and expansion of the well meter data acquisition program is encouraged assuming the improvement recommendations previously mentioned are implemented. Again, these will require additional resources given the suggested time interval of data acquisition. It is viewed that errors dealt with in this analysis are being reduced in the most recent years (not studied due to the FSA acreage availability for model comparison purposes) as the program matures. This metering data could potentially be valuable to producers in evaluating their irrigation practices and in the design of educational programs to assist producers in improving these practices. In the future, if delineated sufficiently, it could also serve as input to the regional irrigation demand model and for other water planning efforts. Subsequently, the enhanced data via a programmed interface module could be integrated into the regional GAM model for periodic assessment of groundwater conditions as well as analyze the conditions mentioned in this report, and used to evaluate market forces, and to investigate the impact of various government programs in the future.

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Appendix

Region A County	2000 FSA Planted Irrigated Acres, pia	TAES Total Water Use, ac-ft
Armstrong	9,918	10,247
Carson	76,666	87,342
Childress	7,444	11,946
Collingsworth	22,297	35,611
Dallam	239,942	366,582
Donley	20,936	29,562
Gray	23,678	28,214
Hall	19,931	33,098
Hansford	160,669	254,546
Hartley	195,974	351,956
Hemphill	1,273	873
Hutchinson	44,586	73,649
Lipscomb	18,827	19,520
Moore	160,323	290,743
Ochiltree	78,620	131,282
Oldham	3,650	5,694
Potter	5,136	10,886
Randall	37,525	62,108
Roberts	15,609	34,593
Sherman	201,969	354,183
Wheeler	6,427	8,660
Total	1,351,398	2,201,298

Table A-1. Year 2000 irrigation water use estimates computed with the TAMA model using FSA acreages and NPET Rainfall for the 21 counties of Region A.

Region A County	2001 FSA Planted Irrigated Acres, pia	TAES Total Water Use, ac-ft
Armstrong	7,565	5,577
Carson	54,781	50,321
Childress	8,357	9,462
Collingsworth	21,401	27,796
Dallam	255,478	421,314
Donley	17,424	24,292
Gray	19,933	24,401
Hall	15,412	20,349
Hansford	137,940	161,843
Hartley	195,585	315,013
Hemphill	1,354	1,485
Hutchinson	38,807	46,691
Lipscomb	21,901	22,557
Moore	146,699	197,110
Ochiltree	64,953	80,642
Oldham	2,388	3,143
Potter	3,228	5,974
Randall	24,814	32,878
Roberts	14,529	30,090
Sherman	190,940	270,723
Wheeler	4,762	4,455
Total	1,248,248	1,756,116

Table A-2. Year 2001 irrigation water use estimates computed with the TAMA model using FSA acreages and NPET Rainfall for the 21 counties of Region A.

Region A County	2002 FSA Planted Irrigated Acres, pia	TAES Total Water Use, ac-ft
Armstrong	8,943	9,879
Carson	59,730	59,634
Childress	10,398	8,409
Collingsworth	25,001	29,665
Dallam	258,632	519,476
Donley	18,791	27,614
Gray	23,756	26,664
Hall	20,476	25,034
Hansford	153,742	243,175
Hartley	196,179	363,671
Hemphill	1,203	1,373
Hutchinson	43,277	72,280
Lipscomb	22,988	27,770
Moore	156,879	251,037
Ochiltree	73,690	103,865
Oldham	3,386	5,508
Potter	4,845	9,082
Randall	25,225	42,352
Roberts	14,659	27,936
Sherman	195,124	355,730
Wheeler	9,660	10,587
Total	1,326,582	2,220,740

Table A-3. Year 2002 irrigation water use estimates computed with the TAMA model using FSA acreages and NPET rainfall for the 21 counties of Region A.

Crop	Growing Season Used in Crop ET Computations	Season Used in Effective Rainfall (ER) Computations	Number of Months Used in ER Calculations
Corn	April 15 - October 15	April 15- August 15	4
Cotton	May 15-October 15	May 15-October 15	5
Grain Sorghum	May 15-October 15	May 15-October 15	5
Hay	April 1-November 1	April 1-November 1	7
Pasture & Other	April 1-November 1	April 1-November 1	7
Peanuts	May 1-November 1	May 1-November 1	6
Soybeans	June 1-November 1	June 1-November 1	5
Wheat	October 1-July 1	October 1-June 15	8.5

Table A-4. Seasonal periods and crop categories used in effective rainfall computations for Region A.

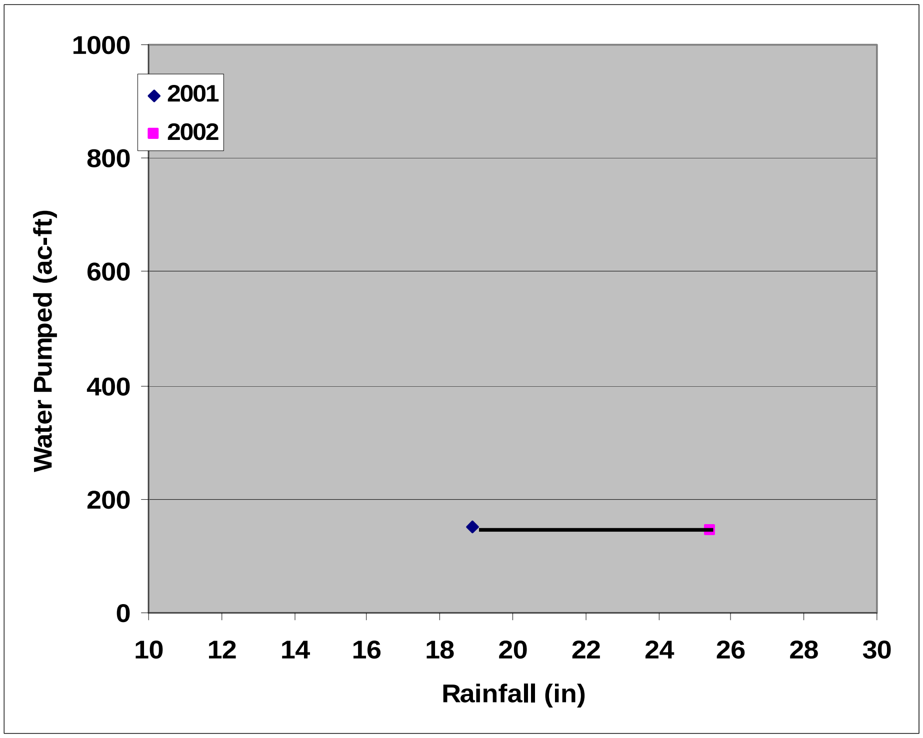

Figure A-1. Rainfall versus water pumped for System A in Wheeler County.

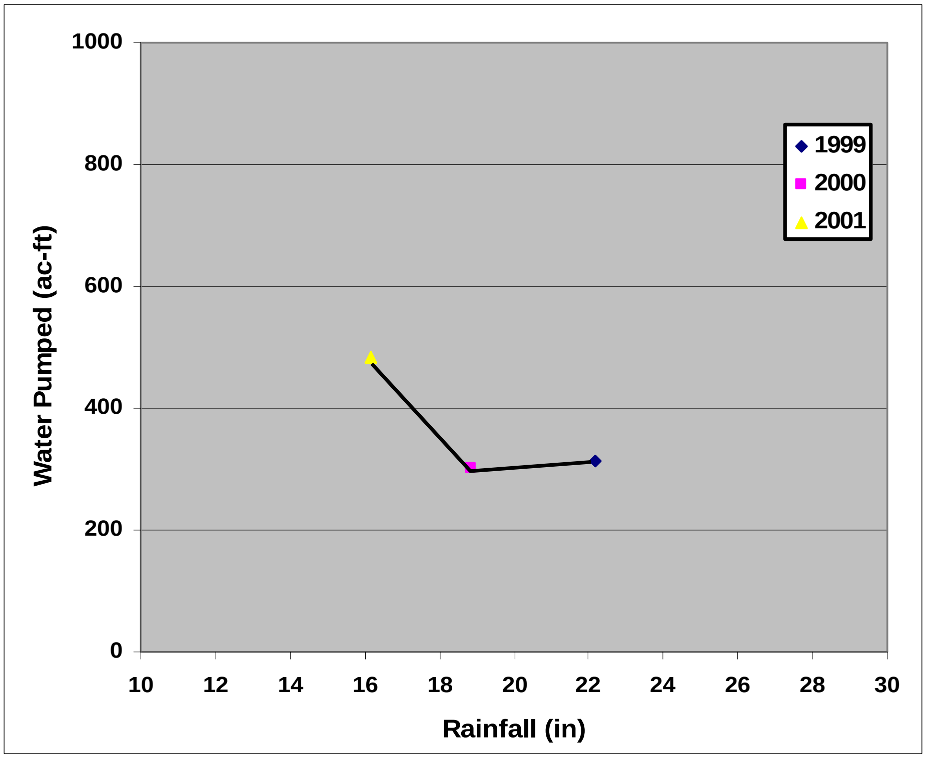

Figure A-2. Rainfall versus water pumped for System B in Roberts County.

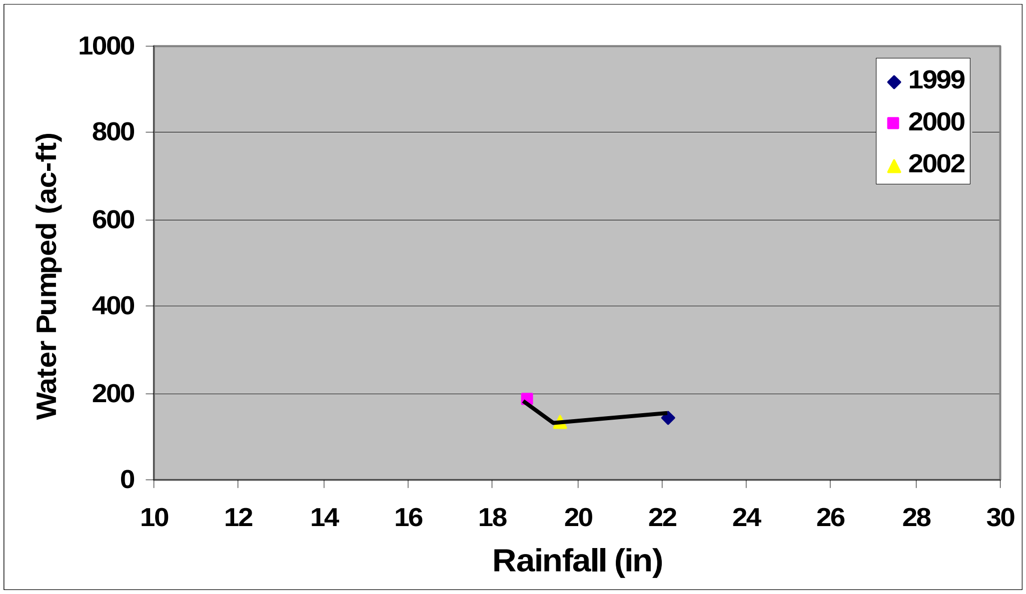

Figure A-3. Rainfall versus water pumped for System E in Carson County.

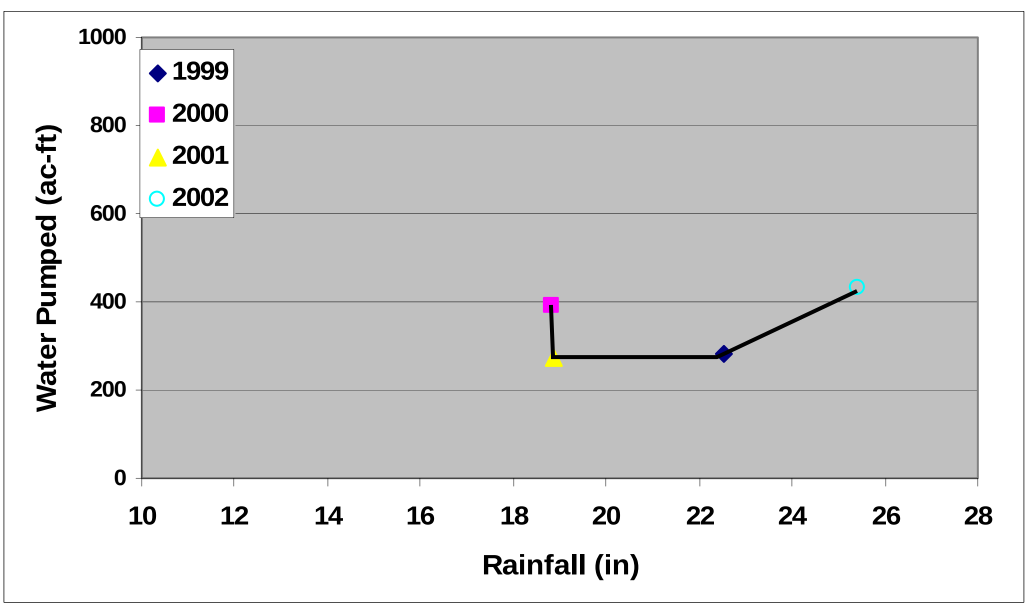

Figure A-4. Rainfall versus water pumped for System F in Carson County.

Region A County	Rain- (in)	Irrig. (in)	Com. (in)	Rain- (in)	Irrig. (in)	Com. (in)	Rain- (in)	Irrig. (in)	Com. (in)
	2000			2001			2002		
Armstrong	6.32	19.29	25.61	7.56	17.27	24.83	8.18	16.94	25.11
Carson	13.57	17.82	31.39	12.83	17.80	30.63	14.37	15.70	30.07
Childress	13.57	-	13.57	12.83	-	12.83	14.37	15.70	30.07
Collingsworth	7.33	19.29	26.62	7.53	20.76	28.29	8.67	16.91	25.58
Dallam	2.54	19.34	21.88	4.96	23.93	28.89	3.53	26.31	29.84
Donley	10.76	17.36	28.12	6.03	-	6.03	7.84	18.90	26.74
Gray	12.01	18.23	30.24	11.51	18.51	30.02	12.95	16.04	28.99
Hall	7.08	-	7.08	7.60	-	7.60	7.99	18.76	26.75
Hansford	6.08	24.93	31.01	10.20	20.94	31.14	10.02	20.57	30.59
Hartley	3.78	23.82	27.61	6.85	21.79	28.64	6.02	23.74	29.77
Hemphill	8.89	-	8.89	8.86	-	8.86	10.10	16.64	26.74
Hutchinson	6.02	25.32	31.34	11.10	19.65	30.75	8.98	22.07	31.05
Lipscomb	8.27	19.09	27.36	8.33	20.31	28.64	9.53	16.75	26.28
Moore	3.96	26.77	30.73	8.46	18.86	27.32	6.84	21.51	28.35
Ochiltree	6.14	23.98	30.12	9.29	22.23	31.52	11.06	19.07	30.13
Oldham	5.92	-	5.92	7.43	-	7.43	9.38	23.06	32.44
Potter	5.92	27.31	33.23	7.43	23.67	31.10	9.38	23.06	32.44
Randall	5.92	27.31	33.23	7.43	23.67	31.10	9.38	23.06	32.44
Roberts	8.63	22.49	31.11	11.09	19.85	30.94	11.50	18.74	30.24
Sherman	5.26	25.39	30.66	7.67	22.92	30.59	8.13	23.51	31.64
Wheeler	12.95	17.99	30.93	12.30	-	12.30	13.80	15.84	29.64

Table A-5. NPET rainfall, irrigation, and combined water for corn in Region A, 2000-2002.

Region A County	Rain-(in)	Irrig. (in)	Com. (in)	Rain-(in)	Irrig. (in)	Com. (in)	Rain-(in)	Irrig. (in)	Com. (in)
	2000			2001			2002		
Armstrong	6.33	-	6.33	8.40	8.40	16.80	9.48	10.02	19.50
Carson	13.58	15.59	29.17	13.86	14.07	27.93	18.76	5.74	24.50
Childress	13.58	15.59	29.17	13.86	14.07	27.93	18.76	5.74	24.50
Collingsworth	7.33	13.54	20.87	9.40	9.40	18.80	9.79	9.56	19.35
Dallam	2.57	20.35	22.92	6.12	17.17	23.29	5.35	-	5.35
Donley	10.79	12.44	23.23	7.72	14.46	22.18	10.07	10.20	20.27
Gray	12.02	15.12	27.14	12.75	13.55	26.30	16.52	6.68	23.20
Hall	7.08	15.04	22.12	9.23	13.33	22.56	9.00	10.99	19.99
Hansford	6.14	-	6.14	11.34	15.23	26.57	11.08	12.18	23.26
Hartley	3.91	21.07	24.98	7.81	16.68	24.49	7.55	13.36	20.90
Hemphill	8.89	-	8.89	10.52	12.45	22.97	12.03	8.58	20.61
Hutchinson	6.09	-	6.09	12.51	14.35	26.86	10.33	12.85	23.18
Lipscomb	8.27	-	8.27	10.07	12.22	22.29	11.14	8.97	20.10
Moore	4.24	20.94	25.18	9.49	14.75	24.24	7.94	12.54	20.48
Ochiltree	6.19	-	6.19	10.17	16.13	26.30	11.82	12.22	24.04
Oldham	5.95	22.75	28.70	7.83	19.65	27.48	11.16	12.71	23.87
Potter	5.95	22.75	28.70	7.83	19.65	27.48	11.16	12.71	23.87
Randall	5.95	22.75	28.70	7.83	19.65	27.48	11.16	12.71	23.87
Roberts	8.67	-	8.67	12.20	-	12.20	13.69	9.92	23.60
Sherman	5.30	21.71	27.01	8.42	18.06	26.48	9.83	13.09	22.92
Wheeler	12.96	15.41	28.37	13.41	13.87	27.28	17.86	6.12	23.98

Table A-6. NPET rainfall, irrigation, and combined water for cotton in Region A, 2000-2002.

Region A County	Rain-(in)	Irrig. (in)	Total (in)	Rain-(in)	Irrig. (in)	Total (in)	Rain-(in)	Irrig. (in)	Total (in)
	2000			2001			2002		
Armstrong	10.73	-	10.73	8.82	39.25	48.07	14.37	33.04	47.41
Carson	20.84	30.83	51.67	15.09	35.66	50.75	29.66	22.22	51.88
Childress	20.84	30.83	51.67	15.09	35.66	50.75	29.66	22.22	51.88
Collingsworth	15.85	-	15.85	9.85	38.83	48.68	17.08	27.28	44.36
Dallam	7.09	36.72	43.81	6.25	38.79	45.04	10.03	37.25	47.28
Donley	16.27	32.36	48.64	10.67	38.61	49.28	11.63	34.44	46.07
Gray	19.59	31.03	50.62	13.78	36.44	50.22	26.52	23.48	49.99
Hall	14.51	33.28	47.79	9.69	39.14	48.83	15.99	29.57	45.56
Hansford	12.49	38.77	51.25	12.20	38.81	51.01	14.91	35.42	50.33
Hartley	9.18	38.26	47.44	8.10	38.25	46.36	11.92	35.54	47.46
Hemphill	17.10	31.41	48.50	11.16	38.02	49.18	20.23	26.00	46.23
Hutchinson	10.76	39.35	50.11	13.64	35.77	49.41	13.92	36.69	50.61
Lipscomb	16.60	31.48	48.08	10.64	38.34	48.98	18.97	26.51	45.48
Moore	11.38	36.70	48.08	9.91	35.06	44.97	12.58	32.89	45.47
Ochiltree	14.21	36.88	51.09	10.76	40.89	51.65	15.90	34.15	50.05
Oldham	8.97	-	8.97	8.19	43.71	51.90	14.40	37.44	51.84
Potter	8.97	44.47	53.44	8.19	43.71	51.90	14.40	37.44	51.84
Randall	8.97	44.47	53.44	8.19	43.71	51.90	14.40	37.44	51.84
Roberts	15.33	35.98	51.31	13.18	-	13.18	19.93	30.72	50.65
Sherman	8.95	42.18	51.13	8.89	41.30	50.19	13.43	37.26	50.69
Wheeler	20.34	30.91	51.25	14.57	35.96	50.53	28.40	22.72	51.12

Table A-7. NPET rainfall, irrigation, and total water use for hay in Region A, 2000-2002.

Region A County	Rain-(in)	Irrig. (in)	Com. (in)	Rain-(in)	Irrig. (in)	Com. (in)	Rain-(in)	Irrig. (in)	Com. (in)
	2000			2001			2002		
Armstrong	10.73	-	10.73	8.82	-	8.82	14.37	32.04	46.41
Carson	20.84	29.83	50.67	15.09	34.66	49.75	29.66	21.22	50.88
Childress	20.84	29.83	50.67	15.09	34.66	49.75	29.66	21.22	50.88
Collingsworth	15.85	37.70	53.55	9.85	-	9.85	17.08	26.28	43.36
Dallam	7.09	35.72	42.81	6.25	37.79	44.04	10.03	36.25	46.28
Donley	16.27	31.36	47.64	10.67	37.61	48.28	11.63	33.44	45.07
Gray	19.59	30.03	49.62	13.78	35.44	49.22	26.52	22.48	48.99
Hall	14.51	32.28	46.79	9.69	38.14	47.83	15.99	28.57	44.56
Hansford	12.49	37.77	50.25	12.20	37.81	50.01	14.91	34.42	49.33
Hartley	9.18	37.26	46.44	8.10	37.25	45.36	11.92	34.54	46.46
Hemphill	17.10	-	17.10	11.16	-	11.16	20.23	25.00	45.23
Hutchinson	10.76	38.35	49.11	13.64	35.77	49.41	13.92	35.69	49.61
Lipscomb	16.60	30.48	47.08	10.64	37.34	47.98	18.97	25.51	44.48
Moore	11.38	35.70	47.08	9.91	34.06	43.97	12.58	31.89	44.47
Ochiltree	14.21	35.88	50.09	10.76	39.89	50.65	15.90	33.15	49.05
Oldham	8.97	43.47	52.44	8.19	42.71	50.90	14.40	36.44	50.84
Potter	8.97	43.47	52.44	8.19	-	8.19	14.40	36.44	50.84
Randall	8.97	43.47	52.44	8.19	42.71	50.90	14.40	36.44	50.84
Roberts	15.33	34.98	50.31	13.18	36.73	49.91	19.93	29.72	49.65
Sherman	8.95	41.18	50.13	8.89	40.30	49.19	13.43	36.26	49.69
Wheeler	20.34	29.91	50.25	14.57	-	14.57	28.40	21.72	50.12

Table A-8. NPET rainfall, irrigation, and combined water for pasture and other in Region A, 2000-2002.

Region A County	Rain-(in)	Irrig. (in)	Com. (in)	Rain-(in)	Irrig. (in)	Com. (in)	Rain-(in)	Irrig. (in)	Com. (in)
	2000			2001			2002		
Armstrong	7.85	-	7.85	8.65	-	8.65	10.56	30.95	41.51
Carson	14.40	-	14.40	14.88	-	14.88	19.85	9.86	29.71
Childress	14.40	31.83	46.23	14.88	15.08	29.96	19.85	15.78	35.63
Collingsworth	11.86	23.71	35.57	9.56	16.45	26.01	11.51	16.29	27.80
Dallam	2.77	-	2.77	6.25	-	6.25	7.23	-	7.23
Donley	16.27	25.09	41.36	9.08	17.28	26.36	10.47	18.44	28.91
Gray	13.77	-	13.77	13.55	-	13.55	17.77	15.90	33.67
Hall	10.83	28.35	39.18	9.40	17.01	26.41	10.53	18.37	28.90
Hansford	7.43	35.10	42.52	12.19	-	12.19	12.15	21.10	33.25
Hartley	4.28	-	4.28	8.09	-	8.09	8.96	22.83	31.79
Hemphill	12.50	-	12.50	10.89	-	10.89	13.60	16.15	29.75
Hutchinson	6.67	-	6.67	13.62	-	13.62	11.27	21.90	33.17
Lipscomb	12.24	-	12.24	10.36	-	10.36	12.76	16.21	28.97
Moore	4.72	-	4.72	9.91	-	9.91	9.14	21.07	30.21
Ochiltree	8.18	-	8.18	10.75	-	10.75	13.03	20.32	33.35
Oldham	6.42	-	6.42	8.14	-	8.14	12.06	23.19	35.25
Potter	6.42	-	6.42	8.14	-	8.14	12.06	23.19	35.25
Randall	6.42	-	6.42	8.14	-	8.14	12.06	23.19	35.25
Roberts	9.80	-	9.80	13.10	-	13.10	14.77	19.24	34.01
Sherman	5.74	-	5.74	8.86	-	8.86	10.94	23.17	34.11
Wheeler	14.15	31.28	45.43	14.35	15.21	29.56	19.02	15.83	34.84

Table A-9. NPET rainfall, irrigation, and combined water for peanuts in Region A, 2000-2002.

Region A County	Rain- (in)	Irrig. (in)	Com. (in)	Rain- (in)	Irrig. (in)	Com. (in)	Rain- (in)	Irrig. (in)	Com. (in)
	2000			2001			2002		
Armstrong	6.33	10.58	16.91	8.40	5.93	14.33	9.48	10.64	20.13
Carson	13.58	10.28	23.86	13.86	7.30	21.16	18.76	6.47	25.23
Childress	13.58	10.28	23.86	13.86	7.30	21.16	18.76	6.47	25.23
Collingsworth	7.33	10.58	17.91	9.40	8.31	17.71	9.79	9.96	19.75
Dallam	2.57	16.62	19.19	6.12	12.48	18.60	5.35	15.21	20.56
Donley	10.79	8.99	19.77	7.72	10.09	17.81	10.07	10.66	20.74
Gray	12.02	10.38	22.39	12.75	7.56	20.30	16.52	7.33	23.84
Hall	7.08	11.54	18.63	9.23	8.91	18.14	9.00	11.44	20.43
Hansford	6.14	14.75	20.89	11.34	8.85	20.19	11.08	12.78	23.85
Hartley	3.91	16.36	20.27	7.81	10.69	18.50	7.55	13.97	21.52
Hemphill	8.89	10.52	19.41	10.52	8.06	18.58	12.03	9.07	21.10
Hutchinson	6.09	13.03	19.12	12.51	7.75	20.26	10.33	13.50	23.83
Lipscomb	8.27	10.55	18.81	10.07	8.16	18.23	11.14	9.42	20.56
Moore	4.24	15.74	19.98	9.49	8.24	17.73	7.94	13.03	20.97
Ochiltree	6.19	14.33	20.52	10.17	9.97	20.14	11.82	12.07	23.89
Oldham	5.95	17.12	23.07	7.83	12.17	20.00	11.16	13.46	24.62
Potter	5.95	17.12	23.07	7.83	12.17	20.00	11.16	13.46	24.62
Randall	5.95	17.12	23.07	7.83	12.17	20.00	11.16	13.46	24.62
Roberts	8.67	13.16	21.83	12.20	8.32	20.51	13.69	10.56	24.25
Sherman	5.30	16.62	21.92	8.42	11	19.74	9.83	13.81	23.64
Wheeler	12.96	10.32	23.28	13.41	7.41	20.82	17.86	6.81	24.67

Table A-10. NPET rainfall, irrigation, and combined water for sorghum in Region A, 2000-2002.

Region A County	Rain-(in)	Irrig. (in)	Com. (in)	Rain-(in)	Irrig. (in)	Com. (in)	Rain-(in)	Irrig. (in)	Com. (in)
	2000			2001			2002		
Armstrong	7.85	25.12	32.97	8.65	6.79	15.44	10.56	9.69	20.25
Carson	14.40	18.11	32.51	14.88	6.85	21.73	19.85	5.39	25.24
Childress	14.40	-	14.40	14.88	6.85	21.73	19.85	5.39	25.24
Collingsworth	11.86	-	11.86	9.56	9.03	18.59	11.51	8.61	20.12
Dallam	2.77	23.64	26.41	6.25	12.32	18.57	7.23	13.19	20.42
Donley	16.27	13.68	29.95	9.08	9.80	18.87	10.47	10.12	20.59
Gray	13.77	17.52	31.28	13.55	7.56	21.11	17.77	6.18	23.95
Hall	10.83	-	10.83	9.40	9.52	18.92	10.53	10.07	20.59
Hansford	7.43	-	7.43	12.19	9.18	21.36	12.15	11.31	23.46
Hartley	4.28	24.36	28.64	8.09	10.71	18.80	8.96	12.43	21.39
Hemphill	12.50	-	12.50	10.89	8.48	19.37	13.60	7.79	21.38
Hutchinson	6.67	20.18	26.85	13.62	7.86	21.48	11.27	12.18	23.45
Lipscomb	12.24	16.07	28.31	10.36	8.70	19.05	12.76	8.11	20.88
Moore	4.72	24.37	29.09	9.91	8.39	18.30	9.14	11.83	20.97
Ochiltree	8.18	21.85	30.03	10.75	10.53	21.28	13.03	10.44	23.47
Oldham	6.42	-	6.42	8.14	12.27	20.41	12.06	12.15	24.21
Potter	6.42	25.83	32.25	8.14	12.27	20.41	12.06	12.15	24.21
Randall	6.42	25.83	32.25	8.14	-	8.14	12.06	12.15	24.21
Roberts	9.80	21.35	31.14	13.10	8.38	21.48	14.77	9.23	24.00
Sherman	5.74	25.10	30.84	8.86	11.36	20.22	10.94	12.36	23.30
Wheeler	14.15	17.87	32.02	14.35	7.06	21.41	19.02	5.71	24.72

Table A-11. NPET rainfall, irrigation, and combined water for soybeans in Region A, 2000-2002.

Region A County	Rain- (in)	Irrig. (in)	Com. (in)	Rain- (in)	Irrig. (in)	Com. (in)	Rain- (in)	Irrig. (in)	Com. (in)
	2000			2001			2002		
Armstrong	14.91	8.92	23.83	13.40	9.33	22.73	7.42	15.62	23.03
Carson	20.95	9.05	30.00	21.50	5.08	26.58	13.09	15.38	28.47
Childress	20.95	-	20.95	21.50	5.08	26.58	13.09	15.38	28.47
Collingsworth	22.50	5.06	27.56	15.51	7.60	23.11	10.97	13.07	24.04
Dallam	7.13	15.23	22.36	11.60	12.56	24.16	5.81	21.77	27.58
Donley	0.78	7.04	7.82	0.52	8.54	9.06	0.07	14.84	14.90
Gray	21.34	8.05	29.39	20.00	5.70	25.70	12.56	14.81	27.37
Hall	13.52	11.40	24.92	14.97	8.44	23.41	10.09	14.65	24.74
Hansford	11.10	15.65	26.75	9.60	13.25	22.85	8.41	19.74	28.15
Hartley	9.27	14.78	24.05	8.83	14.09	22.92	5.72	20.38	26.10
Hemphill	22.11	6.05	28.17	15.21	8.12	23.33	10.56	14.32	24.88
Hutchinson	11.47	16.02	27.49	10.13	13.74	23.87	8.02	19.95	27.97
Lipscomb	23.81	4.69	28.51	16.41	7.22	23.62	11.98	12.93	24.91
Moore	10.32	13.39	23.71	10.76	11.67	22.43	6.37	17.10	23.47
Ochiltree	10.72	16.15	26.87	14.48	9.05	23.53	9.90	18.71	28.61
Oldham	11.45	16.73	28.18	12.65	12.63	25.28	6.06	22.69	28.75
Potter	11.45	16.73	28.18	12.65	12.63	25.28	14.02	16.63	30.65
Randall	11.45	16.73	28.18	12.65	12.63	25.28	6.06	22.69	28.75
Roberts	14.45	13.32	27.77	16.08	8.74	24.82	10.31	18.00	28.30
Sherman	10.59	16.11	26.70	11.83	12.90	24.74	6.37	21.98	28.34
Wheeler	21.11	8.65	29.76	20.90	5.32	26.22	12.88	15.16	28.03

Table A-12. NPET rainfall, irrigation, and combined water for wheat in Region A, 2000-2002.