IRRIGATION SYSTEM AND PUMPING PLANT EFFICIENCY EVALUATIONS: 1978-1981

LP-191

TEXAS DEPARTMENT OF WATER RESOURCES

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IRRIGATION SYSTEM AND PUMPING PLANT EFFICIENCY EVALUATIONS: 1978-1981

Principal Cooperators:

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High Plains Underground Water Conservation District No. 1
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FOREWORD

In 1980, irrigation water use was about 71 percent of the total water use in the State. This use of a limited resource, and the accompanying energy costs to provide this water, is of concern to many local, state, and federal agencies and especially to the irrigation farmer. The Texas Department of Water Resources presents this publication in the interest of promoting cooperative programs to improve irrigation water use efficiency through use of irrigation water conservation practices.

This publication is a combination of two separate reports. Irrigation System Efficiency Evaluations Using Mobile Field Water Labs: 1978-1981 was prepared by the Department with considerable assistance from Soil Conservation Service of the United States Department of Agriculture. The second report, Irrigation Pumping Plant Efficiency Testing on the Texas High Plains, was prepared by the High Plains Underground Water Conservation District No. 1 with assistance from the Soil Conservation Service, the Texas A&M Agricultural Extension Service, and the Bailey County, Deaf Smith County, and Swisher County, and Lighthouse Electric Cooperatives. These reports represent only the initial progress of these programs for irrigation efficiency testing and data collection which are continuing and expanding into other parts of the State.

Texas Department of Water Resources

Charles E. Nemir

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Executive Director

FOREWORD

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Texas Department of Water Resources

Charles E. Nemir

Executive Director

IRRIGATION SYSTEM EFFICIENCY EVALUATIONS USING MOBILE FIELD WATER LABS -- 1978-1981

By staff of the

Texas Department of Water Resources

ABSTRACT

Local, state, and federal agencies have developed a cooperative program of irrigation efficiency testing and data collection service to provide the State's irrigators with a means to evaluate their irrigation systems and increase irrigation water use efficiency. During the period 1978-1981, 425 irrigation systems in the High Plains and Winter Garden areas of Texas were evaluated for irrigation efficiencies by personnel of the United States Department of Agriculture-Soil Conservation Service using Mobile Field Water Laboratories.

The estimated average system efficiency was 61 percent for center-pivots (278 evaluations), 47 percent for side-roll sprinklers (33 evaluations), and 60 percent for furrow systems (98 evaluations). Seventeen sprinkler systems were reevaluated after improvements were made on these systems. System efficiency improved about 10 percent following these improvements. If the systems evaluated are typical of irrigation systems in this portion of Texas, then a 10 percent increase in efficiency is possible and would be beneficial to reduce water use.

Tabulation and analyses of these evaluation results are provided in this report, along with a brief description of the procedures used in evaluation of an irrigation system. If more information is desired, either the Soil Conservation Service or any of the appropriate local agencies (listed in the report) are available to provide assistance concerning the irrigation efficiency study.

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Mr. Wayne Wyatt, Manager, with support of the staff and directors of the High Plains Underground Water Conservation District No. 1, in cooperation with Messrs. Mickey Black, Myron Namken, and the field office staff (Lubbock area) of the United States Department of Agriculture-Soil Conservation Service developed and organized the irrigation system efficiency evaluation program. Others who participated in the program included: 1) the managers, staff and directors of the North Plains Water Conservation District, Panhandle Ground Water Conservation District, Edwards Underground Water District, and Maverick County Water Control and Improvement District; 2) Soil Conservation Service State Office staff, Soil Conservation Service area and field office staff in the Amarillo, Pampa, Big Spring, Vernon, and Uvalde areas; 3) Texas State Soil and Water Conservation Board staff and directors of local soil and water conservation districts; and 4) administrators and staff of the Texas Department of Water Resources.

Appreciation is expressed to those in the news and information media who have informed the public about this program by providing reports on the program activities. In addition, the authors acknowledge the support and interest of the 425 irrigators who cooperated in the evaluations of their irrigation systems during the 1978-1981 period covered in this report.

ACKNOWLEDGMENTS

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IRRIGATION SYSTEM EFFICIENCY EVALUATIONS USING MOBILE FIELD WATER LABS -- 1978-1981

Introduction

The history of irrigation farming in Texas antedates any written record available, and irrigation was widley practiced in several areas of the State before 1900. There was an increase in irrigated acreage in Texas soon after 1900, but a phenomenal rate of increase occurred in the Texas High Plains after World War II. In 1980, irrigation water use in Texas was about 12.7 million acre-feet for 8.1 million acres of irrigated land with irrigation use representing about 71 percent of the 17.8 million acre-feet total water use in the State.

Irrigated agriculture was vital to the existence of the early settlements, especially those in the arid parts of the State. Today, irrigation plays a significant role in the agricultural economy of the State. Data for 1980 indicate that the cash value of crop production statewide was approximately $3.8 billion. Of this amount, the value of irrigated crops was estimated at over 50 percent of total crop production from an estimated one-third of the total cropland in the State.

Recognizing that agriculture is the largest user of water in the State, water conservation (reduction in loss or waste of water, or improvement in water use efficiency) is a major concern of the Texas Department of Water Resources and others. Statewide, on-farm irrigation water use efficiency (amount of irrigation water stored in soil for plant use versus amount of water pumped for irrigation) is estimated to be about 60 to 70 percent. Using available technology, this efficiency could be improved to about 75 to 80 percent, which could reduce irrigation water use to maintain current acreage by about 2.0 million acre-feet annually.

During 1978, the High Plains Underground Water Conservation District No. 1 and United States Department of Agriculture - Soil Conservation Service (USDA-SCS) area staff at Lubbock, Texas developed a program to assist irrigation farmers in evaluating individual irrigation systems. This program was implemented in 1979 using Mobile Field Water Laboratories (trailer units equipped with water meters, pressure gages, soil moisture testers, and other instruments shown in Figures 1, 2, 3 and 4 and Appendix A) with the USDA-SCS providing the personnel to perform the evaluations. The Texas Department of Water Resources provided financial assistance for the program in order to obtain data on irrigation water use and conservation practices as required for the Department's statewide water resource planning. Since that time, other ground-water conservation districts and soil and water conservation districts joined the program to provide this service to irrigation farmers in several parts of the State (Appendix B).

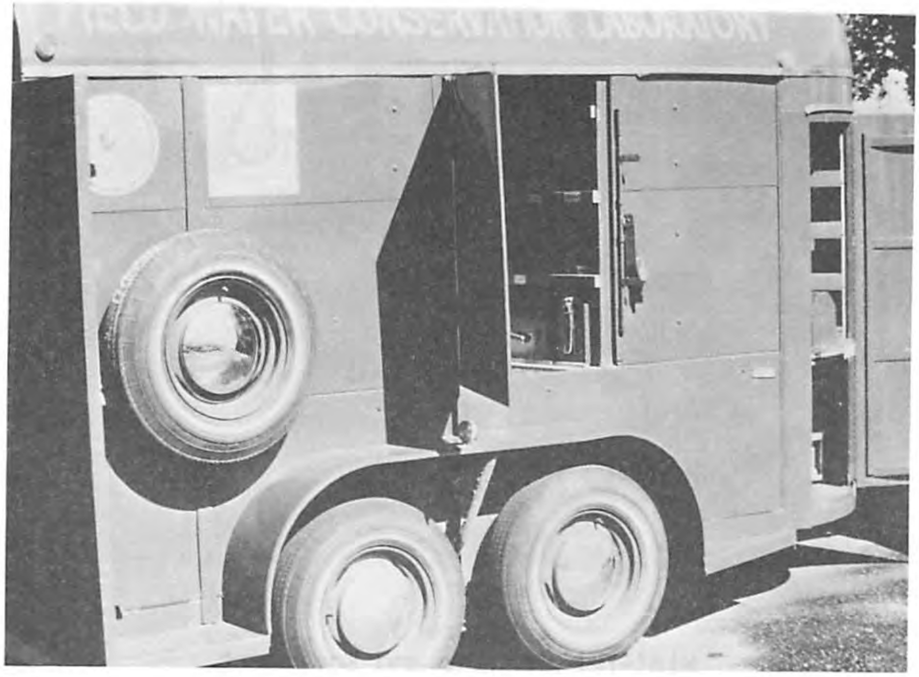


Figure 1
Mobile Field Water Laboratory

Figure 2
Mobile Field Water Laboratory and Equipment

Figure 3
Mini-Lab Trailer and Equipment

Figure 4
Mini-Lab in use at Evaluation Site

Collection of Data[1]

Irrigation efficiencies, as used herein, are defined as follows:

1. Distribution (pattern) - uniformity of application of water across the field with sprinklers, or uniformity of water applied along the furrow length.

2. Application - relationship of how much of the irrigation water enters into and is stored in the soil profile to the amount of water provided for irrigation use from a well or farm headgate.

3. System - combination of distribution and application efficiencies to identify how well the irrigation system is performing the function of providing irrigation water to the crop being irrigated.

To perform the steps necessary to evaluate the irrigation systems, USDA-SCS personnel developed standard procedures, guides and materials for training of and use by field personnel involved in the evaluations. To develop a handbook of material on basic principles and procedural guides for evaluating irrigation systems, existing material was modified and new methods were developed. Guides were prepared to provide information on plant-soil-water relationships, determining soil moisture levels, metering rates of flow, determining gross irrigation application rates, and other related basic irrigation information.

1/ This section is extracted from a paper presented by Myron Namken at the Eighth Annual Conference of the Ground-Water Management Districts Association on December 3, 1981, at Lubbock, Texas and unpublished material developed by USDA-Soil Conservation Service-Texas, Lubbock, Area.

Training guides on how to perform tasks were written so that the following jobs could be accomplished:

Evaluate center-pivot sprinkler systems (Appendix C)

Evaluate other types of sprinkler systems (side-roll, tri-matic, and hand move)

Evaluate furrow systems (Appendix D)

Evaluate border-flood systems

Determine soil moisture levels (Appendix E)

Equipment necessary to collect this information includes turbine water meters, orifice plates, velocity water meters, soil moisture meters, pressure gages, probes, augers, shovels, wrenches, screwdrivers, pliers, hoses, fittings, adapters, and other incidental items (Table 1, pages 23, 24).

One service provided to farmers is a soil moisture guide for his soil. The standard county soil surveys are used to identify the soil types. The SCS Irrigation Guide has information on soil intake families and water-holding capacities. A chart correlates the percent available water, percent water by weight, soil tension, and instrument scales. Using these guides (Appendix E), a graph can be developed to show the quantity of water to apply when the soil water content is measured or by sensing the soil moisture through "feeling" by human touch.

To insure that the farmer is provided with good soil moisture data, tools which may be used are: a soil probe, 3-inch bucket auger, soil volume meter, volume meter extension, camp stove (to dry soil samples), gram scale, pans, metal boxes, and a knife (Figure 5). The soil is normally checked to a depth of 3 feet but may be checked to a depth of 6 feet. While working with an irrigation farmer on soil water, the SCS shows the irrigator how various soil

Figure 5
Gypsum Blocks and Meter to Test Soil Moisture

Figure 6
Drying Soil Moisture Samples

moisture instruments work, how to install them, and how to interpret their readings (Figure 6).

The "lab" can be used to evaluate center-pivot sprinkler systems with impact heads, spray heads, spray heads on drops, and the new drop tube furrow systems. Also, it can be used to evaluate conventional side-roll sprinklers, furrow systems, and border systems.

Center-Pivots and Side Roll Sprinklers

The training guide for center-pivots (Appendix C) provides the detailed procedure to be used. In brief, the evaluation of a center-pivot system requires five activities.

The first step is to check electrical safety. Electrical wiring at the pivot is checked for a short circuit with a voltmeter, ohmmeter, or milliammeter. Observations are made for grounding and insulation on wiring. Farmers are reminded of safety precautions and encouraged to make periodic checks on their own.

Secondly, the quantity of water being pumped must be known. There are several instruments that can be used to measure water well yields. Those most commonly used are the propeller meter and velocity meter. The propeller meters are standard saddle types mounted on a joint of pipe which has been modified with standard size aluminum pipe fittings. Several reducers and increasers are made so the meter can be used on various pipe sizes (Figure 7). The meter can be coupled into most aluminum pipeline or onto outlets. It can also be used to test the capacity of a well under various pressures when planning new sprinkler systems.

The velocity meters can be installed in a one-half inch or larger pipe fitting on a closed pipe system. Adapters are available for other opening

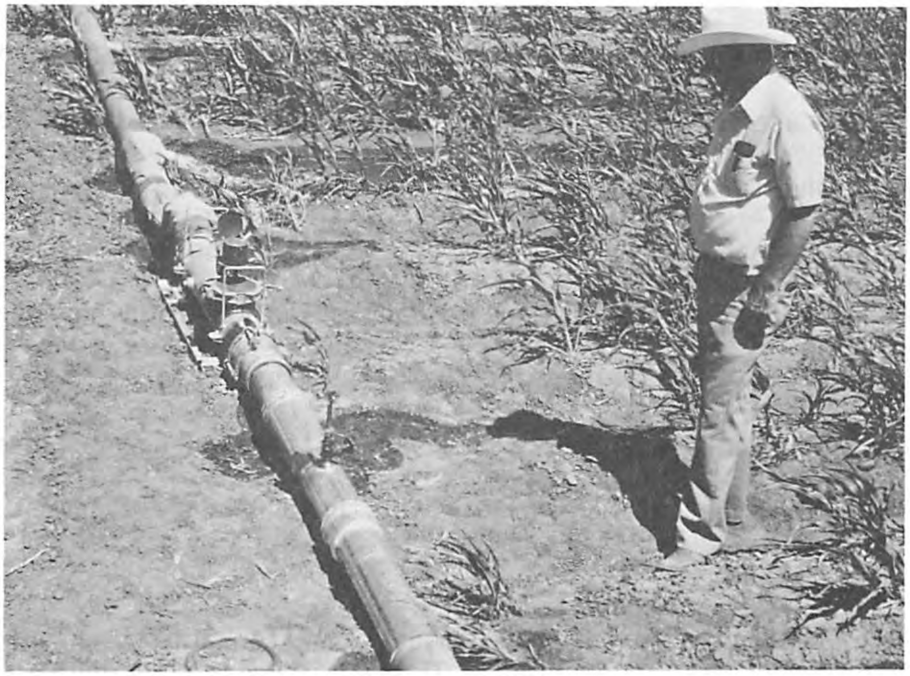


Figure 7
Flow Meter Coupled into Pipeline

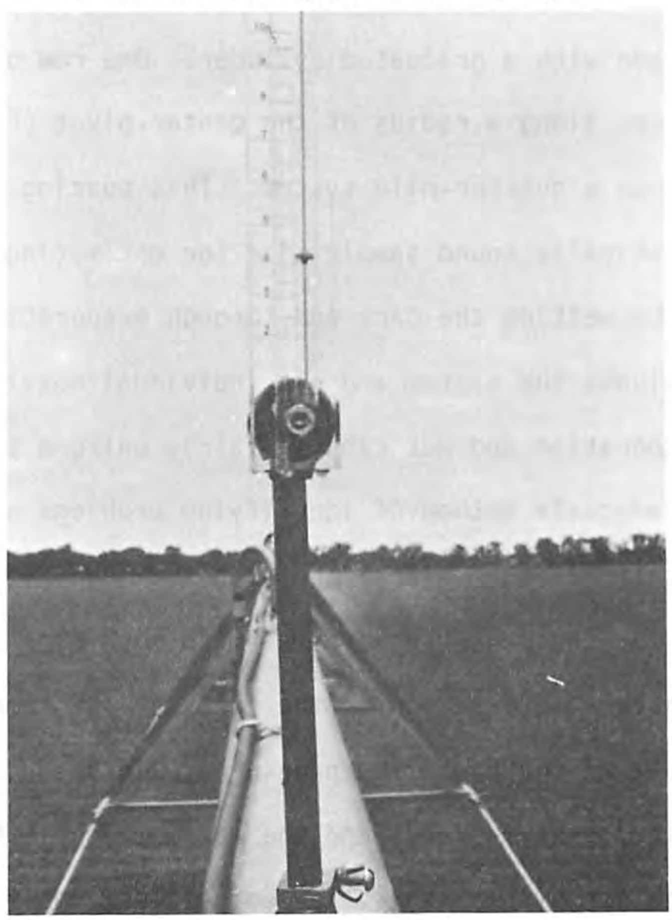


Figure 8
Velocity Meter in Place on a Center-Pivot

sizes. The velocity meter is dependable and reasonably accurate and has proven to be very useful on center-pivot sprinklers (Figure 8). The calibrated scale on the meter, however, is inaccurate for pipe sizes larger than 3 inches. Through a cooperative effort with the Civil Engineering Department at Texas Tech University, the Texas Tech hydraulic lab was used to recalibrate the meter for pipes 4 to 8 inches in diameter. Also, some of the meters were recalibrated by the Science and Education Administration-Agriculture Research (SEA-AR), U.S. Department of Agriculture, at the USDA facilities at Bushland, Texas.

The third step is to measure the amount of water actually applied to the soil surface. On sprinkler systems, spray catch "cans" are used to catch water as the sprinkler passes over the cans. Volumetric measurements of the amount caught are made with a graduated cylinder. One row of cans is set with can spacing at 30 feet along a radius of the center-pivot (Figure 9). This takes about 45 cans on a quarter-mile system. This spacing does not necessarily give a statistically sound sample size for estimating efficiency and some water is lost by wetting the cans and through evaporation. Since the objective is to evaluate the system and not individual nozzles, and since the water loss from evaporation and wet cans is fairly uniform throughout, the procedure gives an adequate method of identifying problems with distribution patterns and application losses within the system.

While waiting for the center-pivot system to move over the cans, the fourth step is to gather information on the flow rate of some of the individual nozzles, as well as the operating pressure, wind speed, air and soil temperature, humidity, system speed, and the maximum application rate. Inspections are made for system leaks, fouled nozzles, inefficient nozzles, water puddling, runoff, loose braces, and a check on the crop appearance, all of which are noted on the evaluation form.

After gathering the data, it is necessary to plot the can catches and compute efficiencies. Experimental errors may affect the value at any one catch site (can). Therefore, as a representative value for the distribution and system efficiency, the minimum catch is computed as the average for the lowest 1/4 of the water depths in the cans. The objective of this efficiency concept is to pinpoint where improvements can be made which will result in more efficient irrigation. The sprinkler efficiencies related to in this publication are defined as follows:

$$\text{Pattern efficiency (Percent)} = \frac{\text{Lowest average catch of 1/4 of the area} \times 100}{\text{Average catch of the entire area}}$$

$$\text{Application efficiency (Percent)} = \frac{\text{Average catch of the entire area} \times 100}{\text{Amount pumped into the system}}$$

$$\text{System efficiency (Percent)} = \frac{\text{Lowest average catch on 1/4 of the area} \times 100}{\text{Amount pumped into the system}}$$

When the evaluation is completed, the farmer is provided a copy along with alternative recommendations for improvements. A copy of the system design for the center-pivot may be supplied by the sprinkler manufacturer and is helpful to compare with the evaluation data. The evaluation data are transmitted to the Texas Department of Water Resources for use in estimating long-range water requirements for irrigation. A typical evaluation on a center-pivot system is found in Appendix C. Basically, other types of sprinklers are evaluated with the same methodology, except for differences in movement of the system.

Figure 9
Catch Cans Under a Center-Pivot

Figure 10
Furrow Evaluation Using an Orifice Plate

Examples of some types of problems identified in these evaluations and what was accomplished by the farmers are as follows:

1) Problem: Five wells did not produce enough water for three side-roll systems operating simultaneously.
   Solution: Install a 22,000 gallon collector tank and booster pump.
   Results: Increased capacity of system by 50 percent and reduced energy cost by 35 percent. Increased sprinkler nozzles two sizes and all three side-rolls can be operated simultaneously.

2) Problem: Low system efficiency of a center-pivot system.
   Solution: Re-design and change sprinkler heads from half-circle sprays on drops to low angle impact.
   Results: Increased system efficiency from 50 percent to 75 percent.

3) Problem: Low center-pivot efficiency.
   Solution: Re-design and re-orifice heads.
   Results: Increase efficiency from 73 percent to 85 percent.

4) Problem: Efficiency of center-pivot at 60 percent, not enough water available.
   Solution: Convert spray nozzles on drops to a drop tube furrow system on skip row pattern.
   Results: System efficiency improved to 82 percent and energy consumption was reduced by 20 percent.

5) Problem: Used gate valve to regulate flow from wells to center-pivot.
   Solution: Trim impellers on booster pump to regulate flow.
   Results: Energy cost of booster pump reduced from $1.16 to $0.64 per acre-inch.

Furrow System and Border Systems

The normal procedure in evaluating a furrow system (Appendix D) is to divert streams of water into several furrows and, with the orifice plates, check the rate at which the stream fronts advance. A modified version, which greatly reduces the time required for an evaluation, uses information obtained from the farmer. This modified version of evaluation is based on how long water stands on five points in the furrow. Knowing when the water was started in the furrow, when it reached the end, and how long it continued to flow, will provide an estimate of how long it stood on each of the five points.

Also, knowing how much water was applied to the furrow and how much ran off as tailwater, if any, is necessary to the evaluation.

If the irrigator knows how much water was applied to the soil and how long the water stood on the soil, the water intake rate for the soil, and how much water entered the soil at each of the five stations, he can compare the water applied to each station to the water needed before irrigation and then compute the efficiency and evaluate the results. As with sprinkler systems, the representative minimum distribution is computed as the average of the lowest 1/4 of the measurements. The furrow efficiency is defined as follows:

$$\text{Pattern (Distribution) Efficiency (Percent)} = \frac{\text{Average water applied to root zone in low 1/4 area} \times 100}{\text{Average water applied to root zone in furrow}}$$

$$\text{Application Efficiency (Percent)} = \frac{\text{Average water applied to root zone in furrow} \times 100}{\text{Water pumped}}$$

$$\text{System efficiency (Percent)} = \frac{\text{Average water applied to root zone in low 1/4 area} \times 100}{\text{Water pumped}}$$

Also, the evaluation measures the water lost in a ditch or estimates it by using a guide. Measurements of flow rate in a ditch or in the furrow is by use of an orifice plate placed in the path of the stream of water (Figure 10). A typical evaluation of a furrow system is found in Appendix D.

Evaluation of a border system is similar to the furrow system. For a border system, the amount of irrigation water needed (soil moisture deficit) is calculated, stream size (flow rate) is computed, time of advancement and recession of water at various stations in the border are measured and intake rate of soils is computed. Data on the time and rate of flow allow one to determine the total amount of water applied which is compared to the amount of water stored in the soil, and the distribution and application efficiencies are computed.

Analysis of
Efficiency Evaluation Data

Analyses of efficiency evaluation data for center-pivot sprinklers, side-roll sprinklers, furrow systems and border systems are presented in the following sections and are summarized in Tables 2, 3, 4, and 5. The tables also include data on wind speed, system pressure, flow rate, nozzle type, and nozzle spacing for sprinklers and data on furrow length, flow rate, slope, and soil intake rate for furrow and border systems. Analysis of these additional parameters in relation to the efficiencies was inconclusive; therefore, only the analyses of the efficiencies (distribution, application, system) are included in this report.

Center-Pivot Sprinklers

Evaluations from 278 center-pivot sprinklers (Table 2) show an average system efficiency of 61 percent, with a range in values from about 30 percent to above 90 percent. The average distribution efficiency was 74 percent, with an average application efficiency of 83 percent. Only 45 of the 278 systems had an application efficiency of less than 70 percent.

Although only four center-pivots with the drop tube and sock outlets were evaluated, it is of interest that all four of these systems had 100 percent application efficiency. Three of the four drop tube and sock systems had distribution efficiencies of over 80 percent. The drop tube and sock system appears to be a very efficient means of applying irrigation water through a center-pivot when the system is adaptable to the crops and farming methods used by the irrigator.

Side-Roll Sprinklers

For the 33 side-roll sprinkler systems evaluated (Table 3), the average system efficiency was 47 percent, with a range in values from about 30 percent to above 70 percent. Twenty-one of the 33 systems had a system efficiency of less than 50 percent. The average distribution efficiency was 62 percent and the average application efficiency was 74 percent. Seven of the systems had an application efficiency of less than 60 percent, however, six of the systems had an application efficiency of more than 90 percent.

Distribution efficiency of the systems evaluated indicates that some side-roll systems need improvement through better selection of nozzle sizes and spacings. Six of the systems had a distribution efficiency of less than 50 percent and an additional 10 systems had distribution efficiencies of less than 60 percent. Only three systems had distribution efficiencies of more than 80 percent. The overall average efficiencies indicate that some side-roll systems could be improved to increase the effective use of water (distribution efficiency) and to reduce pumpage (application efficiency).

Furrow Systems

For the 98 furrow systems evaluated (Table 4), the average system efficiency was 60 percent, with a range in value from about 30 percent to above 90 percent. The average distribution efficiency was 74 percent. Eleven of the systems had a distribution efficiency of less than 50 percent; however, 16 of the systems had a distribution efficiency of more than 90 percent.

Although not shown as a separate value in the summary (Table 4), the average application efficiency of furrow systems evaluated was 81 percent.

Whereas the application loss with sprinklers is generally by evaporation, the application loss with furrow systems is mainly by tailwater or deep percolation. From the results of the furrow system evaluations, it appears that a properly managed furrow system can be an efficient means of water application in situations suited to furrow systems, such as proper soil textures and nearly level slopes.

Border Irrigation Systems

Only three border irrigation systems (Table 5) were evaluated during the 1978-1981 period. These evaluations indicate that these systems have a good efficiency (82, 88, and 89 percent) of distributing water to the root zone throughout the border area. However, in trying to insure that irrigation water is adequately supplied to the lower end of the border, a combination of border length, slope, and intake rate can often result in the water being applied for a longer time period than is necessary to fill the soil profile. Since these are closed border systems, the excess water is lost as deep percolation and the application efficiency (water stored in soil/water applied) is sometimes quite low as indicated by the system efficiency of two of these border systems (Table 5). Conventional improvements for these systems would be to increase the flow rate of the stream to advance water more rapidly or reduce the width of the border which provides more water at a faster rate to the border being irrigated.

Improved Systems - Before and After

Following the completion of an initial irrigation system efficiency evaluation, 17 irrigation systems were improved using the recommendations provided in the evaluations. These systems were then reevaluated in order to compare the efficiency of the improved system to that of the original system. An analysis of the "before and after" evaluations was made for 15 center-pivots and 2 side-roll sprinkler systems (Table 6). During 1978-1981, there were no reevaluations performed on furrow or border irrigation systems.

For the improved systems which were reevaluated, the average distribuion efficiency increased from an initial 71 percent to 77 percent following improvements. Application efficiency improved from 82 percent to 88 percent, and average system efficiency improved from an initial 58 percent to 68 percent following improvements (Table 6).

A case-by-case analysis of these evaluations showed that the efficiencies improved when the pressure matched the system design and the nozzle designs. Replacement of 360° spray nozzles or regular impact nozzles with low angle impact nozzles of the correct size for the pressure used appeared to contribute to the improvement in efficiency.

Conclusions and Recommendations

Based on the number of requests for assistance received by the Soil Conservation Service, Mobile Field Water Labs have proven to be a popular and effective means to assist irrigation farmers in evaluating their irrigation systems. Results of the 425 irrigation system evaluations performed during the 1978-1981 period indicate that many irrigation systems are fairly efficient. However, improvements can and should be made on these as well as on systems which are considerably less efficient than desired or feasible. Improvements of 10 percent or more in overall efficiency can be expected in most systems when they incorporate improvements recommended by an efficiency evaluation.

Based on the results and performance of the irrigation system efficiency evaluation program during 1978-1981, the cooperating entities and sponsors should continue to provide and promote this program. Also, agricultural research and extension agencies, as well as commercial enterprises, should continue to develop and promote practices and equipment (such as improved nozzles, soil moisture testers, pressure regulators, metering devices, and irrigation guides) which assist in improving irrigation efficiencies. Irrigators who are not sure that their systems are operating at satisfactory efficiencies should inquire at the local office of the Soil Conservation Service, soil and water conservation district, underground water conservation district, or Agricultural Extension Service for information on evaluating and improving an irrigation system.

Table 1
Typical Mini-Trailer Unit & Equipment

Quantity	Item
1	Mini-Trailer (See Appendix A)
	Equipment and Instruments*
1	Cox, Piro Velocity Gauge Set
1	500' Drawdown Gauge & extra tip
1	Bouyoucos Moisture Meter
10	Gypsum Blocks
1	Tensiometer vacuum pump/gauge
3	Tensiometers (12"-24"-36")
1	Tube Soil Probe
1	36" Soil Moisture Meter/Meter Mate
1	8" Rockwall Meter
1	8" Pierce In-Line Valve
1	6" McCrometer Meter
1	6" Pierce In-Line Valve
1	4" McCrometer Meter
1	4" Pierce In-Line Valve
1	7" to 6" Reducer
1	6" to 7" Increaser
1	8" to 6" Reducer
1	6" to 8" Increaser
1	6" to 4" Reducer
1	4" to 6" Increaser
1	8" Tube 5' Long w/1" Nipple
1	6" Tube 5' Long w/1" Nipple
1	4" Tube 5' Long w/1" Nipple
1	Senninger 0-100 PSI Gauge/Pitot Tube
1	50' Tape
1	Taylor Pocket Sling Psychrometer
1	Tube Soil Thermometer
1	Wind Velocity Meter
2	3/4" Gate Valve
4	Orifice Plates - various sizes
2	Stop Watch
2	500 ml. Graduated Cylinder
1	100 ml. Graduated Cylinder
1	Sperry V-A Hook-on Meter
1	Sperry Model 142 Multi-Tester
2	Set of Fittings & Bushings (6)
1	Rainbird Pressure gauge-faucet

Table 1. continued

Quantity	
	Tools
1	Tool Box (20" x 8" x 8")
1	18" Pipe Wrench
1	10" Pipe Wrench
1	10" Adjustable Wrench
1	16" Adjustable Wrench
1	6-piece set open end wrenches
1	Regular Pliers
1	Water pump pliers
1	Open end wrench 1-1/4 x 1-5/16
1	Open end wrency 15/16 x 1
1	16' Extension Ladder
1	13 piece set drill bits (64ths)
2	Regular screwdrivers (3/16 x 4, 5/16 x 8)
2	Phillips screwdrivers (No. 1,3)
1	72" tape
1	Hatchet
1	100 point scale
	Miscellaneous
1	25' water hose
1	12' of 2" hose (plastic or rubber)
1	12' of 3/4" water hose
1	Canvas sleeve
1	5 gallon bucket
1	2 gallon can
2	Clipboard
100	Wooden Stakes
50	Spray Catch Cans (quart oil cans)
1	10' security chain
1	Padlock
2	Ponchos
2	Pair Rubber Boots

* Brandnames are for descriptive use only, mention does not imply recommendation of these or exclusion of other brands.

Table 2

Summary of Center-Pivot Sprinkler Evaluations

Table 2 - Summary of Center-Pivot Evaluations

Test No.	SCS Administrative Area (town)	NOZZLE Type	NOZZLE Location	Wind Speed (mph)	PIVOT DATA Pressure (psi)	PIVOT DATA Flowrate (gpm)	EFFICIENCY Pattern (%)	EFFICIENCY Application (%)	EFFICIENCY System (%)
1	Amarillo	spray	drop	12	23	480	74	90	67
2	Amarillo	spray	drop	5	32	500	73	95	70
3	Amarillo	impact	top	11	70	270	76	60	46
4	Amarillo	spray	drop	18	11	260	52	69	36
5	Amarillo	spray	drop	14	30	665	59	85	50
6	Amarillo	360° spray	drop	13	14	270	56	83	47
7	Amarillo	impact & spray	top & side	5	30	370	92	95	87
8	Amarillo	impact	top	12	27	410	69	86	59
9	Amarillo	impact	drop	6	36	600	71	89	63
10	Amarillo	spray	drop	10	26	570	63	88	55
11	Amarillo	impact	top	10	26	510	94	98	92
12	Amarillo	impact	top	8	16	470	42	94	39
13	Amarillo	360° spray	drop	10	36	750	79	62	48
14	Amarillo	spray	top	10	31	700	75	70	53
15	Amarillo	spray	drop	3	45	500	71	98	70
16	Amarillo	impact	drop	25	39	485	53	68	36
17	Amarillo	spray	top	20	32	490	90	93	84
18	Amarillo	inverted impact	drop	2	40	640	62	77	42
19	Amarillo	impact	top	11	56	710	76	79	60
20	Amarillo	impact	top	20	35	545	70	63	44
21	Amarillo	spray	top	10	28	600	73	84	61
22	Amarillo	spray	top	5	28	780	84	59	50
23	Amarillo	180° spray	drop	10	27	450	75	99	74
24	Amarillo	impact	drop	12	39	480	72	100	72
25	Amarillo	180° spray	drop	10	26	500	71	100	71
26	Amarillo	impact	top	12	75	420	57	87	49
27	Amarillo	180° spray	drop	5	26	800	68	72	49

(continued)

Table 2 - Summary of Center-Pivot Evaluations (continued)

Test No.	SCS Administrative Area (town)	NOZZLE Type	NOZZLE Location	Wind Speed (mph)	PIVOT DATA Pressure (psi)	PIVOT DATA Flowrate (gpm)	EFFICIENCY Pattern (%)	EFFICIENCY Application (%)	EFFICIENCY System (%)
28	Amarillo	180° spray	drop	10	25	650	59	92	54
29	Amarillo	180° spray	drop	10	25	700	58	96	56
30	Amarillo	180° spray	drop	5	28	600	61	94	58
31	Amarillo	180° spray	drop	5	29	150	55	94	52
32	Amarillo	180° spray	drop	13	39	1040	68	63	43
33	Amarillo	180° spray	drop	22	34	650	58	96	55
34	Amarillo	impact	top	17	60	850	64	95	60
35	Amarillo	impact	top	5	70	600	61	82	50
36	Amarillo	impact	top	10	45	580	66	85	56
37	Amarillo	180° spray	drop	6	30	620	63	71	45
38	Amarillo	impact	top	12	66	725	83	85	71
38a	Amarillo	impact	top	3	43	725	80	98	78
39	Amarillo	impact	top	7	41	725	83	89	74
40	Amarillo	impact	side	6	41	605	69	97	67
40a	Amarillo	impact	side	10	27	622	82	86	71
41	Amarillo	impact	top	12	45	650	79	81	64
42	Amarillo	impact	top	12	40	790	79	65	52
43	Amarillo	impact	top	13	47	715	76	70	53
44	Amarillo	180° spray	top	15	18	490	59	71	42
45	Amarillo	impact	top	8	56	860	77	59	45
46	Amarillo	impact	top	8	35	490	85	76	65
47	Amarillo	impact	top	10	80	625	70	56	39
48	Amarillo	impact	top	5	28	450	83	95	78
49	Amarillo	180° spray	top	10	24	750	89	95	85
50	Amarillo	impact	top	7	34	540	82	94	77
51	Amarillo	180° spray	drop	12	32	820	63	95	60
52	Amarillo	impact	top	9	61	716	71	70	49
53	Amarillo	impact	top	13	61	680	70	56	39
54	Amarillo	180° spray	drop	15	32	960	83	78	65
55	Amarillo	impact	top	13	68	675	84	96	81

(continued)

Table 2 - Summary of Center-Pivot Evaluations (continued)

Test No.	SCS Administrative Area (town)	NOZZLE Type	NOZZLE Location	Wind Speed (mph)	PIVOT DATA Pressure (psi)	PIVOT DATA Flowrate (gpm)	EFFICIENCY Pattern (%)	EFFICIENCY Application (%)	EFFICIENCY System (%)
56	Amarillo	impact	top	13	85	665	74	80	59
56a	Amarillo	impact	top	13	40	840	80	85	68
57	Amarillo	impact	top	15	75	670	72	69	50
58	Amarillo	impact	top	10	37	510	86	65	56
59	Amarillo	impact	top	7	40	686	71	78	55
60	Amarillo	180° spray	drop	11	16	995	69	73	50
61	Amarillo	180° spray	drop	8	26	905	75	79	59
62	Amarillo	360° spray	drop	15	22	714	75	75	56
63	Amarillo	impact	top	18	54	657	77	53	41
64	Amarillo	impact	top	8	56	775	93	93	86
65	Amarillo	impact	top	6	36	790	82	75	62
66	Amarillo	impact	top	11	23	583	86	60	52
67	Amarillo	impact	top	8	24	430	78	83	65
68	Amarillo	6° impact	top	9	20	476	89	91	81
69	Amarillo	6° impact	top	5	52	787	80	75	60
70	Amarillo	6° impact	top	7	25	467	71	59	42
71	Amarillo	6° impact	top	14	44	947	89	85	76
72	Amarillo	spray	drop	5	40	585	70	78	55
73	Amarillo	spray	drop	10	30	450	45	99	45
74	Amarillo	180° spray	drop	20	25	640	53	81	43
75	Amarillo	impact	top	5	60	675	74	80	59
76	Amarillo	impact	top	8	57	700	75	100	75
77	Amarillo	impact	top	11	20	595	70	45	32
78	Amarillo	impact	top	8	66	510	77	86	66
79	Amarillo	360° spray	drop	12	25	965	80	63	50
80	Amarillo	impact	top	7	37	400	67	84	56
81	Amarillo	180° spray	drop	5	26	631	65	72	47
82	Amarillo	180° spray	drop	7	20	695	54	57	31
83	Amarillo	impact	drop	18	44	660	61	71	43

(continued)

Table 2. Summary of Center-Pivot Evaluations (continued)

Test No.	SCS Administrative Area (town)	NOZZLE Type	NOZZLE Location	Wind Speed (mph)	PIVOT DATA Pressure (psi)	PIVOT DATA Flowrate (gpm)	EFFICIENCY Pattern (%)	EFFICIENCY Application (%)	EFFICIENCY System (%)
84	Amarillo	180° spray	drop	18	18	430	70	97	68
85	Amarillo	impact	top	23	53	780	81	97	79
86	Amarillo	180° spray	drop	8	45	590	65	96	62
87	Amarillo	impact	top	15	55	700	82	86	71
88	Amarillo	impact	top	15	44	660	61	71	43
89	Amarillo	impact	top	3	48	797	89	98	88
90	Amarillo	impact	top	11	43	734	80	83	66
91	Amarillo	180° spray	drop	8	23	501	83	76	63
149a	Lubbock	360° spray	drop	8	40	1200	86	95	81
152a	Lubbock	Modified spray w/tube & sock	drop	3	55	920	59	100	59
92	Lubbock	180° spray	drop	4	38	780	68	87	60
93	Lubbock	180° spray	drop	7	32	800	75	100	75
94	Lubbock	360° spray	drop	8	40	690	80	91	73
95	Lubbock	360° spray	top	8	29	920	76	81	61
96	Lubbock	360° spray	top	10	30	530	85	91	77
195a	Lubbock	180° spray	drop	8	26	470	81	91	74
97	Lubbock	Modified spray w/tube & sock	drop	8	20	310	84	100	84
98	Lubbock	180° spray	drop	10	35	820	75	96	73
99	Lubbock	360° spray	top	16	35	630	78	92	72
100	Lubbock	360° spray	top	12	30	730	85	96	81
188a	Lubbock	Modified spray w/tube & sock	drop	12	32	360	76	100	76
101	Lubbock	180° spray	drop	15	12	430	65	51	33
102	Lubbock	360° spray	drop	7	10	300	76	93	73
103	Lubbock	360° spray	top	10	32	450	87	83	72
194b	Lubbock	Low angle impact	top	15	34	920	83	99	84
104	Lubbock	Low angle impact	top	18	42	800	78	88	69
105	Lubbock	360° spray	drop	16	32	800	76	87	66

(continued)

Table 2. Summary of Center-Pivot Evaluations (continued)

Test No.	SCS Administrative Area (town)	NOZZLE Type	NOZZLE Location	Wind Speed (mph)	PIVOT DATA Pressure (psi)	PIVOT DATA Flowrate (gpm)	EFFICIENCY Pattern (%)	EFFICIENCY Application (%)	EFFICIENCY System (%)
196a	Lubbock	Low angle impact	top	3	40	760	80	97	78
106	Lubbock	360° spray	drop	9	33	850	86	94	81
107	Lubbock	Low angle impact	top	8	36	720	87	92	80
108	Lubbock	Low angle impact	top	6	43	1000	89	80	71
109	Lubbock	Low angle impact	top	9	60	975	88	96	85
110	Lubbock	Low angle impact	top	10	66	900	81	84	68
111	Lubbock	360° spray	drop	12	52	760	71	77	55
111a	Lubbock	360° spray	drop	20	38	870	64	77	49
112	Lubbock	Low angle impact	top	12	40	760	84	93	78
113	Lubbock	Low angle impact	top	3	64	1125	62	84	52
114	Lubbock	360° spray	top	13	40	900	82	88	73
115	Lubbock	Low angle impact	top	7	64	1010	81	83	67
116	Lubbock	Low angle impact	top	18	64	680	82	65	54
117	Lubbock	Low angle impact	top	4	49	1125	87	80	70
118	Lubbock	Reg. angle impact	top	5	60	1150	73	90	66
119	Lubbock	Low angle impact	top	9	65	1200	75	94	71
120	Lubbock	Reg. angle impact	top	12	46	1200	73	74	55
121	Lubbock	360° spray	drop	8	45	840	75	98	73
122	Lubbock	180° spray	top	8	30	650	77	90	70
123	Lubbock	Low angle impact	top	5	38	925	90	97	87
124	Lubbock	360° spray	top	6	35	650	78	97	76
125	Lubbock	360° spray	drop	15	32	650	63	86	54
126	Lubbock	Low angle impact	top	14	43	700	80	90	72
127	Lubbock	Low angle impact	top	11	46	860	88	92	81
128	Lubbock	Low angle impact	top	8	48	760	72	84	61
129	Lubbock	360° spray	top	2	39	735	85	86	74
130	Lubbock	360° spray	top	5	40	755	77	97	74
131	Lubbock	180° spray	top	3	38	850	75	93	70
132	Lubbock	180° spray	top	10	28	850	64	87	56

(continued)

Table 2. Summary of Center-Pivot Evaluations (continued)

Test No.	SCS Administrative Area (town)	NOZZLE Type	NOZZLE Location	Wind Speed (mph)	PIVOT DATA Pressure (psi)	PIVOT DATA Flowrate (gpm)	EFFICIENCY Pattern (%)	EFFICIENCY Application (%)	EFFICIENCY System (%)
133	Lubbock	Low angle impact	top	3	44	400	67	79	53
134	Lubbock	180° spray	drop	8	35	600	43	90	38
135	Lubbock	Reg. angle impact	top	8	65	600	46	70	32
136	Lubbock	Reg. angle impact	top	5	64	800	71	93	66
137	Lubbock	360° spray	drop	8	35	1000	78	94	73
138	Lubbock	Low angle impact	top	10	60	835	74	88	65
139	Lubbock	Low angle impact	top	3	60	950	67	58	39
140	Lubbock	Low angle impact	top	13	43	830	72	95	69
141	Lubbock	180° spray	drop	6	24	660	62	89	55
142	Lubbock	Low angle impact	top	7	40	643	60	86	52
143	Lubbock	Low angle impact	top	14	50	850	69	92	63
144	Lubbock	360° spray	top	12	40	1150	77	53	41
145	Lubbock	Reg. angle impact	top	7	60	620	69	86	60
146	Lubbock	Low angle impact	top	5	50	925	78	93	73
147	Lubbock	360° spray	top	5	31	800	80	96	77
148	Lubbock	Reg. angle impact	top	12	72	780	89	91	81
149	Lubbock	360° spray	drop	5	40	1300	77	92	71
150	Lubbock	180° spray	drop	8	40	400	79	86	68
151	Lubbock	Low angle impact	top	5	42	550	84	88	74
152	Lubbock	Modified spray w/tube & sock	drop	5	39	1020	87	100	87
153	Lubbock	180° spray	top	4	25	680	57	77	44
154	Lubbock	Low angle impact	top	6	44	325	69	93	64
155	Lubbock	Reg. angle impact	top	15	33	520	79	82	65
198a	Lubbock	Low angle impact	top	10	48	550	79	78	62
156	Lubbock	180° spray	drop	3	30	860	80	98	78
157	Lubbock	180° spray	top	10	29	600	73	89	65
158	Lubbock	Low angle impact	drop	5	35	600	80	90	72
159	Lubbock	360° spray	drop	8	30	200	78	84	50

(continued)

Table 2. Summary of Center-Pivot Evaluations (continued)

Test No.	SCS Administrative Area (town)	NOZZLE Type	NOZZLE Location	Wind Speed (mph)	PIVOT DATA Pressure (psi)	PIVOT DATA Flowrate (gpm)	EFFICIENCY Pattern (%)	EFFICIENCY Application (%)	EFFICIENCY System (%)
160	Lubbock	360° spray	drop	10	20	300	74	85	63
161	Lubbock	Low angle impact	top	10	54	660	76	91	69
162	Lubbock	180° spray	drop	10	30	850	71	93	66
163	Lubbock	Reg. angle impact	top	10	65	800	72	93	67
164	Lubbock	Low angle impact	top	3	35	700	76	93	71
165	Lubbock	360° spray	drop	10	31	300	78	84	65
166	Lubbock	180° spray	drop	12	22	685	72	79	57
167	Lubbock	360° spray	drop	7	29	755	74	73	54
168	Lubbock	360° spray	drop	2	26	460	78	96	75
169	Lubbock	Low angle impact	top	6	45	885	82	90	74
197a	Lubbock	Low angle impact	top	12	49	850	74	93	68
170	Lubbock	Low angle impact	top	10	40	940	76	83	63
177a	Lubbock	Low angle impact	top	7	48	755	76	90	68
171	Lubbock	Low angle impact	top	10	44	730	84	97	82
172	Lubbock	180° spray	drop	3	40	925	71	80	57
173	Lubbock	Reg. angle impact	top	3	48	355	61	73	44
174	Lubbock	180° spray	drop	9	20	675	71	82	58
175	Lubbock	180° spray	top	8	36	550	63	65	41
176	Lubbock	180° spray	drop	7	32	590	82	90	73
177	Lubbock	180° spray	top	9	42	1050	67	75	50
178	Lubbock	Reg. angle impact	top	6	55	600	52	89	46
180a	Lubbock	Low angle impact	top	4	52	770	87	94	82
179	Lubbock	180° spray	top	5	28	510	72	81	58
180	Lubbock	Low angle impact	top	12	41	650	71	89	63
181	Lubbock	Low angle impact	top	16	72	820	78	84	66
182	Lubbock	Reg. angle impact	top	20	38	940	57	71	40
183	Lubbock	Reg. angle impact	top	5	37	400	75	98	73
184	Lubbock	360° spray	drop	3	19	500	55	98	54
185	Lubbock	180° spray	top	6	41	850	75	85	64

(continued)

Table 2. Summary of Center-Pivot Evaluations (continued)

Test No.	SCS Administrative Area (town)	NOZZLE Type	NOZZLE Location	Wind Speed (mph)	PIVOT DATA Pressure (psi)	PIVOT DATA Flowrate (gpm)	EFFICIENCY Pattern (%)	EFFICIENCY Application (%)	EFFICIENCY System (%)
186	Lubbock	180° spray	side	8	21	710	35	90	31
187	Lubbock	180° spray	drop	16	63	485	76	74	56
188	Lubbock	180° spray	drop	3	18	405	60	100	60
189	Lubbock	Reg. angle spray	top	13	60	800	75	61	46
190	Lubbock	180° spray	top	6	55	800	72	86	62
191	Lubbock	180° spray	top	9	29	1000	79	91	71
192	Lubbock	Reg. angle impact	top	13	60	800	62	64	40
193	Lubbock	180° spray	top	9	60	700	69	78	54
194	Lubbock	Reg. angle impact	top	8	70	770	87	59	51
194a	Lubbock	Low angle impact	top	7	41	870	87	85	73
195	Lubbock	180° spray	drop	10	30	550	69	100	69
196a	Lubbock	180° spray	top	7	27	860	71	76	54
197	Lubbock	180° spray	top	9	42	1020	67	75	50
198	Lubbock	360° spray	drop	8	53	550	65	92	59
199	DELETED DUE TO INSUFFICIENT DATA								
200	Lubbock	impact	top	5	85	750	76	64	48
201	Lubbock	impact	top	5	85	600	74	59	43
202	Lubbock	spray	top	8	34	820	82	74	61
203	Lubbock	spray	drop	10	34	870	75	81	61
204	Lubbock	spray	top	9	40	730	67	72	48
205	Lubbock	spray	drop	7	35	960	67	91	60
206	Lubbock	spray	drop	25	24	880	73	81	59
207	Lubbock	spray	top	8	27	730	83	77	64
208	Lubbock	spray	top	8	29	850	86	76	64
209	Lubbock	impact	top	12	65	510	69	61	42
210	Pampa	spray	drop	15	27	730	83	77	64
211	Pampa	spray	drop	15	29	850	86	76	64
212	Pampa	spray	drop	4	42	715	63	95	60
213	DELETED DUE TO INSUFFICIENT DATA								

(continued)

Table 2. Summary of Center-Pivot Evaluations (continued)

Test No.	SCS Administrative Area (town)	NOZZLE Type	NOZZLE Location	Wind Speed (mph)	PIVOT DATA Pressure (psi)	PIVOT DATA Flowrate (gpm)	EFFICIENCY Pattern (%)	EFFICIENCY Application (%)	EFFICIENCY System (%)
214	Pampa	360° spray	drop	5	40	679	57	93	53
215	Pampa	spray	drop	3	30	485	72	86	62
216	DELETED DUE TO INSUFFICIENT DATA								
217	DELETED DUE TO INSUFFICIENT DATA								
218	Pampa	spray	drop	12	46	750	88	94	83
219	DELETED DUE TO INSUFFICIENT DATA								
220	Pampa	high pres. impact	top	15	85	720	71	74	53
221	Pampa	spray	top	6	66	900	72	79	57
222	DELETED DUE TO INSUFFICIENT DATA								
223	DELETED DUE TO INSUFFICIENT DATA								
224	Vernon	360° spray	drop	4-6	60	1190	76	55	42
225	Vernon	360° spray	drop	1	10	120	67	75	50
226	Vernon	360° spray	drop	5-8	38	570	64	99	63
227	Vernon	360° spray	drop	10-20	35	435	75	84	63
224a	Vernon	Low angle impact	drop	5-7	55	1100	87	89	77
228	Vernon	360° spray	drop	12-15	5	190	32	69	22
229	Uvalde	360° spray	top	10	71	747	78	81	63
230	Uvalde	360° spray	top	3	62	940	70	73	51
231	Uvalde	360° spray	top	6	70	859	69	92	63
232	Uvalde	180° spray	top	10	52	1350	72	90	65
233	Uvalde	360° spray	top	4	38	1410	94	93	87
234	Uvalde	360° spray	top	1	44	900	69	74	51
235	Uvalde	360° spray	drop	9	50	999	75	70	53
236	Uvalde	360° spray	top	6	46	1190	80	84	67
237	Uvalde	360° spray	top	4	82	1135	55	70	39
238	Uvalde	360° spray	top	5	72	1120	68	90	61
239	Uvalde	180° spray	top	7	35	999	73	88	64
240	Big Spring	360° spray	drop	8	30	450	81	95	77
241	Big Spring	360° spray	drop	10	25	510	75	82	62

(continued)

Table 2. Summary of Center-Pivot Evaluations (continued)

Test No.	SCS Administrative Area (town)	NOZZLE		Wind Speed (mph)	PIVOT DATA		EFFICIENCY		
		Type	Location		Pressure (psi)	Flowrate (gpm)	Pattern (%)	Application (%)	System (%)
242	Big Spring	360° spray	drop	7	26	535	77	89	68
243	Big Spring	180° spray	drop	10	35	1040	77	57	44
244	Big Spring	360° spray	drop	5	28	545	78	79	62
245	Big Spring	impact	top	8	55	520	82	96	79
246	Big Spring	impact	top	10	54	500	82	94	77
247	Big Spring	impact	top	5	40	840	60	76	46
248	Big Spring	180° spray	drop	7	28	445	75	87	65
249	Big Spring	impact	top	6	55	830	85	63	54
250	Big Spring	Low angle impact	top	8	63	820	73	97	71
251	Big Spring	Low angle impact	top	8	38	560	73	82	60
252	Big Spring	Low angle impact	top	9	70	980	78	98	76
253	Big Spring	Low angle impact	top	8	58	450	74	64	47
254	Big Spring	Low angle impact	top	7	37	830	82	57	80
255	Big Spring	Low angle impact	top	7	60	1050	85	95	81
256	Big Spring	Low angle impact	top	0	68	680	88	96	84
257	Big Spring	180° spray	drop	5	58	980	50	67	34
258	Big Spring	360° spray	drop	6	25	430	67	98	66
259	Big Spring	Low angle impact	top	8	50	720	72	52	37
260	Big Spring	360° spray	drop	8	19	660	72	75	54
261	Big Spring	360° spray	drop	8	30	890	84	45	38
262	Big Spring	360° spray	drop	1	17	700	79	77	61
263	Big Spring	360° spray	drop	7	14	422	65	72	47
264	Big Spring	360° spray	drop	7	16	630	64	91	58
265	Big Spring	360° spray	drop	7	34	762	73	88	64
266	Big Spring	360° spray	drop	14	24	1225	84	78	66
267	Big Spring	360° spray	drop	8	20	750	73	74	54
268	Big Spring	360° spray	drop	4	25	450	84	65	55
269	Big Spring	360° spray	drop	9	17	470	73	91	66

NOTE: Designation a, b, etc., following an evaluation number is the first (a) reevaluation, second (b) reevaluation, etc., of the same number system evaluation after the system was reworked.

$$\text{Pattern Efficiency (\%)} = \frac{\text{Lowest average catch on 1/4 of the area}}{\text{Average catch of the entire area}} \times 100$$

$$\text{Application Efficiency (\%)} = \frac{\text{Average catch of the entire area}}{\text{Amount pumped into the system}} \times 100$$

$$\text{System Efficiency (\%)} = \frac{\text{Lowest average catch of 1/4 of the area}}{\text{Amount pumped into the system}} \times 100$$

Table 3

Summary of Side Roll (Stationary) Sprinkler Evaluations

Table 3 - Summary of Side-Roll Evaluations

Test No.	SCS Administrative Area (town)	Type of System	Wind Speed (mph)	OPERATING DATA Pressure (psi)	Flowrate (gpm)	Nozzle Spacing (ft x ft)	EFFICIENCY Pattern (%)	Application (%)	System (%)
1	Amarillo	side-roll	16	44	114	40 x 60	52	86	45
2	Amarillo	side-roll	22	41	237	40 x 40	60	68	41
3	Amarillo	side-roll	12	57	360	40 x 60	63	97	61
4	Amarillo	side-roll	8	41	308	40 x 60	79	100	79
5	Amarillo	side-roll	18	42	150	40 x 45	82	96	79
6	Amarillo	side-roll	6	43	175	40 x 60	80	74	59
7	Amarillo	side-roll	15	43	228	40 x 60	51	35	18
8	Amarillo	side-roll	5	52	130	40 x 60	62	69	43
9	DELETED DUE TO INSUFFICIENT DATA								
10	Amarillo	side-roll	12	28	142	40 x 60	76	66	50
11	Amarillo	side-roll	19	46	200	40 x 60	40	53	21
12	Amarillo	side-roll	19	25	146	40 x 60	55	83	45
13	Amarillo	side-roll	20	30	330	40 x 60	40	57	26
14	Amarillo	side-roll	10	40	257	40 x 45	59	80	47
15	Amarillo	side-roll	10	44	188	40 x 40	57	92	52
16	Amarillo	side-roll	20	41	298	40 x 60	71	85	60
17	Amarillo	side-roll	8	28	345	40 x 50	76	91	69
18	Amarillo	tri-matic	8	30	220	50 x 30	64	80	51
19	Amarillo	hand move	17	40	126	30 x 50	36	40	14
20	Amarillo	side-roll	25	42	156	40 x 50	57	52	30
21	Amarillo	side-roll	3	32	144	40 x 50	76	52	40
22	Amarillo	hand move	10	40	236	30 x 50	72	96	69
23	Amarillo	side-roll	10	40	302	40 x 60	49	99	49
24	Amarillo	side-roll	5	42	154	40 x 60	69	86	60
25	Amarillo	side-roll	6	51	300	40 x 50	67	74	50
26	Lubbock	side-roll	8	40	330	40 x 60	37	67	25
26a	Lubbock	side-roll	3	35	315	40 x 60	66	65	43
27	Lubbock	side-roll	15	38	168	40 x 60	36	61	22

(continued)

Table 3 - Summary of Side-Roll Evaluations (continued)

Test No.	SCS Administrative Area (town)	Type of System	Wind Speed (mph)	OPERATING DATA Pressure (psi)	OPERATING DATA Flowrate (gpm)	Nozzle Spacing (ft x ft)	EFFICIENCY Pattern (%)	EFFICIENCY Application (%)	EFFICIENCY System (%)
28	Lubbock	side-roll	17	28	165	40 x 60	51	67	35
29	Lubbock	side-roll	21	34	228	40 x 50	67	63	42
30	Lubbock	side-roll	18	46	153	40 x 50	50	57	29
31	Amarillo	side-roll	5	40	345	40 x 40	83	90	75
32	Amarillo	side-roll	7	61	302	40 x 60	55	71	39
33	Pampa	side-roll	15	38	360	40 x 47	65	82	53
34	Vernon	side-roll	3-7	54	310	40 x 60	84	81	69
34A	Vernon	side-roll	5-10	38	480	40 x 60	68	77	52
35	Vernon	side-roll	7-15	32	125	40 x 60	53	58	31

NOTE: Designation A, B, etc., following an evaluation number is the first (A) reevaluation, second (B) reevaluation, etc., of the same number system evaluation after the system was reworked.

$$\text{Pattern Efficiency (\%)} = \frac{\text{Lowest average catch on 1/4 of the area}}{\text{Average catch of the entire area}} \times 100$$

$$\text{Application Efficiency (\%)} = \frac{\text{Average catch of the entire area}}{\text{Amount pumped into the system}} \times 100$$

$$\text{System Efficiency (\%)} = \frac{\text{Lowest average catch of 1/4 of the area}}{\text{Amount pumped into the system}} \times 100$$

Table 4

Summary of Furrow Irrigation Evaluations

Table 4 - Summary of Furrow Evaluations

Test No.	SCS Administrative Area (town)	FURROW DATA Length (ft)	Stream (gpm)	Slope	Family Intake Curve (Measured)	EFFICIENCY Distribution (%)	System (%)
1	Amarillo	2170	19	0.20	0.11	63	35
2	Amarillo	1058	24	0.20	0.40	84	55
3	Amarillo	920	24	0.30	0.50	89	73
4	Amarillo	1300	21	0.30	0.25	89	42
5	Amarillo	1300	20	0.20	0.20	87	82
6	Amarillo	1300	16	0.20	0.10	86	53
7	Amarillo	1700	12	0.50	NA	85	46
8	Amarillo	2558	10	0.20	NA	77	54
9	Lubbock	2640	40	0.60	0.04	73	73
10	Lubbock	1320	12	0.30	0.09	75	73
11	Lubbock	2640	18	0.30	0.05	72	71
12	Lubbock	1320	24	0.50	0.40	87	80
13	Lubbock	2640	48	1.00	0.60	100	40
14	Lubbock	600	24	0.20	0.25	79	78
15	Lubbock	2640	28	0.50	0.70	96	60
16	Lubbock	2640	16	0.20	0.25	78	58
17	Lubbock	2640	32	0.20	0.22	76	62
18	Lubbock	2640	12	0.20	0.14	65	63
19	Lubbock	1320	18	1.00	0.45	96	55
20	Lubbock	1320	12	0.50	0.70	100	63
21	Lubbock	1320	30	1.00	0.12	86	67
22	Lubbock	1320	17	0.10	0.23	75	67
23	Lubbock	2400	19	0.15	0.07	87	70
24	Lubbock	1800	23	0.25	0.37	100	75
25	Lubbock	2100	36	0.20	0.20	100	80
26	Lubbock	1500	24	0.90	0.09	93	64
27	Lubbock	1800	21	0.70	0.19	89	63

(continued)

Table 4 - Summary of Furrow Evaluations (continued)

Test No.	SCS Administrative Area (town)	FURROW DATA Length (ft)	FURROW DATA Stream (gpm)	Slope	Family Intake Curve (Measured)	EFFICIENCY Distribution (%)	EFFICIENCY System (%)
28	Lubbock	1800	37	0.50	0.25	100	83
29	DELETED DUE TO INSUFFICIENT DATA						
30	DELETED DUE TO INSUFFICIENT DATA						
31	Lubbock	2600	22	0.20	0.14	100	44
32	Lubbock	2560	24	0.10	0.40	84	53
33	Lubbock	1710	24	0.20	0.08	76	80
34	Lubbock	2600	28	0.10	0.30	83	81
35	Lubbock	1300	17	0.05	0.35	55	41
36	Lubbock	1370	11	0.15	NA	83	75
37	Lubbock	1318	43	0.10	0.50	83	83
38	Lubbock	1214	13	0.30	0.40	45	44
39	Lubbock	2800	11	0.30	0.10	73	64
40	Lubbock	1650	12	0.20	0.20	92	60
41	Lubbock	1600	14	0.10	0.25	50	50
42	Lubbock	2640	13	0.10	0.30	59	45
43	Lubbock	924	8	0.10	0.15	43	39
44	Lubbock	900	43	0.25	0.50	78	78
45	Lubbock	1320	34	0.25	0.30	87	87
46	Lubbock	1800	15	0.70	0.30	65	57
47	Lubbock	1600	56	0.60	0.50	67	55
48	Lubbock	2600	56	0.40	0.35	42	35
49	Lubbock	1860	52	0.45	0.30	63	45
50	Lubbock	1790	46	0.30	0.35	63	52
51	Lubbock	3420	43	0.20	0.25	58	58
52	Lubbock	2600	35	0.60	0.25	85	62
53	Lubbock	2600	43	1.00	0.15	64	38
54	Lubbock	1866	44	0.40	0.30	65	54

(continued)

Table 4 - Summary of Furrow Evaluations (continued)

Test No.	SCS Administrative Area (town)	FURROW DATA Length (ft)	FURROW DATA Stream (gpm)	Slope	Family Intake Curve (Measured)	EFFICIENCY Distribution (%)	EFFICIENCY System (%)
55	Lubbock	2600	47	0.15	0.30	60	54
56	Lubbock	2890	23	0.80	0.20	64	38
57	Lubbock	1325	8	0.05	0.20	77	57
58	Lubbock	1900	22	0.10	0.35	70	52
59	Lubbock	2112	11	1.30	0.15	91	28
60	Lubbock	2112	30	0.30	0.40	87	84
61	Lubbock	1600	29	0.40	0.40	184	53
62	Lubbock	1600	12	0.20	0.25	86	75
63	Lubbock	1275	13	1.00	0.25	65	50
64	Lubbock	1500	8	0.50	0.20	68	51
65	Lubbock	1300	14	0.35	0.25	65	53
66	Lubbock	1950	22	0.40	0.35	72	63
67	Lubbock	1250	10	0.20	0.30	43	41
68	Lubbock	2200	35	0.25	0.25	42	42
69	Lubbock	1320	22	0.20	0.45	91	88
70	Lubbock	1750	20	1.50	0.40	84	82
71	Lubbock	1100	22	0.20	0.35	95	88
72	Lubbock	2100	25	0.70	0.35	86	86
73	Lubbock	2600	28	0.30	0.20	46	63
74	Lubbock	2600	46	0.20	0.20	64	55
75	Lubbock	1280	27	0.20	0.25	65	54
76	Lubbock	1282	22	0.20	0.20	64	55
77	Lubbock	2600	63	0.20	0.35	93	93
78	Lubbock	2228	24	0.20	0.10	72	59
79	Lubbock	1540	25	0.40	0.20	64	50
80	Lubbock	1100	42	1.50	0.45	63	56
81	Lubbock	2640	67	0.20	0.35	62	55

(continued)

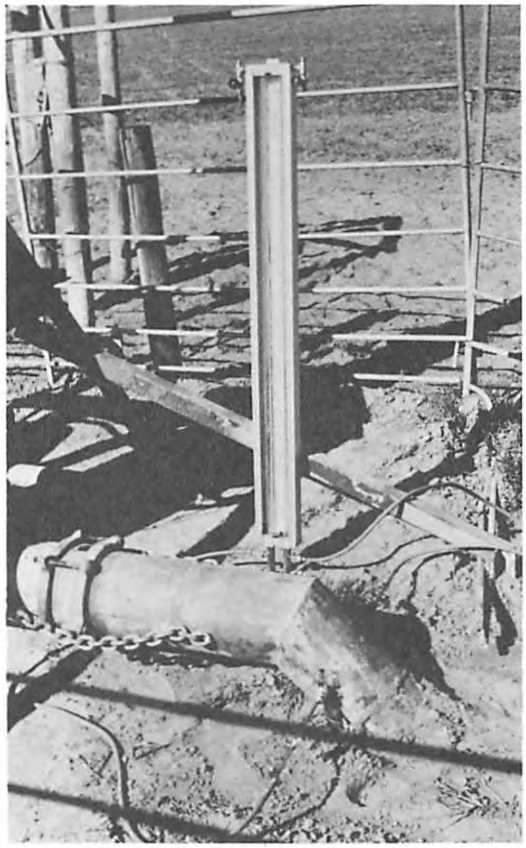
Table 4 - Summary of Furrow Evaluations (continued)

Test No.	SCS Administrative Area (town)	FURROW DATA Length (ft)	FURROW DATA Stream (gpm)	Slope	Family Intake Curve (Measured)	EFFICIENCY Distribution (%)	EFFICIENCY System (%)
82	Lubbock	1877	36	0.40	0.25	65	61
83	Lubbock	2268	33	0.20	0.15	88	88
84	Lubbock	1575	17	2.40	0.15	12	6
85	Lubbock	1600	9	2.80	0.15	11	10
86	Lubbock	1000	7	2.00	0.20	15	12
87	Lubbock	1140	9	0.20	0.30	20	17
88	Lubbock	2032	26	0.10	0.50	83	63
89	Lubbock	2112	3	1.00	0.20	58	36
90	Lubbock	1900	40	0.10	0.30	90	74
91	Lubbock	1230	20	0.05	0.30	83	83
92	DELETED DUE TO INSUFFICIENT DATA						
93	DELETED DUE TO INSUFFICIENT DATA						
94	Pampa	2400	29	0.40	0.30	86	48
95	Pampa	1600	12	0.20	NA	91	80
96	Pampa	2550	13	0.30	NA	65	72
97	Pampa	1200	17	0.30	NA	64	76
98	Vernon	1178	5	0.60	0.07	90	90
99	Uvalde	400	10	1.00	0.40	97	98
100	Uvalde	700	46	0.60	1.20	80	32

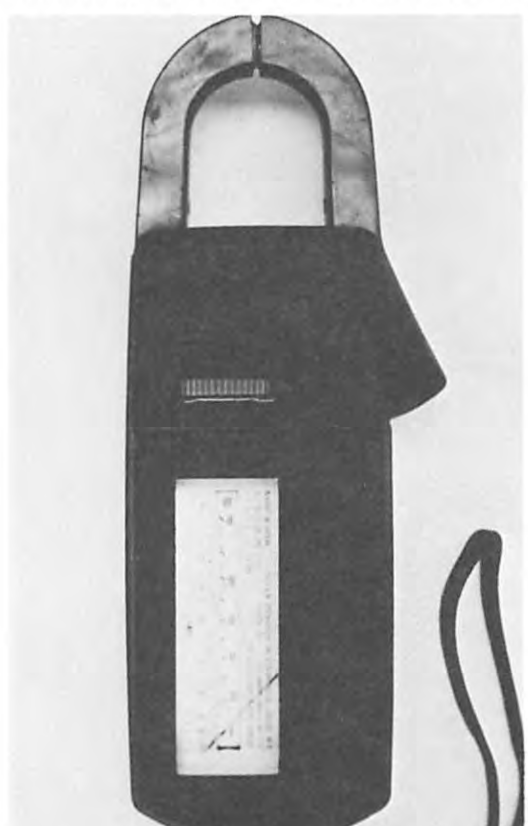
NOTE - System efficiency does not take into account that some runoff may be recoverable.

$$\text{Distribution Efficiency (\%)} = \frac{\text{Average water applied to root zone in furrow}}{\text{Water Pumped}} \times 100$$

$$\text{System Efficiency (\%)} = \frac{\text{Average water applied to root zone in low 1/4 area}}{\text{Water Pumped}} \times 100$$



A Collins Manometer is used to meter water on the pipe leading to a center pivot sprinkler.



An Amp-Volt Meter

Table 5
SUMMARY OF BORDER IRRIGATION EVALUATIONS

No.	Width (ft)	Border Length (ft)	Border Stream (CFS)	Border Slope (%)	Family Intake Curve	Efficiency Distribution In Border (%)	Efficiency System (%)
1.	118	901	7.16	0.28	1.0	81.7	43.6
2.	50	647	3.70	0.60	0.5	89.0	75.7
3.	94	1,090	4.90	0.25	1.0	88.5	26.8

Table 6

Sprinkler Irrigation Systems
Before and After Improvements

Average of Systems (17) Re-evaluated

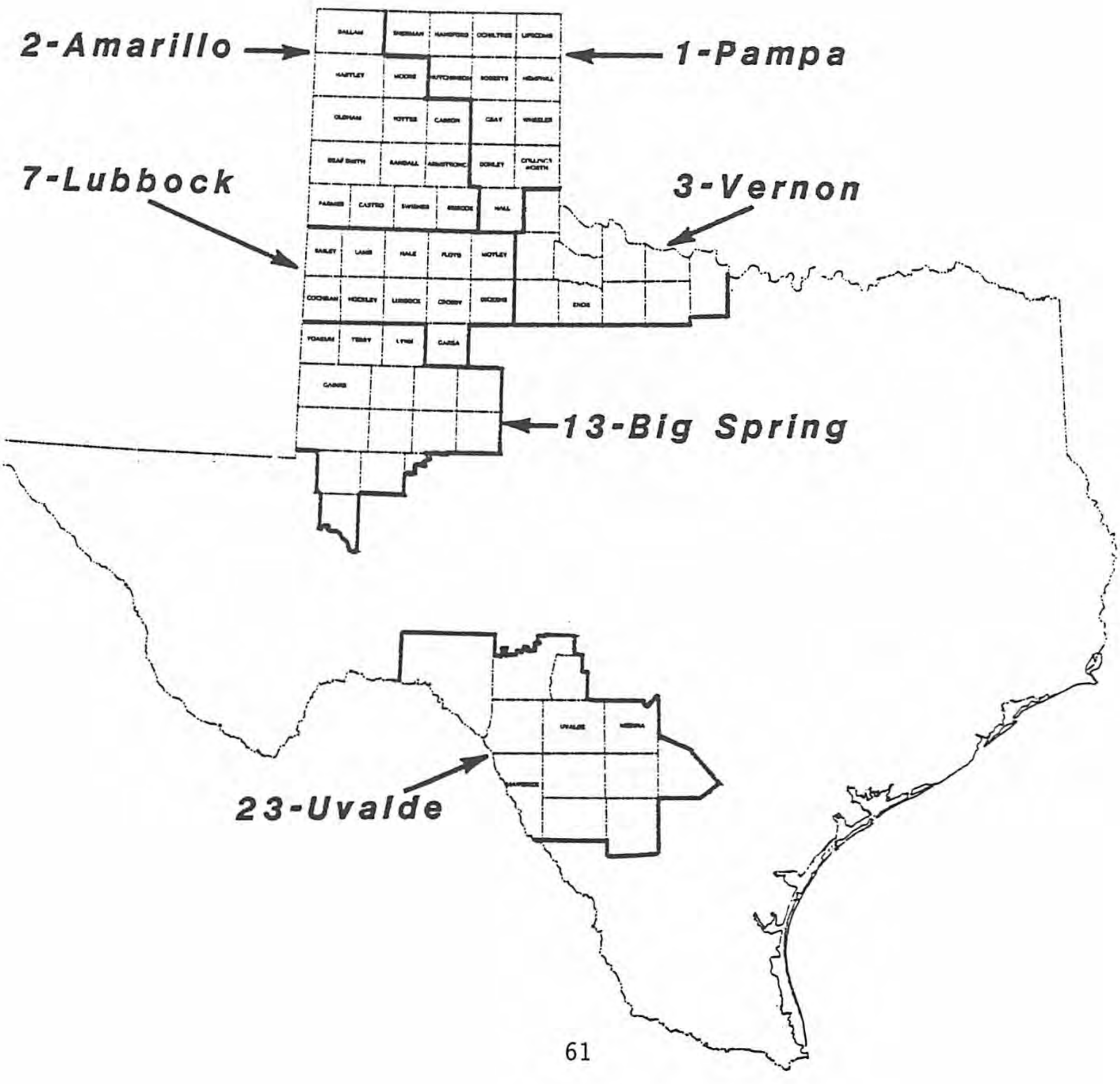
	Distribution Efficiency	Application Efficiency	System Efficiency
Before	71	82	58
After	77	88	68

APPENDIX A. Engineering Drawings of Mini-Labs

APPENDIX B. Soil Conservation Service areas, Soil and Water Conservation Districts and Other Water Conservation Districts Participating in Evaluation Studies: 1978-1981

APPENDIX D. Soil Conservation Service areas, Soil and Water Conservation Districts and Other Water Conservation Districts Participating in Evaluation Studies 1978-1981

SCS ADMINISTRATIVE AREAS PARTICIPATING IN EVALUATION STUDIES



SCS AREAS, SOIL and WATER CONSERVATION DISTRICTS and OTHER WATER CONSERVATION DISTRICTS
PARTICIPATING IN EVALUATION STUDIES

SCS Administrative Area No.	Area Office	County	Soil & Water Conservation District Zone	No.	Name	High Plains Underground Water Conservation District #1	North Plains Water Conservation District #2	Panhandle Groundwater Conservation District #3	Maverick County Water Control Improvement District #1	Edwards Underground Water District
1	Pampa	Collingsworth	1	133	Salt Fork					
		Donley	1	127	Donley County					
		Gray	1	125	Gray County			X		
		Hall	1	109	Hall-Childress					
		Hansford	1	148	Hansford		X			
		Hemphill	1	138	Hemphill County					
		Hutchinson	1	146	Hutchinson		X			
		Lipscomb	1	134	Lipscomb		X			
		Ochiltree	1	142	Ochiltree		X			
		Roberts	1	145	Roberts					
		Sherman	1	159	Sherman County		X			
		Wheeler	1	141	Wheeler County					
2	Amarillo	Armstrong	1	155	Staked Plains	X		X		
		Briscoe	1	126	Cap Rock					
		Carson	1	156	McClellan Creek			X		
		Castro	1	136	Running Water	X				
		Deaf Smith	1	143	Tierra Blanca	X				
		Dallam	1	131	Dallam					
		Hartley	1	152	Hartley		X			
		Moore	1	137	Moore County		X			
		Oldham	1	153	Oldham County					
		Parmer	1	140	Parmer	X				
		Potter	1	160	Canadian River	X	X			
		Randall	1	147	Palo Duro	X				
		Swisher	1	110	Tule Creek					
3	Vernon	Knox	5	544	Wichita-Brazos					
7	Lubbock	Bailey	1	111	Blackwater Valley	X				
		Cochran	1	149	Cochran	X				
		Crosby	1	107	Rio Blanco	X				
		Dickens	1	157	Duck Creek					
		Floyd	1	104	Floyd County	X				
		Garza	1	158	Garza					
		Hale	1	132	Hale County	X				
		Hockley	1	129	Hockley County	X				
		Lamb	1	130	Lamb County	X				
		Lubbock	1	108	Lubbock County	X				
		Motley	1	164	Upper Pease					
13	Big Spring	Gaines	1	166	Gaines County					
		Lynn	1	119	Lynn County	X				
		Terry	1	151	Terry					
		Yoakum	1	150	Yoakum					
23	Uvalde	Maverick	2	240	Chaparal					
		Maverick	2	228	Maverick				X	
		Medina	2	226	Medina Valley					X
		Uvalde	2	221	Nueces-Frio-Sabinal					X

APPENDIX C. Center Pivot Irrigation System Evaluation

1. Training Guide
2. Example Evaluation

SOIL CONSERVATION SERVICE

Date: 3/82

Identification No. 210-19-

ENGINEERING - IRRIGATION

TITLE: A METHOD FOR EVALUATING A CENTER-PIVOT SPRINKLER IRRIGATION SYSTEM FOR IRRIGATION WATER MANAGEMENT

References:

By definition, efficient irrigation water management is determining and controlling the rate, amount, and timing of irrigation water application to soils in order to supply crop water needs in a planned efficient manner. Water management is complex and difficult to achieve.

On the basis of this definition, water management is no accident, nor do local customs or family traditions automatically achieve water management. Water management is achieved by an irrigator who has the knowledge and ability to use an efficient irrigation system in carrying out planned efficient management.

An efficient irrigation system, including the pumping plant, delivery system and distribution system, is essential for an irrigator if he is to achieve a desired level of efficiency. A plan to effectively utilize the available irrigation water supply in managing and controlling the moisture environment of crops to promote the desired crop response, to minimize soil erosion and loss of plant nutrients, to control undesirable water loss, and to protect water quality, must be followed.

To effectively utilize the irrigation system in carrying out the water management plan the irrigator must know:

1. How to determine when irrigation water needs to be applied, based on crop water-use rates and stages of plant growth.

2. How to measure or estimate the amount of water required for each irrigation.

3. How to compute the amount of water delivered to an area.

4. The normal time needed for the soil to absorb the required amount of water and how to detect changes in intake rate.

5. How to adjust stream size, application rate or irrigation time as necessary to compensate for changes in such factors as intake rate or amount of water to be applied.

6. How to recognize erosion caused by irrigation.

7. How to estimate the amount of irrigation runoff from an area.

8. How to evaluate the uniformity of water application.

Location: Lubbock Area | Developed By: M. Namken | Checked By: ERL

GENERAL

Evaluations of irrigation systems are performed to determine adequacy of irrigation water management. Major factors which need to be considered are:

1. Uniformity of Application

   The most efficient use of water requires that the application be as nearly uniform as possible.

2. Total Depth of Application

   Depth of application should be sufficient to meet the needs of the crop. Depth of application should not exceed the water holding capacity of the soil to rooting depth.

3. Maximum Application Rate

   The rate should be such that runoff will not cause erosion. On flat slopes, ponding behind the area of water application will cause unequal water distribution.

Evaluation of the performance of a system will furnish valuable information to an operator. It may point out needed repairs or changes in the system itself or in adjustments of his operation and management.

CENTER-PIVOT SYSTEM

This type of irrigation system operates by moving a lateral sprinkler line in a circle around a water source at the center point of a square field. A lateral sprinkler line is suspended above ground by means of self-propelling towers mounted on wheels or shoes. The system usually irrigates a circular pattern in a square field; however, some systems irrigate parts of the corner areas in the square field.

PIVOT

The pivot is the center point of the system. A stationary pivot tower, usually mounted in concrete, supports a pipeline which supplies water to the suspended lateral sprinkler line. A swivel in the pipeline allows the lateral sprinkler line to rotate around the pivot. Usually the system controls are located at the pivot.

TOWER

A tower is a structural frame mounted on wheels, or shoes, which supports the lateral sprinkler line above ground. Each tower is equipped with a drive mechanism and moves the tower forward or backward. The types of tower drives are electric, water, and hydraulic.

END TOWER

The end tower is the outermost tower on the lateral sprinkler line. The speed at which the system travels is controlled by the movement of the end tower which is controlled by a timing device. Electric systems have a timing device in the control panel, which reads from zero to 100 percent. The percent setting determines the percent of the time the end tower is moving. As an example, if the timer is set on 30 percent, the end tower moves 30 percent of the time and does not move 70 percent of the time. In a time period of one hour, the end tower is moving for 18 minutes and does not move 42 minutes. By means of an alignment mechanism, the end tower controls the movement of all other towers. As the end tower moves forward or backward and gets out of alignment, the other tower drives are activated and move to straighten the alignment.

CORNER ATTACHMENTS

Corner attachments are used to irrigate corners. Each type attempts to increase the area watered by adding water to the corner areas beyond the reach of the lateral sprinkler line. Some systems use large impact type heads, part or full circles, and are manually turned on and off as the system gets to a corner.

A large gun type nozzle is added to the end of some lateral lines. These may have separate control devices, turning it on and off. Some have a booster pump to increase the pressure on the gun type nozzle.

Some systems use an automatic control to swivel a tower in a part circle around the end tower as it passes the corners. The entire section between the last two towers becomes the corner attachment.

EQUIPMENT NEEDED

The equipment needed is listed on the "Equipment Check Sheet for Irrigation Evaluations."

DATA TO BE RECORDED

Data to be recorded is shown on the attached worksheets. All applicable blanks should be filled in, if possible. One copy should be given to the landowner and one copy retained in the office files. A copy of the system design (computer printout) should be obtained, if it is available.

WIND

Record direction that wind is coming from when standing at pivot. Record direction in degrees east or west of north or south as 45^{o} east of north or 30^{o} west of south.

LINE DIRECTION

Record direction of sprinkler lateral when observing it while standing at the pivot and looking toward end tower. Record as above under WIND.

HUMIDITY

Obtain from local weather data if possible. If not, show as dry, moderate, or high.

NET WATER NEEDED

Estimate by "feel method" or other prescribed methods.

MEASURING SYSTEM CAPACITY

Without an accurate measurement of the capacity, the "gross application" and "system efficiency" must be considered an estimate. Therefore, it is important that the system capacity be as accurate as possible. Methods used to determine flow rates are discussed in the National Engineering Handbook, Section 15, Chapter 9. However, with a closed pipeline system few methods are applicable. The volumetric method (see "Procedure for Sprinkler Nozzle Discharge Measurements") applied to each nozzle, can be used, but requires considerable time. When estimates are obtained from land users the approximate date of the last test should be recorded on the evaluation worksheet.

CONSUMPTIVE USE

From available tables, with adjustments for weather conditions, estimate the consumptive use since last irrigation.

MEASURING SYSTEM PRESSURE

A pitot tube, or pressure gauge can be used to measure the operating pressure of a system. On some nozzles the pitot tube can be used, however, on most spray nozzled systems, a gauge must be installed on the lateral line. Pressures should be checked near the pivot and near end tower in order to get loss in lateral line or determining pressure on individual nozzles.

END TOWER SPEED

See "A Method for Determining Gross Applications for Center-Pivot Sprinkler Systems."

MEASURED NOZZLE OUTPUT

See "Procedure for Sprinkler Nozzle Discharge Measurements."

CATCH CANS

Normally quart oil cans, with the tops removed, are used for catching the precipitation from the sprinkler. Quart oil cans are used because of simplicity and convenience. Other types of containers can be used, however, the sides should be perpendicular to the bottom and sides and bottom should be smooth, not corrugated.

SETTING CATCH CANS

Set cans in a line on a radius ahead of the lateral sprinkler line at any uniform interval (usually 30 feet) from the pivot to a point beyond the wetted area. They should be set reasonably level by eye, and embedded about one inch deep into the soil. Move cans four or five feet in any direction to avoid tower wheels, or shoes, and obstructions, such as tall vegetation or posts. If crops are too tall to permit unobstructed catches, the can should be raised above the vegetation. This can be done using strong rubber bands or tying cans to a stake. The stakes should be driven vertically and should not protrude above the cans. When evaluating systems with end guns, or apparent runoff is visible, the cans may need to be staked for added stability. For low pressure systems with drop nozzles, cans should be set on the ground. If crops are too tall, do not evaluate.

MEASURING CATCH IN CANS

When using quart oil cans, the depth can be accurately determined by measuring the volume of catch in a 500 milliliter graduated cylinder. A one inch catch in a quart oil can is approximately equal to 200 cubic centimeters. If a 500 milliliter cylinder is not available, or other types of catch cans are used, the depth can be measured with a thin ruler. It should be calibrated in tenths of a foot, with the zero end at the very end of the ruler. Record can numbers consecutively, beginning with one at unit distance from the pivot. Record volume caught in cubic centimeters or inches.

DETERMINE WEIGHTED FACTORS

In a conventional sprinkler evaluation, each can represents an equal area, but in evaluating a pivotal type system, each can, providing the same distance between cans along a radial line is maintained, represents a different area. Therefore, if conventional type analysis is to be used it is necessary to weight the value of each can proportionately to that area which it represents. By using a constant distance between cans (starting at pivot) the weighting factor becomes the catch can number. See "Procedure for Determining Weighted Factors for Center-Pivot Evaluations." If cans are knocked down or for some other obvious reason do not truly represent conditions, they can be eliminated from the analysis by leaving out the weighted factor and can catch values in the tabulation. Sum all factors and sum all (catch X factor) entries.

MAXIMUM APPLICATION RATE

The maximum application rate should be checked on each system. From visual observations the area which appears to be the wettest should be checked. This is usually near the end tower.

1. Place five catch cans (spaced about ten feet apart) in a line perpendicular to the sprinkler line. One can should be directly under the nozzle when timing is started. Place two cans forward and two cans behind the first can. Cover the cans with plastic lids, small sheets of cardboard or wood, or plastic bags.

2. Remove covers (as quickly as possible) from all cans and start timing when nozzle is directly over center can.

3. After five or ten minutes operation, cover cans (as quickly as possible).

4. Measure quantity caught. The can with the largest quantity will represent the maximum application rate.

5. Compute rate: $\frac{(cc)(60)}{(200)(\text{Time, in minutes})}$ = inches per hour

   or: $\frac{(\text{Inches})(60)}{(\text{Time, in minutes})}$ = inches per hour

PUMPING PLANT EFFICIENCY

For pumping plant and cost data on water see "Procedures for Pumping Plant Evaluation." This procedure is not in this publication.

ANNUAL GROSS APPLICATION

Obtain the best information you can from the landowner and estimate the total water applied and/or to be applied to the crop during the year. Assume that rainfall will occur about normal for an average year for the remaining irrigation season.

CIRCUMFERENCE OF END TOWER

Circumference = (2π) Radius. The radius is the distance from the pivot to the end tower.

HOURS PER REVOLUTION

Hours per revolution = $\frac{\text{Distance traveled by end tower, in feet}}{\text{End tower speed, feet per hour}}$

AREA IRRIGATED

Area irrigated, in acres = $\left[(\pi)(\text{Radius}^2)\right] \div 43{,}560$

The radius is the distance from the pivot to the last catch can to catch water, or the wetted radius. For corner attachments see Evaluating Corner Attachments below.

GROSS APPLICATION

The gross application is the amount of water actually being pumped into the system. It is expressed as inches of water in depth over the area irrigated.

Gross application, in inches = $\frac{(\text{Hours per Revolution})(\text{GPM})}{(453)(\text{Acres})}$

WEIGHTED SYSTEM AVERAGE APPLICATION

The average depth caught in the catch cans: The weighted average catch of the entire area is equal to:

$$\frac{\text{Sum of (Catch x Factor)}}{\text{Sum of Factors}}$$

In conventional sprinkler analysis we use the low 25 percent of the cans as a base from which to arrive at a pattern efficiency. In the conventional analysis, using say 44 cans, the 11 low cans would be representative of the low 25 percent of the area since each can, as stated earlier, represents the same area. In center-pivot evaluations it is necessary to use the weighted average of some unknown number of cans which represents 25 percent of the area. This can be done by picking low value cans and keeping a running total of factors until the running total of factors approximates one quarter of the summation of all factors.

Then: $$\text{Weighted low 25\% average} = \frac{\text{(Sum of cans rep. of low 25\%)(their factors)}}{\text{(Sum of factors of cans rep. low 25\% of area)}}$$

This can be converted from volume in cc's to inches of depth.

PATTERN EFFICIENCY

The pattern efficiency compares to least amount of water on one-fourth of the wetted area to the area wetted. This is the uniformity of water applied to the field.

$$\text{\% Pattern Efficiency} = \frac{\text{(Lowest weighted average catch of 25\% of the area)}}{\text{Weighted average catch of the entire area}} \times 100$$

APPLICATION EFFICIENCY

The application efficiency compares the amount of water pumped (gross application) to the amount caught in the cans. Any difference is a loss that is due to evaporation, drift, leaks or on water drive systems, drive losses. In some cases it can be caused by inaccurate catches in cans due to improper placement or spacing.

$$\text{\% Application Efficiency} = \frac{\text{(Weighted average catch of the entire area)}}{\text{Amount pumped into the system}} \times 100$$

SYSTEM EFFICIENCY

The system efficiency compares the water pumped to the low one-fourth of the field

$$\text{\% System Efficiency} = \frac{\text{Lowest weighted average catch of 25\% of the area}}{\text{Amount pumped into the system}} \times 100$$

This can also be expressed as:

$$\text{\% System Efficiency} = \left[\text{(\% Pattern efficiency)(\% Application Efficiency)}\right] \div 100$$

FIELD OBSERVATIONS

It is important to make and record field observations. They can be the key to identifying many inefficiencies of a sprinkler system.

PLOTTING CAN CATCHES

Plotting the can catches on a worksheet can be the most effective way of showing land user where pattern inefficiencies occur and that corrections or repairs are needed. Plot the depth of water caught in inches against the location of the can. Plot straight lines across the graph for the gross application, weighted average and low 25 percent.

EVALUATING CORNER ATTACHMENTS

The procedure for evaluating a system with a corner attachment is very similar to the procedure for a system without an attachment. The same basic principles involved apply. Due to the many corner type systems on the market, and the method in which they operate, it is almost impossible to get a precise evaluation unless cans are set throughout the corner area.

The following procedure is not a precise method, but is accurate enough to make evaluations for irrigation water management when good judgment is used along with the evaluation. Since most corner systems operate during only part of a complete circle, the evaluation requires two sets of can catches. One catch is made when the corner attachment is off and a second catch is made while the corner attachment is operating. (See Sketch #2 of the "Procedure for Determining Weighted Factors for Center-Pivot Evaluations".)

For each catch complete Sheets 2, 3, and 4 as shown in the example, as if each catch represented the entire circle to arrive at two figures for gross application, average and low 25 percent. To combine these for the system average, multiply each by the percent of the total area each set of data represents, then add the two corrected figures together to get one system figure. As an example, a corner system operates 66.6 percent of the time. One evaluation was made with the corner attachment off and one with the corner attachment on. The results are as follows:

	Corner Att. on	Corner Att. off	Combined System Averages 1/
Gross application	2.5 in.	3.2 in.	2.68 in.
Weighted average	1.25 in.	2.56 in.	1.59 in.
Low 25% of area	0.75 in.	2.18 in.	1.13 in.
Pattern efficiency	60%	85%	71%
Application efficiency	50%	80%	59%
System efficiency	30%	68%	42%

1/ Computed below

The most accurate method of getting the areas is to plot graphically and planimeter. For this example, however, the area is assumed to be 42 acres with the corner attachment off and 118 acres with the corner attachment operating. Assume the entire area, 160 acres, is watered.

Percent of area when off = $\frac{42}{160}$ = 26.25%

Percent of area when on = $\frac{118}{160}$ = 73.75%

To get combined system averages[1/]:

Gross application = (2.5)(0.7375) + (3.2)(0.2625) = 2.68 in.

Weighted average = (1.25)(0.7375) + (2.56)(0.2625) = 1.59 in.

Low 25% = (0.75)(0.7375) + (2.18)(0.2625) = 1.13 in.

Pattern efficiency = $\frac{1.13}{1.59}$ x 100 = 71%

Application efficiency = $\frac{1.59}{2.68}$ x 100 = 59%

System efficiency = 71% x 59% = 42%

SOIL CONSERVATION SERVICE

Date: 4/78

Identification No. 210-19-

Sheet 1 of 1

ENGINEERING - IRRIGATION

TITLE: EQUIPMENT CHECK LIST FOR IRRIGATION EVALUATIONS

References:

Equipment	Drip	Surface	Sprinkler
	IRRIGATION METHOD TO EVALUATE		
Orifice plate		X	
Flume		X	
Weir		X	
Propeller meter		X	
Measuring pail	X		X
Catch cans (50 cans per set)			X
500 ml.graduated cylinder			X
Wind velocity meter			X
Thermometer			X
Stop watch	X	X	X
Pitot tube			X
Pressure gauge	X		X
Garden hose			X
Pipe wrench	X		X
Adjustable wrench	X		X
Pliers	X		X
Soil sampling probe	X	X	X
Soil auger	X	X	X
Level instrument		X	
Stadia board		X	
Flags or stakes		X	
Chain (100' or 200')	X	X	X
Measuring tape (10')	X	X	X
Shovel	X	X	X
Boots		X	X
Rain coat			X
Clip board	X	X	X
Applicable forms	X	X	X

Location: Lubbock Area

Developed By: M. Namken

Checked By: ERL

SOIL CONSERVATION SERVICE	Identification No. 210-19-	Sheet 1 of 1
	ENGINEERING - IRRIGATION	
	TITLE: PROCEDURE FOR SPRINKLER NOZZLE DISCHARGE MEASUREMENTS	
Date: 3/82	References:	

The measurement of sprinkler nozzle discharges plays an important role in the management of sprinkler irrigation systems.

Volumetric Method

The volumetric method is an accurate method because the exact discharge of the nozzle is measured.

The equipment needed to perform the volumetric measurement consists of:

1. 5-gallon container
2. Small length of garden hose
3. Watch with second hand or stop watch

While the sprinkler is operating under pressure, the length of garden hose is slipped over the nozzle, allowing the water to flow through the hose to the ground. The 5-gallon container is then placed under the discharging hose and the time required to fill the container is recorded. From this measurement the sprinkler discharge in GPM is calculated.

EXAMPLE

Time to fill 5-gallon container: 90 seconds = 1.5 minutes

Sprinkler discharge = $\frac{5 \text{ gal.}}{1.5 \text{ min.}}$ = 3.3 GPM

If the sprinkler being measured has a double nozzle, the discharge from each nozzle is added together to get total nozzle discharge.

Note

By checking the discharge of individual nozzles throughout the length of a lateral line, the system capacity can be estimated with reasonable accuracy.

Location: Lubbock Area	Developed By: M. Namken	Checked By: ERL

SOIL CONSERVATION SERVICE

Date: 11/78

Identification No. 210-19-

ENGINEERING - IRRIGATION

TITLE: A METHOD FOR DETERMINING GROSS APPLICATIONS FOR CENTER-PIVOT SPRINKLER SYSTEMS

References:

OBJECTIVE

To develop a table that relates the center-pivot timer to gross water (in inches) applied. This table can be used by the irrigator to adjust the system speed to obtain a desired gross application.

PROCEDURE

1. Determining Speed of End Tower:

Set a stake by a wheel on the end tower. Start timing when the wheel starts moving forward. Continue timing until the wheel has moved 20 to 30 feet. Stop timing and stake second point by wheel when wheel starts another move. Read time and measure distance between the two stakes. From the time and distance measured, the end tower speed can be determined as follows:

$$\text{End tower speed (ft per min)} = \frac{(\text{distance traveled in feet})(60 \text{ min per hour})}{(\text{time in minutes})}$$

A more accurate method is to set a stake by the wheel on the end tower and start timing when the wheel begins to move forward. After the can catch is made, stop time and set second stake as the wheel begins to move forward. Determine time required for travel and the distance between two stakes. Compute speed as above.

2. Determining Time per Revolution:

Once speed is determined, compute time of travel for one revolution.

Circumference of end tower = 2(distance from pivot to end tower)(3.1416)

$$\left.\begin{array}{l}\text{Time per revolution (hrs.)}\\ \text{at \% setting on timer}\end{array}\right\} = \frac{\text{Circumference of end tower (feet)}}{\text{Speed of end tower (feet per hour)}}$$

3. Determining Hours per Revolution for 100% Dial Setting:

$$\text{Hours per revolution at 100\%} = (\text{hours per revolution}) = \frac{\text{dial setting}}{100\%}$$

Note: Use the dial setting on the control panel at the time the speed was determined. This can be any setting from 0 to 100%.

Location: Lubbock Area | Developed By: M. Namken | Checked By: ERL

4. Determining Hours Per Revolution for all Dial Settings:

$$\text{Time per revolution at } X\% = \frac{(\text{hours per revolution at } 100\%)(100\%)}{(X\%)}$$

5. Determining Gross Application for Each Dial Setting:

$$\text{Gross application} = \frac{(\text{hours per revolution for dial setting})(\text{GPM})}{(453)(\text{Acres irrigated})}$$

Note: For acres irrigated, use design acres. If not available, use the effective wetted area.

6. Example: The center pivot timer was set on 60% and the end tower traveled 87.7 feet in 19 minutes. The distance from the pivot to the end tower is 1,205 feet. The system is applying 850 gpm on 130.09 acres.

a. Determine system speed:

$$\text{speed} = \frac{(87.7)(60)}{19} = 276.9 \text{ feet per hour}$$

b. Determine time per revolution:

$$\text{Circumference} = (2)(1205)(3.1416) = 7{,}571.3 \text{ feet}$$

$$\text{Time per revolution} = \frac{7{,}571.3}{276.9} = 27.34 \text{ hours}$$

c. Determine hours per revolution for 100% dial set:

$$\text{Hours per Rev}(100\%) = 27.34\frac{(60\%)}{(100\%)} = 16.4 \text{ hours}$$

d. Determine hours per revolution for all other dial settings:

$$\text{For } 90\% \text{ hours} = \frac{(16.4)(100\%)}{90\%} = 18.2 \text{ hours}$$

$$\text{For } 80\% \text{ hours} = \frac{(16.4)(100\%)}{80\%} = 20.5 \text{ hours}$$

$$\text{For } 70\% \text{ hours} = \frac{(16.4)(100\%)}{70\%} = 23.4 \text{ hours}$$

$$\text{For } 60\% \text{ hours} = \frac{(16.4)(100\%)}{60\%} = 27.3 \text{ hours}$$

$$\text{For } 50\% \text{ hours} = \frac{(16.4)(100\%)}{50\%} = 32.8 \text{ hours}$$

$$\text{For } 40\% \text{ hours} = \frac{(16.4)(100\%)}{40\%} = 41.0 \text{ hours}$$

$$\text{For } 30\% \text{ hours} = \frac{(16.4)(100\%)}{30\%} = 54.7 \text{ hours}$$

$$\text{For } 20\% \text{ hours} = \frac{(16.4)(100\%)}{20\%} = 82.0 \text{ hours}$$

$$\text{For } 10\% \text{ hours} = \frac{(16.4)(100\%)}{10\%} = 164.0 \text{ hours}$$

e. Determine gross application for each dial setting:

$$100\% \text{ setting} = \frac{(16.4)(850)}{(453)(130.09)} = 0.24 \text{ inch}$$

$$90\% \text{ setting} = \frac{(18.2)(850)}{(453)(130.09)} = 0.26 \text{ inch}$$

$$80\% \text{ setting} = \frac{(20.5)(850)}{(453)(130.09)} = 0.30 \text{ inch}$$

$$70\% \text{ setting} = \frac{(23.4)(850)}{(453)(130.09)} = 0.34 \text{ inch}$$

$$60\% \text{ setting} = \frac{(27.3)(850)}{(453)(130.09)} = 0.39 \text{ inch}$$

$$50\% \text{ setting} = \frac{(32.8)(850)}{(453)(130.09)} = 0.47 \text{ inch}$$

$$40\% \text{ setting} = \frac{(41.0)(850)}{(453)(130.09)} = 0.59 \text{ inch}$$

$$30\% \text{ setting} = \frac{(54.7)(850)}{(453)(130.09)} = 0.79 \text{ inch}$$

$$20\% \text{ setting} = \frac{(82.0)(850)}{(453)(130.09)} = 1.18 \text{ inches}$$

$$10\% \text{ setting} = \frac{(164.0)(850)}{(453)(130.09)} = 2.37 \text{ inches}$$

SUMMARY

Dial Setting	Hours/Revolution	Gross Application (inches)
100	16.4	0.24
90	18.2	0.26
80	20.5	0.30
70	23.4	0.34
60	27.3	0.39
50	32.8	0.47
40	41.0	0.59
30	54.7	0.79
20	82.0	1.18
10	164.0	2.37

SOIL CONSERVATION SERVICE

Date: 3/82

Identification No. 210-19-

ENGINEERING - IRRIGATION

TITLE: PROCEDURE FOR DETERMINING WEIGHTED FACTORS FOR CENTER-PIVOT EVALUATIONS

References:

A. Weighted Factor for Systems Without Corner Attachments

When catch cans are set on uniform spacings, the area weighted factor becomes the can number and simplifies computations. As an example (See sketch No. 1), the first can is set 30 feet from the pivot, the second can (30 feet from No. 1) 60 feet from the pivot, and can No. 3 (30 feet from No. 2) 90 feet from the pivot. This continues for a distance beyond the last nozzle. There are usually 43 or 44 cans for a regular quarter section system without a corner attachment.

The area weighted factor for can No. 1 is 1; for can No. 2, it is 2; and for can No. 3, it is 3; and so on. The weighted factor 2 is a ratio of the land area for which can No. 2 catches water as compared to the land area for which can No. 1 catches water. The land area of can 3 is 3 times as large as can No. 1, and so on.

Can No. 1 is 30 feet from the pivot. It represents a land area from 15 feet (halfway to pivot) to 45 feet (halfway to can No. 2). Cans 2, 3, and others represent an area halfway to the can on either side of them. The area of a circle is equal to 3.1416 times the radius squared.

A1 = the area represented by can No. 1 = $3.1416(45)^2 - 3.1416(15)^2$

= 6,361.74 - 706.86

= 5,654.88 square feet

A2 = the area represented by can No. 2 = $3.1416(75)^2 - 3.1416(45)^2$

= 17,671.6 - 6,361.74

= 11,309.76 square feet

A3 = the area represented by can No. 3 = $3.1416(105)^2 - 3.1416(75)^2$

= 34,636.14 - 17,671.6

= 16,964.54 square feet

Location: Lubbock Area | Developed By: M. Namken | Checked By: ERL

The weighted factor for can No. 1 is its area compared to itself or:

$$\frac{5,654.88}{5,654.88} = 1$$

The weighted factor for can No. 2 is its area compared to can No. 1 or:

$$\frac{11,309.76}{5,654.88} = 2$$

The weighted factor for can No. 3 is its area compared to can No. 1 or:

$$\frac{16,964.54}{5,654.88} = 3$$

The procedure can be followed in determining all other can weighted factors.

The procedure can be used to determine can weighted factors for other uniform spacings and for nonuniform spacing.

B. Weighted Factors for Systems with a Corner Attachment

The weighted factor for cans on a corner attachment are the same as those on a system without the corner attachment for a distance equal to the circle radius. For a conventional system this would be 1,320 feet. Beyond this point the corner attachment is operating only during part of the circle, creating an arc or part of a circle in each of the four corners of the field. See sketch No. 2.

When computing the weighted factor for a can beyond the circle, the area of land represented by the can is compared to the area of land represented by can No. 1 as previously discussed. To compute the area represented by a can beyond the circle, develop a graph as shown in sketch No. 3. For the X-coordinate, calculate distances from the last complete circle radius (value #1) to the diagonal distance from the pivot to a corner (value #2). For a conventional 160-acre system this would be 1,320 feet (value #1) and 1,866.7 feet (value #2) which establishes two X (or abscissa) values.

Along the Y-coordinate calculate the arc length from 0 (value #2) to that of the arc of the radius of the circle when the corner attachment is operating (value #1). This distance is one-fourth of the circumference times the percent operating time. For example, the circumference of a circle with a radius of 1,320 feet is 8,293.8 feet. The arc length of one-fourth of the circle is 2,073.5 feet. Assuming the system operates 66.7 percent of the time without the corner attachment being on, the system's arc length while operating is 1,383 feet (value #1). This establishes two Y (or ordinate) values.

Plot the two points established by the above coordinates. One point has the coordinates of 1,320 feet (abscissa) and 1,383 feet (ordinate). The other point has the coordinates of 1,866.7 feet (abscissa) and 0 feet (ordinate). Although the shape of the curve between the two points is actually curvilinear, the algebraic equation can be approximated by a straight line. Therefore, draw a straight line between the two points and label it as the pivotal line. To determine arc lengths for cans beyond 1,320 feet, enter the X-coordinate at the distance that the can is from the center pivot, move vertically up to the pivotal line, then horizontally to the Y-coordinate and read arc length.

As an example, can No. 50 is 1,500 feet from the center pivot. Enter 1,500 feet on the abscissa, move vertically to the pivotal line, and then horizontally to the ordinate. Read 930 feet. Since the can spacing times the arc length gives one-fourth the area for can No. 50, the corner area is therefore (930')(30') = 27,900 square feet. The area for can No. 50 is then 4(27,900) or 111,600 square feet. The area of can No. 1 is $3.1416(45)^2 - 3.1416(15)^2$ or 5,654.87 square feet. The weighted factor for can No. 50 then becomes:

$$\frac{111{,}600.00}{5{,}654.87} = 19.735 \text{ or } 19.7$$

The weighted factor for any can beyond 1,320 feet can be obtained in this manner regardless of can spacing. It must be recognized that no center pivot sprinkler system will water exactly to a fence line or exactly to a corner. When determining the arc length in a corner and adjusting this length (+) or (-), by visually observing the wetted pattern, a reasonable area for the corner cans can be obtained.

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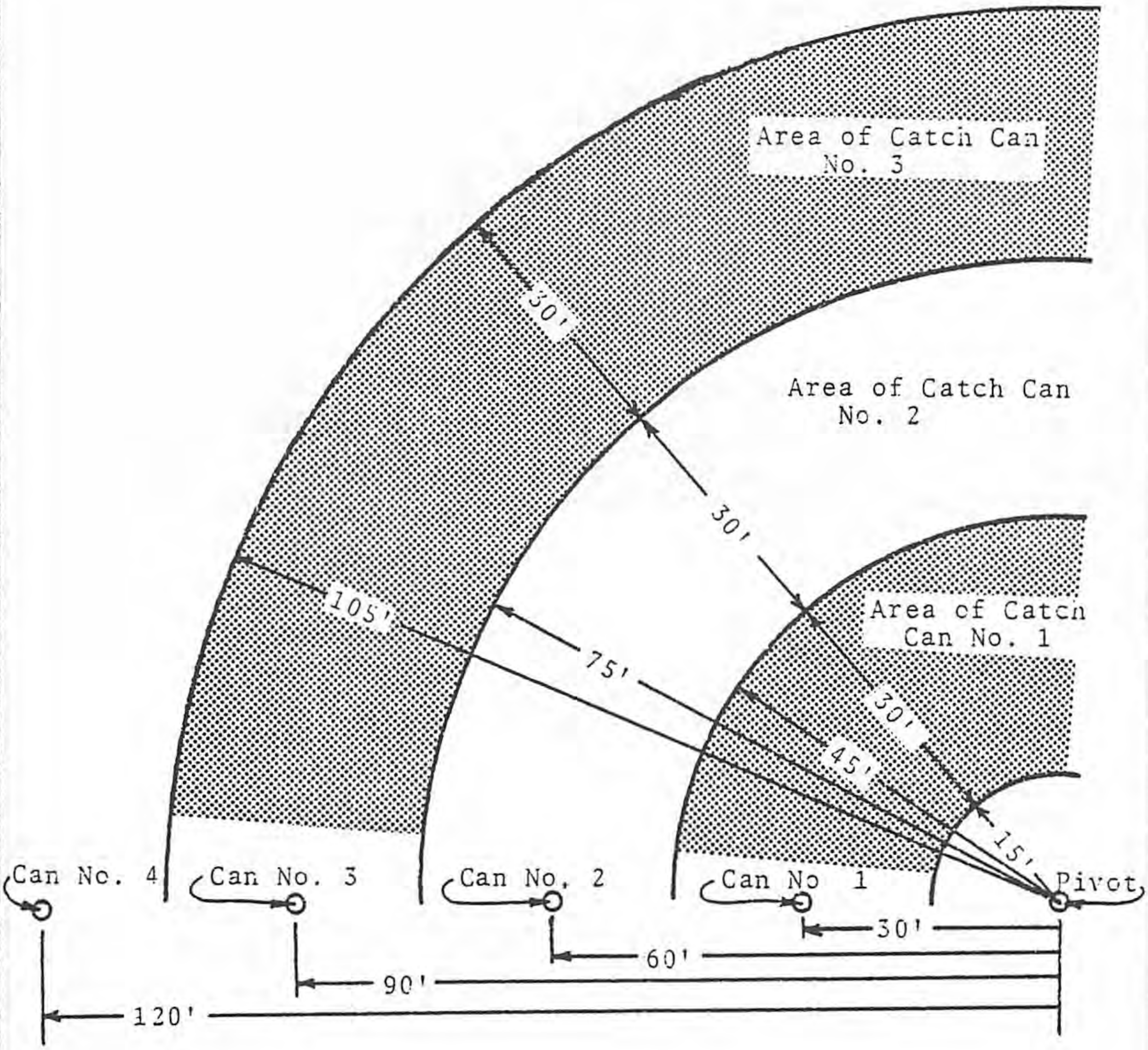
Sheet 4 of 6



SKETCH NO. 1

Area of 2,640 foot square = $\frac{(L)(W)}{43,560} = \frac{(2,640)(2,640)}{43,560}$ = 160 acres

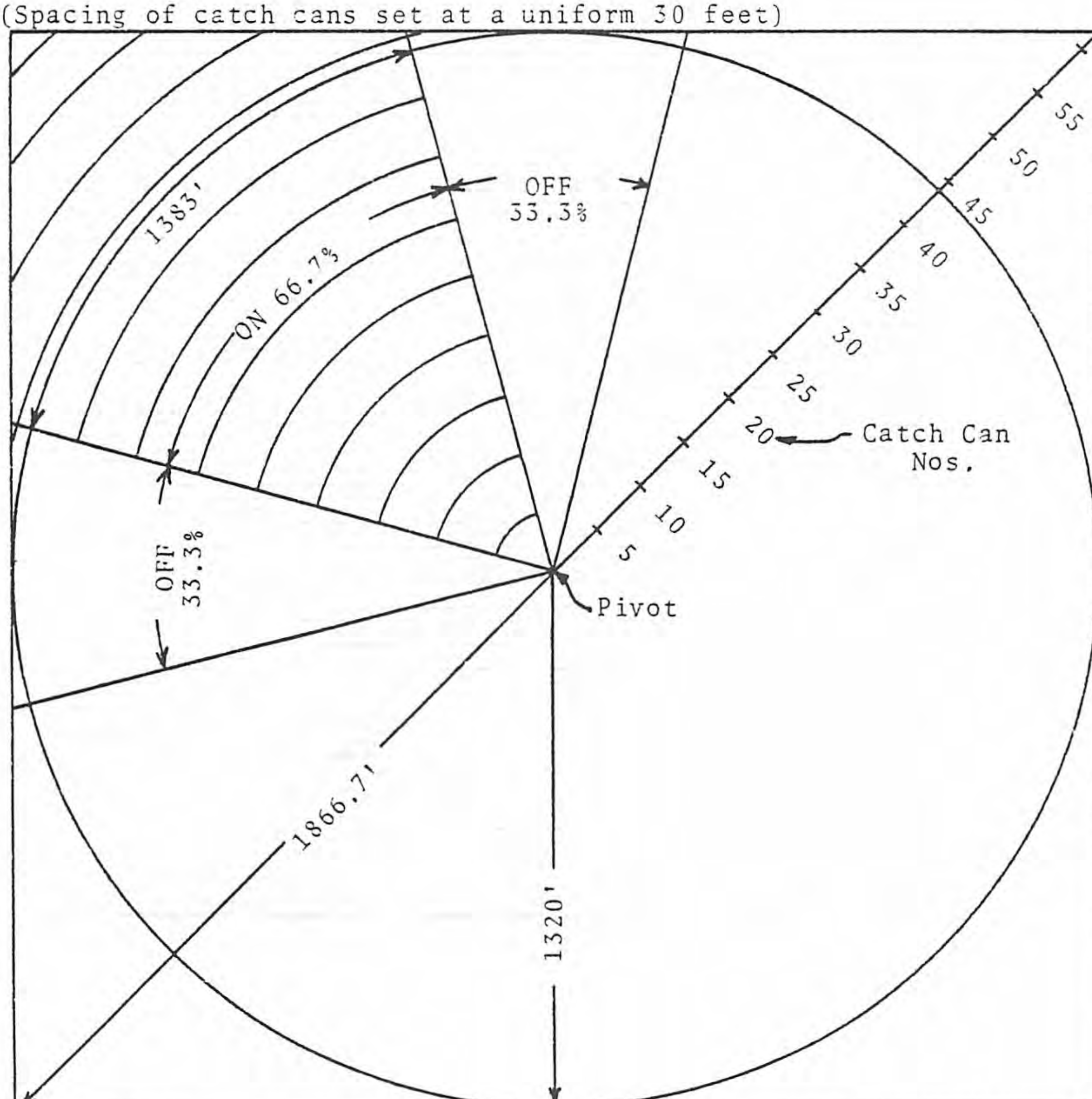
Area of circle with 1,320 foot radius = πr^2 = $(3.1416)(1,320^2)$ = 125.664 acres

Diagonal from center to corner = $\sqrt{r^2 + r^2} = \sqrt{(1,320^2)(1,320^2)}$ = 1,866.76 feet

Circumference of circle (C) = $2\pi r$ = (2)(3.1416)(1,320) = 8,293.8'

Wetted length of arc at 1,320' = (C/4)($\frac{2}{3}$ Time on) = (8,293.8/4) (0.667) = 1,383 feet

(Spacing of catch cans set at a uniform 30 feet)

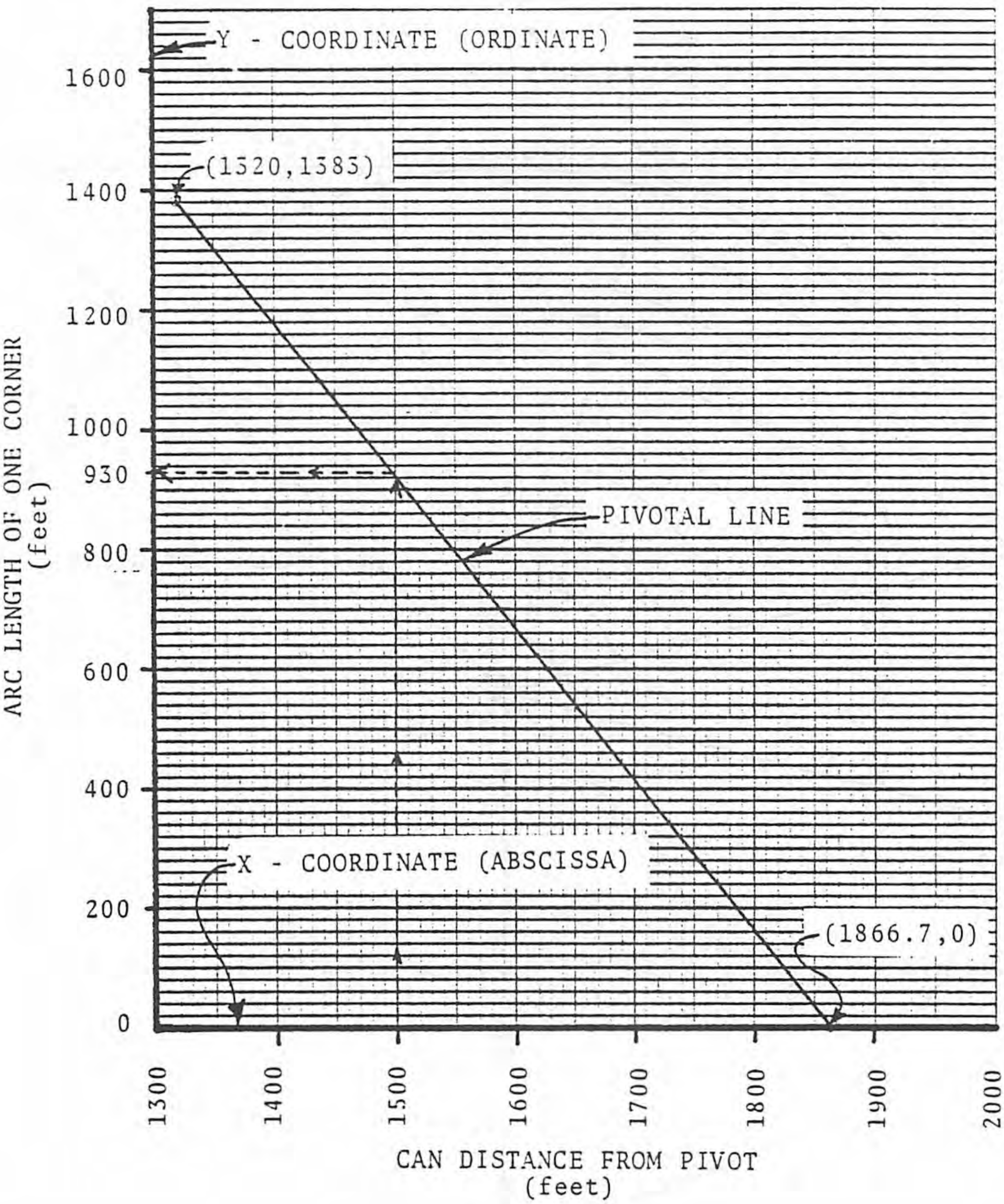


Scale: 1" = 400'

SKETCH NO. 2

Identification No. 210-19 - Sheet 6 of 6

Radius of circle = 1,320 feet
Circumference = (2)(π)(r) = 8,293.8 feet



SKETCH NO. 3

SOIL CONSERVATION SERVICE

Date: 3/82

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Sheet 1 of 5

ENGINEERING - IRRIGATION

TITLE: CENTER-PIVOT SPRINKLER IRRIGATION SYSTEM EVALUATION SHEET

References:

Name of Land User - Date 7-24-78

SCS Office - Technician -

HARDWARE INVENTORY

Brand name and model Valley - Low Pressure Model 4171

Is design available? Yes No. towers 7

Nozzle: Type Senninger Spray Pattern 1/2 circle Position Trailing

Spacing 8 ft Height 12 to 15 ft

Is pressure regulated on each nozzle? No

Type tower drive Electric

If water type, distribution patterns of drive water NA

System design capacity 800 gpm Design operating pressure 32 psi

End gun capacity 71 gpm Operating pressure 17.7 psi

Design wetted diameter of nozzles 20 ft (# 5) 20 ft (# 25) 20 ft (# 90) 20 ft (# 150)

FIELD DATA INVENTORY

Wind: Speed 5 to 6 mph Direction (from) S45°E

Line direction: From center to outer tower East moving Counter-clock

Time of day 10:45 - 13:15 Humidity 70 %

Air temperature upwind 80 °F Downwind 76 °F

Soil temperature (3" depth) before 83 °F after 78 °F

Type crop Cotton Height of crop 16 in.

Soil type Amarillo fsl Net water needed 3 in.

Days since last irrigation 21 Estimated consumptive use 3.15 in.

Location: Lubbock Area Developed By: M. Namken Checked By: ERL

Identification No. 210-19-   Sheet 2 of 5

Distance from center to: End tower 1,205 ft   Wetted edge 1,345 ft

System capacity 850 gpm   How obtained Estimated from operating pressure

Operating pressure at: Pivot 36 psi   End tower 22 psi

End tower speed 277 ft/hr

Measured wetted diameter of nozzles 30 ft (# 5)   25 ft (# 25)   20 ft (# 90)   20 ft (# 150)

Measured Nozzle Data:

Location & Type	Rate - gpm	Pressure - psi
#10- 1/4 K 7.5	1.4	35
#80- 3/8 K 35	5.5	24
#150- 1/2 K 60	8.5	19

Type and size catch cans used quart oil can   Height above ground 5 1/2 in.

Setting of the speed indicator 60%

Maximum application rate 2.1 inch per hour

Pumping plant efficiency 63.9 %

Cost per unit of fuel $0.032/Kwh   Total dynamic head 242 ft

Cost per acre foot per foot of head $0.051 (fuel)

Annual gross application 14 in.

EVALUATION

Circumference of end tower 7,571.24 ft

Hours per revolution 27.33 hr

Area irrigated 130.47 acres

Gross application = $\frac{\text{(Hrs. per revolution)(gpm)}}{(453)\text{(acres)}} = \frac{(27.33)(850)}{(453)(130.47)} = 0.393$ in.

Weighted System Average

Sum of (Factors) 984   Sum of (Catch)(Factor) 65,205

Weighted Average = $\frac{\text{Sum of (Catch)(Factor)}}{\text{Sum of Factors}}$

$= \frac{65,205}{984} = 66.265$ cc $= 0.331$ in.

Identification No. 210-19 - | Sheet 3 of 5

Weighted Low 25% Average

Sum of (Factors) 242 Sum of (Catch X Factor) 11,840

$$\text{Weighted Average} = \frac{\text{Sum of (Catch)(Factor)}}{\text{Sum of Factors}}$$

$$= \frac{11,840}{242} = 48.926 \text{ cc} = 0.245 \text{ in.}$$

$$\text{Pattern Efficiency} = \frac{\text{Weighted Average (Low 25\%)(100)}}{\text{Weighted Average (System)}}$$

$$= \frac{(0.245)(100)}{0.331} = 73.8 \%$$

$$\text{Application Efficiency} = \frac{\text{(Weighted Average Catch (System))(100)}}{\text{Gross Application}}$$

$$= \frac{(0.331)(100)}{0.393} = 84.2 \%$$

System Efficiency = Pattern Efficiency x Application Efficiency ÷ 100

$$= \frac{(73.8)(84.2)}{100} = 62.1 \%$$

FIELD OBSERVATIONS

Crop uniformity Fair - crop shorter beyond end tower

Water runoff Not significant

Erosion Splash erosion from end gun

Tower rutting 3" to 6" deep

System leaks About 5gpm at pivot

Fouled nozzles None apparent

Other observations End gun operates continuously and discharges beyond field boundary along sides of field

RECOMMENDATIONS

(1) Operate end gun as half circle back toward pivot or eliminate gun. (2) Check low catch at nozzles #24, 25, 87, 88, 103 and from 132 to end. (3) Check high catch at nozzles #46, 69, 106, and 129. (4) Possibly re-nozzle if orifices are O.K.

Identification No. 210-19- Sheet 4 of 5

Can No.	Factor	Catch (cc)	Catch X Factor	Catch (in.)
1	1	Placed 30' from pivot		
2	2	and 30' thereafter		
3	3	–	–	–
4	4	60	240	0.30
5	5	75	375	0.38
6	6	75	450	0.38
7	7	60	420	0.30
8	8	70	560	0.35
9	9	75	675	0.38
10	10	70	700	0.35
11	11	80	880	0.40
12	12	75	900	0.38
13	13	85	1,105	0.43
14	14	70	980	0.35
15	15	70	1,050	0.35
16	16	70	1,120	0.35
17	17	70	1,190	0.35
18	18	85	1,530	0.43
19	19	100	1,900	0.50
20	20	80	1,600	0.40
21	21	65	1,365	0.33
22	22	65	1,430	0.33
23	23	75	1,725	0.38
24	24	60	1,440	0.30
25	25	65	1,625	0.33
26	26	80	2,080	0.40
27	27	75	2,025	0.38
28	28	55	1,540	0.28
29	29	85	2,465	0.43
30	30	70	2,100	0.35
31	31	75	2,325	0.38
32	32	70	2,240	0.35
33	33	65	2,145	0.33
34	34	65	2,210	0.33
35	35	85	2,975	0.43
36	36	55	1,980	0.28
37	37	65	2,405	0.33
38	38	55	2,090	0.28
39	39	70	2,730	0.35
40	40	60	2,400	0.30
41	41	65	2,665	0.33
42	42	55	2,310	0.28
43	43	40	1,720	0.20
44	44	35	1,540	0.18
Sum	984	–	65,205	–

25% Factor Sum = 984 ÷ 4 = 246

Low 25% Cans

Can No.	Factor	Catch (cc)	Catch X Factor	Catch (in.)
44	44	35	1,540	–
43	43	40	1,720	–
42	42	55	2,310	–
38	38	55	2,090	–
36	36	55	1,980	–
28	28	55	1,540	–
7	7	60	420	–
4	4	60	240	–
Sum	242	–	11,840	–

Maximum Application Rate
(5 min. Catch)

1	–	15		–
2	–	25		–
3	–	35	Max.	0.175
4	–	25		–
5	–	20		–

Max. Rate = $\frac{(0.175)(60)}{(5)}$ = 2.1 in./hr.

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Sheet 5 of 5

Land User —

Technician —

Date 7-24-78

Gross Application 0.393 in.

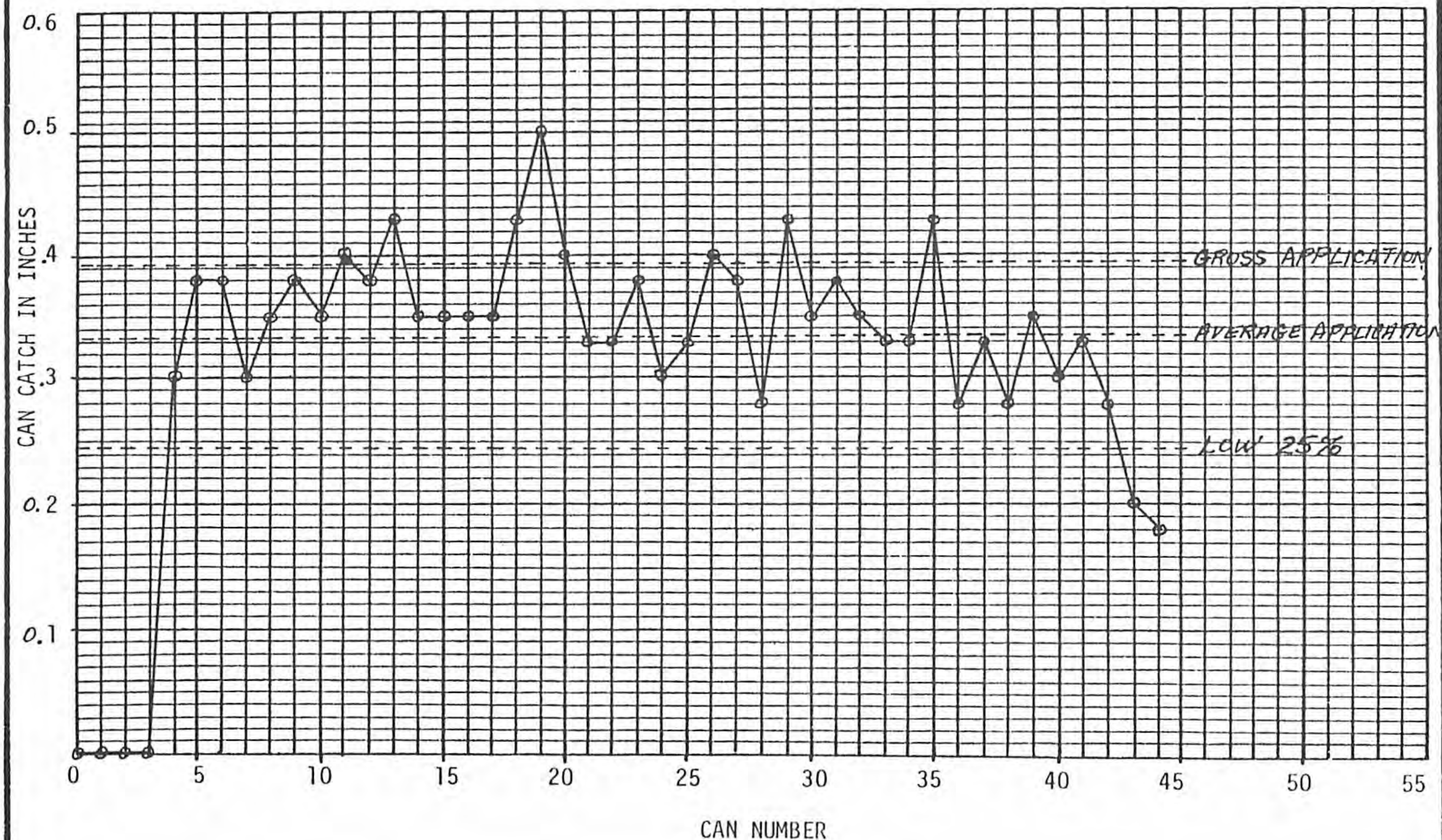
Average Application 0.331 in.

Low 25% Average 0.245 in.

Pattern Efficiency 73.8 %

Application Efficiency 84.2 %

System Efficiency 62.1 %



APPENDIX D. Furrow Irrigation System Evaluation

1. Training Guide
2. Example Evaluation

SOIL CONSERVATION SERVICE

Date: 10/80

Identification No. 210-19 -

ENGINEERING - IRRIGATION

TITLE: TRAINING GUIDE FOR FURROW SYSTEM EVALUATION

References:

The purpose of this procedure is to provide a simple, quick, reasonably accurate method of evaluating a furrow irrigation system so that problems can be identified and alternative recommendations for improving the system can be presented to the irrigator. The training guide serves as a reference for training and maintains consistency throughout the area. It is not intended to establish SCS policy or be for research or statistical data.

Elements such as production, scheduling, pumping plant, conveyance, tailwater, and water management are not included in this evaluation procedure but should be considered during the evaluation and if determined needed, applicable additional evaluations should be made.

This evaluation was prepared so that it can be used to evaluate a furrow system (a) using data provided by an irrigator, requiring very little time, or (b) it can be used with data obtained from detailed field investigations, requiring considerably more time. The accuracy of the evaluation is directly related to the accuracy of the data collected by interview or investigation and will vary by jobs and farms.

The method selected on individual jobs of the evaluation, such as measuring water, runoff, soil moisture, opportunity time, etc., will vary from site to site because many variables occur in the field and the limited time available. No single method will work for the variable conditions of all sites. Knowledge, experience and good judgment must be used to select the best method. The extent to which each individual job is investigated should, however, be such that the accuracy of the data remains fairly consistent for all jobs of the evaluation. If one job is estimated, a lot of time should not be spent gathering data for the other jobs. Instead, select a method that requires the least time. If detailed data is desirable, gather detailed data throughout the evaluation.

There are many ways to gather data needed for individual jobs. The worksheet does not provide space for computing all data. The computations used to arrive at values for the worksheet should be recorded on computation sheets and attached to evaluation worksheet.

It is suggested that each individual assemble a book of material containing guides, charts, graphs, formulas, examples, etc., that are tailored to his needs for his area of work.

Location: ______ Developed By: ______ Checked By: ______

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HEADING: Record the farm or producer's name, field office area in which farm is located, technician or technicians doing the evaluation and the date field work was completed.

WATER PUMPED: The amount of water pumped is expressed in inches of depth over the area irrigated. Usually it is based on the irrigation set being watered during the evaluation; however, in special cases, it may be desirable to base it on the area of a furrow, field, a system or farm. If tailwater is added, the stream size varies or a cutback stream is used, necessary adjustments can be made by computing the volume applied on the area irrigated to get depth pumped.

The SCS-NEH, Section 15, Chapter 5, training guides, and manufacturer's literature provide instructions on metering water. The options available will be dictated by site conditions, equipment available, time required, and the desired accuracy.

The area irrigated can be determined by chaining, measurements taken from topographic maps or aerial photos. Turnrows, roads and odd area, not actually irrigated, should not be included in the area irrigated.

Charts, graphs, tables, slip stocks or math equations can be used to convert the metered stream size to inches of depth. References are in SCS-NEH Section 15 Chapter 9, training guides, working tools, and manufacturer's literature.

A simple math procedure that has a wide range of use in irrigation is as follows:

Rule to Remember

450 Gallons Per Minute (gpm) is equal to 1 cubic foot per second (cfs) and when flowing for a period of 1 hour, applies 1 inch of water on 1 acre.

Procedure

1. Determine acre-inches of water pumped.

$$\text{Acre-inches of water pumped} = \frac{(\text{metered stream in gpm})(\text{time pumped in hours})}{450\ \text{gpm/cfs}}$$

2. Determine acres irrigated.

$$\text{Acres irrigated} = \frac{(\text{width in feet})(\text{length in feet})}{43{,}560\ \text{sq ft/ac}}$$

Note: Width can be found from

$$(\text{width in feet}) = \frac{(\text{row width in inches})(\text{number of rows per set})}{12}$$

3. Determine depth of water pumped.

$$\text{Depth of water pumped in inches} = \frac{\text{Acre-inches of water pumped}}{\text{Acres irrigated}}$$

WATER LOST IN DELIVERY SYSTEM: The amount of water lost in the delivery system is expressed in inches of depth over the area irrigated. It is very difficult to get an accurate measurement of the delivery loss in many systems because of the limits of available equipment and the conditions at the site. Delivery losses exceed distribution system losses in some cases; therefore, it is important to make at least a good estimate of the loss when applicable.

The equipment and methods used to determine the amount of water pumped also apply to delivery losses. When the flow cannot be metered, an estimate of soil infiltration and evaporation rates can be made to determine delivery loss. See "Training Guide for Determining Delivery Losses," or refer to Report 79-02, "Cost Analysis of Irrigation Ditch Losses," High Plains Underground Water Conservation District No. 1, 2930 Avenue Q, Lubbock, Texas 79405.

WATER APPLIED TO FURROW: The water applied to furrows is expressed in inches of depth over the area irrigated. It is the amount of water applied to the upstream end of the furrows and is determined by subtracting the delivery loss from the water pumped. If there are no delivery losses, the water applied to furrows would be the same as water pumped.

WATER RUNOFF AS TAILWATER: The tailwater runoff is expressed in inches of depth over the area irrigated. The limited equipment, site conditions, and the time available will make it difficult to meter tailwater in many cases. The methods of metering water and converting flow rates to inches of depth used in determining water pumped apply to metering tailwater. When tailwater cannot be metered an estimate can be made. Field experience and use of good judgment will enable reasonable estimates of tailwater runoff. References can be found in:

1. Engineering-Irrigation Memorandum TX-1, Irrigation-Design Criteria for Irrigation System Tailwater Runoff.

2. Guide to Irrigation Tailwater Recovery Report No. 77-01, published by the High Plains Underground Water Conservation District No. 1.

3. Training guides.

WATER INTAKE INTO FURROW SOIL: The amount of water entering the soil is expressed in inches of depth over the area irrigated. The water intake is found by subtracting tailwater runoff from the water applied to furrows. When no tailwater runoff occurs, the water intake is equal to water applied to furrows.

PERCENT TAILWATER REUSED: The percent tailwater reused compares the amount of tailwater pumped back into the system to the amount of water pumped. It is usually based on gallons per minute but could be based on cfs, acre-inches, or inches of depth. The pumpback rate should be an average based on the same time frame used on the water source. As an example, an 800 gpm well is pumped 24 hours daily. A collector system collects the tailwater and pumps it back at a rate of 300 gpm for 8 hours daily. The average pumpback for 24 hours would be 100 gpm (8/24 x 300 = 100).

The percent of tailwater reused = $\left(\frac{100 \text{ gpm}}{800 \text{ gpm}}\right)(100) = 12.5\%$

The 12.5 percent tailwater reused is not the same as tailwater runoff since water is lost in the collector system. It is only the water recycled into the irrigation system and becomes part of the source on future sets.

When evaluating an irrigation set that uses recycled tailwater as part of the source, the tailwater should be added to the pump capacity or streamflow when determining water pumped. No other adjustment to the evaluation is necessary.

STATIONS: The stations are points along the length of furrows at which specific data is gathered. Since efficiencies compare the application on one-fourth of the furrow length to the entire furrow length, adequate data for the evaluation can be obtained by using only 5 points, upstream end or 0, stations at 1/4, 1/2, and 3/4 of the furrow length and the downstream end of the furrow. When more specific data is desired the station can be extended by taping on a second sheet of paper to record additional stations as needed.

AVERAGE SLOPE: The average slope is shown in percent of the furrow length between stations. Normally, minor furrow slope changes are not significant and a close estimate is sufficient for recognizing a problem. Major slope changes are significant, however, and should be identified as well as furrows that flatten out on the downstream end.

DOMINANT SOIL: The dominant soil should be determined for the length or area between stations. Normally, a soil change would not be significant; however, when moisture holding capacities vary over about 1 inch or intake families vary more than 1 family curve number, the soil may have a significant effect on the efficiency and should be considered. This would be especially true when it represents an area large enough or so located that reorganization of the system to better fit the soil would be feasible.

IRRIGATION TIME: The irrigation time is expressed in minutes and is the total time of set or the time water is being applied to the furrows at the upstream end of the furrow.

ADVANCE TIME: The advance time is expressed in minutes. It represents the time required for water to travel to a station after the set is started at 0 or upstream end. Since all furrows in a set do not have the same advance time, an average advance time should be estimated. This can be done by comparing the area or total furrow length wetted beyond the station to the area or total furrow length that has not yet received water. It is more accurate to estimate area or total length than taking the time when water in half of the furrows passes the station. When the advance time goes beyond normal working hours, it may be advantageous to locate the stations with flags or stakes and have the irrigator determine the time when water reaches each station.

When time is not available to actually measure the rate of advance, a reasonable estimate can be made if the starting time, the advance time to the end station, and the total irrigation time are known. By analyzing the advance time of furrows, it has been found that the rate of advance to a station can be estimated as a percent of the advance time to the end station. When slopes and soils are uniform the advance time for the 1/4 station is approximately 10 percent of the time required for water to reach the end of furrow. For the 1/2 station it is 30 percent and for the 3/4 station it is 60 percent. Field experience will enable corrective adjustments to be made when slopes or soils are significantly variable. Refer to the graph "Rate of Advance for Uniform Furrows."

Slope, length, roughness, size and the rate of application are not significant in this procedure so long as they are uniform throughout the furrow. Adjustments can be made on the basis of visual observations when factors are not uniform by adjusting advance time or recession time.

When a significant slope change or soil change occurs, the advance time can still be estimated if the time of advance to the break point and the time of advance to the end of the furrow is known. Each section should be treated as an individual furrow when using the rate of advance graph. The advance time for the first section is based on the time required to get to the break point. The second section will start the advance time when water reaches the break point and continue to the end of the furrow.

TIME OF RECESSION: The time of recession is expressed in minutes. It is the time water remains on the surface at a station after the furrow stream is stopped. When measuring or timing the recession time, visual observations and/or experience will be necessary. The recession time should be taken when the water has disappeared from about 50 percent to 75 percent of the wetted perimeter. This will account for most of the volume of water in the furrow. For level furrows or graded furrows, the recession time is taken in the same manner. If the 50 percent to 75 percent rule becomes hard to apply, judgment can be used as to when an insignificant amount of water is left in the furrow.

OPPORTUNITY TIME: The opportunity time is expressed in minutes. It is the time that water stands on the surface, enabling water to penetrate the soil. It is computed for stations by subtracting the advance time from the irrigation time and adding recession time.

AVERAGE OPPORTUNITY TIME FOR FURROWS: The average opportunity time for the furrows is expressed in minutes. It is found by adding the opportunity time of stations and dividing the sum by the number of stations.

INTAKE FAMILY FOR THIS IRRIGATION: The intake family is expressed in a decimal or whole number. It is found by entering the graph "Family Intake Curves for Furrow Systems" with the average opportunity time and the water intake into furrow soils. The family intake for this irrigation is found where the two lines intersect. The family curve is extended from the points parallel with adjacent families. The family intake curve should be similar to the family curve for the soil as shown in the irrigation guide or irrigation interpretations for soils.

WATER APPLIED TO STATIONS: The water applied to stations is expressed in inches of depth at that station. It is found by entering the graph with the opportunity time for the station and reading accumulated inches on the left of the point where the opportunity time intersects the family intake group for this irrigation. The average of all stations should equal to the water intake into the furrow.

WATER HOLDING CAPACITY OF ROOT ZONE: The water holding capacity of the root zone is expressed in inches of depth. It is found in the irrigation guide or irrigation interpretations for soils. Adjustments should be made to figures in the guide if better data is available or site conditions differ from standard guide data. Soil depth, bulk density, exclusions and surface modifications are factors that would require adjustments to figures in the guide.

WATER IN ROOT ZONE BEFORE IRRIGATION: The water in the root zone before irrigation is expressed in inches of depth. It is found by field examination of the profile, using any one of several methods such as "feel method," speedy moisture method, oven method, or the volume percent moisture method.

It is not always necessary to sample all stations. Experience and judgment will, to a great extent, dictate the number of samples needed. An estimate of water in the soil can be made on the basis of consumptive use since last irrigation when detailed accuracy is not important. Generally samples should be taken from at least two sites.

NET WATER REQUIRED: The net water required is expressed in inches of depth. It is found by subtracting the water in the root zone before irrigation from the water holding capacity of the root zone. This is normally referred to as net irrigation requirements. It can be estimated from consumptive use tables if detailed accuracy is not important.

WATER APPLIED IN ROOT ZONE TO STATIONS: The water applied in the root zone to stations is expressed in inches of depth. It is the lesser of the water applied to stations or net irrigation required.

AVERAGE WATER APPLIED IN ROOT ZONE TO FURROW: The average water applied in the root zone to the furrow is expressed in inches. It is found by adding the water applied in the root zone to stations, for all stations, and dividing the sum by the number of stations.

AVERAGE WATER APPLIED IN ROOT ZONE TO 1/4 AREA: The average water applied in the root zone is expressed in inches of depth. It is found by averaging the adjacent amounts of water applied in root zones to stations.

WATER DISTRIBUTION IN FURROW: The percent water distribution in the furrow compares the low station to the high station. This is not the system efficiency since it does not consider net irrigation required, the water holding capacity of the soil or 1/4 the area. It is a simple way of expressing maximum/minimum application by stations.

A good working tool for the landowner can be developed on a graph that shows depth of water on the left and stations across the bottom. Plot water in inches of depth before irrigation, plot water holding capacity of the soil and plot total water in soil after irrigation. The graph will show the available water, the effective water added, the pattern, and deep percolation.

PATTERN EFFICIENCY: The pattern efficiency compares the effective irrigation water applied on 1/4 the furrow length to the average effective water applied to the entire furrow. A 100 percent pattern efficiency shows that the entire root zone is at field capacity. Pattern efficiencies less than 100 percent show that there is a dry area in the root zone and the percent that is dry.

APPLICATION EFFICIENCY: The application efficiency compares the average effective water applied in the furrow to the water pumped. A 100 percent application efficiency would indicate no delivery losses or tailwater runoff occurred. Efficiency less than 100 indicates how much water was lost either as delivery or tailwater runoff. Application efficiency also accounts for deep percolation losses.

SYSTEM EFFICIENCY: The system efficiency compares the effective water applied on 1/4 the furrow length to the water pumped. Pattern efficiency multiplied by application efficiency equals the system efficiency. Tailwater runoff and delivery losses lower system efficiency as it did in application efficiency. Deep percolation is also accounted for.

WATER USE EFFICIENCY: The water use efficiency considers the tailwater recovery system. When evaluating the application and system efficiency the distribution of water in the furrow is compared to the water pumped. Although tailwater helps in uniformly distributing water in the furrow and can be reused, it is lost as far as the irrigation system is concerned. The water use efficiency will show that a reuse system was used and how much water was reused. If no tailwater is recovered, the system efficiency will equal the water use efficiency. Two like systems, one reusing tailwater and the other not, would have the same system efficiency but different water use efficiency.

SOIL WATER METHOD OF EVALUATING A FURROW SYSTEM

With a few modifications, the foregoing procedure applies to systems on soils that do not fit into a uniform intake group or on systems where opportunity time is difficult or undesirable to obtain.

The worksheet for furrow system evaluations is used as previously described with the exception of deleting the following items:

Irrigation time (min)

Advance time (min)

Time of recession (min)

Opportunity time (min)

Average opportunity time for furrows (min)

Intake family for this irrigation

Considerably more care should be taken in determining water in the root zone before irrigation, and water applied to stations.

To determine the water applied to stations, soil samples must be taken about 24 hours after an irrigation and the water available in and below the root zone must be determined. The water applied is computed by subtracting the soil water before irrigation from the water after irrigation.

The procedure has one problem in that if deep percolation occurs it is difficult to auger or probe deep enough to determine penetration depth which makes it difficult to determine the exact amount of moisture added for each foot. With good judgment and field experience, a reasonable estimate can be made for identifying the problems with the system. A check can be made by comparing the average of the water applied to stations to the water intake into furrow soil.

EXAMPLE No. 1 - FURROW EVALUATION

This is an 80-acre farm. The field is 2,640 feet wide and 1,320 feet long. The furrow system is 2,640 feet wide with 1,300-foot long rows. Water from a well is pumped to the high corner of the field in a plastic pipeline. A ditch 2,640 feet long carries water to the furrows. Siphon tubes apply water from the ditch to the furrows.

The irrigator states that he uses a 600 gpm well to irrigate 30 rows.

His equipment is set on 40 inches.

He plants solid cotton and waters every row for 8-hour sets.

He has blocked the ends of the furrows and no tailwater runs off the field, some does break over into adjacent sets.

It takes about 5 hours for the water to reach the end where it stands about 2 hours after he changes the set.

It has been 3 weeks since the field was irrigated. The weather has been about normal, with some thunderstorm activity in the afternoons in which 2 light showers wetted the soil surface.

Water pumped: $\text{Ac-in. pumped} = \dfrac{(600\ \text{gpm})(8\ \text{hrs})}{450\ \text{gpm/ac-in.}} = 10.67\ \text{ac-in.}$

$$\text{Ac irrigated} = \frac{\left(30\ \text{in.} \times \dfrac{40\ \text{in.}}{12\ \text{in.}}\right)(1{,}300\ \text{ft})}{43{,}560\ \text{sq ft/ac}} = 2.98\ \text{ac}$$

$$\text{Depth pumped} = \frac{10.67\ \text{ac-in.}}{2.98\ \text{ac}} = \underline{3.58}\ \text{in.}$$

Water lost in delivery system: The "Training Guide for Determining Delivery Losses" shows the ditch loss in Amarillo loam to be about 8.9 ac-in. per mile per day.

The average miles of ditch used is $\dfrac{2{,}640\ \text{ft}}{(2)(5{,}280\ \text{ft})}$ or 0.25 miles

The 8-hour set is equal to 8/24 or 0.33 days.

Total ditch loss = (8.9 ac-in.)(0.25 mi)(0.33 days) = 0.73 ac-in.

$$\text{Depth lost} = \frac{0.73 \text{ ac-in.}}{2.98 \text{ ac}} = \underline{0.24 \text{ in.}}$$

Water applied to furrow: The water pumped (3.58 in. minus the water loss in delivery, 0.24 in.) is equal to 3.34 in. applied to the furrow.

Water runoff as tailwater: Assume no tailwater is lost since the water breaking out of the furrows in the set being evaluated is compensated by water inflow from the last set or from next set.

Water intake into furrow soil: Since no tailwater ran off, the water intake into the soil is the same as the water applied to the furrow (3.34 in.).

Percent tailwater reused: A tailwater recovery system is not part of the irrigation system; therefore no tailwater is reused. If it had, the average gpm for the 24 hours would be compared to average pumped in 24 hours to get the percent.

$$\frac{(\text{Average tailwater gpm reused})(100)}{\text{Average pumped}} = \text{percent reused}$$

Stations: One-fourth stations are assumed since a field evaluation will not be made.

Average slope: Based on landowner's comments, general knowledge of the area and the dominant soil, a uniform slope of 0.3 percent is assumed.

Dominant soil: The county soil survey shows significant soil to be on Amarillo loam.

Irrigation time: The irrigation time is 8 hours or 480 minutes (8 x 60).

Advance time: The advance time at zero feet is zero and at 1,300-foot it is 5 hours or 300 minutes (5 x 60). Since the time at 1/4, 1/2, and 3/4 is not known, it is estimated are 10 percent, 30 percent, and 60 percent of the advance time to 1,300. (See the graph "Rate of Advance for Uniform Furrows.") For the 1/4 station, the advance time is estimated to be 30 minutes (0.10 x 300); for the 1/2 station, 90 minutes (0.30 x 300); and for the 3/4 station, 180 minutes (0.60 x 300).

Time of Recession: From past experience the recession time is estimated as 15 minutes for zero, 20 minutes for the 1/4, 1/2, and 3/4 stations and from landowner's data, 120 minutes for 1,300.

Opportunity time: The opportunity time is computed for the zero station by taking the irrigation time, 480 minutes, minus advance time zero, plus recession time (15 minutes) for a total of 495 minutes. At the 1/4 station it is 470 minutes (480 - 30 + 20). For the 1/2 station it is 410 minutes (480 - 90 + 20). For the 3/4 station it is 320 minutes (480 - 180 + 20). For the 1,300-foot station it is 300 minutes (480 - 300 + 120).

Average opportunity time: $= \frac{495 + 470 + 410 + 320 + 300}{5} = \frac{1,995}{5} = 399$ minutes

Intake family for this irrigation: Using the graph "Family Intake Curves for Furrow Systems" enter the average opportunity time of 399 minutes and water intake into soil of 3.34 inches. Read the curve number of 0.35 for this irrigation set. (Note: Irrigation interpretations for soils show average family to be 0.5.)

Water applied to stations: Using the graph "Family Intake Curves for Furrow Systems" enter time of opportunity by stations, curve No. 0.35 and read water intake in inches.

0 station, 495 minutes = 3.8 inches
1/4 station, 470 minutes = 3.7 inches
1/2 station, 400 minutes = 3.4 inches
3/4 station, 320 minutes = 2.9 inches
1300 station, 300 minutes = 2.8 inches

Average = 3.32 inches

Average should equal intake into furrow soil (3.34 inches).

Water holding capacity of root zone: This is found from irrigation interpretations of soils. This value is 6.0 inches.

Water in root zone before irrigation: The available moisture before irrigation can be estimated from consumptive use tables. The average consumptive use for the 3-week period prior to July 15 is 0.15 inches per day. The crop, therefore, has used (0.15 x 21) = 3.15 inches. The remaining water is 2.85 inches (6.0-3.15).

Net irrigation required: This is equal to 3.15 inches (6.0 - 2.85).

Water applied in root zone: This is found by selecting the lesser amount of the water applied versus net irrigation required. For zero station, net irrigation is 3.15, which is less than amount applied 3.8. The water applied in root zone is, therefore, 3.15.

For 1/4 station, 3.15 is less than 3.7, use 3.15
For 1/2 station, 3.15 is less than 3.3, use 3.15
For 3/4 station, 2.9 is less than 3.15, use 2.9
For 1300 station, 2.8 is less than 3.5, use 2.8

Average water applied in root zone to furrow:

$$\frac{3.15 + 3.15 + 3.15 + 2.9 + 2.8}{5} = \frac{15.15}{5} = 3.03 \text{ inches}$$

Average water applied in root zone to stations:

For first (1/4) station $\frac{3.15 + 3.15}{2} = 3.15$ inches

For second (1/4) station $\frac{3.15 + 3.15}{2} = 3.15$ inches

For third (1/4) station $\frac{3.15 + 2.9}{2} = 3.03$ inches

For last (1/4) station $\frac{2.9 + 2.8}{2} = 2.85$ inches

Water distribution in furrow: This compares total water applied to lowest station (1,300 feet) to total water applied to greatest station.

This is $\frac{(2.8)(100)}{3.8} = 74\%$

$$\text{Pattern efficiency} = \frac{(\text{Average applied to low 1/4 area})(100)}{\text{Average water applied to root zone}} = \frac{(2.85)(100)}{3.03} = 94\%$$

$$\text{Application efficiency} = \frac{(\text{Average water applied to furrow})(100)}{\text{Water pumped}} = \frac{3.03}{3.58} = 85\%$$

$$\text{System efficiency} = \frac{(\text{Water applied to low 1/4 area})(100)}{\text{Water pumped}} = \frac{(2.85)(100)}{3.58} = 80\%$$

Water use efficiency remains at 80 percent since no tailwater ran off.

SOIL CONSERVATION SERVICE

Date: 2/79

Identification No. 210-19-

Sheet 1 of 2

ENGINEERING - IRRIGATION

TITLE: TRAINING GUIDE FOR DETERMINING DELIVERY LOSSES

References: Richards, Jack W. 1979. Cost analysis of irrigation ditch losses. High Plains Underground Water Conservation District No. 1 report 79-02. Lubbock, Texas

The above reference presents very usable data on the expected economic return when replacing earth ditches with underground pipelines.

The percolation loss in the ditch was computed as follows:

Gallons per foot per hour =

$$\frac{(\text{intake in./hr})(\text{4-foot width})(\text{1-foot length})(\text{7.48 gal/cu ft})}{\text{12 in./ft}}$$

To determine the evaporation loss from the irrigation ditch, 29.5699 inches was used as the total average evaporation for a 2,000-hour irrigation season from April through August.

The evaporation loss was computed as follows:

Gallons per foot per hour =

$$\frac{(\text{29.5699 in./season})(\text{4-foot width})(\text{1-foot length})(\text{7.48 gal/cu ft})}{(\text{12 in./ft})(\text{2,000 hrs/season})}$$

The total loss was obtained from adding the percolation loss to the evaporation loss.

The total water lost in acre-inches per mile of irrigation ditch per day was computed as follows:

Acre-inches per mile per day =

$$\frac{(\text{total loss gal})(\text{5,280 ft/mi})(\text{24 hrs/day})}{\text{27,157 gal/ac-in.}}$$

From the irrigation system plan and the soil map, an estimate can be made of the number of feet of ditch existing or planned on each soil. From the plan or the landowner, determine hours or days the ditch is in use. A common figure in the Lubbock area used for irrigation pumping plants is 2,000 hours per season. The average pump costs, or from pump evaluations, the cost per acre-foot of water can be found. The estimated loss can be quickly estimated.

To convert gallons to acre-inches, divide total gallons lost by 27,157. For acre-feet divide total gallons lost by 325,882.

Location: Lubbock Area | Developed By: M. Namken | Checked By: ERL

WATER LOSS IN EARTH DITCH

Soil Name	Texture	Intake Rate inches/hour	Percolation Loss gal/hour/foot	Evaporation Loss gal/hour/foot	Total Loss gal/hour/foot	Total Loss ac/in./mile/day
Amarillo	fine sandy loam	1.06	2.6429	0.03686	2.6798	12.50
Amarillo Mansker Portales Portales	loamy fine sand loam loam caliche soils	1.25	3.1166	0.03686	3.1535	14.71
Amarillo	loam	0.75	1.8700	0.03686	1.9068	8.90
Acuff	loam	0.92	2.2939	0.03686	2.3307	10.88
Brownfield Mansker Portales	fine sand fine sandy loam fine sandy loam	1.87	4.6625	0.03686	4.6993	21.93
Estacado	clay loam	0.97	2.4185	0.03686	2.4553	11.46
Olton	loam	0.62	1.5458	0.03686	1.5827	7.39
Portales	loamy fine sand	2.50	6.2333	0.03686	6.2701	29.26
Pullman	clay loam	0.35	0.8727	0.03686	0.9095	4.24
Pullman	clay	0.20	0.4987	0.03686	0.5355	2.50
Tivoli	fine sand	5.75	14.3365	0.03686	14.3733	67.07

SOIL CONSERVATION SERVICE

Date: 11/80

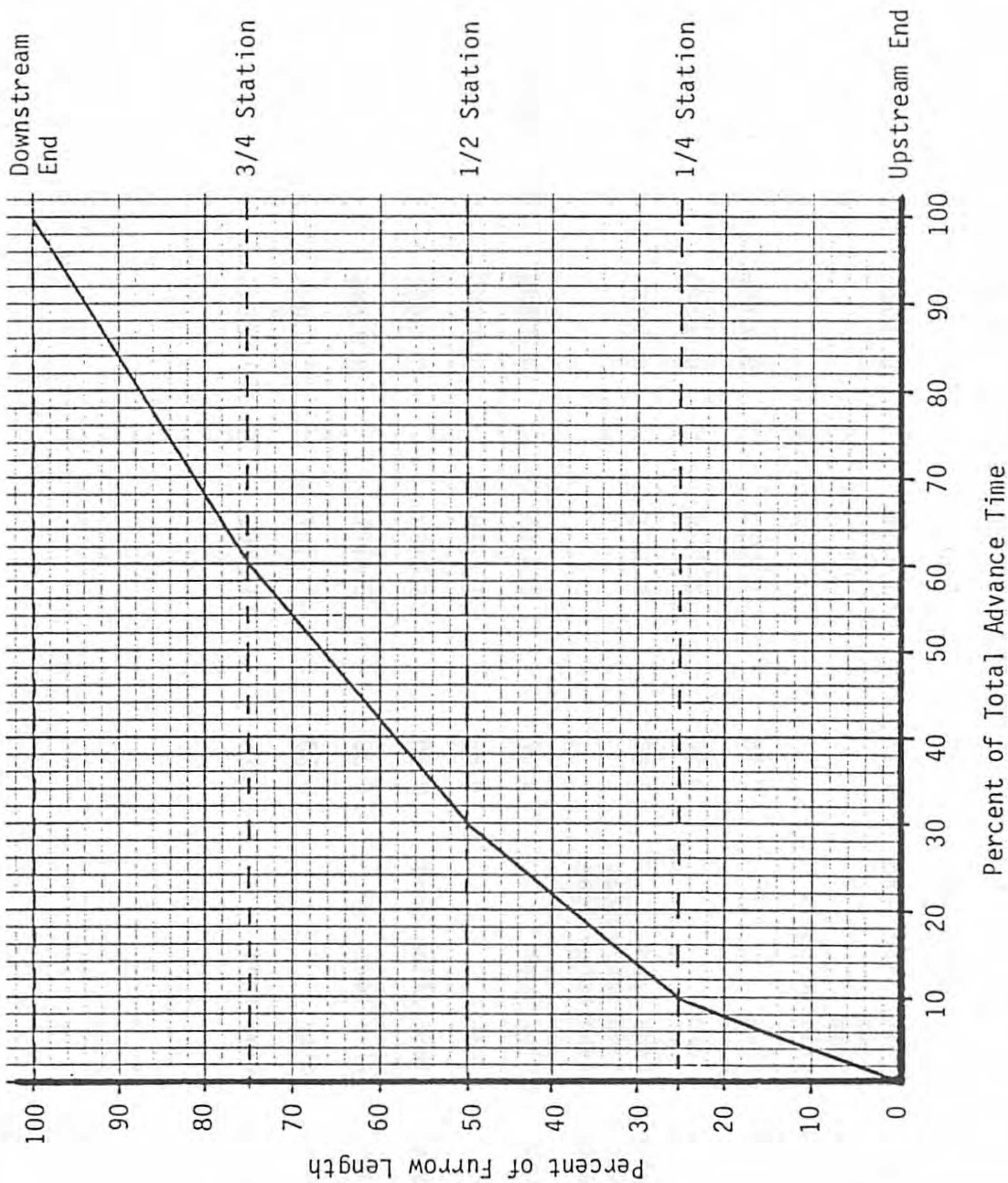
Identification No. 210-19-

Sheet 1 of 1

ENGINEERING - IRRIGATION

TITLE: RATE OF ADVANCE FOR UNIFORM FURROWS

References:



Location: Lubbock Area

Developed By: M. Namken

Checked By: ERL

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Date: 11/80

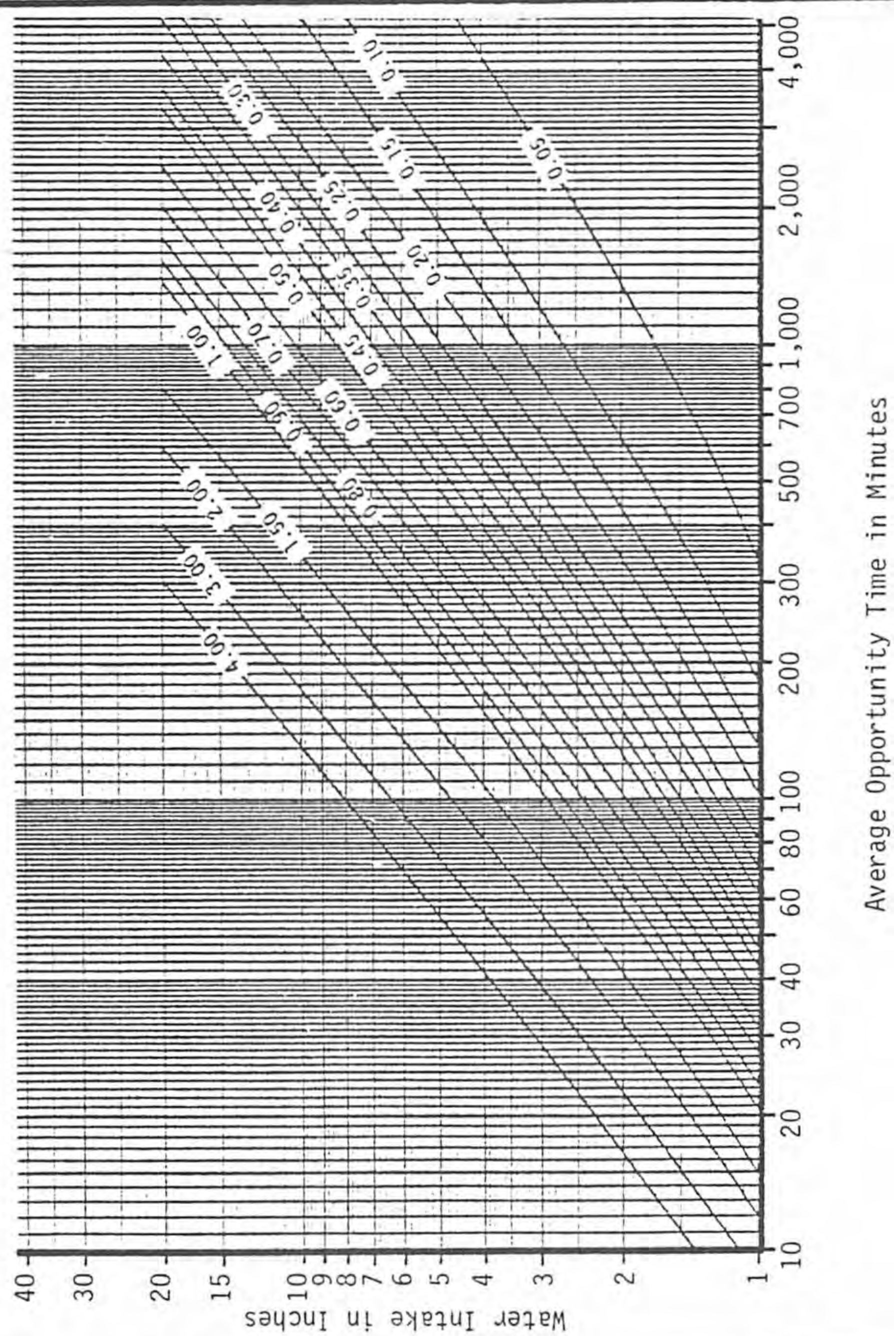
Identification No. 210-19-

Sheet 1 of 1

ENGINEERING - IRRIGATION

TITLE: FAMILY INTAKE CURVES FOR FURROW SYSTEMS

References:



Location:

Developed By.

Checked By:

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Identification No. 210-19-

Sheet 1 of 2

ENGINEERING - IRRIGATION

TITLE: WORKSHEET FOR FURROW SYSTEM EVALUATION

References:

Date: 10/80

Producer	Field Office	Technician	Date
-	-	-	7-15-80

Water pumped 3.58 in.
Water lost in delivery system 0.24 in.
Water applied to furrows 3.34 in.
Water runoff as tailwater 0 in.
Water intake into furrow soil 3.34 in.
Percent tailwater reused 0 in.

Stations	0	1/4	1/2	3/4	1,300'
Average slope (%)	0.3	0.3	0.3	0.3	
Dominant soil	Amarillo loam	Amarillo loam	Amarillo loam	Amarillo loam	

Irrigation time = 480 min.

Advance time (min)	0	30	90	180	300
Time of recession (min)	15	20	20	20	120
Opportunity time (min)	495	470	410	320	300

Average opportunity time for furrows = 399 min.

Intake family for this irrigation = 0.35

Water applied to stations (in.)	3.8	3.7	3.4	2.9	2.8
Water holding capacity of root zone (in.) (total)	6	6	6	6	6
Water in root zone before irrigation (in.)	2.85	2.85	2.85	2.85	2.85
Net irrigation required (in.)	3.15	3.15	3.15	3.15	3.15
Water applied in root zone to stations (in.)	3.15	3.15	3.15	2.9	2.8

Average water applied in root zone to furrow (in.) = 3.03 in.

Average water applied in root zone to 1/4 area (in.)	3.15	3.15	3.03	2.85

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$$\text{Water distribution in furrow} = \frac{\text{Water applied to low station (in.)} \times 100}{\text{Water applied to high station (in.)}}$$

$$= \frac{2.8}{3.8} \times 100 = 74\ \%$$

$$\text{Pattern efficiency} = \frac{\text{Average water applied to low 1/4 area (in.)} \times 100}{\text{Average water applied in root zone (in.)}}$$

$$= \frac{2.85}{3.03} \times 100 = 94\ \%$$

$$\text{Application efficiency} = \frac{\text{Average water applied to furrow (in.)} \times 100}{\text{Water pumped (in.)}}$$

$$= \frac{3.03}{3.58} \times 100 = 85\ \%$$

$$\text{System efficiency} = \frac{\text{Water applied to low 1/4 area (in.)} \times 100}{\text{Water pumped}}$$

$$= \frac{2.85}{3.58} \times 100 = 80\ \%$$

Water use efficiency = (system efficiency) + (percent tailwater reused)

$$= 80\ \% + 0\ \% = 80\ \%$$

APPENDIX E. Training Gudie for Determining Soil Moisture Needs

SOIL CONSERVATION SERVICE

Date: 11/80

Identification No. 210-19- Sheet 1 of 12

ENGINEERING - IRRIGATION

TITLE: TRAINING GUIDE - WORKSHEET FOR SOIL WATER NEEDS

References:

The worksheet is intended to be versatile when working with landowners on soil-water needs. It can be used to provide general information or adapted to specific soils, crops, or instruments. In addition, the guide can be used as a visual aid when discussing the relationship between percent available water, percent water (dry weight basis), soil tension, and instrumentation.

When working with irrigators, the guide should not get too detailed or specific because many variables occur in the field. Such things as consumptive use, water application intake rates, water holding capacities, and soil and plant tension are factors that make specific data difficult to use in the field.

The X-coordinate (abscissa) on the worksheet correlates the percent available water, percent water (dry weight basis), soil tension, and instrumentation. The inches of water (Y-coordinate or ordinate) reflects the need of the soil and not what is available.

The center dark vertical line represents a critical moisture or stress level and will be designated as "visual wilting point." This occurs when the crop shows visible signs of wilting during the high consumptive use period of the day. The 50 percent available water capacity is used as the level when water needs to be applied to a soil if optimum crop production is desirable. So long as the water level stays above 50 percent, the plant grows and fruits. If the water level falls below 50 percent, the plant stops growing and fruiting and uses the water just to stay alive. If it is desirable to use a level other than the 50 percent, a line at the desired level can be drawn in.

The right side of the graph represents the water level at field capacity. This is reached when the force or pull of gravity has removed the free water from the soil, usually 24 to 36 hours after an irrigation.

The left side of the graph represents the permanent wilting point. When the water level reaches this point, a crop will no longer respond to water sufficiently to produce fruiting.

GRAPH FOR PERCENT AVAILABLE WATER

The upper graph (percent available water) will probably be the most used portion of the worksheet since it can be used with the feel and appearance method of determining soil water levels. If the percent available water is the only concern of the irrigator, then the remaining three graphs do not need to be completed.

Location: Lubbock Area | Developed By: M. Namken | Checked By: ERL

To develop the graph, the available moisture for the soil must be determined from irrigation interpretations or an irrigation guide. When tailoring to a specific area, the site should be sampled to verify the soil map and interpretations of the soil. If discrepancies are found, the data should be corrected or adjusted before entering it on the worksheet.

Once the total water holding capacity for the soil profile is determined, locate the value on the left side of the graph (permanent wilting point). Draw a straight line from this point to the lower right hand corner of the graph (field capacity) where no (zero) water needs to be replaced.

Usually only one rooting depth for a crop would be shown. If, however, the guide is developed for several crops, the individual diagonal lines would need to be labeled indicating the different depths.

When using the graph, the percent available water will be found in the field. The percent is then entered on the X-coordinate (abscissa) of the graph, move vertically up to the diagonal line and read inches to be replaced in the soil profile on the left (Y-coordinate or ordinate) scale.

GRAPH FOR PERCENT WATER (DRY WEIGHT BASIS)

The graph for percent water (dry weight basis) is very similar to the percent available water graph and is used in the same manner. However, it does differ in two ways. The inches of water to be replaced is for only one foot of soil and not the profile. The percent water includes total water and not just available water.

To develop the graph, the inches of water to be replaced per foot of soil must be determined. This value is obtained by dividing the inches of water to be replaced in the soil profile by the moisture replacement depth.

Locate this value on the left side of the graph (permanent wilting point). Draw a straight line from this point to the lower right hand corner of the graph (field capacity) where no (zero) water needs to be replaced.

The scale for the X-coordinate (abscissa) or percent water must be adjusted to correspond with the percent available water scale. The scale will increase from left to right. As an example, a clay loam soil has 27 percent water at field capacity and 13 percent at the permanent wilting point (see graph No. 4). Record the 13 percent on the left side of the graph and record 27 percent on the right side. Divide the scale accordingly using 20 percent on the center dark vertical line.

To use the graph, a soil sample is taken and weighed wet, dried, and weighed again (usually in grams). The percent moisture (dry weight basis) is defined as:

$$\frac{(\text{wet weight-dry weight})(100)}{\text{dry weight}}$$

Enter this percent value on the X-coordinate (abscissa) of the graph, move vertically up to the diagonal line and read inches needed per foot of soil on the left (Y-coordinate or ordinate) scale.

As an alternative, enter the percent value on the abscissa, move vertically up to the diagonal on "Percent Available Water" graph, and read the inches of water needed in the profile on the ordinate scale.

SOIL TENSION SCALE

The soil tension scale is developed from charts, graphs, or interpretations. The scale will be variable by textures and must correlate to percent available water and percent water (dry weight basis) graphs. The scale will decrease from left to right.

INSTRUMENT READING SCALE

The instrument scale is also a variable scale and must correlate to the scales on the percent available water and percent water (dry weight basis) graphs. Generally, the manufacturer will provide instructions that relate the instrument readings to percent available water or soil tension.

The tensiometer scale will decrease from left to right. The gypsum block scale will increase from left to right.

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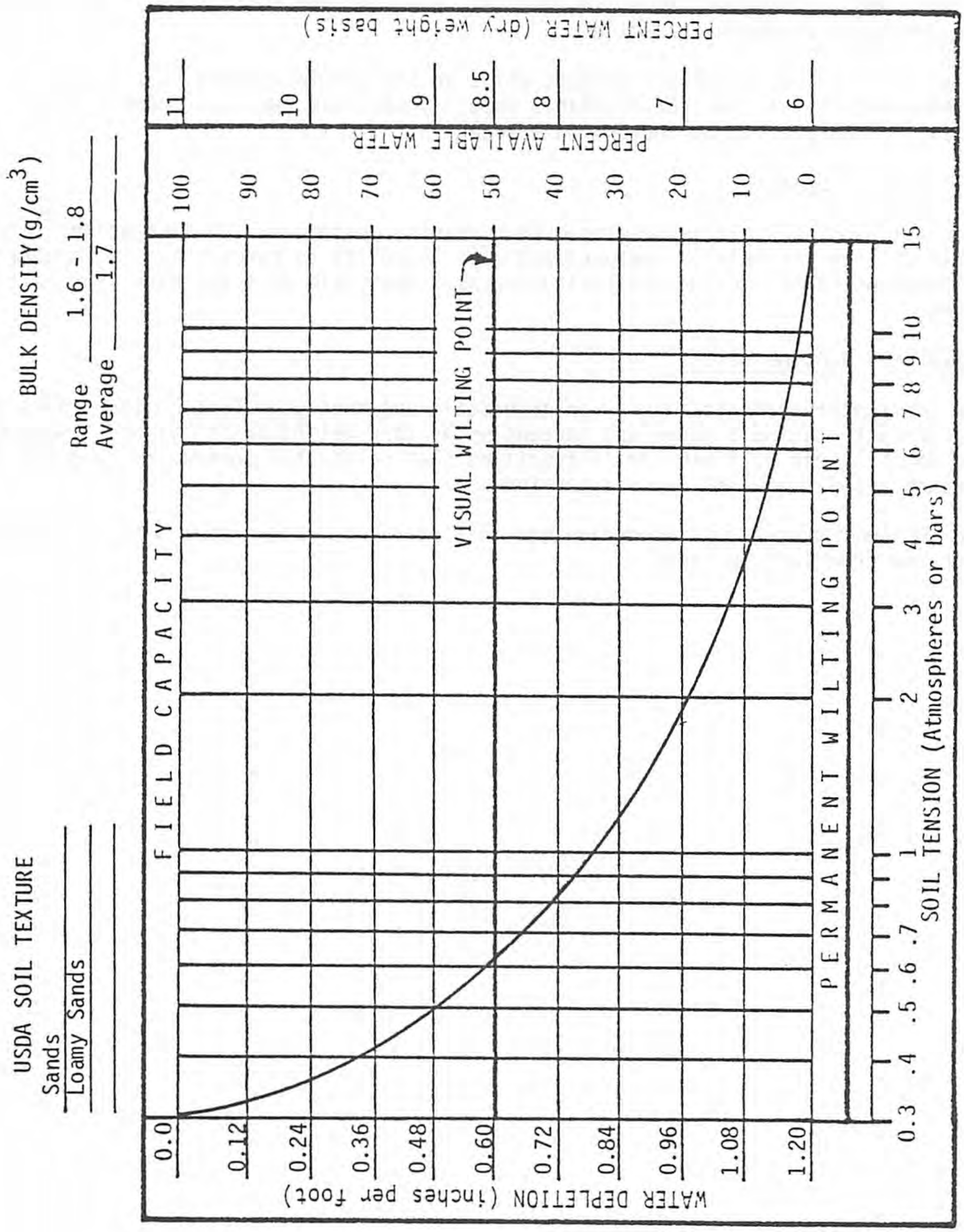
Sheet 4 of 12



GRAPH NO. 1

Identification No. 210-19-

Sheet 5 of 12

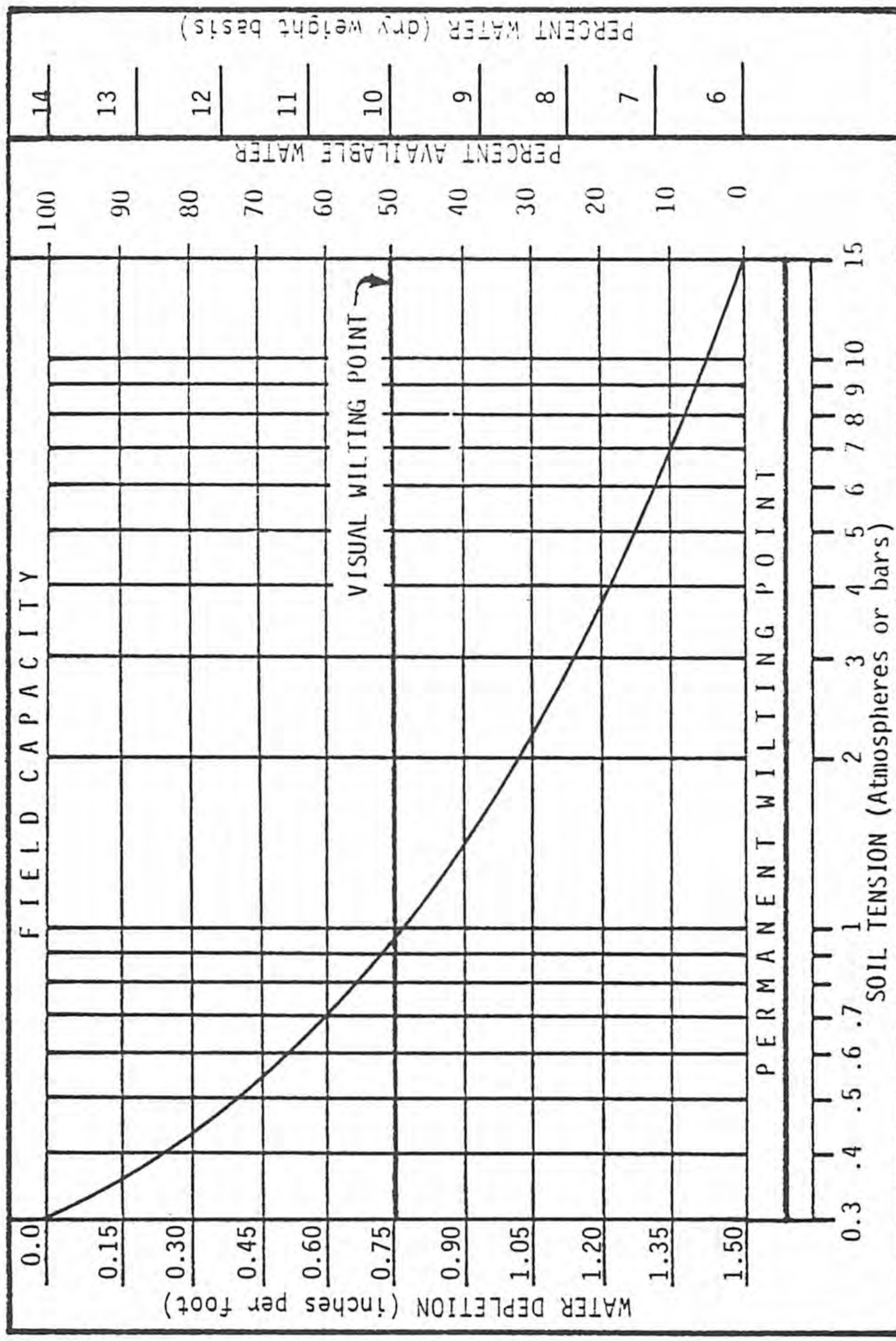
USDA SOIL TEXTURE

Sandy Loam

BULK DENSITY (g/cm^3)

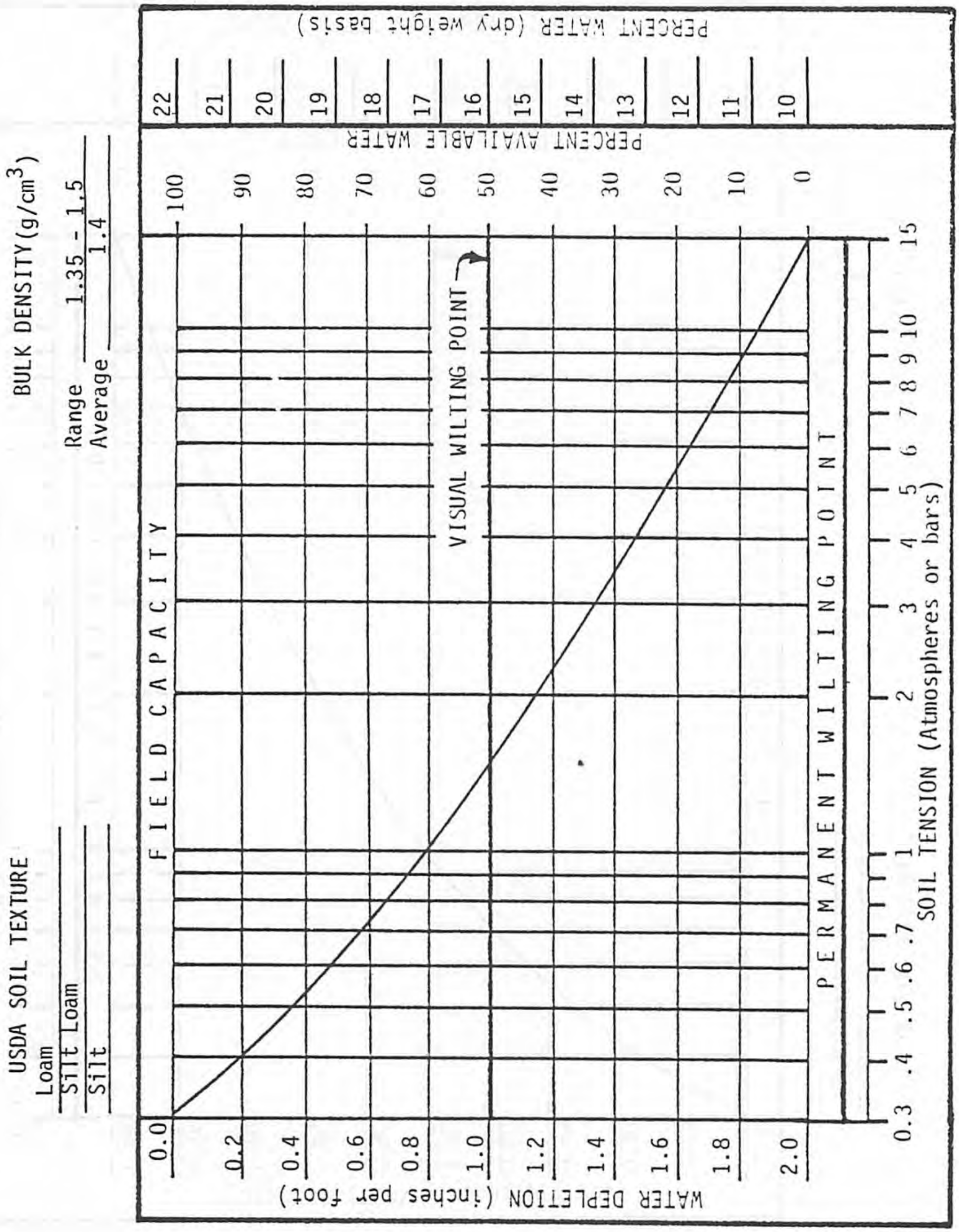
Range 1.4 - 1.6

Average 1.5



GRAPH NO. 2

Identification No. 210-19-

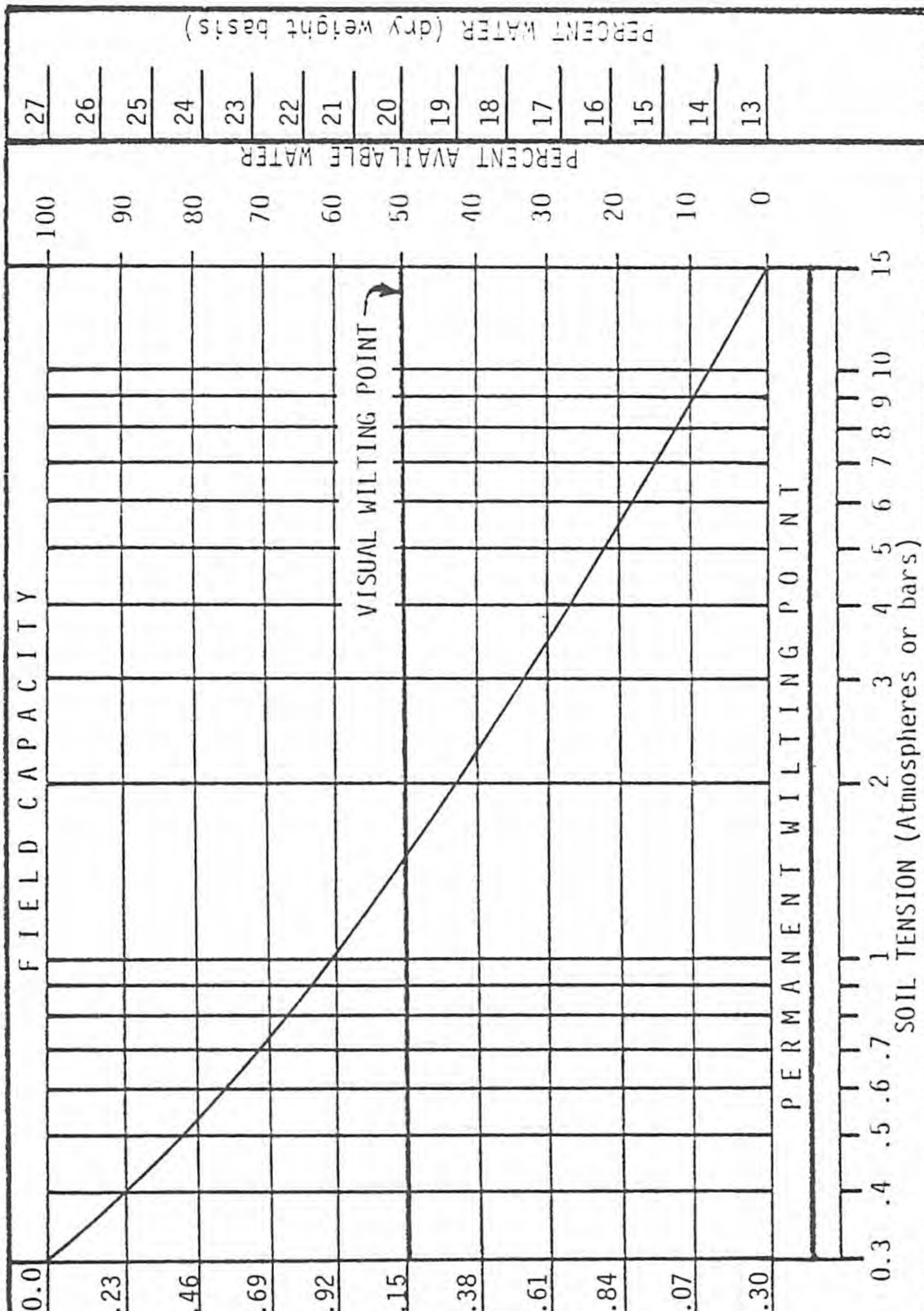


GRAPH NO. 3

Identification No. 210-19-   Sheet 7 of 12

USDA SOIL TEXTURE
Clay Loam
Silty Clay Loam
Sandy Clay Loam

BULK DENSITY (g/cm^3)
Range 1.3 -1.4
Average 1.35



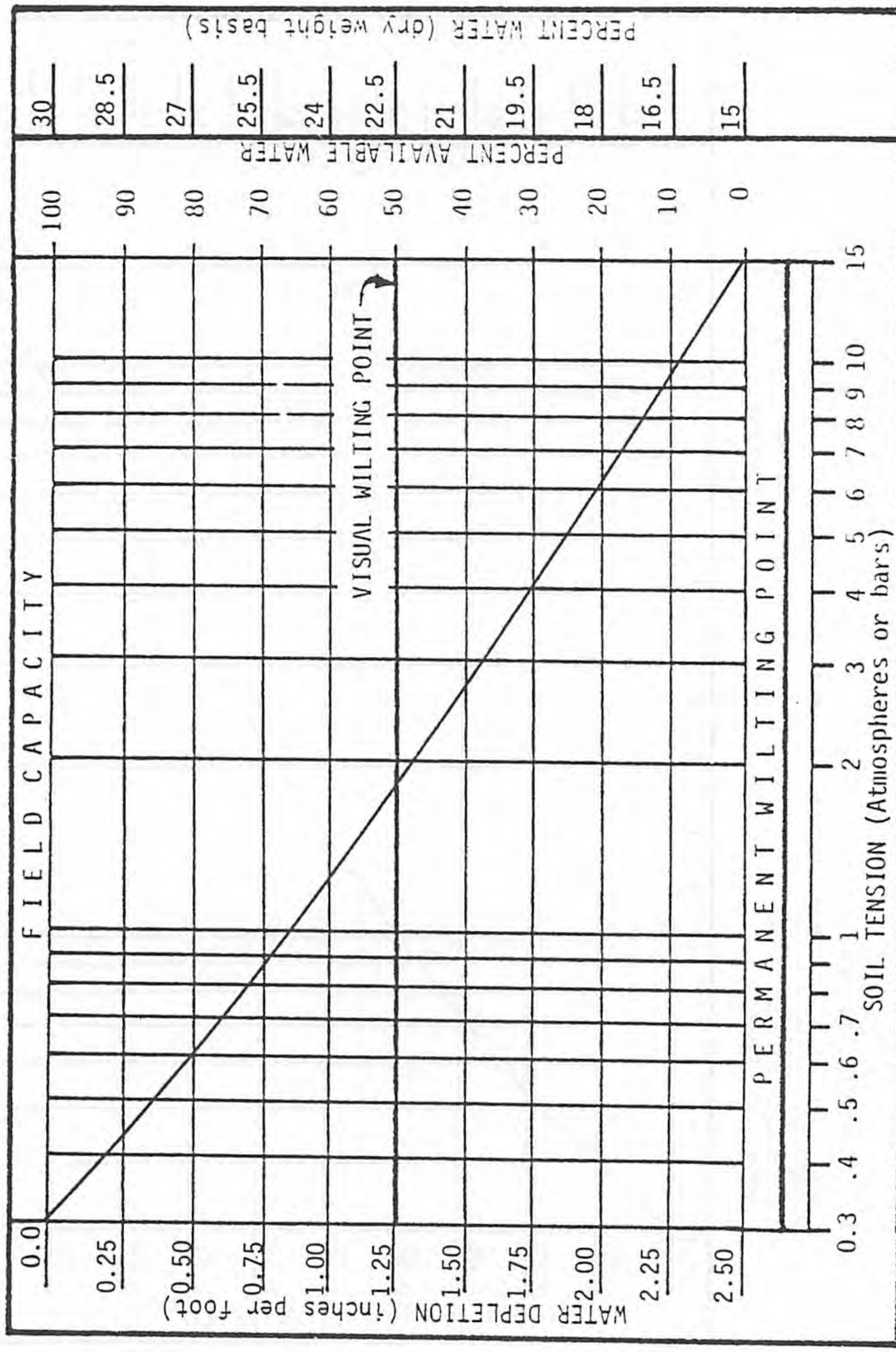
GRAPH NO. 4

Identification No. 210-19-

Sheet 8 of 12

USDA SOIL TEXTURE
Sandy Clay
Silty Clay

BULK DENSITY (g/cm^3)
Range 1.25 - 1.35
Average 1.3



GRAPH NO. 5

Identification No. 210-19- | Sheet 9 of 12

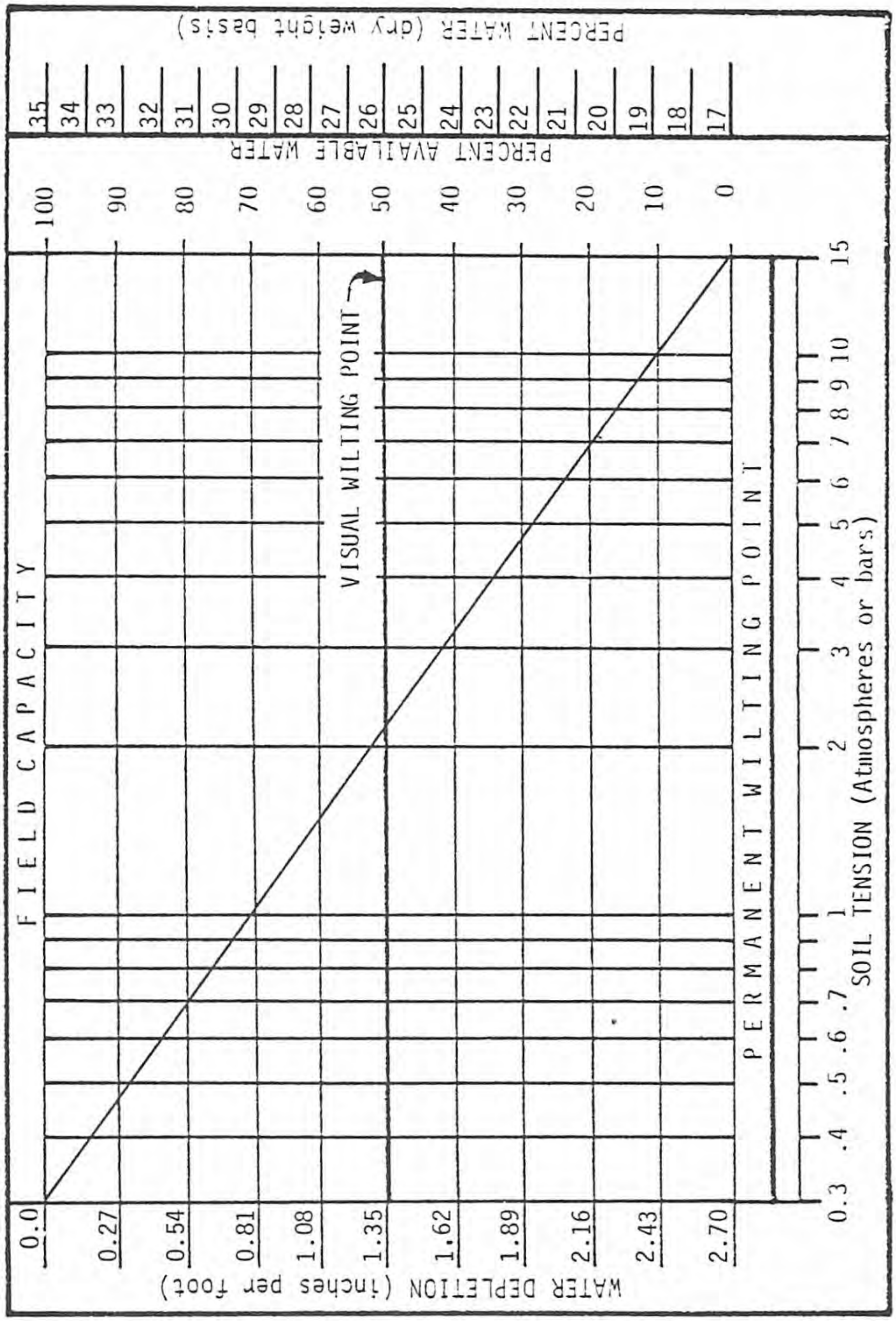
USDA SOIL TEXTURE

Clay

BULK DENSITY(g/cm^3)

Range 1.2 - 1.3

Average 1.25



GRAPH NO. 6

EXAMPLE - WORKSHEET FOR SOIL WATER NEEDS

You are providing irrigation water management assistance to a producer who is using a graded furrow system to irrigate cotton on an Amarillo loam soil. According to the irrigation guide, the net moisture to be replaced is 4.0 inches.

Using the "Percent Available Water" graph on the worksheet, enter the value 4.0 on the Y-coordinate (ordinate). Enter the value 100 on the X-coordinate (abscissa) since at field capacity, no water needs to be replaced. Draw a straight line between the two values (points). Using the "feel method," the percent available water is estimated to be 65%. Enter the 65% on the abscissa, go vertically to the diagonal line, and then left to read 1.4 inches of water needed to be replaced in the soil profile.

The irrigation guide indicates that the moisture replacement depth for cotton is 4.0 feet. Therefore, the inches of water to be replaced per foot of soil is 1.0 inch (4.0 ÷ 4.0). Enter the 1.0 value on the ordinate of the "Percent Water (Dry Weight Basis)" graph. Using graph No. 3, the percent water (dry weight basis) for a loam soil ranges from 10 - 22 percent. Therefore, the scale of the abscissa will start at 10 and end at 22. Enter the 22 value on the abscissa and then draw a straight line between the two values (points).

A soil sample is obtained and weighed:

Wet weight: 91.8 grams
Dry weight: 77.9 grams

$$\text{Percent water (dry weight basis)} = \frac{(\text{wet weight} - \text{dry weight})(100)}{(\text{dry weight})}$$

$$\text{Percent water (dry weight basis)} = \frac{(91.8 - 77.9)(100)}{77.9}$$

$$\text{Percent water (dry weight basis)} = 17.8\%$$

Enter the 17.8% on the abscissa of the "Percent Water (Dry Weight Basis)" graph, go vertically to the diagonal line, and then left to read 0.35 inch of water to be replaced per foot of soil. As an alternative, enter the 17.8% on the abscissa and go vertically to the diagonal line on the "Percent Available Water" graph, and then left to read 1.4 inches of water to be replaced in the soil profile. A field determination shows that the bulk density of the soil is 1.44 grams/cm^3; therefore, the correct graph (No. 3) was used.

To establish the "Soil Tension" scale, use graph No. 3 again. At 60% available water, the soil tension is 1.0 bar. At 80% available water, it is 0.53 bar. Move vertically downward on the 60% available waterline (upper graph) amd mark the soil tension scale as 1.0. Move vertically downward on the 80% available water line and mark the soil tension scale as 0.53. Project the line vertically downward from 65% available moisture, through the 17.8% water (dry weight basis), to the soil tension scale. This value would be 0.85 bar.

Tensiometer readings correlate to the soil tension. A reading of zero corresponds to 1/3 bar and 100 corresponds to 1.0 bar. Projecting a vertical line down from the 65% available moisture, through the 17.8% water (dry weight basis), through the 0.85 bar soil tension, to the instrument reading scale, establish the tensiometer's value of 100 directly below the 1.0 bar soil tension. Divide the scale accordingly. The reading would be 85.

Gypsum block readings correlate to the percent available water. A reading of zero corresponds to permanent wilting point and 10C corresponds to field capacity. Establish the scale from zero to 100 and the reading would be 65.

SOIL CONSERVATION SERVICE

Identification No. 210-19 -

ENGINEERING - IRRIGATION

TITLE: WORKSHEET FOR SOIL WATER NEEDS

References:

Date: 3/82

DATE: 3/15/82

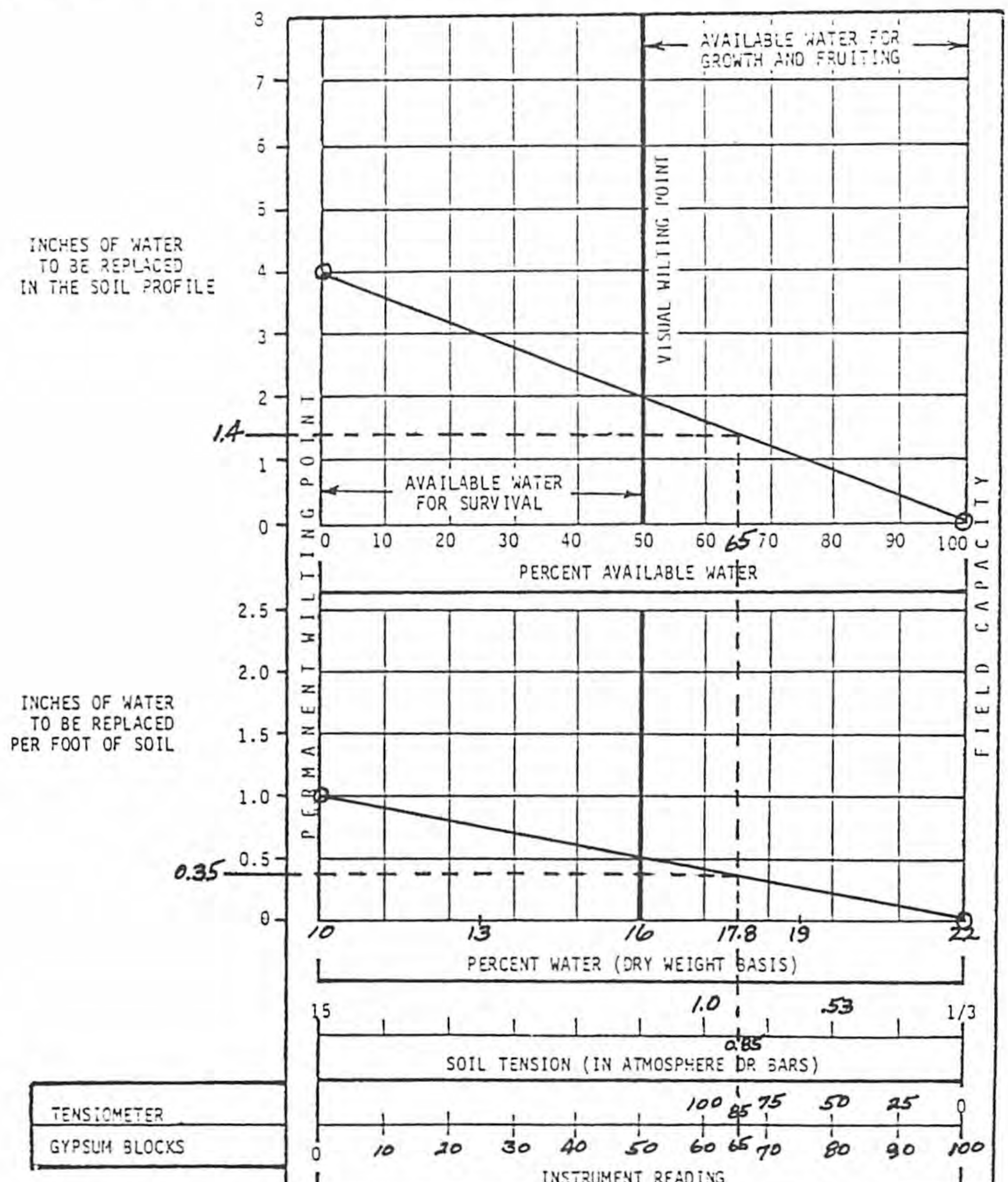
TECHNICIAN: -

CROP: Cotton

SOIL: Amarillo loam

FIELD OFFICE: -

PRODUCER: -



Location: Lubbock Area

Developed By: M. Namken

Checked By: ERL

IRRIGATION PUMPING PLANT

EFFICIENCY TESTING

ON THE

TEXAS HIGH PLAINS

By staff of the

High Plains Underground Water
Conservation District No. 1

ABSTRACT

Irrigation plays a major role in the economic viability of the highly productive Texas High Plains. It has stabilized crop production at a high level, thereby, adding to farm income. Also, it has helped to eliminate the boom-bust cycle of the area during the dryland era.

The rising fuel costs today are causing great concern among the irrigation farmers. The fuel bills for pumping irrigation water are a major part of the farming budget. The agencies involved in providing pumping plant efficiency tests are trying to demonstrate to farmers how efficiency affects fuel use.

The Texas Agriculture Extension Service, U.S. Department of Agriculture - Soil Conservation Service, High Plains Underground Water Conservation District No. 1, Bailey County Electric Cooperative Association, Deaf Smith County Electric Cooperative Incorporated, Lighthouse Electric Cooperative Incorporated, and Swisher County Electric Cooperative Incorporated have joined together in publishing the results of their efficiency tests. A broader understanding of the efficiencies reported can be gained by looking at the total number of pumping plants tested across the entire area.

Efficiency test results are included for the years 1978 through 1981. Some agencies did not test during this entire period, while others had begun testing prior to this period. Texas Agriculture Extension Service reports data from 1975 when they first began testing.

Fuel prices used to report all efficiency tests in this publication were 6 cents per kilowatt-hour for electricity and $3.00 per thousand cubic feet of natural gas. Diesel fuel is priced at $1.15 per gallon. This allows direct comparison of pumping plant efficiency from one area to another.

In 832 electric powered pumping plants tests, the average overall efficiency was 40.6 percent. The average cost per acre-foot of water was $41.44, with a $3.45 average cost per acre-inch. The average cost per acre-foot per foot of lift was $0.19.

The natural gas powered pumping plants average overall efficiency was 11.3 percent. A total of 442 natural gas powered plants were tested. In 334 tests, the pump and motor efficiencies were separated. The average pump efficiency was 56.1 percent. The average efficiency of the natural gas powered engine was 20.1 percent.

Only one agency evaluated diesel powered pumping plants. The average overall efficiency was 20 percent. The average engine efficiency was 31 percent, with an average pump efficiency of 67 percent for the 26 units tested.

While, as a group, the diesel powered pumping plants were approaching the desired level of efficiency, some individual pumping plants in each group did reach the desired level of efficiency. This means that any pumping plant can be designed to produce at peak efficiency. Also, it shows that there is room for improvement.

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ACKNOWLEDGEMENTS

Since many individuals were involved in the collection of data for this publication, it is impossible to list each person. However, their efforts need to be recognized and to all who made this report possible, we express our appreciation.

Our sincere gratitude is expressed to the following individuals and organizations: Dr. Daniel C. Pfannstiel, former Director, Texas Agriculture Extension Service; George C. Marks, former State Conservationist, Texas Soil Conservation Service; Carl Spencer, former Executive Director, Texas State Soil and Water Conservation Board; and A. Wayne Wyatt, Manager, High Plains Underground Water Conservation District No. 1.

The electric cooperatives in the area offered their support and we are grateful. The following furnished data and extended to us a very needed helping hand: Connie Gupton, Manager, Bailey County Electric Cooperative Incorporated; James T. Hull, General Manager, Deaf Smith County Electric Cooperative Incorporated; Alton Higginbotham, Manager, Lighthouse Electric Cooperative Incorporated; Lyle M. Robinson, Manager, Swisher County Electric Cooperative Incorporated.

Also our appreciation is extended to all the landowners and operators who participated in the efficiency testing program by having their pumping plants tested.

INTRODUCTION

In the late 1960's, Texas Tech University conducted an irrigation pumping plant efficiency testing project. Results showed that the average overall efficiencies for electric and natural gas powered pumping plants were 48.6 percent and 10.8 percent, respectively.

Fuel costs then were not a major concern of farmers as they are today. Therefore, efforts to improve the pumping plant efficiency were not undertaken. Today, however, times have changed and fuel prices have a tremendous impact on the irrigation farmers' budgets.

The electric rate in the late 1960's was approximately 1.5¢ per kilowatt-hour (kwh). Today the electric cooperative's rates are being renegotiated with the wholesale power supplier and will probably average around 8¢ per kwh. The increase in the price of electricity has come about because of the increase in demand, requiring more generation power, and the rising cost of fuels, labor, and inflation. The cost of natural gas has risen from about 35¢ per thousand cubic feet (MCF) in the late 1960's to more than $4.50 per MCF in some areas of the Texas High Plains.

Currently over 70,000 wells exist in the High Plains of Texas. Many are inefficient due to changes in pumping conditions. The pumping level has declined over the years causing the pumps to lift water from greater depths. This condition results in higher energy use due to more work required by the pump. Pumping plant efficiency testing programs conducted on the Texas High Plains are designed to provide more exact information to the farmer. This information, when put in practice, can save thousands of dollars by improving efficiencies and preventing potential problems.

Collection of Data

Methods used to test the efficiency of irrigation pumping plants varied slightly among the agencies. However, they were similar enough to ignore any minor differences. There are certain basic measurements that have to be made to perform an efficiency test. The following measurements are required for diesel, natural gas, and electric powered pumping plants except for the fifth measurement which is required only for natural gas and diesel powered pumping plants:

1. Discharge rate in gallons per minute.
2. Pumping lift in feet
3. Pump discharge pressure in feet
4. Pipe line friction loss in feet
5. Brake horsepower (natural gas and diesel only)
6. Input energy per unit of time used by the power unit.

1. Discharge Rate. Since pump installations vary widely, many different devices were used by the agencies to measure the production of the pump. Usually, on an open discharge system, the propeller flowmeter was connected to measure the flow. The same was normally used on an underground pipe system. On systems that are connected to sprinklers, a velocity gage was installed in place of the first sprinkler head on the main line, otherwise a flowmeter was placed in the line. Also, a manometer and pitot tube was sometimes used on this type of system by the High Plains Underground Water Conservation District No. 1. The manometer measures the difference in velocity between the leading and trailing orifices of the pitot tube which is inserted by drilling and tapping two holes into the system, running the tube through the pipe, and then connecting the pitot tube to the manometer by means of two rubber hoses.

By knowing the difference in velocities of the pitot tube and the size of the pipe, a chart was used to calculate the discharge rate.

2. Pumping Lift. The pumping lift was obtained for each well tested by means of an electric water level measuring device (E-line). To obtain the pumping lift the E-line was lowered into the well casing through an airline hole. In some wells, a hole was created by chipping off portions of concrete next to the pumpbase and cutting into the casing with an acetylene torch. The E-line was lowered into the well until it indicated that the pumping level had been reached.

3. Discharge Pressure. Discharge pressure is an important measurement, especially on sprinkler systems and where a squeeze valve is used to prevent the pump from pumping off. This measurement is made at the well location. Discharge pressure was obtained by attaching a pressure gage to a three-quarter inch faucet fitting and screwing the gage onto the faucets which are on the discharge pipes of most of the wells in the area. On those wells which did not have faucet fittings, a three-eighth inch hole was drilled and tapped, and the pressure gage was screwed directly into the discharge pipe. The discharge pressure was then converted to feet by multiplying by 2.31.

4. Friction Loss Estimation. Friction loss was calculated on all closed systems by estimating the length and size of the tile line or flow line between the discharge and the device being used to measure the discharge rate. A friction chart was consulted to calculate the head loss. Many times this was estimated or ignored, especially on an open discharge system where it was felt to be insignificant. This friction loss was added to the discharge pressure and pumping lift to obtain the total dynamic head. The total dynamic head is a necessary component in calculating water horsepower which is the power output required at the pump to provide the given discharge rate.

5. Brake Horsepower (BHP). Brake horsepower was measured for natural gas and diesel powered pumping plants using a torque cell. Electric motor efficiencies were used to calculate electric horsepower. This is accomplished from electric power measurements taken from the existing electric meter.

In measuring brake horsepower of natural gas or diesel powered installations, a torque-sensing device was attached in place of the regular drive shaft (between the internal combustion engine and the gearhead) to measure the actual horsepower delivered by the engine.

6. Input Energy. The amount of energy used by the power unit was measured for all pumping plants by reading the watt-hour meter for electric plants and the fuel flowmeter for natural gas plants. For electric powered plants, the watt-hour meter was read by counting the number of revolutions of the revolving disc per unit of time. The only other information required for the electric input horsepower (IHP) was the Kh factor, also taken from the watt-hour meter. The formula is IHP = 4.8 x Kh factor x disc revolutions ÷ time in seconds.

For natural gas plants, the natural gas meter was read by counting the time in seconds in which a fixed amount of gas was consumed by the engine. The fixed amount of gas, usually 100 cubic feet, was then divided by the corresponding time. The Texas Agriculture Extension Service used their own test meter by connecting it into the gas line at the engine.

The amount of energy consumed was also calculated for the purpose of determining the pumping cost. On electric powered plants, a formula similar to the input horsepower formula was used to calculate kilowatt-hours, which is the unit of measure used by power companies for billing customers. For natural gas plants, the cubic feet per hour was multiplioed by 1,000, the results being the unit of measure (MCF) used for billing natural gas customers.

The Texas Agriculture Extension Service was the only agency to test diesel units. The method for measuring fuel use was to set up a gage to determine consumption for a given amount of time. The amount of fuel in gallons per hour could then be calculated. Finally, the input horsepower was calculated and used in finding the engine efficiency and the overall efficiency.

"Standard for Attainable Efficiencies" (Table 1) shows the efficiency that pumping plant components can achieve when they are properly selected. It also allows a comparison with an actual test result to find how much improvement is possible. The dollars saved in energy cost can then be calculated based on an improved efficiency.

TABLE 1

Standard for Attainable Efficiencies

Type	Attainable Efficiency Percentage
Submersible Pumps	67
Vertical Turbine Pumps	75 - 82
Right Angle Pump Drive (gearhead)	95
Automotive Engines	20 - 26
Industrial Engines	
Diesel	25 - 37
Natural Gas	24 - 35
Electric Motors	85 - 92

Recommendations for Improving Pump Efficiencies

The average overall efficiency of pumping plants today are similar to the 1960's. However, there are ways to improve the efficiency of pumping plants, and efforts are being made to inform irrigation farmers about the options available for changing poor efficiencies that result in high energy bills.

There are many pump plant installations where minor adjustments can make a contribution in energy savings. However, most installations will require a substantial capital expenditure in order to make a major improvement in energy savings. In making various adjustments to save energy, one must be able to evaluate the system after the adjustments to determine whether or not the desired results are achieved. The adjustments could have an adverse effect on the system rather than a beneficial effect.

The reduction of the gearhead speed can make a difference in the amount of fuel consumed. Usually when the gearhead speed is lowered, fuel consumption is reduced. However, the output work is also reduced. The efficiency may go up, down, or stay the same. Sometimes, even though the output work is reduced, the efficiency may increase and the fuel consumption decrease, which could be an energy savings.

Another reason some pumps are not as efficient as they should be is improper selection of the pump. Many times pump selection is based on the best guesses of the pump dealer and the farmer. Some rely only on past experiences to determine the total head the pump will operate against. Also, an incorrect estimate of the well yield could result in the installation of an inefficient pump.

Pump efficiency and fuel consumption can also be affected by adjustment of the pump impellers, provided they are open-type impellers. This adjustment will either increase or decrease the amount of water being pumped; however, an adjustment could be made to increase the efficiency and reduce the fuel being consumed.

Many irrigators have changed the method of distributing water on their farms by installing sprinkler systems to replace the furrow method of applying water. This causes a greater head due to the high pressure required by the sprinklers, and in many instances, this changes efficiency of the pump. As a result , many irrigators have lowered their pump efficiencies by changing the method of irrigation.

A choke valve installed in the discharge pipe is a fairly common occurrence, especially on smaller capacity pumps. The purpose is to reduce the volume of water being pumped. This is necessary if the pump is pumping air with the water (breaking suction), but the practice adds additional pressure (lift) to the pump. Sometimes a pump can use a choke valve and still have a good efficiency. However, since it has the added pressure, it is using more fuel and pulling more horsepower than is be necessary.

Many times, pumps are worn to the point where they are no longer picking up the amount of water they were designed to lift. To improve their efficiency it is necessary to repair or replace the bowls.

Internal combustion engines are often overlooked as having energy savings potential. Many times minor tune-ups can increase the fuel efficiency of an engine. Other adjustments in timing or carburetion can improve the operation of an engine.

The pump in an irrigation well is normally where the greatest potential for energy savings is possible. It also requires the greatest capital expenditure to achieve its full potential in efficiency. Therefore, a detailed evaluation of the present efficiency of a pump is necessary. A management decision can then be formed and acted upon based on the facts from the evaluation.

Irrigation pumping plant efficiency test results identify where improvements can be made. The total fuel cost to operate a pump that is 35 percent efficient with 3¢/kwh electricity is the same as that needed for a pump at 70 percent efficiency with 6¢/kwh electricity costs. The cost comparison is similar with natural gas. Improving the pump efficiency will in many instances pay for the repairs in a short period of time and provide savings for several years.

One way to evaluate the pumping plant's efficiency is for the irrigator to measure his pumping lift, then take his hourly pumping cost and insert the figures into the accompanying charts (Tables 19 and 20). Suppose he had a pumping lift of 250 feet and the hour cost for natural gas is $2.05. Find 250 on the left side of the chart (Table 19) then go across to the figure nearest to $2.05. We find $2.01 on the chart and follow that column to the top to find the approximate pump efficiency of 50 percent. The purpose of the charts is to give a quick general reference for finding pump efficiencies which, in turn, may indicate possible problems. If a possible problem is indicated, then a complete efficiency test should be conducted on the pumping plant.

Any irrigator who is not sure that his pumping plant efficiency is satisfactory should inquire at the local office of the Soil Conservation Service, Agriculture Extension Service, water conservation district, or electric cooperative for information on evaluating the pumping plant.

Texas Agricultural Extension Service

The Texas A&M University System
College Station 77843

IRRIGATION PUMPING PLANT TESTING PROGRAM

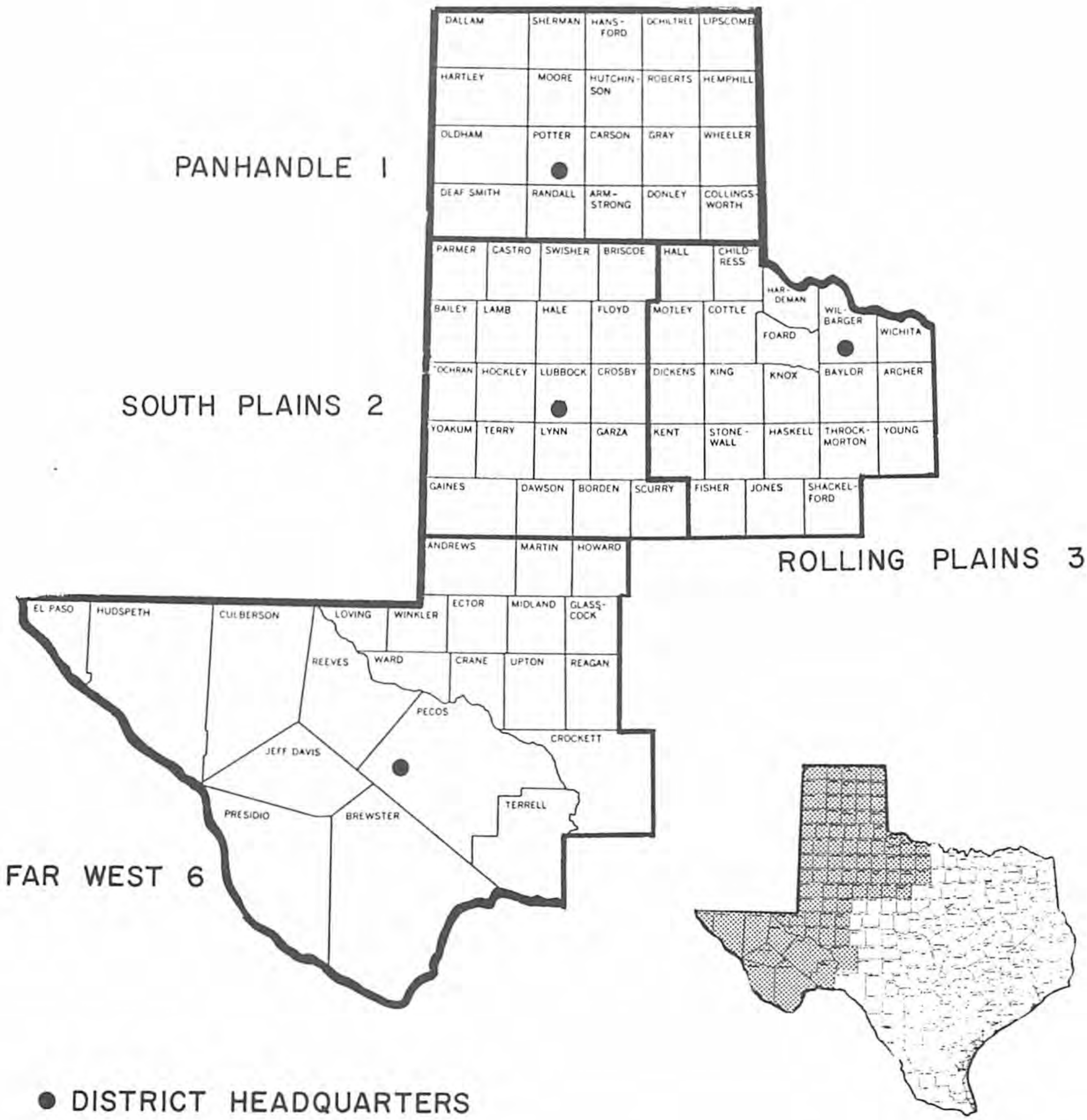


Figure 1. Area Served By Texas A&M Extension Service Pumping Plant Testing Program

ELECTRICAL MOTOR POWERED UNITS

The Texas Agricultural Extension Service has reported the results of their testing program on 93 electrically powered pumping plants (Table 2). The overall efficiency was found to be 49.3 percent. This is the average of all electric motor types and the different irrigation methods.

The electric pumping plants were separated into the type of motor and different irrigation methods (Table 2). Using a vertical hollowshaft motor and applying water through a center-pivot, the average overall efficiency of the pumping plant was 63.8 percent. Using the furrow irrigation method and the vertical hollowshaft, belt drive, and submersible type motors, the overall efficiency was 50.8, 28.1, and 40.9 percent, respectively. While the furrow group had a lower overall efficiency than the center-pivot group, there were installations of both high and low efficiency. This points to the fact that either group can achieve a very good efficiency.

The average cost associated with all the electric pumping plants was $37.68 per acre-foot or $3.14 per acre-inch. The hourly cost of operation was $2.71. The cost per acre-foot per 100 foot of head was $14.64 or $0.15 per acre-foot per foot of head.

TABLE 2. IRRIGATION PUMPING PLANT EFFICIENCY TESTS

Electricity

A R E A

1975 - 1981

			MOTOR					PUMP						Electricity cost @ 6.0¢/KWH		
Location	County	Irri-gation Method	Type	Rated HP	HP Load	KW Load	% Eff.	GPM	Pumping Lift-ft	Dis-charge psi	% Eff.	Percent Overall Eff.	KWH Ac-In/ 100' Head	Per Ac-In $	Per Hour $	Ac-In/ 100' Head $
E120	Hartley	Pivot	VHS	150	118	96	91	640	490	30	77	69.9	12.2	4.08	5.79	.73
E68	Lipscomb	Pivot	VHS	125	87	71	91	810	166	68	76	69.4	12.3	2.39	4.27	.74
E48	Lipscomb	Pivot	VHS	125	107	88	91	800	215	82	76	69.2	12.4	3.00	5.28	.74
E58	Lipscomb	Pivot	VHS	125	105	86	91	750	213	90	76	69.2	12.4	3.12	5.16	.74
E36	Dallam	Pivot	VHS	150	155	127	91	950	300	75	73	67.0	12.8	3.64	7.61	.77
E100	Hemphill	Pivot	VHS	60	54	44	90	450	132	94	74	66.5	12.9	2.67	2.67	.77
E121	Gray	Pivot	VHS	200	136	113	90	775	380	53	75	65.5	13.0	3.92	6.75	.78
E90	Lipscomb	Pivot	VHS	150	129	106	91	840	244	78	71	64.7	13.5	3.44	6.36	.81
E110	Hemphill	Pivot	VHS	60	55	46	90	410	145	95	69	61.7	13.9	3.04	2.73	.83
E139	Lamb	Pivot	VHS	75	81	67	90	700	223	40	69	62.3	13.7	2.60	4.01	.83
E171	Lamb	Pivot	VHS	75	88	74	87	770	226	35	70	60.6	14.0	2.59	4.41	.84
E129	Lamb	Pivot	VHS	75	82	68	90	700	205	40	64	57.8	14.8	2.64	4.08	.89
E331	Wheeler	Pivot	VHS	75	86	72	90	525	250	65	62	55.3	15.4	3.68	4.29	.92
E309	Gaines	Pivot	VHS	50	43	36	90	525	116	34	60	54.1	15.8	1.87	2.16	.95
E299	Lamb	Pivot	VHS	50	50	41	90	500	130	35	60	53.7	15.9	2.25	2.48	.96
E181	Parmer	Pivot	VHS	60	37	31	90	225	301	27	56	50.4	16.8	3.66	1.82	1.01
E111	Gray	Pivot	VHS	200	180	149	90	725	375	70	57	49.2	17.3	5.55	8.94	1.03
E60	Lamb	Pivot	VHS	75	83	69	90	720	111	46	47	42.6	20.1	2.61	4.15	1.20
E201	Parmer	Pivot	VHS	40	31	25	90	150	255	55	47	42.4	20.0	4.58	1.53	1.20
E191	Parmer	Pivot	VHS	60	43	37	90	150	315	30	33	29.3	28.7	6.60	2.19	1.72

TABLE 2. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

Electricity

A R E A

1975 - 1981

			MOTOR					PUMP						Electricity cost @ 6.0 ¢/KWH		
Location	County	Irri-gation Method	Type	Rated HP	HP Load	KW Load	% Eff.	GPM	Pumping Lift-ft	Dis-charge psi	% Eff.	Percent Overall Eff.	KWH Ac-In/ 100' Head	Per Ac-In $	Per Hour $	Ac-In/ 100' Head $
AVERAGE	ALL	PIVOT	VHS	99	88	72	90	606	240	57	65	58.0	15.4	3.40	4.33	.92
E70	Gaines	Pivot	Belt	40	40	34	88	520	128	27	73	55.0	15.5	1.77	2.03	.93
E80	Gaines	Pivot	Belt	40	41	35	88	520	113	26	65	48.7	17.6	1.83	2.09	1.05
AVERAGE		Pivot	Belt	40	41	35	88	520	121	27	69	51.9	16.6	1.80	2.06	.99
AVERAGE	ALL	Pivot		94	83	69	90	598	229	54	65	57.5	15.5	3.25	4.13	.93
E38	Hudspeth	Furrow	VHS	150	149	122	91	1725	260	2	78	70.6	12.1	1.92	7.32	.72
E69	Deaf Smith	Furrow	VHS	100	98	81	90	940	294	5	74	66.9	12.8	2.34	4.86	.76
E220	Ochiltree	Furrow	VHS	200	150	122	92	1190	350	5	72	66.5	12.8	2.77	7.30	.77
E18	Hudspeth	Furrow	VHS	200	185	150	92	1575	325	5	73	66.8	13.3	2.58	8.98	.77
E28	Hudspeth	Furrow	VHS	200	192	156	92	1625	330	2	72	65.8	13.0	2.60	9.35	.78
E240	Pecos	Furrow	VHS	150	151	124	91	1000	410	5	71	64.2	13.6	3.36	7.44	.80
E40	Lamb	Furrow	VHS	50	59	49	90	725	215	2	69	61.6	13.9	1.83	2.93	.83
E30	Lamb	Furrow	VHS	75	75	62	90	825	232	4	67	60.6	14.1	2.03	3.71	.84
E27	Deaf Smith	Furrow	VHS	40	45	37	90	525	222	0	67	60.1	14.2	1.91	2.22	.85
E50	Lamb	Furrow	VHS	50	67	55	90	760	223	1	65	58.5	14.6	1.97	3.32	.87
E170	Hale	Furrow	VHS	60	58	54	90	550	288	9	63	56.6	15.1	2.68	3.26	.90
E319	Moore	Furrow	VHS	100	83	69	90	725	280	0	62	55.4	15.4	2.58	4.15	.92

TABLE 2. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

Electricity
A R E A
1975 - 1981

			MOTOR					PUMP						Electricity cost @ 6.0¢/KWH		
Location	County	Irri-gation Method	Type	Rated HP	HP Load	KW Load	% Eff.	GPM	Pumping Lift-ft	Dis-charge psi	% Eff.	Percent Overall Eff.	KWH Ac-In/ 100' Head	Per Ac-In $	Per Hour $	Ac-In/ 100' Head $
E79	Deaf Smith	FurrowBP	VHS	40	42	35	90	490	206	0	60	54.2	15.8	1.94	2.10	.94
E17	Deaf Smith	Furrow	VHS	40	47	39	90	495	222	1	60	53.6	15.9	2.14	2.34	.95
E59	Deaf Smith	Furrow BP	VHS	30	26	21	90	270	206	3	57	50.9	16.8	2.14	1.28	1.00
E11	Pecos	Furrow	VHS	100	41	35	87	410	213	6	57	49.8	17.1	2.33	2.11	1.03
E16	Randall	Furrow	VHS	75	70	58	90	610	225	0	50	44.9	19.1	2.56	3.46	1.14
E250	Pecos	Furrow	VHS	150	88	72	91	440	370	1	47	42.7	20.0	4.44	4.32	1.20
E109	Deaf Smith	Furrow BP	VHS	30	16	13	90	120	243	2	47	42.0	20.2	2.98	.79	1.21
E29	Deaf Smith	Furrow	VHS	50	35	29	90	315	205	1	47	42.0	20.4	2.51	1.75	1.22
E46	Moore	Furrow	VHS	100	78	65	90	500	280	2	46	41.3	20.7	3.51	3.89	1.24
E26	Randall	Furrow	VHS	50	38	31	90	300	225	0	50	40.9	20.9	2.81	1.87	1.25
E41	Pecos	Furrow	VHS	100	53	44	90	340	270	1	44	39.5	21.6	3.51	2.64	1.30
E37	Deaf Smith	Furrow	VHS	30	25	21	90	200	212	1	43	39.1	21.9	2.81	1.24	1.31
E47	Deaf Smith	Furrow	VHS	40	46	38	90	300	222	4	38	34.5	37.2	3.44	2.28	1.48
E89	Deaf Smith	Furrow BP	VHS	50	19	16	90	125	221	0	37	33.5	25.6	3.38	.93	1.53
E51	Pecos	Furrow	VHS	100	29	24	90	160	245	1	34	30.7	27.8	4.10	1.45	1.67
E39	Deaf Smith	Furrow	VHS	50	37	31	90	235	208	2	34	30.5	28.1	3.57	1.86	1.68
AVERAGE		Furrow	VHS	86	72	59	90	624	257	2	57	50.8	18.4	2.74	3.54	1.07
E78	Lipscomb	Sideroll	VHS	25	23	19	89	240	40	50	42	37.1	23.0	2.16	1.15	1.39
E20	Midland	Sideroll	VHS	40,30,20	82	68	90	935	57	62	41	37.3	16.4	1.97	4.05	.99

TABLE 2. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

Electricity

A R E A

1975 - 1981

			MOTOR					PUMP						Electricity cost @ 6.0¢/KWH		
Location	County	Irrigation Method	Type	Rated HP	HP Load	KW Load	% Eff.	GPM	Pumping Lift-ft	Discharge psi	% Eff.	Percent Overall Eff.	KWH Ac-In/ 100' Head	Per Ac-In $	Per Hour $	Ac-In/ 100' Head $
E260	Reeves	Sideroll	VHS	200	218	177	92	850	550	60	68	62.4	13.7	5.67	10.61	.82
AVERAGE		Sideroll	VHS	63	108	88	90	675	216	57	50	45.6	17.7	3.27	5.27	1.07
E10	Midland	Hand move sprinkler	VHS	30	30	25	90	240	110	44	43	38.5	22.2	2.83	1.49	1.33
E161	Lamb	Hand move sprinkler	VHS	50	35	29	90	185	140	50	33	29.2	29.1	4.35	1.73	1.75
AVERAGE		Hand move sprinkler	VHS	40	33	27	90	213	125	47	38	33.9	25.7	3.59	1.61	1.54
E131	Terry	Sideroll	Belt	40	29	24	90	275	97	55	57	48.8	17.4	2.35	1.43	1.05
E141	Yoakum	Sideroll	Belt	40	23	19	90	190	84	53	52	39.5	21.5	2.65	1.12	1.29
AVERAGE		Sideroll	Belt	40	26	22	90	233	91	54	55	44.2	19.5	2.50	1.28	1.17
E200	Lubbock	Furrow BP	Belt	15	12	10	89	120	150	4	49	37.4	22.9	2.20	.58	1.37
E210	Lubbock	Furrow BP	Belt	15	9	8	89	100	143	2	47	35.6	24.0	2.13	.47	1.44
E180	Lubbock	FurrowBP	Belt	25	16	14	88	165	152	3	47	35.2	24.3	2.31	.84	1.45
E259	Terry	Furrow BP	Belt	25	24	21	88	250	117	2	37	27.5	31.1	2.25	1.24	1.87
E190	Lubbock	Furrow BP	Belt	25	23	19	88	150	175	3	36	26.9	31.8	3.48	1.15	1.91
E151	Lamb	Furrow	Belt	40	25	21	90	105	150	16	23	17.4	48.1	5.40	1.26	2.89
E269	Terry	Furrow BP	Belt	15	17	14	89	100	121	2	22	16.8	50.9	3.81	.84	3.05
AVERAGE		Furrow BP	Belt	23	18	15	89	141	144	5	37	28.1	33.3	3.08	.91	2.00

TABLE 2. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

Electricity
A R E A
1975 - 1981

			MOTOR					PUMP						Electricity cost @ 6.0¢/KWH		
Location	County	Irri-gation Method	Type	Rated HP	HP Load	KW Load	% Eff.	GPM	Pumping Lift-ft	Dis-charge psi	% Eff.	Percent Overall Eff.	KWH Ac-In/ 100' Head	Per Ac-In $	Per Hour $	Ac-In/ 100' Head $
E71	Pecos	Furrow	Sub	40	43	37	87	320	400	2	75	65.1	13.1	3.16	2.24	.79
E49	Deaf Smith	Furrow	Sub	20	15	14	80	240	200	1	79	63.4	13.5	1.64	.87	.81
E279	Terry	Furrow BP	Sub	7.5	5	5	80	110	116	5	74	59.3	14.4	1.12	.27	.86
E101	Pecos	Furrow	Sub	40	40	35	87	260	390	2	64	55.3	15.4	3.62	2.08	.92
E61	Pecos	Furrow	Sub	40	43	37	87	300	360	2	63	54.9	15.5	3.37	2.24	.93
E81	Pecos	Furrow	Sub	30	32	27	87	240	315	0	60	52.2	16.3	3.08	1.63	.98
E149	Lubbock	Furrow BP	Sub	2	2	2	72	25	137	25	72	52.1	16.4	1.92	.11	.98
E99	Deaf Smith	Furrow BP	Sub	15	16	15	81	170	216	1	60	48.4	17.7	2.32	.87	1.06
E140	Floyd	Furrow	Sub	15	19	16	80	110	319	11	57	45.4	18.9	3.89	.94	1.13
E239	Lubbock	Furrow BP	Sub	5	5	5	77	55	118	42	59	45.2	19.0	2.44	.29	1.14
E19	Upton	Furrow	Sub	10	9	8	78	60	240	40	57	44.8	19.7	3.81	.50	1.18
E179	Lubbock	Furrow BP	Sub	7.5	6	5	80	65	138	18	52	41.8	20.4	2.20	.32	1.22
E169	Lubbock	Furrow BP	Sub	3	3	3	73	45	110	13	55	40.3	21.3	1.79	.17	1.28
E119	Deaf Smith	Furrow BP	Sub	20	20	19	80	165	238	3	50	40.0	21.4	3.13	1.15	1.29
E150	Floyd	Furrow	Sub	20	16	15	80	125	240	7	49	39.6	21.7	3.31	.91	1.30
E130	Floyd	Furrow	Sub	15	15	14	80	80	340	12	49	39.3	21.8	4.80	.85	1.30
E31	Pecos	Furrow	Sub	30	34	29	87	190	312	6	45	38.8	21.9	4.19	1.76	1.32
E91	Pecos	Furrow	Sub	10	9	10	75	60	320	0	50	37.3	22.9	4.38	.58	1.37
E320	Oldham	Furrow BP	Sub	25	23	19	88	140	258	0	41	35.7	24.0	3.72	1.15	1.44
E189	Lubbock	Furrow BP	Sub	7.5	6	6	80	50	135	35	43	34.0	25.2	3.27	.36	1.51

TABLE 2. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

Electricity

A R E A
1975 - 1981

			MOTOR					PUMP						Electricity cost @ 6.0¢/KWH		
Location	County	Irri-gation Method	Type	Rated HP	HP Load	KW Load	% Eff.	GPM	Pumping Lift-ft	Dis-charge psi	% Eff.	Percent Overall Eff.	KWH Ac-In/ 100' Head	Per Ac-In $	Per Hour $	Ac-In/ 100' Head $
E230	Terry	Furrow BP	Sub	7.5	10	9	80	70	160	26	41	32.9	26.0	3.43	.53	1.56
E211	Reagan	Furrow	Sub	10	11	10	75	60	289	0	45	31.2	27.2	4.71	.63	1.63
E249	Terry	Furrow BP	Sub	7.5	8	7	80	81	135	2	38	30.7	27.9	2.32	.41	1.67
E209	Lubbock	Furrow BP	Sub	3	4	4	73	25	151	45	42	30.6	28.0	4.28	.24	1.68
E159	Lubbock	Furrow BP	Sub	5	5	5	77	50	125	11	39	29.8	28.7	2.57	.28	1.72
E229	Lubbock	Furrow BP	Sub	7.5	7	6	80	75	125	5	37	29.5	29.1	2.36	.39	1.75
E199	Lubbock	Furrow BP	Sub	3	3	3	73	20	138	23	39	28.2	30.3	3.47	.15	1.81
E219	Lubbock	Furrow BP	Sub	3	4	4	73	20	140	60	36	26.0	33.0	5.52	.24	1.97
E160	Floyd	Furrow	Sub	14	14	13	80	84	283	15	46	37.0	24.7	4.65	.75	1.48
E21	Pecos	Furrow	Sub	40	29	25	87	90	272	6	22	19.1	44.4	7.41	1.48	2.67
AVERAGE		Furrow	Sub	15	15	14	80	113	224	14	51	40.9	22.7	3.40	.81	1.36
AVERAGE	ALL	ELECTRIC		58	52	43	87	403	224	22	55	46.9	20.3	3.13	2.71	1.22

NATURAL GAS ENGINE UNITS

The average overall efficiency of 242 natural gas powered units (Table 3) was 12.2 percent. The standard used for an overall efficiency on a natural gas pumping plant is 17 percent (Table 1). The average pump efficiency was found to be 60 percent and the average engine efficiency was 20 percent. On turbine pumps the standard used is 75 percent efficiency. An automotive type irrigation engine efficiency of 23 percent is considered to be very good, while on the industrial type irrigation engine, the efficiency should be 26 percent or above to be operating at its peak. Engine efficiencies varied from 16 percent from the group used on side-roll systems to 20 percent for engines used on center-pivot and furrow irrigation systems (Table 3).

The average pumping plant used 1100 cubic feet of natural gas per hour. The pumping plants used for furrow irrigation consumed 1023 cubic feet per hour. On the center-pivot systems, fuel use increased to 1322 cubic feet of gas per hour.

On the average, pumping an acre-foot of water cost $39.84 or $3.32 per acre-inch for fuel. This is for all the irrigation methods. On an hourly basis the cost was $1.49. The cost per acre-foot per 100 foot of head was $10.50 or $0.11 per acre-foot per foot of head.

TABLE 3. IRRIGATION PUMPING PLANT EFFICIENCY TESTS

A R E A
1975 - 1981
Natural Gas

			ENGINE						PUMP							Fuel Cost @ $3.00 mcf		
Location	Co.	Irri-gation Method	Model	RPM	HP	Fuel Ft^3/HR	Cu. Ft./ HP	% Eff.	RPM	GPM	Pumping Lift-ft	Dis-charge Head-Psi	% Eff.	Percent Overall Eff.	Ft^3/ Ac-In/ 100' Head	Per Ac-In $	Per Hour $	$ Cost/ Ac-In/ 100' Hd.
G118	Moore	Furrow	Moline 800	1545	133	1208	9.1	28	1720	980	398	8	81	21.6	135	1.68	3.62	.40
G411	Ochi	Furrow	Moline 800	1770	142	1256	8.9	29	1770	860	430	17	76	20.6	141	1.98	3.78	.42
G30	Moore	Furrow	Moline 800	1365	120	1132	9.4	27	1720	935	350	5	75	19.2	152	1.64	3.40	.46
G108	Moore	Furrow	Moline 800	1333	147	1325	9.0	28	1790	930	395	9	70	18.8	156	1.94	3.97	.47
G310	Carso	Furrow	Moline 800	1585	138	1344	9.7	26	1740	740	488	10	73	18.1	161	2.47	4.03	.48
G601	Rober	Furrow	Cat G342	1189	187	1693	9.0	28	1782	1050	445	2	67	17.9	162	2.18	5.08	.49
G611	Rober	Furrow	Chrysler 2-413	2358	175	1796	10.3	26	1770	1160	405	10	73	17.8	163	2.09	5.39	.49
G138	Moore	Furrow	Moline 800	1545	163	1760	10.8	24	1820	1200	401	3	80	17.9	163	1.99	5.28	.49
G271-1	Carso	Furrow	Moline 800T	1570	161	1647	10.2	25	1885	835	520	6	74	17.4	166	2.66	4.94	.50
G271-2	Carso	Furrow	Moline 800T	1700	202	2055	10.2	25	2040	950	540	15	71	16.9	171	2.92	6.16	.51
G670	Moore	Furrow	Moline 800	1348	100	1065	10.7	24	1650	900	303	9	78	17.5	167	1.61	3.19	.50
G10	Moore	Furrow	Moline 800	1280	140	1250	8.9	29	1700	890	365	8	65	17.5	167	1.91	3.76	.50
G320	Cars	Furrow	Moline 800	1630	107	1122	10.5	24	1634	625	465	7	75	17.2	170	2.45	3.37	.51

TABLE 3. IRRIGATION PUMPING PLANT EFFICIENCY (continued)

A R E A

1975 - 1981

Natural Gas

Location	Co.	Irri-gation Method	ENGINE						PUMP					Percent Overall Eff.	Ft^3/ Ac-In/ 100' Head	Fuel Cost @ $3.00 mcf		
			Model	RPM	HP	Fuel Ft^3/HR	Cu. Ft./ HP	% Eff.	RPM	GPM	Pumping Lift-ft	Dis-charge Head-Psi	% Eff.			Per Ac-In $	Per Hour $	$ Cost/ Ac-In/ 100' Hd.
G70-1	Moore	Furrow	Roiline 884	2060	160	1843	11.5	22	1580	1000	408	35	81	17.1	171	2.51	5.53	.51
G70-2	Moore	Furrow	Roiline 884	1900	125	1502	12.0	21	1425	850	390	26	81	16.4	178	2.41	4.51	.54
G580	Ochi	Furrow	Moline 800	1480	113	1150	10.2	25	1790	800	373	3	72	17.0	172	1.96	3.46	.51
G391	Ochi	Furrow	GMC 702(81)	2030	110	1180	10.7	24	1625	910	335	2	75	16.9	172	1.75	3.54	.52
G128	Moore	Furrow	Moline 800	1455	122	1376	11.3	23	1765	880	385	9	78	16.7	175	2.12	4.13	.52
G291	Lamb	Furrow	Chev 292(81)	2018	46	583	12.7	20	1680	750	186	2	82	15.7	184	1.05	1.75	.55
G221	Cars	Furrow	Chry 413	2336	105	1113	10.6	24	1750	530	505	1	68	15.5	186	2.84	3.34	.56
G590	Ochi	Furrow	Moline HD 800	1730	135	1303	9.7	26	1940	800	385	6	63	15.7	186	2.22	3.91	.56
G331-2	Lamb	Furrow	Ford 428	1820	54	600	11.1	23	1813	780	185	0	71	15.4	187	1.04	1.80	.56
G331-1	Lamb	Furrow	Ford 428	2130	71	887	12.5	20	2100	800	190	0	56	11.0	263	1.50	2.66	.79
G660-2	Moore	Furrow	Int'l 605	2253	106	1183	11.2	23	1700	860	306	11	71	15.5	189	1.87	3.55	.57
G660-1	Moore	Furrow	Int'l 605	2182	88	1041	11.8	21	1640	780	298	10	76	15.5	189	1.81	3.12	.57
G110	Lamb	Furrow	Ford 428	1863	72	793	11.0	23	1580	990	175	5	69	15.0	195	1.09	2.38	.58

TABLE 3. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

A R E A

1975 - 1981
Natural Gas

			ENGINE						PUMP							Fuel Cost @ $3.00 mcf		
Location	Co.	Irri-gation Method	Model	RPM	HP	Fuel Ft^3/HR	Cu. Ft./ HP	% Eff.	RPM	GPM	Pumping Lift-ft	Dis-charge Head-Psi	% Eff.	Percent Overall Eff.	Ft^3/ Ac-In/ 100' Head	Per Ac-In $	Per Hour $	$ Cost/ Ac-In/ 100' Hd.
G211	Cars	Furrow	Moline 800T	1396	159	1711	10.8	24	1675	800	430	28	66	14.9	194	2.89	5.13	.58
G241-2	Cars	Furrow	Moline 800T	1364	154	1538	10.0	25	1742	840	420	0	61	14.8	196	2.47	4.61	.59
G241-1	Cars	Furrow	Moline 800T	1408	140	1441	10.3	25	1690	780	416	0	62	14.5	199	2.49	4.32	.60
G140	Castr	Furrow	Moline 800	1322	99	1047	10.6	24	1780	1040	215	7	65	14.7	198	1.37	3.14	.59
G20	Moore	Furrow	Moline 800	1315	80	904	11.3	23	1680	570	355	4	69	14.8	196	2.16	2.71	.59
G31	Moore	Furrow	Ford 534	2522	99	1144	11.6	22	1680	890	293	1	71	14.7	197	1.74	3.43	.59
G100	Hale	Furrow	Chev 427	2150	69	758	11.0	23	1780	820	200	5	66	14.6	200	1.26	2.28	.60
G621	Rober	Furrow	Chry 413	2510	95	1105	11.6	22	1673	550	445	3	70	14.5	200	2.71	3.32	.60
G550	Ochi	Furrow	Moline 800	1741	120	1452	12.1	21	1740	800	385	8	72	14.3	204	2.47	4.36	.61
G251-1	Cars	Furrow	Chry 413	2335	100	1029	10.3	21	1750	460	480	2	59	11.6	205	2.98	3.05	.62
G251-2	Cars	Furrow	Chry 413	2192	74	774	10.5	20	1640	290	456	2	48	9.2	262	3.60	2.32	.79
G570	Ochi	Furrow	2-GMC 478	2300	163	1790	11.0	23	1830	1050	334	19	65	14.2	205	2.32	5.38	.62
G88	Hutch	Furrow	Roiline 884	1950	157	1798	11.5	22	1770	1080	355	2	66	13.8	211	2.27	5.40	.63

TABLE 3. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

A R E A

1975 - 1981
Natural Gas

			ENGINE						PUMP							Fuel Cost @ $3.0? mcf		
Location	Co.	Irri-gation Method	Model	RPM	HP	Fuel Ft³/hr	Cu. Ft./HP	% Eff.	RPM	GPM	Pumping Lift-ft	Dis-charge Head-Psi	% Eff.	Percent Overall Eff.	Ft^3/ Ac-In/ 100' Head	Per Ac-In $	Per Hour $	$ Cost/ Ac-In/ 100' Hd.
G258	Dalla	Furrow	Moline 800	1420	126	1380	11.0	23	1705	775	383	1	63	13.9	210	2.42	4.14	.63
G151	Hale	Furrow	Chry 413	1996	78	955	12.2	21	1662	840	235	3	69	13.6	212	1.54	2.87	.64
G890-2	Gray	Furrow	Chry 413	2530	104	1190	11.4	22	1700	535	465	3	64	13.6	214	3.02	3.58	.64
G890-1	Gray	Furrow	Chry 413	2500	100	1181	11.8	21	1675	510	463	3	63	13.0	224	3.16	3.54	.67
G361-2	D.S.	Furrow	Moline 800	1006	37	470	12.7	20	1765	360	270	0	71	13.4	216	1.76	1.41	.65
G361-1	D.S.	Furrow	Moline 800	1003	34	459	13.5	19	1750	335	270	0	71	12.7	228	1.85	1.38	.80
G98	Hutch	Furrow	Roiline 884	1975	158	1875	11.9	21	1795	1115	349	2	66	13.5	216	2.29	5.63	.65
G51	Moore	Furrow	GMC 702	2145	128	1705	13.3	19	1780	860	395	7	73	13.3	218	2.72	5.12	.66
G191	Lamb	Furrow	Olds 455	1990	60	702	11.7	22	1493	810	177	0	64	13.1	220	1.17	2.11	.66
G341-3	D.S.	Furrow	Waukesha GZ 145	1330	60	837	14.0	18	1730	535	307	4	74	13.0	223	2.11	2.51	.67
G341-2	D.S.	Furrow	Waukesha GZ 145	1298	59	820	13.9	18	1728	525	305	3	75	12.9	225	2.11	2.46	.67
G341-1	D.S.	Furrow	Waukesha GZ 145	1304	49	770	15.7	16	1755	420	285	2	66	10.2	284	2.48	2.31	.85
G351-2	D.S.	Furrow	Chry 318	2128	36	513	14.2	18	1775	430	238	1	77	12.9	224	1.61	1.54	.67

TABLE 3. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

A R E A

1975 - 1981

Natural Gas

			ENGINE						PUMP							Fuel Cost @ $3.00 mcf		
Location	Co.	Irri-gation Method	Model	RPM	HP	Fuel Ft^3/HR	Cu. Ft./ HP	% Eff.	RPM	GPM	Pumping Lift-ft	Dis-charge Head-Psi	% Eff.	Percent Overall Eff.	Ft^3/ Ac-In/ 100' Head	Per Ac-In $	Per Hour $	$ Cost/ Ac-In/ 100' Hd.
G351-1	D.S.	Furrow	Chry 318	2132	35	505	14.4	18	1770	395	237	1	72	12.0	241	1.73	1.52	.67
G80	Moore	Furrow	Waukesha NKR (1905)	1040	135	1767	13.1	19	1550	900	386	6	71	13.1	223	2.68	5.30	.72
G68	Pecos	Furrow	Moline 800	1635	90	1054	11.7	22	--	475	450	2	64	13.2	223	3.04	3.18	.67
G21	Moor	Furrow	Ford 534	2698	95	1145	12.1	21	1800	720	317	1	64	12.9	225	2.16	3.44	.67
G401	Ochi	Furrow	GMC 702	2268	130	1426	11.0	23	1705	765	370	1	59	12.9	225	2.52	4.28	.68
G541	D.S.	Furrow	Moline 605	1280	53	655	12.3	21	1707	575	225	1	66	12.8	226	1.54	1.97	.68
G120	Lamb	Furrow	Chry 318	2045	44	575	13.1	19	1725	475	230	6	71	12.9	225	1.64	1.73	.68
G81	Moor	Furrow	Moline 800	1441	83	1105	13.3	19	1810	500	425	7	71	12.8	227	2.00	3.32	.68
G131	Floy	Furrow	GMC 478	1945	70	845	12.1	21	1560	600	276	1	63	12.7	228	1.90	2.54	.68
G261	Cars	Furrow	Waukesha GZ 145	1130	50	666	13.3	19	1510	220	590	0	69	12.5	231	4.09	2.00	.68
G11	D.S.	Furrow	Chev 292	1868	40	549	13.7	19	1558	500	216	1	73	12.7	226	1.50	1.65	.69
G470	Floy	Furrow	Ford 460	2330	62	815	13.1	19	1740	425	370	1	68	12.5	233	2.62	2.45	.70
G450	Floy	Furrow	Ford 428	2175	92	1023	11.1	23	1750	865	221	4	57	12.4	234	1.61	3.07	.70

TABLE 3. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

A R E A
1975 - 1981
Natural Gas

			ENGINE						PUMP							Fuel Cost @ $3.00 mcf		
Location	Co.	Irri-gation Method	Model	RPM	HP	Fuel Ft^3/HR	Cu. Ft./ HP	% Eff.	RPM	GPM	Pumping Lift-ft	Dis-charge Head-Psi	% Eff.	Percent Overall Eff.	Ft^3/ Ac-In/ 100' Head	Per Ac-In $	Per Hour $	$ Cost/ Ac-In/ 100' Hd.
G900-3	Gray	Furrow	2-Chry 413	2490	164	1864	11.4	22	1872	1000	357	1	58	12.4	235	2.54	5.59	.71
G900-2	Gray	Furrow	2-Chry 413	2416	150	1812	12.1	21	1815	920	355	1	58	11.6	251	2.69	5.44	.75
G900-1	Gray	Furrow	2-Chry 413	2275	126	1692	13.4	19	1715	750	351	1	56	10.0	291	3.07	5.08	.87
G148	Moore	Furrow	Ford 534	2310	108	1423	13.2	19	1745	650	410	3	67	12.3	238	2.98	4.27	.71
G40	Moore	Furrow	Moline 800	1440	95	986	10.4	25	1780	430	432	0	52	12.1	241	3.12	2.96	.72
G90-1	Moore	Furrow	Chry 413 & Chry 440	2615	145	1819	12.5	20	1775	750	447	3	63	12.1	242	3.30	5.46	.72
G90-2	Moore	Furrow	Chry 413 & Chry 440	2530	125	1657	13.3	19	1700	670	440	2	63	11.5	253	3.37	4.97	.76
G850-2	Oldh	Furrow	Chev 292	2120	52	613	11.8	22	1595	500	230	0	59	12.1	241	1.67	1.84	.72
G850-1	Oldh	Furrow	Chev 292	1882	26	388	14.9	17	1420	175	223	1	40	6.5	448	3.02	1.16	1.34
G28	Pecos	Furrow	Moline 800T	1520	183	1762	9.6	26	--	700	470	2	48	12.1	241	3.43	5.29	.72
G67	D.S.	Furrow	Moline 605	1172	53	616	11.6	22	1760	450	246	4	58	12.0	243	1.86	1.85	.73
G57-2	D.S.	Furrow	Moline 605	900	60	703	11.7	22	1635	435	295	2	58	11.9	242	2.20	2.11	.73
G57-1	D.S.	Furrow	Moline 605	970	61	715	11.7	22	1710	425	295	2	56	11.5	255	2.29	2.15	.76

TABLE 3. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

A R E A

1975 - 1981

Natural Gas

Location	Co.	Irrigation Method	ENGINE: Model	RPM	HP	Fuel Ft^3/HR	Cu. Ft./HP	% Eff.	PUMP: RPM	GPM	Pumping Lift-ft	Discharge Head-Psi	% Eff.	Percent Overall Eff.	Ft^3/Ac-In/100' Head	Fuel Cost @ $3.00 mcf: Per Ac-In $	Per Hour $	$ Cost/Ac-In/100' Hd.
G640	Gray	Furrow	Chry 413	2494	104	1201	11.5	22	1650	500	416	11	56	11.8	248	3.28	3.60	.74
G840	Oldh	Furrow	Chev 292	2050	33	437	13.2	19	1640	250	320	0	64	11.8	248	2.38	1.31	.74
G41-2	Moor	Furrow	Ford 534	2436	120	1457	12.1	22	1835	640	396	8	59	12.3	249	3.09	4.37	.75
G41-1	Moor	Furrow	Ford 534	2329	96	1448	15.1	18	1750	580	390	8	62	11.1	277	3.39	4.34	.83
G531	D.S.	Furrow	Moline 605-6A	1272	46	580	12.6	20	1696	365	285	1	61	11.6	250	2.15	1.74	.75
G61	Moor	Furrow	GMC 702	1992	105	1407	13.4	19	1660	730	330	8	64	11.6	250	2.61	4.21	.75
G560-2	Ochi	Furrow	Ford 534	2370	66	912	13.8	18	1780	460	356	1	67	11.6	251	2.70	2.74	.75
G560-1	Ochi	Furrow	Ford 534	2232	52	777	14.9	17	1675	400	346	0	71	11.5	254	2.64	2.33	.76
G270	D.S.	Furrow	Chry 318	2180	39	531	13.6	18	1830	390	245	0	66	11.6	252	1.86	1.60	.76
G480	Hale	Furrow	Chev 292	2150	54	605	11.2	23	1790	420	250	4	54	11.6	252	1.96	1.81	.76
G130	Lamb	Furrow	Chry 440	2365	88	1065	12.1	21	1800	1010	182	3	58	11.5	253	1.44	3.19	.76
G500	Ochi	Furrow	GMC 702(80)	2030	116	1310	11.3	23	1650	700	329	1	53	11.4	256	2.54	3.94	.77
G530	Ochi	Furrow	Ford 428	2310	80	984	12.3	21	1780	430	397	4	58	11.4	256	2.95	3.12	.77

TABLE 3. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

A R E A

1975 - 1981
Natural Gas

Location	Co.	Irri-gation Method	ENGINE						PUMP					Percent Overall Eff.	Ft^3/ Ac-In/ 100' Head	Fuel Cost @ $3.00 mcf		
			Model	RPM	HP	Fuel Ft^3/HR	Cu. Ft./ HP	% Eff.	RPM	GPM	Pumping Lift-ft	Dis-charge Head-Psi	% Eff.			Per Ac-In $	Per Hour $	$ Cost/ Ac-In/ 100' Hd.
G380	Hart	Furrow	2-Int'l 549	2280	170	2558	15.0	17	1650	860	500	7	69	11.2	262	4.06	7.68	.78
G50-2	Moore	Furrow	Moline 800	1395	70	787	11.2	23	1675	340	407	0	53	11.3	258	3.16	2.36	.78
G50-1	Moore	Furrow	Moline 800	1345	55	678	12.3	21	1615	275	371	0	49	9.7	302	3.36	2.04	.90
G440	Floyd	Furrow	Ford 460	2160	68	959	14.1	18	1780	730	215	5	65	11.1	263	1.79	2.88	.79
G591	D.S.	Furrow	Chev 292	2024	40	500	12.5	21	1686	335	225	12	56	10.9	265	2.01	1.50	.79
G460	Floyd	Furrow	Chev 427	2150	82	1207	14.7	17	1760	710	283	3	67	11.0	266	2.32	3.62	.80
G290	Parm	Furrow	Moline 800	1210	95	1200	12.6	20	1650	715	283	1	57	10.9	266	2.28	3.60	.80
G48	Pecos	Furrow	Moline 800T	1765	135	1484	11.0	23	--	555	450	2	50	10.9	267	3.64	4.45	.80
G321	Lamb	Furrow	Chev 292	1775	42	568	13.5	19	1775	410	230	1	60	10.7	269	1.87	1.70	.81
G700-1	Cast	Furrow	Moline 605	1244	58	741	12.8	20	1650	330	380	0	58	10.9	268	3.06	2.22	.81
G700-2	Cast	Furrow	Moline 605	1190	53	676	12.8	20	1590	310	345	0	54	10.2	287	2.98	2.03	.86
G511	Dalla	Furrow	Chrysler 413 & 413	2368	145	2037	14.0	18	1775	870	384	2	62	10.6	272	3.16	6.11	.81
G250	D.S.	Furrow	Moline 605	1200	49	715	14.6	17	1970	450	262	0	65	10.6	274	2.16	2.15	.82

TABLE 3. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

AREA

1975 - 1981

Natural Gas

			ENGINE						PUMP							Fuel Cost @ $3.00 mcf		
Location	Co.	Irrigation Method	Model	RPM	HP	Fuel Ft^3/HR	Cu. Ft./HP	% Eff.	RPM	GPM	Pumping Lift-ft	Discharge Head-Psi	% Eff.	Percent Overall Eff.	Ft^3/ Ac-In/ 100' Head	Per Ac-In $	Per Hour $	$ Cost/ Ac-In/ 100' Hd.
G581	D.S.	Furrow	Chry 413	1910	53	763	14.3	18	1590	540	230	1	63	10.6	273	1.91	2.29	.82
G171	Hale	Furrow	Chry 413	1632	30	438	14.6	17	1360	315	225	1	65	10.5	273	1.87	1.31	.82
G510	Ochi	Furrow	GMC 478	2128	59	822	13.9	18	1730	435	297	7	61	10.6	274	2.57	2.47	.82
G410	Dalla	Furrow	Ford 534	2541	145	1877	12.9	20	1905	915	328	2	56	10.4	280	2.80	5.63	.84
G330	Lips	Furrow	Int'l 549	1720	60	840	14.0	18	1450	350	388	0	61	10.4	281	3.26	2.52	.84
G551	D.S.	Furrow	Moline 605	1100	39	522	13.3	19	1660	315	260	2	57	10.2	283	2.24	1.57	.85
G400	Hart	Furrow	2-Chry 413	2094	122	2034	16.7	15	1750	880	366	2	71	10.3	283	3.14	6.11	.85
G520	Ochi	Furrow	Int'l 549	2450	123	1566	12.7	20	1830	690	352	5	54	10.3	283	3.10	4.70	.85
G248	Dall	Furrow	GMC V-12	2325	131	1678	12.8	20	1745	675	386	3	54	10.2	287	3.38	5.04	.86
G78	Pecos	Furrow	Moline 800	1800	89	1064	12.0	21	--	325	510	0	50	10.0	291	4.46	3.19	.87
G121	Hale	Furrow	Chry 413	2060	42	505	12.0	21	1650	290	260	0	48	9.6	301	2.35	1.52	.90
G47-1	D.S.	Furrow	Chev 292	2375	30	450	15.0	17	1910	300	220	2	60	9.6	303	2.04	1.36	.91
G47-2	D.S.	Furrow	Chev 292	2235	27	408	15.1	17	1800	180	215	1	39	6.2	472	3.08	1.22	1.42

TABLE 3. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

A R E A

1975 - 1981

Natural Gas

			ENGINE						PUMP							Fuel Cost @ $3.00 mcf		
Location	Co.	Irri-gation Method	Model	RPM	HP	Fuel Ft^3/HR	Cu. Ft./ HP	% Eff.	RPM	GPM	Pumping Lift-ft	Dis-charge Head-Psi	% Eff.	Percent Overall Eff.	Ft^3/ Ac-In/ 100' Head	Per Ac-In $	Per Hour $	$ Cost/ Ac-In/ 100' Hd.
G47-3	D.S.	Furrow	Chev 292	2225	25	390	15.6	16	1790	140	210	1	32	4.9	594	3.79	1.18	1.78
G680	Cast	Furrow	Moline 605	1295	80	990	12.4	21	1725	365	380	8	48	9.4	309	3.70	2.98	.93
G240	Lamb	Furrow	Chev 292(80)	2176	52	626	12.0	21	1830	525	175	0	47	9.4	309	1.62	1.88	.93
G141	Floyd	Furrow	Waukesha 145 GZ	1364	105	1568	14.9	17	1818	750	292	3	57	9.2	314	2.82	4.70	.94
G671	Cros	Furrow	Chev 292	2114	41	462	11.3	22	1760	200	308	7	43	9.0	322	3.13	1.39	.97
G571	D.S.	Furrow	Chry 413	2100	56	1030	18.3	14	1704	610	238	0	69	9.0	322	2.30	3.12	.97
G230	Lamb	Furrow	Ford 300	2580	54	663	12.3	21	2000	550	169	0	46	9.0	324	1.64	1.99	.97
G830	Oldh	Furrow	Chry 413	2268	62	1119	18.0	14	1700	470	310	11	68	9.0	323	3.24	3.36	.97
G650	Moor	Furrow	Ford 534	2146	77	1081	14.0	18	1640	470	306	2	51	8.7	335	3.13	3.24	1.00
G71	Moor	Furrow	Moline 800	1453	85	1077	12.7	20	1740	350	390	10	46	8.6	337	4.17	3.23	1.00
G721	Brisc	Furrow	Chev 292	1927	46	517	11.2	23	1925	305	220	3	40	8.6	337	2.29	1.55	1.01
G521	Dall	Furrow	Int'l 549	2150	85	1119	13.2	19	1615	385	380	0	46	8.4	344	3.92	3.36	1.03
G150	Cast	Furrow	Moline 605	1240	61	904	14.8	17	1880	465	250	0	51	8.3	351	2.65	2.71	1.05

TABLE 3. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

A R E A

1975 - 1981
Natural Gas

			ENGINE						PUMP							Fuel Cost @ $3.00 mcf		
Location	Co.	Irri-gation Method	Model	RPM	HP	Fuel Ft^3/HR	Cu. Ft./ HP	% Eff.	RPM	GPM	Pumping Lift-ft	Dis-charge Head-Psi	% Eff.	Percent Overall Eff.	Ft^3/ Ac-In/ 100' Head	Per Ac-In $	Per Hour $	$ Cost/ Ac-In/ 100' Hd.
G870	Oldh	Furrow	Chev 292	1865	40	440	11.0	23	1695	250	225	1	38	8.3	352	2.40	1.32	1.06
G58	Pecos	Furrow	Moline 800	1635	90	1094	12.2	21	--	250	550	2	42	8.3	353	5.98	3.29	1.06
G690	Cast	Furrow	Moline 800	1313	84	1014	12.1	21	1750	330	376	5	41	8.1	360	4.19	3.05	1.08
G27-1	D.S.	Furrow	Chev 292	2290	49	733	15.0	17	1910	395	232	1	50	8.1	359	2.53	2.20	1.08
G27-2	D.S.	Furrow	Chev 292	2110	40	583	14.5	18	1750	310	228	1	47	7.8	371	2.56	1.75	1.11
G280	Parm	Furrow	Moline 800	1342	55	993	18.1	14	1810	450	275	0	60	8.0	364	3.00	2.98	1.09
G158	Dall	Furrow	Chev 292	1925	51	729	14.3	18	1440	500	180	0	47	7.9	368	1.98	2.18	1.10
G711	Gray	Furrow	Ford 460	2240	59	813	13.8	19	1680	250	395	0	45	7.8	370	4.39	2.44	1.11
G37-1	D.S.	Furrow	Waukesha GZ 145	990	41	580	14.1	18	1730	245	275	6	46	7.9	371	3.23	1.74	1.11
G37-2	D.S.	Furrow	Waukesha GZ 145	915	31	507	16.3	15	1600	150	275	6	38	5.5	530	4.61	1.52	1.58
G490-1	Hale	Furrow	Chev 454	2200	57	808	14.2	18	1850	410	230	2	45	7.6	381	2.69	2.42	1.14
G490-2	Hale	Furrow	Chev 454	2106	55	788	14.3	18	1800	390	225	1	43	7.2	404	2.75	2.36	1.21
G490-3	Hale	Furrow	Chev 454	2116	49	735	15.0	17	1750	310	220	0	38	6.0	487	3.23	2.21	1.46

TABLE 3. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

A R E A

1975 - 1981

Natural Gas

Location	Co.	Irrigation Method	ENGINE Model	RPM	HP	Fuel Ft^3/Hr	Cu. Ft./HP	% Eff.	PUMP RPM	GPM	Pumping Lift-ft	Discharge Head-Psi	% Eff.	Percent Overall Eff.	Ft^3/Ac-In/100' Head	Fuel Cost @ $3.00 mcf Per Ac-In $	Per Hour $	$ Cost/Ac-In/100' Hd.
G38	Peco	Furrow	Cat G333	1525	57	898	15.8	16	--	250	420	2	50	7.6	383	4.88	2.69	1.15
G600	Terr	Furrow	Chev 292	1632	17	260	15.3	17	1600	150	145	26	48	7.6	382	2.36	.78	1.15
G260	D.S.	Furrow	Waukesha GZ 145	1198	51	731	14.3	18	1810	275	303	0	44	7.3	397	3.62	2.20	1.19
G17-1	D.S.	Furrow	Moline 605	1115	60	783	13.0	20	1490	425	201	2	39	7.2	408	2.51	2.35	1.22
G17-2	D.S.	Furrow	Moline 605	1080	52	706	13.5	19	1445	310	198	1	32	5.6	517	3.10	2.12	1.55
G860	Oldh	Furrow	Chev 292	2370	71	839	11.8	22	1777	360	255	1	35	7.1	412	3.18	2.52	1.24
G18	Peco	Furrow	Moline 800	1610	89	1016	11.4	22	--	240	450	4	33	7.0	418	5.76	3.05	1.25
G630	Gray	Furrow	Chry 440	1952	50	626	12.5	20	1500	150	396	7	33	6.3	462	5.69	1.88	1.38
G161	Hale	Furrow	Chry 413	2000	48	678	14.1	18	1600	265	230	3	35	5.9	488	3.45	2.03	1.46
G880	Oldh	Furrow	Chev 292	1884	39	473	12.1	21	1713	195	215	5	30	6.0	489	3.30	1.42	1.46
G561	D.S.	Furrow	Moline 605	1079	47	723	15.3	17	1620	260	255	0	38	5.9	490	3.75	2.17	1.47
G620	Terr	Furrow	AMC	1552	19	285	15.0	17	1570	125	155	17	34	5.5	533	3.11	.85	1.60
G681-1	Cros	Furrow	Chry 413	1756	83	948	11.4	22	3512	230	290	11	23	4.9	589	5.56	2.84	1.77

TABLE 3. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

A R E A

1975 - 1981
Natural Gas

Location	Co.	Irrigation Method	ENGINE Model	ENGINE RPM	ENGINE HP	ENGINE Fuel Ft^3/HR	ENGINE Cu. Ft./ HP	ENGINE % Eff.	PUMP RPM	PUMP GPM	PUMP Pumping Lift-ft	PUMP Discharge Head-Psi	PUMP % Eff.	Percent Overall Eff.	Ft^3/ Ac-In/ 100' Head	Fuel Cost @ $3.00 mcf Per Ac-In $	Fuel Cost @ $3.00 mcf Per Hour $	Fuel Cost @ $3.00 mcf $ Cost/ Ac-In/ 100' Hd.
G681-2	Cros	Furrow	Chry 413	1700	73	826	11.3	23	3400	125	276	11	13	2.9	988	8.92	2.48	2.96
G610	Terr	Furrow	AMC -6	1869	15	488	32.5	8	1600	210	153	11	68	4.9	595	3.17	1.46	1.60
G201	Lamb	Furrow	GMC -6	1553	27	446	16.5	15	1550	225	142	0	32	4.6	628	2.68	1.34	1.89
G300	Parm	Furrow	Chry 413	2340	62	990	16.0	16	1765	185	260	0	21	3.1	934	7.28	2.98	2.81
AVERAGE	ALL	FURROW		1839	84	1023	12.8	20	1664	561	323	4	58	11.5	287	2.72	3.07	.86
G540	Ochi	Pivot	Moline 800	1590	179	1730	9.7	26	1780	1200	348	48	82	20.5	143	1.97	5.20	.43
G60	Moor	Pivot	Moline 800T	1660	195	1869	9.6	27	1840	795	549	58	74	18.7	156	3.17	5.60	.47
G661	Peco	Pivot	Moline 800	1410	98	1000	10.2	25	1680	1100	178	35	77	18.3	158	1.23	3.00	.47
G461-1	Hart	Pivot	Cat 3306	1710	132	1282	9.7	26	1710	735	460	5	70	17.4	166	2.35	3.85	.50
G461-2	Hart	Pivot	Cat 3306	1756	131	1267	9.7	26	1756	565	455	34	61	15.3	189	3.03	3.80	.57
G461	Hart	Pivot boost	Cat 3306									52		14.5	200	.72	1.18	.60

TABLE 3. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

A R E A

1975 - 1981

Natural Gas

			ENGINE						PUMP							Fuel Cost @ $3.00 mcf		
Location	Co.	Irri-gation Method	Model	RPM	HP	Fuel Ft^3/HR	Cu. Ft./HP	% Eff.	RPM	GPM	Pumping Lift-ft	Dis-charge Head-Psi	% Eff.	Percent Overall Eff.	Ft^3/Ac-In/100' Head	Per Ac-In $	Per Hour $	$ Cost/Ac-In/100' Hd.
G178	Dall	Pivot	Moline 800	1310	112	1217	10.9	23	1590	750	232	87	77	17.1	170	2.21	3.65	.51
G101	Moor	Pivot	Moline 800	1455	134	1509	11.3	23	1600	860	398	28	79	17.0	171	2.38	4.53	.51
G421	Lips	Pivot	Int'l 549	2310	129	1380	10.7	24	1740	725	307	81	74	16.7	173	2.57	4.14	.52
G501	Dall	Pivot	Moline 800	1261	115	1227	10.7	24	1683	1075	170	52	72	16.3	177	1.54	3.68	.53
G930-2	Dall	Pivot	Moline 800	1765	157	1600	10.2	25	1763	705	355	94	68	16.2	180	3.10	4.80	.54
G930-1	Dall	Pivot	Moline 800	1658	130	1334	10.3	25	1658	625	345	75	67	15.6	187	2.90	4.01	.56
G381	Ochi	Pivot	Chev 292	2226	52	591	11.4	22	1675	455	230	38	74	15.7	183	1.75	1.77	.55
G491	Dall	Pivot	Moline 800	1383	107	1217	11.4	22	1729	900	189	63	75	15.9	182	1.83	3.65	.55
G910	Dall	Pivot	Moline 800	1508	131	1437	11.0	23	1660	730	350	59	73	16.0	183	2.66	4.31	.55
G920	Dall	Pivot	Moline 800	1865	123	1356	11.0	23	1695	695	325	65	72	15.8	185	2.64	4.07	.56
G940	Dall	Pivot	Moline 800	1681	135	1450	11.0	23	1680	650	355	78	69	15.4	189	3.04	4.36	.57
G281	Lamb	Pivot	Ford 460	2290	78	877	11.2	23	1840	800	155	45	71	15.2	191	1.48	2.63	.57
G311	Lamb	Pivot	Ford 460	2110	73	967	13.2	19	1600	680	225	47	82	15.1	192	1.92	2.90	.58

TABLE 3. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

A R E A

1975 - 1981
Natural Gas

Location	Co.	Irrigation Method	ENGINE Model	ENGINE RPM	ENGINE HP	ENGINE Fuel Ft^3/HR	ENGINE Cu. Ft./HP	ENGINE % Eff.	PUMP RPM	PUMP GPM	PUMP Pumping Lift-ft	PUMP Discharge Head-Psi	PUMP % Eff.	Percent Overall Eff.	Ft^3/Ac-In/100' Head	Fuel Cost @ $3.00 mcf Per Ac-In $	Fuel Cost @ $3.00 mcf Per Hour $	Fuel Cost @ $3.00 mcf $ Cost/Ac-In/100' Hd.
G188	Dall	Pivot	Moline 800	1390	120	1271	10.6	24	1565	900	264	30	66	15.2	193	1.92	3.82	.58
G820-1	Yoak	Pivot	Moline 605	1154	75	801	10.7	24	1730	950	108	37	66	14.8	197	1.15	2.40	.59
G820-2	Yoak	Pivot	Moline 605	1150	75	801	10.7	24	1725	1250	115	12	63	14.3	203	.88	2.40	.61
G91	Moor	Pivot	Moline 800	1519	155	1933	12.5	20	1670	930	392	34	75	14.6	199	2.82	5.80	.60
G210	Gain	Pivot	Ford 428	1878	87	956	11.0	23	1600	720	114	80	66	14.5	202	1.81	2.87	.60
G208	Dall	Pivot	Moline 800	1525	148	1644	11.1	23	1855	750	325	70	66	14.3	204	2.99	4.93	.61
G430	Dall	Pivot	Moline 800T	1363	106	1274	12.0	21	1620	825	240	42	70	14.0	208	2.10	3.83	.62
G431	Lips	Pivot	Ford 534	2420	126	1517	12.0	21	1600	740	253	82	69	13.9	209	2.77	4.55	.63
G740	Sher	Pivot	Cummins GNA-250-10	1680	121	1430	11.8	22	1680	770	316	38	68	13.8	209	2.53	4.30	.63
G950	Dall	Pivot	Moline 800	1658	136	1808	13.2	19	1660	735	325	78	72	13.2	221	3.35	5.42	.66
G451	Hart	Pivot	Moline 800	1446	174	1913	11.0	23	1735	910	375	24	60	13.2	220	2.84	5.74	.66
G451	Hart	Pivot Booster	Ford 534									80		12.6	229	1.27	2.57	.69
G190	Gain	Pivot	Ford 300	1820	51	620	12.2	21	1515	650	114	35	66	13.1	222	1.30	1.87	.67

TABLE 3. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

A R E A
1975 - 1981
Natural Gas

			ENGINE						PUMP							Fuel Cost @ $3.00 mcf		
Location	Co.	Irri-gation Method	Model	RPM	HP	Fuel Ft^3/HR	Cu. Ft./HP	% Eff.	RPM	GPM	Pumping Lift-ft	Dis-charge Head-Psi	% Eff.	Percent Overall Eff.	Ft^3/ Ac-In/ 100' Head	Per Ac-In $	Per Hour $	$ Cost/ Ac-In/ 100' Hd.
G360	Hart	Pivot	Int'l 549	2480	112	1369	12.2	21	1680	680	345	29	67	13.2	222	2.74	4.10	.67
G720	Dall	Pivot	Moline 800	1359	92	1041	11.3	23	1355	800	157	46	61	13.0	224	1.78	3.12	.67
G340	Hart	Pivot	Moline 800T	1420	131	1513	11.5	22	1715	630	432	20	61	12.8	228	3.52	4.54	.68
G200	Gain	Pivot	Ford 428	2110	75	931	12.4	21	1770	685	131	60	66	12.8	229	1.85	2.80	.69
G770	Dall	Pivot	Moline 800	1210	97	1122	11.5	22	1620	700	197	50	60	12.5	232	2.18	3.37	.70
G198	Dall	Pivot	Ford 534	2305	133	1742	13.1	19	1735	800	252	75	68	12.5	233	2.96	5.23	.70
G218	Dall	Pivot	Ford 534S.C.	2285	112	1432	12.8	20	1725	540	365	65	66	12.5	234	3.61	4.30	.70
G631	Rob	Pivot	Leroi L3000	866	183	2772	15.1	17	1732	1075	240	112	77	12.4	233	3.48	8.32	.70
G220	Gain	Pivot	Ford 428	1760	53	716	13.5	19	1410	680	114	37	69	12.3	236	1.44	2.15	.71
G170	Gain	Pivot	Ford 428	1785	53	588	11.1	23	1480	600	100	38	57	12.3	237	1.33	1.76	.71
G790-2	Dall	Pivot	Moline 800	1468	94	1109	11.8	22	1620	710	216	35	59	12.2	239	2.12	3.32	.72
G790-1	Dall	Pivot	Moline 800	1467	95	1109	11.7	22	1615	710	217	32	58	12.0	244	2.12	3.32	.73
G180	Gain	Pivot	Ford 300	1914	46	546	11.9	22	1605	550	105	35	59	12.0	242	1.36	1.64	.73

TABLE 3. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

A R E A

1975 - 1981
Natural Gas

			ENGINE						PUMP							Fuel Cost @ $3.00 mcf		
Location	Co.	Irri-gation Method	Model	RPM	HP	Fuel Ft^3/HR	Cu. Ft./HP	% Eff.	RPM	GPM	Pumping Lift-ft	Dis-charge Head-Psi	% Eff.	Percent Overall Eff.	Ft^3/Ac-In/100' Head	Per Ac-In $	Per Hour $	$ Cost/Ac-In/100' Hd.
G370	Hart	Pivot	2 Int'l 549	2426	158	2289	14.5	18	1800	685	525	40	71	11.9	246	4.55	6.86	.74
G350	Hart	Pivot	2 Chry 413	2544	168	2044	12.2	21	1910	730	444	33	60	11.9	246	3.84	6.13	.74
G710-1	D.S.	Pivot	Moline 800	1360	89	1157	13.0	20	1655	580	270	40	63	11.7	250	2.71	3.47	.75
G710-2	D.S.	Pivot	Moline 800	1330	78	1168	14.9	17	1620	550	270	36	66	10.7	273	2.89	3.50	.82
G651	Rob	Pivot	LeroiL3000	817	152	2451	16.0	16	1636	980	325	50	75	11.4	255	3.38	7.35	.77
G390-1	Hart	Pivot	Chrysler 413 & 440	2640	163	2418	14.8	17	1990	905	379	40	69	11.3	257	3.64	7.26	.77
G390-2	Hart	Pivot	Chrysler 413 & 440	2372	107	1696	15.9	16	1800	630	369	21	65	10.0	293	3.67	5.09	.88
G760	Dall	Pivot	Chry 440	1812	42	628	15.0	17	1810	420	210	22	69	11.2	260	2.04	1.88	.78
G481-2	Hart	Pivot	Chry 440	2310	69	921	13.3	19	1735	300	450	33	61	11.0	262	4.14	2.76	.79
G481-1	Hart	Pivot	Chry 440	2266	64	871	13.6	19	1705	285	443	30	61	10.8	269	4.13	2.61	.81
G730	Dall	Pivot	Moline 800	1578	103	1304	12.7	20	1733	855	130	57	58	11.0	265	2.08	3.91	.79
G441-2	Hart	Pivot	Chrysler 413 & 440	2186	146	2157	14.8	17	1645	675	346	77	64	10.5	274	4.31	6.47	.82
G441-1	Hart	Pivot	Chrysler 413 & 440	2100	127	1916	15.1	17	1580	615	341	64	63	10.1	288	4.21	5.75	.86

TABLE 3. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

A R E A

1975 - 1981

Natural Gas

Location	Co.	Irri-gation Method	ENGINE						PUMP					Percent Overall Eff.	Ft^3/ Ac-In/ 100' Head	Fuel Cost @ $3.00 mcf		
			Model	RPM	HP	Fuel Ft^3/HR	Cu. Ft./ HP	% Eff.	RPM	GPM	Pumping Lift-ft	Dis-charge Head-Psi	% Eff.			Per Ac-In $	Per Hour $	$ Cost/ Ac-In/ 100' Hd.
G780-2	Dall	Pivot	Moline 800	1278	109	1471	13.5	19	1703	790	206	43	59	10.5	277	2.53	4.42	.83
G780-1	Dall	Pivot	Moline 800	1267	106	1459	13.8	18	1680	810	207	37	60	10.4	279	2.45	4.38	.84
G160	Gain	Pivot	Ford 428	1944	52	728	14.0	18	1560	605	98	42	60	10.4	280	1.64	2.18	.84
G641	Rob	Pivot	LeroiL3000	851	155	2800	18.0	14	1700	1000	310	59	76	10.2	283	3.87	8.40	.85
G810	Dall	Pivot	Moline 800	1116	75	1031	13.7	19	1484	510	245	32	58	10.1	288	2.75	3.10	.86
G228	Dall	Pivot	Ford 534	2425	185	2762	14.9	17	1820	1400	154	68	63	10.1	288	2.69	8.29	.86
G371	Daw	Pivot	Ford 300	1790	33	407	12.3	20	1480	450	93	20	52	9.9	293	1.22	1.22	.88
G238	Dall	Pivot	GMC V-12	2360	132	1682	12.7	20	1770	580	379	25	51	9.7	301	3.95	5.05	.90
G471	Hart	Pivot	Chry 413	2088	52	863	16.6	15	1670	250	450	27	62	9.5	303	4.66	2.59	.91
G168	Dall	Pivot	Chev 292	1995	54	766	14.2	18	1495	450	185	24	53	9.1	322	2.32	2.30	.97
G750-1	Dall	Pivot	Moline 800	1354	112	1479	13.2	19	1803	680	215	36	48	8.8	331	2.96	4.44	.98
G750-2	Dall	Pivot	Moline 800	1313	109	1438	13.2	19	1750	650	220	26	44	8.1	359	3.01	4.32	1.08
G420	Dall	Pivot	Moline 800	1144	68	1207	17.8	14	1570	725	130	28	56	7.5	388	2.27	3.62	1.17

TABLE 3. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

A R E A

1975 - 1981

Natural Gas

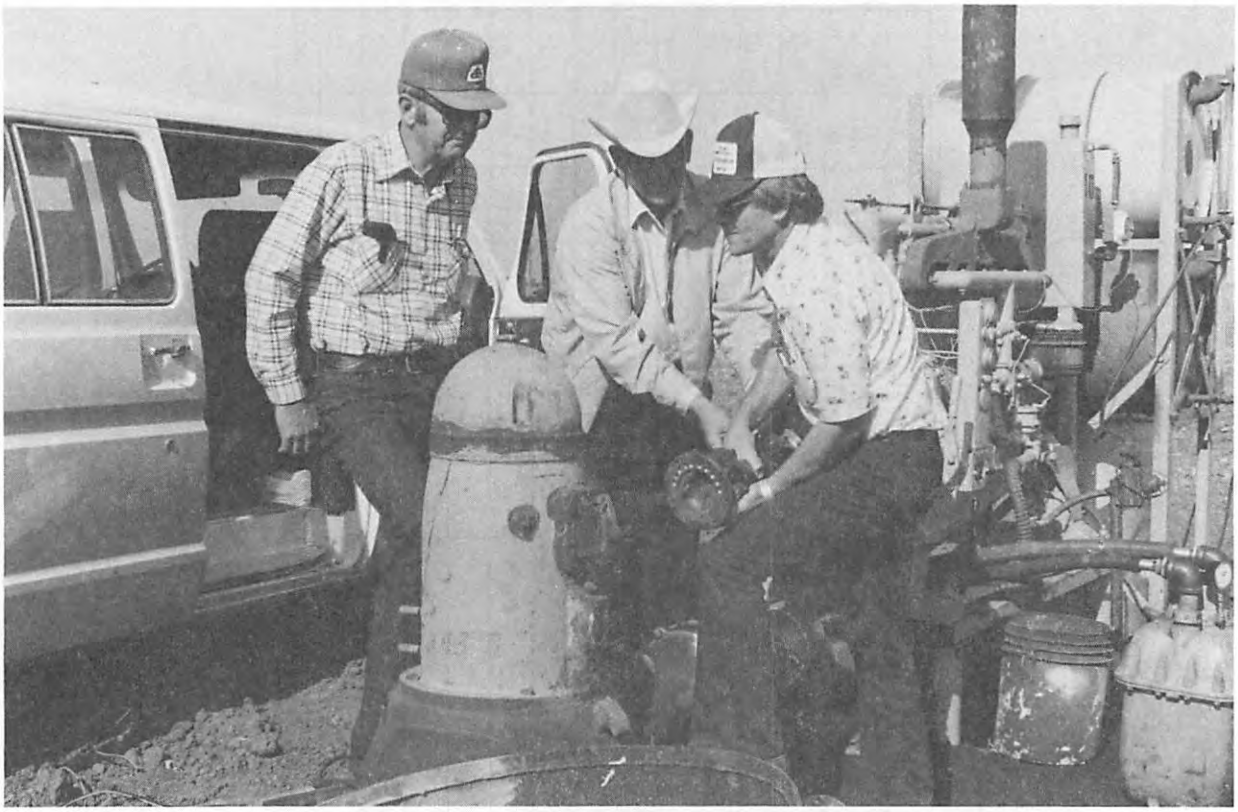
Location	Co.	Irri-gation Method	ENGINE						PUMP					Percent Overall Eff.	Ft^3/ Ac-In/ 100' Head	Fuel Cost @ $3.00 mcf		
			Model	RPM	HP	Fuel Ft^3/HR	Cu. Ft./ HP	% Eff.	RPM	GPM	Pumping Lift-Ft	Dis-charge Head-Psi	% Eff.			Per Ac-In $	Per Hour $	$ Cost/ Ac-In/ 100' Hd.
G800-1	Dall	Pivot	Moline 800	1311	99	1192	12.0	21	1750	475	228	27	37	7.4	393	3.42	3.58	1.18
G800-2	Dall	Pivot	Moline 800	1295	99	1192	12.0	21	1725	475	228	26	37	7.4	396	3.42	3.58	1.19
G301	Lamb	Pivot	Chry 440	2370	94	1032	11.0	23	1780	800	190	52	43	9.5	484	1.74	3.10	1.45
AVERAGE	ALL	PIVOT		1676	106	1322	12.2	20	1936	705	263	46	63	12.8	241	2.58	4.02	.73

TABLE 3. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

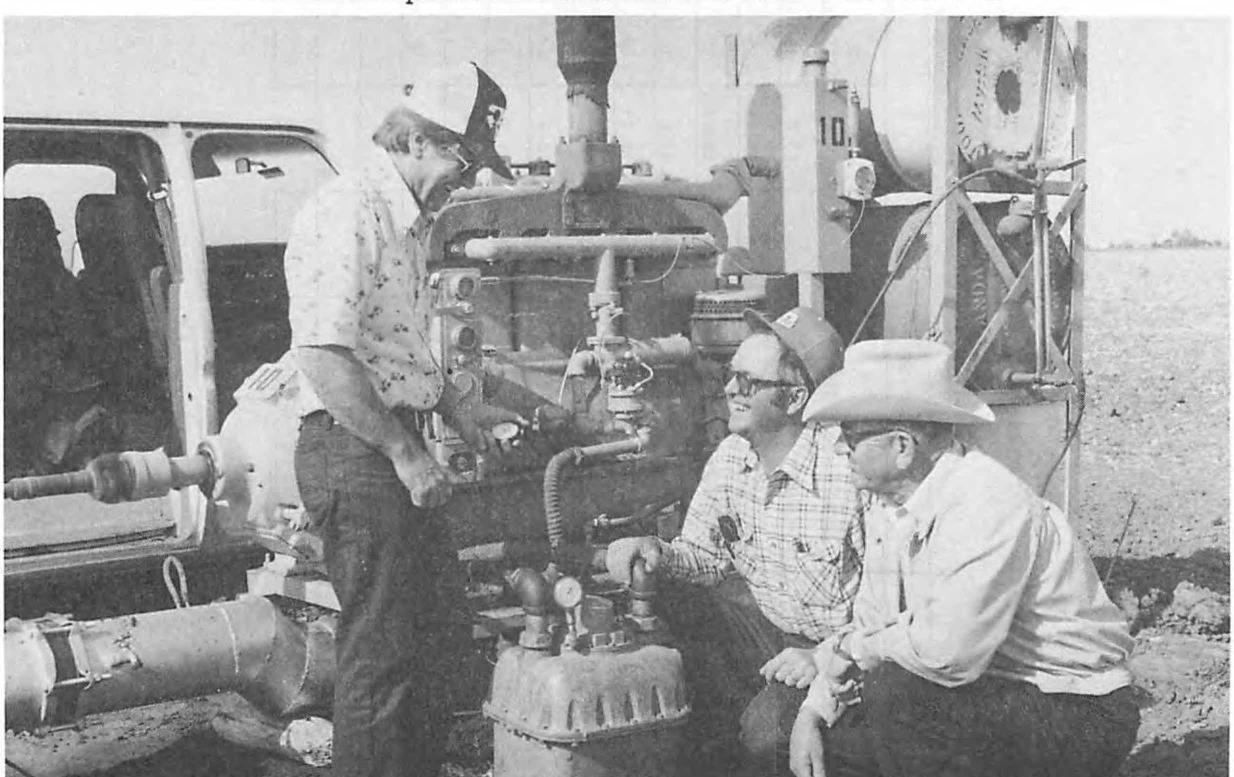
A R E A

1975 - 1981
Natural Gas

Location	Co.	Irri-gation Method	ENGINE						PUMP					Percent Overall Eff.	Ft^3/ Ac-In/ 100' Head	Fuel Cost @ $3.00 mcf		
			Model	RPM	HP	Fuel Ft^3/HR	Cu. Ft./ HP	% Eff.	RPM	GPM	Pumping Lift-Ft.	Dis-charge Head-Psi	% Eff.			Per Ac-In $	Per Hour $	$ Cost/ Ac-In/ 100' Hd.
G741-2	Old	Sideroll	Chev 292	1930	35	460	13.1	19	1750	235	215	77	71	12.9	224	2.65	1.38	.68
G741-1	Old	Sideroll	Chev 292	1718	26	350	13.5	19	1565	185	215	46	61	10.9	265	2.55	1.05	.80
G111	Hock	Sideroll	Chry 413	2282	49	758	15.5	17	1940	385	170	59	63	10.6	291	2.67	2.27	.87
G731	Bris	Sideroll	Ford 534	1873	30	413	13.8	18	1565	315	95	43	54	9.5	305	1.77	1.24	.91
G181	Yoak	Sideroll	Ford 428	1953	38	536	14.1	18	1625	325	115	53	54	9.2	313	2.23	1.61	.94
G701	Gray	Sideroll	Chev 292	1550	17	348	20.5	12	1290	320	42	12	36	4.1	699	1.47	1.04	2.10
G691-1	Gray	Sideroll	Chev 292	2130	32	584	18.3	14	2130	125	83	51	21	2.8	1046	6.31	1.75	3.14
G691-2	Gray	Sideroll	Chev 292	2000	26	514	19.8	13	2000	100	82	41	19	2.2	1307	6.94	1.54	3.92
AVERAGE	ALL	SIDEROLL		1930	32	495	16.1	16	1733	249	127	48	47	7.8	556	3.32	1.49	1.67
AVERAGE		OVER ALL		1794	90	1100	12.8	20	1678	595	299	19	60	12.2	281	2.73	3.30	.85



Leon New and Juston McBride, Deaf Smith County Agent, install a torquemeter while Charles Schlabs looks on.



Leon New measures the fuel consumption while Juston McBride and Charles Schlabs observes.

DIESEL POWERED UNITS

On diesel powered pumping plants, the average overall efficiency of 26 tests was found to be 20 percent (Table 4). This is very good since the standard overall efficiency is 20.1 percent. Pump efficiency of the diesel tests averaged 67 percent, which is fairly close to the 75 percent standard. When comparing the engine efficiency, the average tested to be 31 percent (Table 4) which is higher than the standard of 28 percent.

In looking at the pumping cost using diesel, the average hourly cost of $7.25 is very high compared to natural gas or electricity. The cost per acre-foot was $58.56 or $4.88 per acre-inch. Calculating the cost per acre-foot per 100 foot of head shows how the pumping plants compare. The cost per acre-foot per 100 foot of head was $15.36 or $0.15 per acre-foot per foot of head which is competitive with electricity, but higher than natural gas. Diesel has a higher hourly and acre-foot cost because of the higher production capacity and the greater total head (lift + Psi) than the electrical or natural gas units tested.

TABLE 4. IRRIGATION PUMPING PLANT EFFICIENCY TESTS

A R E A

1975 - 1981

Diesel

Location	Co.	Irri-gation Method	ENGINE						PUMP					Percent Overall Eff.	Gal. Ac-In/ 100' Head	Fuel Cost @ $1.15 Gal		
			Model	RPM	HP	Fuel Gal/HR	Gal/HR ÷ HP	% Eff.	RPM	GPM	Pumping Lift-ft	Dis-charge Head-Psi	% Eff.			Per Ac-In $	Per Hour $	$ Cost/ Ac-In/ 100' Hd
D37	Dall	Pivot	Detroit 671	1805	140	7.6	.054	35	1805	730	320	93	74	25	.88	5.39	8.73	1.01
D18-2	Dall	Pivot	Deere 6404	2008	120	7.2	.060	31	1675	870	220	84	80	24	.91	4.32	8.28	1.04
D18-1	Dall	Pivot	Deere 6404 AR	1866	91	5.6	.061	31	1560	665	203	80	75	22	.99	4.39	6.44	1.13
D68-2	Dall	Pivot	Deutz BF6	2325	107	6.5	.060	31	1745	750	322	42	74	23	.94	4.53	7.48	1.08
D68-1	Dall	Pivot	Deutz BF6 L913	2215	91	5.5	.060	31	1650	650	316	30	73	22	1.00	4.42	6.33	1.14
D11	Hemp	Pivot	Detroit GV53	2047	85	5.0	.059	32	1536	570	305	50	72	23	.94	4.56	5.75	1.08
D21	Hart	Pivot	Deere 466	1612	182	10.1	.055	34	1775	950	397	46	70	23	.95	5.50	5.75	1.08
D28	Dall	Pivot	Cat 3306	1715	144	8.6	.059	32	1715	880	310	68	76	23	.95	5.10	9.89	1.09
D10	Dall	Pivot	Deere 6619 AF	1803	173	10.5	.060	31	1796	1200	300	50	77	23	.96	4.56	12.08	1.10
D78	Dall	Pivot	Alis Chalmers MK11	1515	150	8.2	.054	35	1835	825	260	88	68	22	.98	5.19	9.43	1.12
D38	Dall	Pivot	Cat 3306 P.C.	1717	154	9.1	.059	32	1717	915	301	63	71	21	1.00	5.13	10.40	1.15
D57	Dall	Pivot	Detroit 671	1500	107	6.3	.059	32	1500	790	253	42	69	21	1.03	4.16	7.25	1.19
D20-2	Dall	Pivot	Deere 466	1788	145	8.4	.058	33	1785	835	324	49	67	21	1.05	5.25	9.67	1.20

TABLE 4. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

A R E A

1975 - 1981

Diesel

			ENGINE						PUMP							Fuel Cost @ $1.15 Gal		
Location	Co.	Irri-gation Method	Model	RPM	HP	Fuel Gal/HR	Gal/HR ÷ HP	% Eff.	RPM	GPM	Pumping Lift-ft	Dis-charge Head-Psi	% Eff.	Percent Overall Eff.	Gal. Ac-In/ 100' Head	Per Ac-In $	Per Hour $	$ Cost/ Ac-In/ 100'Hd
D20-3	Dall	Pivot	Deere 466	1788	145	8.4	.058	33	1785	835	324	49	67	21	1.05	5.25	9.67	1.20
D20-1	Dall	Pivot	Deere 466	1591	99	5.8	.058	33	1590	595	313	23	58	18	1.20	5.05	6.61	1.38
D48	Dall	Pivot	Detroit 671	1680	117	7.4	.063	30	1535	675	300	50	65	19	1.17	5.73	8.51	1.34
D88-1	Dall	Pivot	Detroit 471	1750	152	8.6	.057	33	1750	665	355	53	56	18	1.23	6.77	9.91	1.42
D88-2	Dall	Pivot	Detroit 471	1600	111	6.4	.058	32	1600	500	345	35	51	16	1.37	6.72	7.40	1.57
D58	Dall	Pivot	Detroit 671	1780	126	8.8	.070	27	1780	550	420	58	64	16	1.32	8.38	10.16	1.51
D47	Dall	Pivot	Detroit 671	1765	120	8.7	.073	26	1765	475	412	93	66	16	1.33	9.56	10.01	1.53
AVERAGE	ALL	PIVOT		1794	128	7.6	.060	32	1695	746	315	57	69	21	1.06	5.50	8.49	1.22
D27-3	Old	Furrow	Deutz BF4	2110	39	2.3	.061	31	1760	575	179	5	75	22	.98	2.14	2.71	1.13
D27-2	Old	Furrow	Deutz BF4	1990	30	1.9	.064	30	1665	425	172	2	67	19	1.16	2.36	2.20	1.33
D27-1	Old	Furrow	Deutz BF4	1860	20	1.4	.071	27	1555	250	168	2	58	15	1.48	2.94	1.62	1.71
D17-3	D.S.	Furrow	Deutz BF6	2165	67	4.2	.063	30	1805	800	195	2	64	18	1.20	2.77	4.88	1.38

TABLE 4. IRRIGATION PUMPING PLANT EFFICIENCY TESTS (continued)

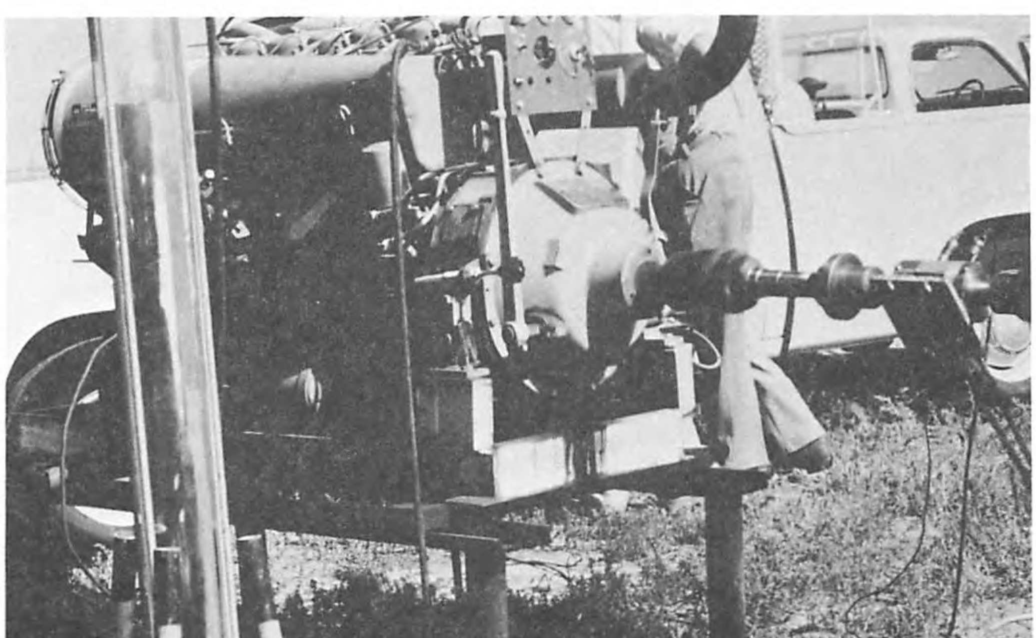
A R E A

1975 - 1981

Diesel

			ENGINE						PUMP							Fuel Cost @ $1.15 Gal		
Location	Co.	Irri-gation Method	Model	RPM	HP	Fuel Gal/HR	Gal/HR ÷ HP	% Eff.	RPM	GPM	Pumping Lift-ft	Dis-charge Head-Psi	% Eff.	Percent Overall Eff.	Gal. Ac-In/ 100' Head	Per Ac-In $	Per Hour $	$ Cost/ Ac-In/ 100' Hd
D17-2	D.S.	Furrow	Deutz BF6	2085	59	3.7	.063	30	1740	640	190	2	57	16	1.35	3.01	4.26	1.55
D17-1	D.S.	Furrow	Deutz BF6	1895	41	2.7	.067	28	1580	400	190	2	51	14	1.59	3.57	3.15	1.84
AVERAGE	ALL	FURROW		2018	43	2.7	.065	29	1684	515	182	3	62	17	1.29	2.80	3.14	1.49
AVERAGE	ALL			1845	108	6.5	.061	31	1692	693	284	45	67	20	1.12	4.88	7.25	1.28

Leon New metering a well with a flow meter.



New checking the fuel consumption on a diesel engine during an efficiency test.

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
IRRIGATION PUMPING PLANT TESTING PROGRAM

Figure 2. Three SCS Administrative Areas Participating In The Irrigation Pumping Plant Efficiency Testing Program

TABLE 5

SCS AREAS AND SOIL AND WATER CONSERVATION DISTRICTS AREAS INVOLVED IN PUMPING PLANT TESTING PROGRAM

SCS Administrative Area			Soil & Water Conservation District		
No.	Area Office	County	Zone	No.	Name
1	Pampa	Collingsworth	1	133	Salt Fork
		Donley	1	127	Donley County
		Gray	1	125	Gray County
		Hall	1	109	Hall-Childress
		Hansford	1	148	Hansford
		Hemphill	1	138	Hemphill County
		Hutchinson	1	146	Hutchinson
		Lipscomb	1	134	Lipscomb
		Ochiltree	1	142	Ochiltree
		Roberts	1	145	Roberts
		Sherman	1	159	Sherman County
		Wheeler	1	141	Wheeler County
2	Amarillo	Armstrong	1	155	Staked Plains
		Briscoe	1	126	Cap Rock
		Carson	1	156	McClellan Creek
		Castro	1	136	Running Water
		Deaf Smith	1	143	Tierra Blanca
		Dallam	1	131	Dallam
		Hartley	1	152	Hartley
		Moore	1	137	Moore County
		Oldham	1	153	Oldham County
		Parmer	1	140	Parmer
		Potter	1	160	Canadian River
		Randall	1	147	Palo Duro
		Swisher	1	110	Tule Creek
7	Lubbock	Bailey	1	111	Blackwater Valley
		Cochran	1	149	Cochran
		Crosby	1	107	Rio Blanco
		Dickens	1	157	Duck Creek
		Floyd	1	104	Floyd County
		Garza	1	158	Garza
		Hale	1	132	Hale County
		Hockley	1	129	Hockley County
		Lamb	1	130	Lamb County
		Lubbock	1	108	Lubbock County
		Motley	1	164	Upper Pease

ELECTRIC POWERED UNITS

The Soil Conservation Service calculated that the average overall efficiency for pumping plants tested in the Lubbock, Amarillo, and Pampa areas was 42.64 percent (Table 6). This was based on 123 tests of electric powered pumping plants. The three Soil Conservation Service administrative areas involved in the program have a wide range of diverse conditions under which the tests occurred. Pumping lifts ranged from less than 100 feet to conditions over 500 feet. Most other agencies didn't have conditions this diverse, except for the Texas Agriculture Extension Service.

Using the assumed motor efficiencies for the electric motors, the average pump efficiency was determined to be 49.2 percent. When considering that the standard is 75 percent, this shows the need for improvements. The average cost to pump an acre-foot of water with the pumps tested by the Soil Conservation Service was $37.78. The acre-inch cost was $3.15. The cost per acre-foot per foot of lift was $0.18 and the average hourly power consumption was 35.7 kwh. This is $2.14 per hour to operate the average pumping plant.

TABLE 6. USDA-SOIL CONSERVATION SERVICE PROGRAM

ENERGY EFFICIENCY DATA ON ELECTRIC WELLS

Well Evaluation No.	Well Evaluation Date	SCS Administrative Area (Town)	Total Lift (ft)	GPM	Horsepower Water	Horsepower Input	Assumed Motor Efficiency (%)	Pump Efficiency (%)	Overall Efficiency (%)	Annual Consumption (Kwh)	Annual Fuel Cost	Ac-Ft Pumped	Cost/ Ac-Ft	Cost/ Ac-In	Cost/ Ac-Ft/ Ft. Lift
1	9/81	Amarillo	507	630	80.7	127.7	91.0	69.4	63.2	190,512	$11,430.72	233.3	$48.99	$ 4.08	$ 0.10
2	7/3/81	"	346	600	52.4	101.7	91.0	56.6	51.5	151,800	9,108.00	222.2	40.97	3.42	0.12
3	7/3/81	"	354	740	66.2	182.4	91.0	39.8	36.3	272,200	16,332.00	274.1	59.59	4.97	0.17
4	7/3/81	"	355	800	71.7	117.4	91.0	67.1	61.1	175,200	10,512.00	296.3	35.48	2.96	0.10
5	9/7/81	"	319	330	26.6	80.7	91.0	36.2	32.9	120,400	7,224.00	122.2	59.11	4.93	0.19
6	9/7/81	"	338	630	53.8	104.7	91.0	56.4	51.3	156,200	9,372.00	233.3	40.17	3.35	0.12
7	9/10/81	"	331	605	50.6	79.8	91.0	69.7	63.4	119,000	7,140.00	224.1	31.86	2.66	0.10
8	9/10/81	"	317	735	58.8	109.2	91.0	59.2	53.9	163,000	9,780.00	272.2	35.93	2.99	0.11
9	8/27/81	"	300	510	38.6	87.3	91.0	48.6	44.3	130,240	7,814.40	188.9	41.37	3.45	0.14
10	9/3/81	"	346	600	52.4	101.7	91.0	56.6	51.5	151,800	9,108.00	222.2	40.99	3.42	0.12
11	4/9/81	"	340	575	49.4	105.7	91.0	51.3	46.7	157,800	9,468.00	213.0	44.46	3.71	0.13
12	4/9/81	"	340	200	17.2	54.3	91.0	34.8	31.6	810,000	4,860.00	74.1	65.61	5.47	0.19
13	4/9/81	"	340	320	27.5	81.8	91.0	36.9	33.6	122,000	7,320.00	118.5	61.76	5.15	0.18
14	4/9/81	"	340	520	44.6	93.6	91.0	52.4	47.7	139,600	8,376.00	192.6	43.49	3.62	0.13
15	5/20/81	"	412	610	63.5	109.9	91.0	63.5	57.8	163,940	9,836.40	225.9	43.54	3.63	0.11
16	5/20/81	"	426	615	66.1	113.2	91.0	64.2	58.4	168,960	10,137.60	227.8	44.51	3.71	0.10
17	7/24/81	"	545	700	96.3	128.6	91.0	82.3	74.9	191,920	11,515.20	259.3	44.42	3.70	0.08
18	7/24/81	"	392	400	39.6	68.2	91.0	63.8	58.0	101,800	6,108.00	148.1	41.23	3.44	0.11
19	6/1/81	"	214	370	20.0	63.1	90.0	35.2	31.7	94,200	5,652.00	137.0	41.24	3.44	0.19
19A	6/1/81	"	214	480	25.9	63.1	90.0	45.6	41.1	94,200	5,652.00	177.8	31.79	2.65	0.15
20	6/8/81	"	204	570	29.4	64.8	90.0	50.4	45.3	96,660	5,799.60	211.1	27.47	2.29	0.14
21	6/8/81	"	214	650	35.1	64.6	90.0	60.4	54.4	96,400	5,784.00	240.7	24.03	2.00	0.11
22	6/8/81	"	270	588	40.1	65.6	91.0	67.2	61.1	97,820	5,869.20	217.8	26.95	2.25	0.10
23	5/81	"	220	31	1.7	5.8	80.0	37.1	29.6	8,640	518.40	11.4	45.30	3.77	0.21
24	5/81	"	220	44	2.5	7.2	80.0	42.3	33.8	10,800	$ 648.00	16.3	$ 39.67	$ 3.31	$ 0.18

TABLE 6. USDA-SOIL CONSERVATION SERVICE PROGRAM (continued)

ENERGY EFFICIENCY DATA ON ELECTRIC WELLS

Well Evaluation		SCS Administrative Area	Total Lift		Horsepower		Assumed Motor Efficiency	Pump Efficiency	Overall Efficiency	Annual Consumption	Annual Fuel	Ac-Ft	Cost/	Cost/	Cost/ Ac-Ft/
No.	Date	(Town)	(ft)	GPM	Water	Input	(%)	(%)	(%)	(Kwh)	Cost	Pumped	Ac-Ft	Ac-In	Ft. Lift
25	5/81	Amarillo	220	44	2.5	7.4	80.0	41.5	33.2	11,020	$ 661.20	16.3	$ 40.48	$ 3.37	$ 0.18
26	5/81	"	220	31	1.7	6.0	80.0	35.6	28.5	9,000	540.00	11.4	47.18	3.93	0.21
27	5/81	"	252	56	3.6	10.2	80.0	43.8	35.0	15,200	912.00	20.7	43.97	3.66	0.17
28	5/81	"	342	44	3.8	6.5	80.0	73.3	58.7	9,700	582.00	16.3	35.60	2.97	0.10
29	5/81	"	315	56	4.5	11.6	80.0	48.0	38.4	17,280	1,036.80	20.7	49.99	4.17	0.16
30	7/10/81	Lubbock	260	55	3.6	12.7	80.0	35.4	28.3	19,000	1,140.00	20.3	55.96	4.66	0.22
31	7/10/81	"	260	50	3.3	18.0	80.0	22.8	18.2	26,800	1,608.00	18.5	86.83	7.23	0.33
32	6/23/81	"	300	100	7.6	34.7	80.0	27.2	21.8	51,800	3,108.00	37.0	83.91	6.99	0.28
33	6/23/81	"	380	150	14.4	32.4	80.0	55.4	44.3	48,400	2,904.00	55.5	52.27	4.35	0.14
34	4/30/81	"	323	90	7.3	22.3	80.0	41.2	32.9	33,200	1,992.00	33.3	59.76	4.98	0.19
35	4/30/81	"	405	190	19.4	34.0	80.0	71.3	57.0	50,800	3,018.00	70.3	43.31	3.60	0.11
36	4/30/81	"	303	110	8.4	20.5	80.0	51.2	41.0	30,600	1,836.00	40.7	45.00	3.75	0.15
37	4/30/81	"	328	150	12.4	28.3	80.0	54.9	43.9	42,200	2,532.00	55.5	45.57	3.79	0.14
38	4/30/81	"	383	110	10.6	18.6	80.0	71.3	57.0	27,800	1,668.00	40.7	40.94	3.41	0.11
39	9/24/81	"	330	275	22.9	46.2	80.0	61.9	49.5	69,000	4,140.00	101.8	40.64	3.38	0.12
40	5/15/81	"	182	185	8.5	15.4	90.0	61.2	55.1	23,000	1,380.00	68.5	20.14	1.67	0.11
41	5/15/81	"	288	210	15.3	19.3	80.0	98.9	79.1	28,800	1,728.00	77.7	22.21	1.85	0.08
42	6/8/81	"	182	190	8.7	24.8	90.0	39.1	35.2	37,000	2,220.00	70.3	31.54	2.62	0.17
43	6/8/81	"	188	215	10.2	37.3	90.0	30.4	27.3	55,600	3,336.00	79.6	41.89	3.49	0.22
44	6/8/81	"	195	265	13.0	38.6	90.0	37.5	33.8	57,600	3,456.00	98.1	35.21	2.93	0.18
45	6/17/81	"	171	260	11.2	25.7	90.0	48.4	43.6	38,400	2,304.00	96.2	23.92	1.99	0.14
46	5/26/81	"	171	175	7.6	18.5	90.0	45.3	40.8	27,600	1,656.00	64.8	25.55	2.12	0.15
47	5/26/81	"	183	130	6.0	13.9	80.0	53.8	43.0	20,800	1,248.00	48.1	25.92	2.16	0.14
48	5/26/81	"	180	25	1.1	10.1	90.0	12.5	11.3	15,000	900.00	9.2	97.20	8.10	0.54
49	6/12/81	"	250	400	25.3	49.6	90.0	56.5	50.9	74,000	$4,440.00	148.1	$ 29.97	$ 2.49	$ 0.12

TABLE 6. USDA-SOIL CONSERVATION SERVICE PROGRAM (continued)

ENERGY EFFICIENCY DATA ON ELECTRIC WELLS

Well Evaluation No.	Well Evaluation Date	SCS Administrative Area (Town)	Total Lift (ft)	GPM	Horsepower Water	Horsepower Input	Assumed Motor Efficiency (%)	Pump Efficiency (%)	Overall Efficiency (%)	Annual Consumption (Kwh)	Annual Fuel Cost	Ac-Ft Pumped	Cost/ Ac-Ft	Cost/ Ac-In	Cost/ Ac-Ft/ Ft. Lift
50	6/12/81	Lubbock	250	240	15.2	81.8	90.0	20.5	18.5	122,000	$ 7,320.00	88.8	$ 82.35	$ 6.86	$ 0.33
51	6/12/81	"	250	85	5.4	23.2	90.0	25.7	23.1	34,600	2,076.00	31.4	65.94	5.49	0.26
52	4/20/81	"	120	115	3.5	20.1	88.0	19.6	17.3	30,000	1,800.00	42.5	42.26	3.52	0.35
53	4/20/81	"	101	105	2.7	19.3	88.0	15.7	13.8	28,800	1,728.00	38.8	44.43	3.70	0.44
54	4/20/81	"	67	220	3.7	13.8	90.0	29.9	26.9	20,600	1,236.00	81.4	15.16	1.26	0.23
55	3/25/81	"	132	220	7.3	21.7	80.0	42.2	33.7	32,400	1,944.00	81.4	23.85	1.98	0.18
56	3/25/81	"	130	210	6.9	22.1	80.0	38.9	31.1	33,000	1,980.00	77.7	25.45	2.12	0.20
57	3/25/81	"	130	160	5.3	13.1	90.0	44.4	39.9	19,600	1,176.00	59.2	19.84	1.65	0.15
58	4/7/81	"	161	160	6.5	26.8	88.0	27.5	24.2	40,000	2,400.00	59.2	40.50	3.37	0.25
58A	4/7/81	"	163	280	11.5	33.2	88.0	39.3	34.6	49,600	2,976.00	103.7	28.69	2.39	0.18
58B	4/7/81	"	166	400	16.8	36.9	88.0	51.6	45.4	55,000	3,300.00	148.1	22.27	1.85	0.13
59	4/7/81	"	151	140	5.3	13.1	80.0	50.7	40.6	19,600	1,176.00	51.8	22.68	1.89	0.15
60	3/26/81	"	150	210	8.0	20.8	88.0	43.5	38.2	31,000	1,860.00	77.7	23.91	1.99	0.16
61	3/26/81	"	140	39	1.4	5.1	80.0	33.8	27.0	7,600	456.00	14.4	31.56	2.63	0.23
62	4/14/81	"	220	30	1.7	6.4	80.0	32.3	25.9	9,600	576.00	11.1	51.84	4.32	0.24
63	4/14/81	"	188	80	3.8	14.7	80.0	32.1	25.7	22,000	1,320.00	29.6	44.55	3.71	0.24
64	3/26/81	"	110	60	1.7	5.1	80.0	40.8	32.7	7,600	456.00	22.2	20.52	1.71	0.19
65	4/22/81	"	111	400	11.2	34.3	90.0	36.3	32.6	51,200	3,072.00	148.1	20.73	1.72	0.19
65A	4/22/81	"	90	400	9.1	21.3	90.0	47.3	42.6	31,800	1,908.00	148.1	12.87	1.07	0.14
66	8/20/81	"	140	75	2.7	18.4	80.0	18.0	14.4	27,400	1,644.00	27.7	59.18	4.93	0.42
67	8/20/81	"	144	29	1.1	5.1	80.0	25.8	20.7	7,600	456.00	10.7	42.45	3.53	0.30
68	8/20/81	"	150	37	1.4	5.1	80.0	34.3	27.5	7,600	456.00	13.7	33.27	2.77	0.22
69	8/20/81	"	145	63	2.3	7.0	80.0	41.3	33.0	10,400	624.00	23.3	26.74	2.22	0.18
70	8/12/81	"	127	920	29.5	58.8	90.0	55.7	50.1	87,800	5,268.00	340.7	15.46	1.28	0.12
71	9/2/81	"	160	150	6.1	17.3	80.0	43.8	35.0	25,800	$1,548.00	55.5	27.86	$2.32	$ 0.17

TABLE 6. USDA-SOIL CONSERVATION SERVICE PROGRAM (continued)

ENERGY EFFICIENCY DATA ON ELECTRIC WELLS

Well Evaluation No.	Well Evaluation Date	SCS Administrative Area (Town)	Total Lift (ft)	GPM	Horsepower Water	Horsepower Input	Assumed Motor Efficiency (%)	Pump Efficiency (%)	Overall Efficiency (%)	Annual Consumption (Kwh)	Annual Fuel Cost	Ac-Ft Pumped	Cost/ Ac-Ft	Cost/ Ac-In	Cost/ Ac-Ft/ Ft. Lift
72	9/2/81	Lubbock	160	160	6.5	19.3	80.0	41.8	33.4	28,800	$ 1,728.00	59.2	$ 29.16	$ 2.43	0.18
73	9/14/81	"	140	470	16.6	33.0	88.0	57.2	50.3	49,200	2,952.00	174.0	16.95	1.41	0.12
74	7/15/81	"	80	200	4.0	8.7	90.0	51.5	46.3	13,000	780.00	74.0	10.53	0.87	0.13
75	7/81	"	80	45	0.9	4.7	80.0	24.2	19.3	7,000	420.00	16.6	25.20	2.10	0.32
76	7/11/81	"	100	120	3.0	7.0	80.0	54.3	43.4	10,400	624.00	44.4	14.04	1.17	0.14
77	4/24/81	"	260	790	51.9	64.3	90.0	89.5	80.6	96,000	5,760.00	292.5	19.68	1.64	0.08
78	6/1/81	"	290	525	38.4	67.3	90.0	63.4	57.1	100,400	6,024.00	194.4	30.98	2.58	0.11
79	6/2/81	"	250	148	9.3	27.6	80.0	42.2	33.8	41,200	2,472.00	54.8	45.09	3.75	0.18
80	6/19/81	"	233	620	36.5	79.4	90.0	51.0	45.9	118,400	7,104.00	229.6	30.93	2.57	0.13
81	8/4/81	"	255	156	10.0	24.0	90.0	46.5	41.8	35,800	2,148.00	57.7	37.17	3.09	0.15
82	8/4/81	"	205	167	8.6	26.9	90.0	35.6	32.0	40,200	2,412.00	61.8	38.99	3.25	0.19
83	8/4/81	"	255	187	12.0	29.5	90.0	45.3	40.8	44,000	2,640.00	69.2	38.11	3.17	0.15
84	8/4/81	"	255	234	15.1	33.9	90.0	49.3	44.4	50,600	3,036.00	86.6	35.03	2.91	0.14
85	8/4/81	"	255	263	16.9	34.7	90.0	54.2	48.7	51,800	3,108.00	97.4	31.90	2.65	0.13
86	8/4/81	"	255	116	7.5	25.1	90.0	33.1	29.7	37,400	2,244.00	42.9	52.23	4.35	0.21
87	8/4/81	"	230	524	30.4	54.6	90.0	61.9	55.7	81,400	4,884.00	194.0	25.16	2.09	0.11
88	8/4/81	"	255	169	10.9	28.3	90.0	42.7	38.4	42,200	2.532.00	62.5	40.45	3.37	0.16
89	8/4/81	"	255	207	13.3	24.4	90.0	60.7	54.6	36,400	2,184.00	76.6	28.48	2.37	0.11
90	8/4/81	"	230	417	24.2	47.1	90.0	57.1	51.4	70,200	4,212.00	154.4	27.27	2.27	0.12
91	8/4/81	"	230	246	14.3	30.2	90.0	52.6	47.3	45,000	2,700.00	91.1	29.63	2.47	0.13
92	7/23/81	"	261	943	62.2	96.5	90.0	71.5	64.3	144,000	8,640.00	349.2	24.73	2.06	0.10
93	7/28/81	"	271	822	56.3	85.8	90.0	72.8	65.5	128,000	7,680.00	304.4	25.22	2.10	0.09
94	7/28/81	"	284	769	55.2	84.7	90.0	72.3	65.0	126,400	7,584.00	284.8	26.62	2.21	0.09
95	7/28/81	"	281	648	46.0	96.5	90.0	52.9	47.6	144,000	8,640.00	240.0	36.00	3.00	0.13
96	7/81	"	292	841	62.0	79.4	90.0	86.8	78.1	118,400	$7,104.00	311.4	$ 22.80	$ 1.90	$ 0.08

TABLE 6. USDA-SOIL CONSERVATION SERVICE PROGRAM (continued)

ENERGY EFFICIENCY DATA ON ELECTRIC WELLS

Well Evaluation No.	Well Evaluation Date	SCS Administrative Area (Town)	Total Lift (ft)	GPM	Horsepower Water	Horsepower Input	Assumed Motor Efficiency (%)	Pump Efficiency (%)	Overall Efficiency (%)	Annual Consumption (Kwh)	Annual Fuel Cost	Ac-Ft Pumped	Cost/ Ac-Ft	Cost/ Ac-In	Cost/ Ac-Ft/ Ft. Lift
97	7/81	Lubbock	280	1,034	73.1	86.9	90.0	93.5	84.1	129,600	7,776.00	382.9	$ 20.30	$ 1.69	$ 0.07
98	7/15/81	"	224	623	35.2	63.9	90.0	62.0	55.8	94,200	5,652.00	230.7	24.49	2.04	0.11
99	8/7/81	"	242	200	12.2	39.7	80.0	38.5	30.8	59,200	3,552.00	74.0	47.95	3.99	0.20
100	--	"	252	621	39.5	75.5	90.0	58.1	52.3	112,600	6,756.00	230.0	29.37	2.44	0.12
101	--	"	253	410	26.2	58.4	90.0	49.7	44.8	87,200	5,232.00	151.8	34.45	2.87	0.14
102	--	"	209	142	7.5	27.6	80.0	33.9	27.1	41,200	2,472.00	52.5	47.00	3.91	0.23
103	--	"	225	158	9.0	27.6	80.0	40.6	32.5	41,200	2,472.00	58.5	42.24	3.52	0.19
104	--	"	230	92	5.3	15.7	80.0	42.5	34.0	23,400	1,404.00	34.0	41.20	3.43	0.18
105	7/8/81	"	205	120	6.2	23.6	90.0	29.2	26.3	35,200	2,112.00	44.4	47.52	3.96	0.23
106	--	"	210	150	8.0	20.8	80.0	47.8	38.2	31,000	1,860.00	55.5	33.48	2.79	0.16
107	--	"	210	91	4.8	18.6	80.0	32.3	25.8	27,800	1,668.00	33.7	49.49	4.12	0.24
108	--	"	210	71	3.8	26.5	90.0	15.7	14.1	39,600	2,376.00	26.2	90.35	7.53	0.43
109	8/31/81	"	185	811	37.9	103.8	90.0	40.5	36.5	154,800	9,288.00	300.3	30.92	2.57	0.17
110	9/30/81	"	225	960	54.5	112.7	90.0	53.7	48.3	168,200	10,092.00	355.5	28.38	2.36	0.13
111	4/1/81	"	148	65	2.4	5.4	90.0	50.2	45.1	8,020	481.00	24.0	19.98	1.66	0.14
112	--	"	148	60	2.2	5.5	80.0	51.0	40.8	8,200	492.00	22.2	22.14	1.84	0.15
113	--	"	148	45	1.7	5.1	80.0	41.2	33.0	7,600	456.00	16.6	27.36	2.28	0.19
114	--	"	148	130	4.9	11.7	90.0	46.2	41.6	17,400	1,044.00	48.1	21.68	1.80	0.15
115	--	"	128	120	3.9	6.6	90.0	65.6	59.0	9,800	588.00	44.4	13.23	1.10	0.10
116	--	"	148	45	1.7	2.7	80.0	78.4	62.8	4,000	240.00	16.6	14.40	1.20	0.10
117	7/14/81	"	80	40	0.8	3.8	80.0	26.9	21.5	5,600	336.00	14.8	22.68	1.89	0.28
118	--	"	80	80	1.6	7.4	80.0	27.4	21.9	11,000	660.00	29.6	22.27	1.85	0.28
119	--	"	80	50	1.0	5.6	80.0	22.4	17.9	8,400	504.00	18.5	27.21	2.26	0.34
120	7/13/81	"	100	140	3.5	15.3	90.0	25.7	23.1	22,800	1,368.00	51.8	26.38	2.19	0.26
121	--	"	100	125	3.2	11.0	80.0	35.8	28.7	16,400	$ 984.00	46.2	$ 21.25	$ 1.77	$ 0.21

TABLE 6. USDA-SOIL CONSERVATION SERVICE PROGRAM (continued)

ENERGY EFFICIENCY DATA ON ELECTRIC WELLS

Well Evaluation No.	Well Evaluation Date	SCS Administrative Area (Town)	Total Lift (ft)	GPM	Horsepower Water	Horsepower Input	Assumed Motor Efficiency (%)	Pump Efficiency (%)	Overall Efficiency (%)	Annual Consumption (Kwh)	Annual Fuel Cost	Ac-Ft Pumped	Cost/ Ac-Ft	Cost/ Ac-In	Cost/ Ac-Ft/ Ft. Lift
122	7/1/81	Lubbock	157	95	3.8	10.1	80.0	46.8	37.4	15,000	$ 900.00	35.1	$ 25.57	$ 2.13	$ 0.16
123	7/16/81	Pampa	490	1083	134.0	197.0	92.0	73.9	68.0	294,000	17,640.00	398.8	44.23	3.69	0.09
	Average		238.11	313.78	21.25	43.82	89.0	49.24	42.64	71,308.23	3,922.88	116.15	37.78	3.15	0.18

NOTE: The designation A, B, etc., following an evaluation number is the first (A) re-evaluation, second (B) re-evaluation, etc., of the same number well after it was reworked.

Cost is adjusted to 6¢/KWH.

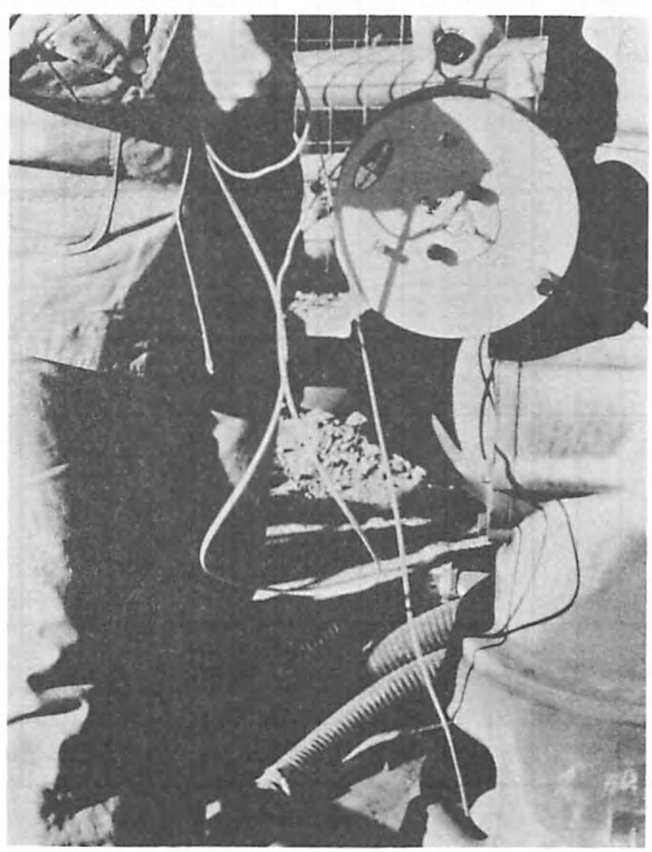
NATURAL GAS UNITS

The average overall efficiency of 108 natural gas pumping plants tested by the Soil Conservation Service was 10.76 percent (Table 7). The standard used for a natural gas overall efficiency is 17 percent. Therefore, the pumping plants tested by the Soil Conservation Service averaged about two-thirds as efficient as they could be.

The pumping lifts and volumes were greater than the electric units. The cost per acre-foot for the average natural gas unit was $36.53 which was $1.25 less than the electric units tested. However, more important was the cost per acre-foot per foot of lift. The gas plant was $0.12 as compared to the electric's $0.18. This indicates that the gas units tested were more efficient than the electric units tested, or that the price of $3.00 MCF for gas is a better fuel buy than $0.06 kwh for electricity.

Traditionally, the natural gas powered pumping plants are in the areas where the aquifer yields are greater and where the lifts are also greater.

Soil Conservation Service employee checking the gearhead speed (RPM).



A well sounder (E-line) is used to measure the depth to water while the well is pumping.

TABLE 7. USDA-SOIL CONSERVATION SERVICE PROGRAM

ENERGY EFFIENCY DATA ON NATURAL GAS WELLS

Well Evaluation No.	Well Evaluation Date	SCS Administrative Area (Town)	Total Lift (ft)	GPM	Horsepower Water	Horsepower Input	Overall Efficiency (%)	Annual Consumption (MCF)	Annual Fuel Cost	Ac-Ft Pumped	Cost/ Ac-Ft	Cost/ Ac-In.	Cost/ Ac-Ft/ Ft Lift
1	8/81	Amarillo	349	805	70.9	584.1	12.2	2,973	$ 8,819	298.1	$ 29.92	$ 2.49	$ 0.09
2	8/81	"	275	605	42.0	467.6	9.0	2,380	7,140	224.1	31.86	2.66	0.12
3	8/81	"	289	740	54.0	467.6	11.6	2,380	7,140	274.1	26.01	2.17	0.09
4	8/81	"	317	490	39.2	396.5	9.9	2,018	6,054	181.5	33.36	2.78	0.11
5	8/81	"	297	380	28.5	436.5	6.5	2,222	6,665	140.7	47.36	3.95	0.16
6	4/2/81	"	422	650	69.3	730.7	9.5	3,719	11,157	240.7	46.34	3.86	0.11
7	4/2/81	"	508	840	107.8	785.9	13.7	4,000	12,000	311.1	38.57	3.21	0.08
8	6/8/81	"	409	530	54.7	500.0	11.0	2,545	7,634	196.3	38.89	3.24	0.10
9	6/8/81	"	432	530	57.8	395.1	14.6	2,011	6,034	196.3	30.74	2.56	0.07
10	9/81	"	446	265	29.8	466.2	6.4	2,373	7,120	98.1	72.55	6.05	0.16
11	9/81	"	365	780	71.9	807.5	8.9	4,110	12,331	288.9	42.69	3.56	0.12
12	9/81	"	372	400	37.6	515.9	7.3	2,626	7,879	148.1	53.18	4.43	0.14
13	9/81	"	375	615	58.2	434.0	13.4	2,209	6,628	227.8	29.10	2.43	0.08
14	9/81	"	315	660	52.5	559.3	9.4	2,847	8,540	24.4	34.94	2.91	0.11
15	9/81	"	555	500	70.1	548.5	12.8	2,792	8,377	185.2	45.24	3.77	0.08
16	9/81	"	478	415	50.1	466.2	10.7	2,373	7,120	153.7	46.32	3.86	0.10
17	4/21/81	"	495	207	25.9	360.1	7.2	1,833	5,500	76.7	71.74	5.98	0.15
18	7/17/81	"	427	458	49.4	485.1	10.2	2,469	7,408	169.6	43.67	3.64	0.10
19	9/80	"	278	193	13.5	209.2	6.5	1,065	3,195	71.5	44.70	3.73	0.16
20	9/80	"	273	233	16.1	196.5	8.2	1,000	3,000	86.3	34.77	2.90	0.13
21	8/26/81	"	474	550	65.8	605.1	10.9	3,080	9,240	203.7	45.36	3.78	0.10
22	7/29/81	"	462	950	110.8	558.4	19.9	2,842	8,526	351.9	24.23	2.02	0.05
23	5/19/81	"	397	445	44.6	506.3	8.8	2,577	7,730	165.8	46.90	3.91	0.12
24	8/31/81	"	363	740	67.8	523.4	13.0	2,664	7,992	274.1	29.16	2.43	0.08
25	8/25/81	"	320	550	44.4	488.0	9.1	2,484	$ 7,452	203.7	$ 36.59	$ 3.05	$ 0.11

TABLE 7. USDA-SOIL CONSERVATION SERVICE PROGRAM (continued)

ENERGY EFFIENCY DATA ON NATURAL GAS WELLS

Well Evaluation No.	Date	SCS Administrative Area (Town)	Total Lift (ft)	GPM	Horsepower Water	Horsepower Input	Overall Efficiency (%)	Annual Consumption (MCF)	Annual Fuel Cost	Ac-Ft Pumped	Cost/ Ac-Ft	Cost/ Ac-In.	Cost/ Ac-Ft/ Ft Lift
26	8/25/81	Amarillo	325	900	73.9	514.0	14.4	2,616	$ 7,848	333.3	$ 23.54	$ 1.96	$ 0.07
27	8/25/81	"	321	680	55.1	528.1	10.4	2,688	8,064	251.9	32.02	2.67	0.10
28	8/31/81	"	355	625	56.0	391.4	14.3	1,992	5,976	231.5	25.82	2.15	0.07
29	8/31/81	"	361	575	52.4	443.2	11.8	2,256	6,768	213.0	31.78	2.65	0.09
30	8/31/81	"	355	550	49.3	433.8	11.4	2,208	6,624	203.7	32.52	2.71	0.09
31	8/31/81	"	360	570	1.8	457.4	11.3	2,328	6,984	211.1	33.08	2.76	0.09
32	8/4/81	"	375	220	20.8	328.9	6.3	1,674	5,021	81.5	61.62	5.14	0.16
33	3/81	"	445	340	38.2	313.6	12.2	1,596	4,789	125.9	38.03	3.17	0.09
34	3/81	"	455	750	86.2	548.5	15.7	2,792	8,377	277.8	30.16	2.51	0.07
35	7/24/81	"	531	650	87.2	673.7	12.9	3,429	10,286	240.7	42.73	3.56	0.08
36	7/16/81	"	540	865	118.0	572.3	20.6	2,913	8,738	320.4	27.27	2.27	0.05
37	8/6/81	"	188	207	9.8	135.6	7.2	690	2,070	76.7	27.00	2.25	0.14
38	5/5/81	"	261	420	27.7	173.9	15.9	885	2,656	155.6	17.07	1.42	0.07
39	6/4/81	"	330	282	23.5	228.5	10.3	1,163	3,488	104.3	33.46	2.79	0.10
40	7/81	"	242	1,000	61.1	410.0	14.9	2,087	6,261	370.4	16.91	1.41	0.07
41	5/81	"	221	307	17.1	186.4	9.2	949	2,848	113.7	25.05	2.09	0.11
42	5/81	"	157	285	11.3	101.2	11.2	515	1,544	105.6	14.62	1.22	0.09
43	5/81	"	280	550	38.5	294.7	13.2	1,500	4,500	203.7	22.09	1.84	0.08
44	7/27/81	Lubbock	360	170	15.5	227.9	6.7	1,160	3,480	62.9	55.27	4.60	0.15
45	7/27/81	"	350	240	21.2	314.3	6.7	1,600	4,800	88.8	54.00	4.50	0.15
46	8/6/81	"	240	600	36.4	349.7	10.3	1,780	5,340	222.2	24.03	2.00	0.10
47	8/6/81	"	233	600	35.3	357.6	9.8	1,820	5,460	222.2	24.57	2.04	0.11
48	5/15/81	"	184	400	18.6	196.5	9.4	1,000	3,000	148.1	20.25	1.68	0.11
49	5/15/81	"	182	350	16.1	243.6	6.6	1, 40	3,720	129.6	28.69	2.39	0.16
50	6/11/81	"	214	440	23.8	404.7	5.8	2,060	$ 6,180	162.9	$ 37.92	$ 3.16	$ 0.18

TABLE 7. USDA-SOIL CONSERVATION SERVICE PROGRAM (continued)

ENERGY EFFIENCY DATA ON NATURAL GAS WELLS

Well Evaluation No.	Well Evaluation Date	SCS Administrative Area (Town)	Total Lift (ft)	GPM	Horsepower Water	Horsepower Input	Overall Efficiency (%)	Annual Consumption (MCF)	Annual Fuel Cost	Ac-Ft Pumped	Cost/ Ac-Ft	Cost/ Ac-In.	Cost/ Ac-Ft/ Ft Lift
51	8/7/81	Lubbock	280	90	6.4	302.6	2.1	1,540	$ 4,620	33.3	$ 38.60	$ 11.55	$ 0.50
52	8/7/81	"	280	140	9.9	192.5	5.1	980	2,940	51.8	56.70	4.72	0.20
53	8/7/81	"	280	55	3.9	212.2	1.8	1,080	3,240	20.3	159.05	13.25	0.57
54	6/25/81	"	240	520	31.5	412.6	7.6	2,100	6,300	192.5	32.71	2.72	0.14
55	6/25/81	"	241	220	13.4	290.8	4.6	1,480	4,440	81.4	54.49	4.54	0.23
56	5/18/81	"	182	350	16.1	235.8	6.8	1,200	3,600	129.6	27.77	2.31	0.15
57	5/18/81	"	184	265	12.3	149.3	8.2	760	2,280	98.1	23.23	1.93	0.13
58	5/18/81	"	250	150	9.5	172.9	5.4	880	2,460	55.5	47.52	3.96	0.19
59	4/22/81	"	302	530	40.4	310.4	13.0	1,580	4,740	196.2	24.14	2.01	0.08
60	3/13/81	"	215	590	32.0	243.6	13.1	1,240	3,720	218.5	17.02	1.41	0.08
61	3/13/81	"	297	500	37.5	306.5	12.2	1,560	4,680	185.1	25.27	2.10	0.09
62	3/13/81	"	305	570	43.9	314.3	13.9	1,600	4,800	211.1	22.73	1.89	0.08
63	4/14/81	"	190	190	9.1	161.1	5.6	820	2,460	70.3	34.95	2.91	0.18
64	4/14/81	"	282	170	12.1	169.0	7.1	860	2,580	62.9	40.97	3.41	0.15
65	4/81	"	190	190	9.1	161.1	5.6	820	2,460	70.3	34.95	2.91	0.18
66	4/27/81	"	268	360	24.4	381.1	6.3	1,940	5,820	133.3	43.65	3.63	0.16
67	8/10/81	"	81	315	6.4	62.9	10.2	320	960	116.6	8.22	0.68	0.10
68	6/1/81	"	294	377	28.0	212.2	13.1	1,080	3,240	139.6	23.20	1.93	0.08
69	6/1/81	"	304	317	24.3	212.2	11.4	1,080	3,240	117.4	27.59	2.30	0.09
70	6/1/81	"	287	399	28.9	334.0	8.6	1,700	5,100	147.7	34.51	2.87	0.12
71	6/1/81	"	300	331	25.1	271.1	9.2	1,380	4,140	122.5	33.77	2.81	0.11
72	8/4/81	"	177	200	8.9	227.9	3.9	1,160	3,480	74.0	46.98	3.91	0.27
73	7/81	"	256	353	22.8	381.1	5.9	1,940	5,820	130.7	44.51	3.71	0.17
74	7/28/81	"	306	316	24.4	188.6	12.9	960	2,880	117.0	24.60	2.05	0.08
75	7/13/81	"	321	317	25.7	809.4	3.1	4,120	$12,360	117.4	$ 105.27	$ 8.77	$ 0.33

TABLE 7. USDA-SOIL CONSERVATION SERVICE PROGRAM (continued)

ENERGY EFFIENCY DATA ON NATURAL GAS WELLS

Well Evaluation No.	Well Evaluation Date	SCS Administrative Area (Town)	Total Lift (ft)	GPM	Horsepower Water	Horsepower Input	Overall Efficiency (%)	Annual Consumption (MCF)	Annual Fuel Cost	Ac-Ft Pumped	Cost/ Ac-Ft	Cost/ Ac-In.	Cost/ Ac-Ft/ Ft Lift
76	8/7/81	Lubbock	265	520	34.8	742.6	4.6	3,780	11,340	192.5	$ 58.88	$ 4.90	$ 0.22
77	8/7/81	"	245	525	32.5	314.3	10.3	1,600	4,800	194.4	24.68	2.05	0.10
78	8/7/81	"	248	146	9.1	149.3	6.1	760	2,280	54.0	42.16	3.51	0.17
79	8/24/81	"	175	976	43.1	365.4	11.8	1,860	5,580	361.4	15.43	1.28	0.09
80	7/81	Pampa	322	340	27.6	434.0	6.4	2,210	6,630	125.0	53.04	4.42	0.16
81	7/81	"	434	350	38.4	442.4	8.7	2,252	6,756	128.8	52.47	4.37	0.12
82	7/81	"	420	290	30.8	406.3	7.6	2,068	6,204	106.7	58.15	4.85	0.14
83	7/81	"	366	260	24.0	458.9	5.2	2,336	7,008	95.7	73.26	6.10	0.20
84	7/81	"	347	655	57.4	616.9	9.3	3,140	9,420	241.0	39.09	3.26	0.11
85	11/30/81	"	339	1,068	91.4	393.3	23.2	2,002	6,006	393.0	15.28	1.27	0.05
86	6/20/81	"	352	1,119	99.5	440.5	22.6	2,242	6,726	411.8	16.34	1.36	0.05
87	6/30/81	"	376	1,118	112.8	517.1	21.8	2,632	7,896	437.2	18.06	1.50	0.05
88	7/16/81	"	484	790	96.6	405.5	23.8	2,064	6,192	290.7	21.30	1.78	0.04
89	7/21/81	"	353	580	51.7	465.6	11.1	2,370	7,110	213.4	33.32	2.78	0.09
90	7/81	"	415	600	62.9	371.3	16.9	1,890	5,670	220.8	25.69	2.14	0.06
91	7/29/81	"	354	870	77.8	420.0	18.5	2,138	6,414	320.2	20.04	1.67	0.06
92	7/81	"	349	880	77.6	415.7	18.7	2,116	6,348	323.8	19.60	1.63	0.06
93	7/81	"	415	365	38.3	447.2	8.6	2,276	6,828	134.3	50.84	4.24	0.12
94	7/81	"	404	380	38.8	502.2	7.7	2,556	7,668	139.8	54.85	4.57	0.14
95	8/3/81	"	355	1,300	116.5	531.6	21.9	2,706	8,118	478.4	16.97	1.41	0.05
96	8/25/81	"	399	1,090	109.8	772.9	14.2	3,934	11,802	401.1	29.43	2.45	0.07
97	8/81	"	321	450	36.5	421.6	8.7	2,146	6,438	165.6	38.89	3.24	0.12
98	8/81	"	320	430	34.7	344.6	10.1	1,754	5,262	158.2	33.26	2.77	0.10
99	8/81	"	322	410	33.3	219.3	15.2	1,116	3,348	150.9	22.19	1.85	0.07
100	8/81	"	245	666	41.2	466.0	8.8	2,372	$ 7,116	245.1	$ 29.04	$ 2.42	$ 0.12

TABLE 7. USDA-SOIL CONSERVATION SERVICE PROGRAM (continued)

ENERGY EFFIENCY DATA ON NATURAL GAS WELLS

Well Evaluation No.	Well Evaluation Date	SCS Administrative Area (Town)	Total Lift (ft)	GPM	Horsepower Water	Horsepower Input	Overall Efficiency (%)	Annual Consumption (MCF)	Annual Fuel Cost	Ac-Ft Pumped	Cost/ Ac-Ft	Cost/ Ac-In.	Cost/ Ac-Ft/ Ft Lift
101	8/81	Pampa	289	700	51.1	405.1	12.6	2,062	$ 6.186	257.6	$ 24.02	2.00	$ 0.08
102	8/81	"	384	660	64.0	713.6	9.0	3,632	10,896	242.9	44.87	3.74	0.12
103	8/81	"	392	650	64.3	737.1	8.7	3,753	11,256	239.2	47.07	3.92	0.12
104	9/17/81	"	349	850	74.9	443.6	16.9	2,258	6,774	312.8	21.66	1.80	0.06
105	9/17/81	"	355	1,050	94.1	571.3	16.5	2,908	8,724	386.4	22.58	1.88	0.02
106A	10/31/81	"	--	481	--	393.0	--	970	2,910	177.0	16.44	1.37	0.03
106	8/7/80	"	--	200	--	120.0	--	1,260	3,780	74.0	51.37	4.28	0.26
107	11/13/80	"	340	1,068	91.7	490.8	18.7	2,500	$ 7,500	393.3	$ 19.08	$ 1.59	$ 0.06
		Average	326	516.94	44.72	397.9	10.76	2,022	5,994	18898	36.53	3.12	.12

NOTE: Evaluation number 106A is a re-evaluation of 106 after the well was re-worked. Cost is adjusted to $3.00/MCF.

HIGH PLAINS UNDERGROUND WATER
CONSERVATION DISTRICT NO. 1
IRRIGATION PUMPING PLANT TESTING PROGRAM

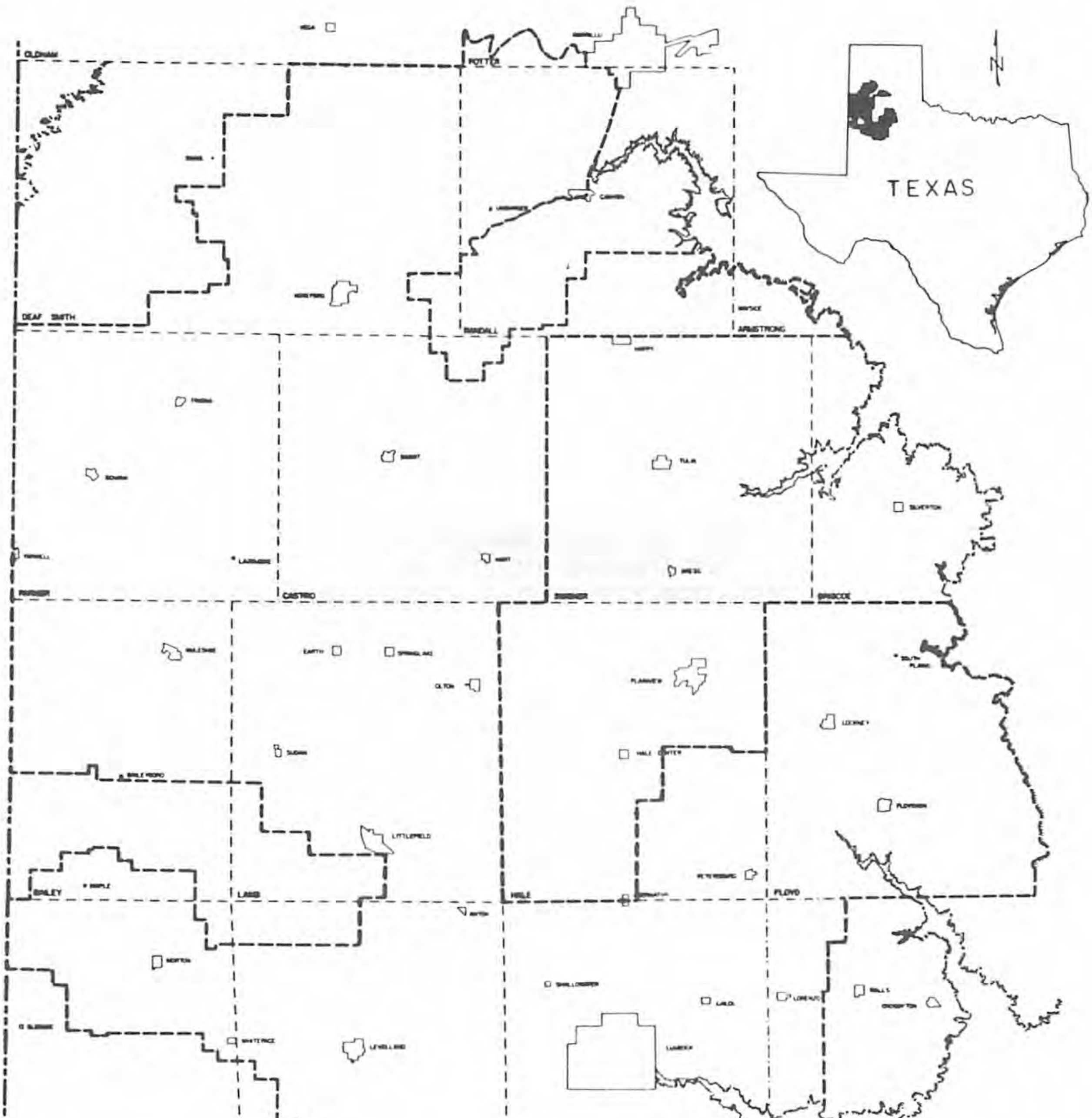


Figure 3. High Plains Underground Water Conservation District No. 1 Service Area

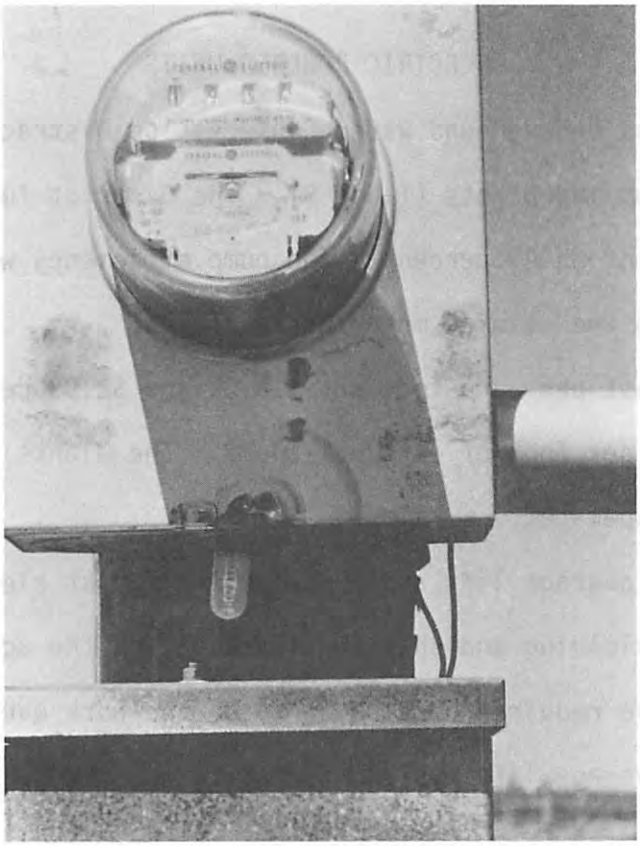
ELECTRIC POWERED UNITS

The High Plains Underground Water Conservation District No. 1 tested 168 electric powered pumping plants (Table 8). The District found an average overall efficiency of 35.29 percent. The pump efficiency was computed at 40.94 percent using the assumed motor efficiencies.

The average cost per acre-foot was $35.89 and $2.99 per acre-inch. The cost per acre-foot per foot of lift was $0.20. The plants averaged costing $1.26 per hour to operate.

Observing the average lift and GPM (Table 8), most electric pumps tested were in the small yielding and shallow lift areas of the aquifer. Other evidence of this is the required horsepower to do the work even with the low efficiency. The average lift was 185 feet with an average production of 212 gallons per minute.

Table 9 gives the number of pumps tested and the percent that fell in the various efficiency ranges. Only 19 pumps, or 11.3 percent, were in the 60 percent or better pump efficiency range and 37 pumps, or about 31 percent, were below the 30 percent pump efficiency range. The majority had between 30 and 60 percent pump efficiency, all of which points up the need for improvements.



A Watt-hour Meter at an irrigation well meters the kilowatts being consumed.

The pressure is being checked to find the additional work required by the pump above the pump lift.

TABLE 8. ENERGY EFFICIENCY DATA ON ELECTRIC WELLS - HIGH PLAINS UNDERGROUND WATER CONSERVATION DISTRICT NO. 1

Well No.	Total Lift	GPM	Water HP	Input HP	Motor Eff.	Pump Eff.	Overall Eff.	Annual (KWH) Consumption	Annual Fuel Cost	Ac. Ft. Pumped	Cost/ Ac. Ft.	Cost/ Ac. In.	Cost/Ac. Ft./ 100 Ft. Lift	Cost/Ac. In./ 100 Ft. Lift
4-E	170	85	3.65	10.16	80	44.91	35.93	15,240	914.40	31.30	29.21	2.43	17.18	1.43
4847	177	220	9.83	18.19	90	60.05	54.04	27,280	1,636.80	81.02	20.20	1.68	11.41	0.95
4-D	185	135	6.31	16.07	90	43.63	39.27	24,120	1,447.20	49.72	29.11	2.43	15.74	1.31
4-B	178	100	4.49	11.15	90	44.74	40.27	16,720	1,003.20	36.83	27.24	2.27	15.30	1.28
4-C	173	100	4.37	12.02	90	40.40	36.36	18,040	1,082.40	36.83	29.39	2.45	16.99	1.42
4-A	160	270	10.91	36.38	88	34.08	29.99	54,560	3,273.60	99.43	32.92	2.74	20.58	1.71
4-F	174	65	2.86	10.16	90	31.28	28.15	15,240	914.40	23.94	38.20	3.18	21.95	1.83
4-F	182	120	5.52	17.50	80	39.43	31.54	26,240	1,574.40	44.19	35.63	2.97	19.58	1.63
6834	176	150	6.67	18.19	80	45.84	36.67	27,280	1,636.80	55.24	29.63	2.47	16.84	1.40
4-C	178	240	10.79	26.08	90	45.97	41.37	39,120	2,347.20	88.38	26.56	2.21	14.92	1.24
6503	172	80	3.47	10.47	90	36.82	33.14	15,700	942.00	29.46	31.98	2.66	18.59	1.55
4-D	172	60	2.61	10.39	80	31.40	25.12	15,600	936.00	22.10	42.35	3.53	24.62	2.05
4-B	170	165	7.08	16.86	80	52.49	41.99	25,280	1,516.80	60.76	24.96	2.08	14.68	1.22
4-C	165	170	7.08	15.03	90	52.34	47.11	22,540	1,352.40	62.61	21.60	1.80	13.09	1.09
2905	160	160	6.46	20.33	90	35.31	31.78	30,500	1,830.00	58.92	31.06	2.59	19.41	1.62
4848	168	230	9.76	19.20	90	56.48	50.83	28,800	1,728.00	84.70	20.40	1.70	12.14	1.01
4-A	165	145	6.04	17.72	90	37.87	34.09	26,580	1,594.80	53.40	29.87	2.49	18.10	1.51
4554	155	160	6.26	20.33	90	34.21	30.79	30,500	1,830.00	58.92	31.06	2.59	20.04	1.67
2	179	290	13.11	34.56	90	42.15	37.93	51,840	3,110.40	106.80	29.12	2.43	16.27	1.36
1	196	100	4.95	23.83	90	23.07	20.76	35,750	2,145.00	36.83	58.24	4.85	29.71	2.48
40380	268	300	20.30	89.18	90	25.28	22.76	133,780	8,026.80	110.48	72.65	6.05	27.11	2.26
2025	273	700	48.26	92.16	90	58.17	52.36	138,240	8,294.40	257.79	32.18	2.68	11.79	0.98
7183	100	140	3.54	10.32	80	42.83	34.27	15,474	928.44	51.56	18.01	1.50	18.01	1.50
4-A	105	95	2.52	6.28	90	44.54	40.09	9,426	565.56	34.99	16.16	1.35	15.39	1.28
4895	104	110	2.89	12.13	90	26.47	23.82	18,180	1,090.80	40.51	26.93	2.24	25.89	2.16
4896	149	170	6.40	24.69	90	28.79	25.91	37,020	2,221.20	62.61	35.48	2.96	23.81	1.98
5116	111	60	1.68	13.04	90	14.31	12.88	19,562	1,173.72	22.10	53.11	4.43	47.85	3.99
4-B	100	100	2.53	10.97	90	25.60	23.02	16,458	987.48	36.83	26.81	2.23	26.81	2.23
731	141	85	3.03	7.54	90	44.61	40.10	11,310	678.60	31.30	21.68	1.81	15.38	1.28
2303	164	170	7.04	13.55	90	57.72	51.94	20,310	1,218.60	62.61	19.46	1.62	11.87	0.99
3	146	55	2.03	7.28	90	30.97	27.87	10,914	654.84	20.25	32.34	2.69	22.15	1.85
40162	226	630	35.95	65.83	90	60.69	54.62	98,740	5,924.40	232.00	25.54	2.13	11.30	0.94
1456	207	19	0.99	4.39	80	28.20	22.56	6,582	394.92	7.00	56.42	4.70	27.26	2.27
1	245	860	53.20	93.33	90	62.00	55.80	143,000	8,580.00	316.70	27.09	2.26	11.06	0.92
7023	120	25	0.76	6.57	80	14.41	11.53	9,800	588.00	9.21	63.84	5.32	53.20	4.43
3153	135	95	3.24	7.21	80	56.17	44.94	10,820	649.20	34.99	18.55	1.55	13.74	1.15
5231	124	65	2.04	7.43	80	34.32	27.46	11,140	668.40	23.94	27.92	2.33	22.52	1.88

TABLE 8. (Continued) ENERGY EFFICIENCY DATA ON ELECTRIC WELLS - HIGH PLAINS UNDERGROUND WATER CONSERVATION DISTRICT NO. 1

Well No.	Total Lift	GPM	Water HP	Input HP	Motor Eff.	Pump Eff.	Overall Eff.	Annual (KWH) Consumption	Annual Fuel Cost	Ac. Ft. Pumped	Cost/ Ac. Ft.	Cost/ Ac. In.	Cost/Ac. Ft./ 100 Ft. Lift	Cost/Ac. In./ 100 Ft. Lift
4	259	186	12.17	28.80	80	52.83	42.26	43,200	2,592.00	68.50	37.84	3.15	14.61	1.22
2	256	94	6.08	19.61	80	38.76	31.00	29,420	1,765.20	34.61	51.00	4.25	19.92	1.66
1	250	146	9.22	36.86	80	31.25	25.00	55,300	3,318.00	53.77	61.71	5.14	24.68	2.06
3603	335	600	50.76	86.40	91	64.56	58.75	129,600	7,776.00	220.96	35.19	2.93	10.50	0.88
C-620	341	800	68.89	125.67	91	60.24	54.82	188,500	11,310.00	294.61	38.39	3.20	11.26	0.94
4-E	160	148	5.98	19.47	90	34.13	30.71	29,200	1,752.00	54.50	32.15	2.68	20.09	1.67
4711	164	85	3.52	20.03	90	19.53	17.57	30,060	1,803.60	31.30	57.62	4.80	35.13	2.93
3991	161	120	4.88	13.55	90	40.00	36.01	20,320	1,219.20	44.19	27.59	2.30	17.14	1.43
4-A	165	200	8.33	20.33	90	45.53	40.97	30,500	1,830.00	73.65	24.85	2.07	15.06	1.26
3990	164	160	6.63	17.72	90	41.57	37.42	26,580	1,594.80	58.92	27.07	2.26	16.51	1.38
2451	168	250	10.61	33.31	90	35.39	31.85	49,960	2,997.60	92.07	32.56	2.71	19.38	1.62
4-C	165	190	7.92	20.33	90	43.28	38.96	30,480	1,828.80	69.97	26.14	2.18	15.84	1.32
2087	161	90	3.66	18.68	90	21.77	19.59	28,020	1,681.20	33.14	50.73	4.23	31.51	2.63
4-D	171	160	6.91	15.36	80	56.23	44.99	23,040	1,382.40	58.92	23.46	1.96	13.72	1.14
4-B	165	150	6.25	20.64	90	33.65	30.28	30,960	1,857.60	55.24	33.63	2.80	20.38	1.70
269	121	24	0.73	5.96	80	15.30	12.30	8,936	536.16	8.84	60.65	5.05	50.12	4.18
4459	117	13	0.38	4.37	80	10.98	8.79	6,560	393.60	4.79	82.17	6.85	70.23	5.85
50036	111	120	3.36	10.02	80	41.92	33.52	15,020	901.20	44.19	20.39	1.70	18.37	1.53
2362	252	900	57.27	92.16	90	69.04	62.14	138,240	8,294.40	331.44	25.03	2.09	9.93	0.83
1786	250	880	55.56	98.74	90	62.52	56.27	148,120	8,887.20	324.07	27.42	2.29	10.97	0.91
3173	230	655	38.04	76.80	90	55.03	49.53	115,200	6,912.00	241.21	28.66	2.39	12.46	1.04
9	256	395	25.53	53.17	90	53.34	48.01	79,740	4,784.40	145.47	32.89	2.74	12.85	1.07
10	274	310	21.45	46.08	90	51.71	46.54	69,120	4,147.20	114.16	36.33	3.03	13.26	1.10
11	267	270	18.20	45.32	90	44.61	40.15	67,980	4,078.80	99.43	41.02	3.42	15.36	1.28
8	278	425	29.83	54.21	90	61.13	55.02	81,300	4,878.00	156.51	31.17	2.60	11.21	0.93
2023	174	180	7.91	19.20	88	46.82	41.20	28,800	1,728.00	66.29	26.07	2.17	14.98	1.25
4-B	165	230	9.58	21.27	88	51.18	45.04	31,900	1,914.00	81.02	23.62	1.97	14.32	1.19
4830	160	160	6.46	14.71	80	54.89	43.92	22,060	1,323.60	58.92	22.46	1.87	14.04	1.17
4-E	166	50	2.10	7.03	90	33.19	29.87	10,540	632.40	18.41	34.35	2.86	20.69	1.72
3739	177	220	9.83	27.65	90	39.50	35.55	41,480	2,488.80	81.02	30.72	2.56	17.36	1.45
3928	175	170	7.51	18.19	90	45.87	41.29	27,280	1,636.80	62.60	26.15	2.18	14.94	1.25
C-83	164	120	4.97	16.86	80	36.85	29.48	25,280	1,516.80	44.19	34.32	2.86	20.93	1.74
7012	158	100	3.99	15.71	80	31.75	25.40	23,560	1,413.60	36.83	38.38	3.20	24.29	2.02
6833	165	155	6.46	18.19	80	44.39	35.51	27,280	1,636.80	57.08	28.68	2.39	17.38	1.45
7015	261	110	7.25	14.11	80	64.23	51.38	21,160	1,269.60	40.51	31.34	2.61	12.01	1.00
4-A	187	195	9.21	19.75	80	58.29	46.63	29,620	1,777.20	71.81	24.75	2.06	13.24	1.10
4728	190	130	6.24	16.86	90	41.12	37.01	25,280	1,516.80	47.87	31.68	2.64	16.67	1.39

TABLE 8. (Continued) ENERGY EFFICIENCY DATA ON ELECTRIC WELLS - HIGH PLAINS UNDERGROUND WATER CONSERVATION DISTRICT NO. 1

Well No.	Total Lift	GPM	Water HP	Input HP	Motor Eff.	Pump Eff.	Overall Eff.	Annual (KWH) Consumption	Annual Fuel Cost	Ac. Ft. Pumped	Cost/ Ac. Ft.	Cost/ Ac. In.	Cost/Ac. Ft./ 100 Ft. Lift	Cost/Ac. In./ 100 Ft. Lift
2873	176	282	12.53	39.50	90	35.25	31.72	59,240	3,554.40	103.85	34.23	2.85	19.45	1.62
2872	200	237	11.97	51.20	90	25.98	23.38	76,800	4,608.00	87.28	52.80	4.40	26.40	2.20
2858	265	436	29.18	62.84	90	51.59	46.44	94,260	5,655.60	160.56	35.22	2.94	13.29	1.11
2871	225	656	37.27	69.12	90	59.90	53.90	74,540	4,472.40	241.58	18.51	1.54	8.23	0.69
1680	277	248	17.35	38.94	90	49.51	44.56	58,420	3,505.20	91.33	38.38	3.20	13.86	1.15
2870	164	305	12.63	51.20	90	27.41	24.67	76,800	4,608.00	112.32	41.02	3.42	25.01	2.08
900	103	356	9.26	32.15	90	32.00	28.80	48,220	2,893.20	131.10	22.07	1.84	21.43	1.79
2859	154	278	10.81	36.86	90	32.59	29.33	55,300	3,318.00	102.38	32.41	2.70	21.05	1.75
	283	130	9.29	31.73	90	32.53	29.28	47,600	2,856.00	47.87	59.66	4.97	21.08	1.76
50003	234	160	9.45	72.76	90	14.43	12.99	109,140	6,548.40	58.92	111.14	9.26	47.50	3.96
1410	240	760	46.06	86.40	90	59.23	53.31	129,600	7,776.00	279.88	27.78	2.32	11.58	0.96
	281	80	5.68	20.77	80	34.18	27.35	31,160	1,869.60	29.46	63.46	5.29	22.58	1.88
3200	253	230	14.69	25.13	90	64.95	58.46	37,700	2,262.00	84.70	26.71	2.23	10.56	0.88
2597	230	182	10.57	43.89	90	26.76	24.08	65,820	3,949.20	67.02	58.93	4.91	25.62	2.14
3010	246	200	12.42	48.51	90	28.45	25.60	72,760	4,365.60	73.65	59.27	4.94	24.09	2.01
876	302	83	6.33	20.18	90	34.86	31.37	30,280	1,816.80	30.57	59.43	4.95	19.68	1.64
3201	360	54	4.91	18.07	90	30.19	27.17	27,100	1,626.00	19.89	81.75	6.81	22.71	1.89
3214	170	200	8.59	23.83	88	40.96	36.05	35,760	2,145.60	73.65	29.13	2.43	17.14	1.43
50103	175	62	2.74	9.00	80	38.05	30.44	13,500	810.00	22.83	35.48	2.96	20.27	1.69
54	258	225	14.66	30.72	88	54.23	47.72	46,080	2,764.80	82.86	33.37	2.78	12.93	1.08
2622	181	185	8.46	23.04	88	41.73	36.72	34,560	2,073.60	68.13	30.44	2.54	16.82	1.40
4563	176	100	4.44	14.25	90	34.62	31.16	21,380	1,282.80	36.83	34.83	2.90	19.79	1.65
4585	302	840	64.06	125.67	91	56.02	50.97	188,500	11,310.00	309.34	36.56	3.05	12.11	1.01
4465	302	870	66.35	131.66	91	55.38	50.39	197,500	11,850.00	320.39	36.99	3.08	12.25	1.02
4437	314	620	49.16	98.74	90	55.32	49.79	98,320	5,899.00	228.33	25.84	2.15	8.23	0.69
4513	339	910	77.90	131.65	91	65.02	59.17	197,480	11,848.80	335.12	35.36	2.95	10.43	0.87
-	154	90	3.50	11.71	88	33.95	29.88	17,560	1,053.60	33.14	31.79	2.65	20.64	1.72
-	154	120	4.66	13.04	80	44.66	35.73	19,560	1,173.60	44.19	26.56	2.21	17.25	1.44
-	100	181	4.57	27.11	88	19.16	16.86	40,660	2,439.60	66.66	36.60	3.05	36.60	3.05
-	87	377	8.28	24.69	88	38.11	33.54	37,020	2,221.20	138.84	16.00	1.33	18.38	1.53
13	315	235	18.69	37.50	90	55.38	49.84	55,940	3,356.40	86.54	38.78	3.23	12.31	1.03
12	266	230	15.45	46.86	90	36.63	32.97	70,300	4,218.00	84.70	49.80	4.15	18.72	1.56
9	252	162	10.31	28.80	80	44.75	35.80	43,200	2,592.00	59.66	43.45	3.62	17.24	1.44
8	236	175	10.43	23.83	80	54.71	43.77	35,760	2,145.60	64.50	33.27	2.77	14.10	1.17
7	237	104	6.22	17.50	80	44.43	35.54	26,240	1,574.40	38.30	41.11	3.43	17.35	1.45
6	233	48	2.82	8.80	80	40.00	32.00	13,200	792.00	17.68	44.80	3.73	19.23	1.60
5	234	79	4.67	12.29	80	47.50	38.00	18,440	1,106.40	29.09	38.03	3.17	16.25	1.35

TABLE 8. (Continued) ENERGY EFFICIENCY DATA ON ELECTRIC WELLS - HIGH PLAINS UNDERGROUND WATER CONSERVATION DISTRICT NO. 1

Well No.	Total Lift	GPM	Water HP	Input HP	Motor Eff.	Pump Eff.	Overall Eff.	Annual (KWH) Consumption	Annual Fuel Cost	Ac. Ft. Pumped	Cost/ Ac. Ft.	Cost/ Ac. In.	Cost/Ac. Ft./ 100 Ft. Lift	Cost/Ac. In./ 100 Ft. Lift
1477	133	54	1.81	7.98	80	28.35	22.68	11,960	717.60	19.89	36.08	3.01	27.13	2.26
4	156	174	6.85	12.13	80	70.58	56.47	18,180	1,090.80	64.08	17.02	1.43	10.91	0.91
3	225	93	5.28	14.71	80	44.87	35.89	22,060	1,323.60	34.25	38.65	3.22	17.18	1.43
1	119	134	4.03	9.53	80	52.86	42.29	14,300	858.00	49.35	17.39	1.45	14.61	1.23
2	139	140	4.90	12.68	80	48.30	38.64	19,020	1,141.20	51.56	22.13	1.84	15.92	1.33
7115	396	50	5.00	18.19	80	34.36	27.48	27,280	1,636.80	18.41	88.91	7.41	22.45	1.87
5287	200	580	29.29	60.10	90	54.15	48.73	90,160	5,409.60	213.59	25.33	2.11	12.67	1.06
4113	182	390	17.92	58.82	90	33.85	30.47	88,240	5,294.40	143.62	36.86	3.07	20.25	1.69
4337	161	85	3.45	21.27	90	18.02	16.22	31,900	1,914.00	31.30	61.15	5.10	37.98	3.17
5424	150	135	5.11	23.04	90	24.63	22.17	34,560	2,073.60	49.72	41.71	3.48	27.81	2.32
3018	209	340	17.94	55.29	90	36.05	32.45	83,480	5,008.80	125.21	40.00	3.33	19.14	1.59
1-A	143	25	0.90	4.43	80	25.46	20.37	6,640	398.40	9.20	43.30	3.61	30.28	2.52
2-A	138	10	0.35	6.38	90	6.05	5.45	9,560	573.60	3.68	155.87	12.99	112.95	9.41
3-A	115	85	2.47	8.75	90	31.37	28.23	13,120	787.20	31.30	25.15	2.10	21.87	1.82
1-B	137	220	7.61	14.55	90	58.11	52.30	21,820	1,309.20	81.02	16.16	1.35	11.80	0.98
2-B	157	280	11.10	35.45	88	35.58	31.31	53,160	3,189.60	103.11	30.93	2.58	19.70	1.64
3-B	141	310	11.04	54.21	90	22.62	20.36	81,320	4,879.00	114.16	42.74	3.56	30.31	2.53
4-B	165	13	0.54	4.23	80	15.97	12.78	6,346	380.76	4.79	79.49	6.62	48.18	4.01
1-C	115	45	1.31	7.35	90	19.73	17.76	11,028	661.68	16.57	39.93	3.33	34.72	2.89
2-C	105	28	0.74	3.10	90	26.63	23.97	4,640	278.40	10.31	27.00	2.25	25.71	2.14
3-C	109	20	0.55	2.53	80	27.21	21.77	3,788	227.28	7.37	30.84	2.57	28.29	2.36
4-C	132	43	1.43	4.69	80	38.22	30.58	7,028	421.68	15.84	26.62	2.22	20.17	1.68
5-C	131	68	2.25	13.55	90	18.43	16.59	20,320	1,219.20	25.04	48.69	4.06	37.17	3.10
6-C	129	165	5.38	24.66	90	24.21	21.79	36,992	2,219.52	60.76	36.53	3.04	28.32	2.36
7-C	126	125	3.98	7.90	80	62.98	50.38	11,840	710.40	46.03	15.43	1.29	12.25	1.02
1-D	134	65	2.20	7.20	80	38.19	30.56	10,800	648.00	23.94	27.07	2.26	20.20	1.68
2-D	138	225	7.84	19.75	80	49.62	39.70	29,620	1,777.20	82.86	21.45	1.79	15.54	1.30
3-D	178	450	20.23	41.27	80	61.27	49.02	61,900	3,714.00	165.72	22.41	1.87	12.59	1.05
4-D	176	165	7.33	13.96	80	65.61	52.49	20,942	1,256.52	60.76	20.68	1.72	11.75	0.98
5-D	217	130	7.12	20.94	80	42.50	34.00	31,400	1,884.00	47.87	39.36	3.28	18.14	1.51
6-D	208	135	7.09	23.04	80	38.37	30.70	34,560	2,073.60	49.72	41.71	3.48	20.05	1.67
7-D	142	400	14.34	47.66	90	33.42	30.08	71,500	4,290.00	147.31	29.12	2.43	20.51	1.71
8-D	120	240	7.27	33.72	80	26.96	21.57	50,574	3,034.44	88.38	34.33	2.86	28.61	2.38
40012	141	125	4.45	19.20	80	28.97	23.18	28,800	1,728.00	46.03	37.54	3.13	26.62	2.22
50037	201	40	2.03	5.92	80	42.86	34.29	8,880	532.80	14.73	36.17	3.01	18.00	1.50
272	178	75	3.37	11.92	80	35.34	28.27	17,880	1,072.80	27.62	38.84	3.24	21.82	1.82
245	181	105	4.80	18.19	80	32.99	26.39	27,280	1,636.80	38.67	42.33	3.53	23.39	1.95

TABLE 8. (Continued) ENERGY EFFICIENCY DATA ON ELECTRIC WELLS - HIGH PLAINS UNDERGROUND WATER CONSERVATION DISTRICT NO. 1

Well No.	Total Lift	GPM	Water HP	Input HP	Motor Eff.	Pump Eff.	Overall Eff.	Annual (Kwh) Consumption	Annual Fuel Cost	Ac. Ft. Pumped	Cost/ Ac. Ft.	Cost/ Ac. In.	Cost/Ac. Ft./ 100 Ft. Lift	Cost/Ac. In./ 100 Ft. Lift
50034	123	70	2.17	8.53	80	31.80	25.44	12,800	768.00	25.78	29.79	2.48	24.22	2.02
260	148	110	4.11	7.47	80	68.78	55.02	11,200	672.00	40.51	16.59	1.38	11.21	0.93
50035	136	50	1.72	3.58	80	60.00	48.03	5,360	321.60	18.41	17.47	1.46	12.85	1.07
40013	134	80	2.70	10.16	90	29.54	26.58	15,240	914.40	29.46	31.04	2.59	23.16	1.93
259	136	90	3.09	6.01	80	64.27	51.41	9,020	541.20	33.14	16.33	1.36	12.01	1.00
780	200	530	26.77	78.99	90	37.66	33.89	118,480	7,108.80	195.18	36.42	3.04	18.21	1.52
3322	173	610	26.65	60.10	90	49.27	44.34	90,180	5,410.80	224.64	24.09	2.01	13.92	1.16
633	150	88	3.33	12.02	88	31.48	27.70	18,040	1,082.40	32.41	33.41	2.78	22.27	1.86
1069	172	220	9.56	36.38	88	29.86	26.28	54,560	3,273.60	81.02	40.41	3.37	23.49	1.96
3865	159	268	10.76	27.28	88	44.82	39.44	40,920	2,455.20	98.70	24.88	2.07	15.65	1.30
43986	159	300	12.05	43.20	88	31.70	27.89	64,800	2,592.00	110.48	35.19	2.93	22.13	1.84
7117	148	150	5.60	9.87	80	70.90	56.74	14,800	888.00	55.24	16.08	1.34	10.86	0.91
1	162	133	5.44	12.57	90	48.09	43.28	18,860	1,131.60	48.98	23.10	1.93	14.26	1.19
2197	171	163	7.04	13.42	90	58.29	52.46	20,140	1,208.40	60.03	20.13	1.68	11.77	0.98
3	144	100	3.64	10.15	80	44.83	35.86	15,220	913.20	39.63	23.04	1.92	16.00	1.33
4	203	130	6.66	22.30	88	33.94	29.87	33,440	2,006.40	47.87	41.91	3.49	20.65	1.72
4766	164	122	5.05	19.20	90	29.20	26.30	28,800	1,248.00	44.93	38.46	3.21	23.45	1.95
M-2	185	83	3.88	17.50	90	24.60	22.20	26,240	1,574.40	30.57	51.50	4.29	27.84	2.32
M-3	150	95	3.60	19.30	88	21.19	18.65	29,000	1,740.00	34.99	49.73	4.14	33.15	2.76
1325	104	236	6.20	12.90	88	53.40	48.10	19,380	1,162.80	86.91	13.38	1.11	12.87	1.07
TOTAL	31082	35698	1907.97	4798.80	14521	6878.66	5929.37	7,057,540	425,564.00	14,257.83	6029.91	502.54	3440.74	286.74
Average	185.01	212.49	11.36	28.56	86.43	40.94	35.29	42,009.17	2,533.12	84.87	35.89	2.99	20.48	1.71

TABLE 9

Summary of Pump Efficiencies of Electric Wells

Pumps	Performance Level Rating
One (1)	tested less than 10 percent efficient
11 or 15.27 percent	ranged between 10 and 20 percent
25 or 14.88 percent	ranged between 20 and 30 percent
47 or 27.98 percent	ranged between 30 and 40 percent
37 or 22.02 percent	ranged between 40 and 50 percent
28 or 16.67 percent	ranged between 50 and 60 percent
17 or 10.12 percent	ranged between 60 and 70 percent
Two (2)	tested over 70 percent

NATURAL GAS UNITS

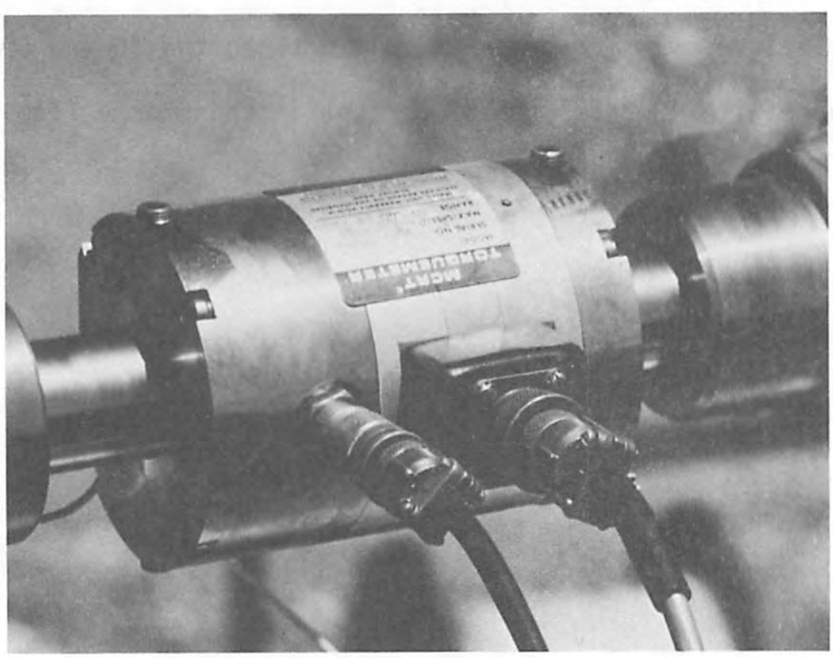
The High Plains Underground Water Conservation District No. 1 report on natural gas pumping plants (Table 10) reveal the average overall efficiency at 9.44 percent, and shows the engine efficiency at 20.47 percent and the pump efficiency at 45.79 percent (Table 10).

An average cost of water pumped was $30.29 per acre-foot and $2.52 per acre-inch. The cost for an acre-foot of water pumped per foot of lift was $0.14. It takes $2.28 per hour to operate these pumping plants.

The natural gas units tested by the District had an average pumping lift of 226 feet and produced 515 GPM. These pumping plants have greater lifts and production than the electric powered plants tested by the District. This follows the same pattern as those tested by the Soil Conservation Service and the Texas Agriculture Extension Service.

Only 16 units, or less than 18 percent of those tested, were above 60 percent pump efficiency. The majority fell between the 40 and 60 percent efficiency range with 49 tests, or 53 percent in this range (Table 11).

Dan Seale is checking the efficiency of a pumping plant.



The torquemeter is in the drive shaft between the engine and gearhead. It measures the brake horsepower.

TABLE 10. ENERGY EFFICIENCY DATA ON NATURAL GAS WELLS - HIGH PLAINS UNDERGROUND WATER CONSERVATION NO. 1

Well No.	Total Lift	GPM	Water HP	Input HP	Brake HP	Motor Eff.	Pump Eff.	Overall Eff.	Annual (MCF) Consumption	Annual Fuel Cost	Ac. Ft. Pumped	Cost/ Ac. Ft.	Cost/ Ac. In.	Cost/Ac. Ft./ 100 Ft. Lift	Cost/Ac. In./ 100 Ft. Lift
2880	175	284	12.55	150.47	23.7	15.75	52.95	8.34	766.0	2,298.00	104.59	21.97	1.83	12.55	1.05
2879	180	73	3.32	108.84	16.2	14.88	20.48	3.04	554.0	1,662.00	26.88	61.83	5.15	34.35	2.86
C266	171	175	7.55	124.07	18.8	15.15	40.15	6.08	632.0	1,896.00	64.45	29.42	2.45	17.20	1.43
C270	163	349	14.37	178.00	34.3	19.26	41.88	8.07	906.0	2,718.00	128.53	21.15	1.76	12.96	1.08
2851	155	189	7.40	103.33	14.3	13.83	51.72	7.15	526.0	1,578.00	69.60	22.67	1.89	14.63	1.22
C400	162	276	11.29	133.59	23.2	17.36	48.66	8.45	680.0	2,040.00	101.64	20.07	1.67	12.39	1.03
2878	173	174	7.60	105.69	27.5	26.00	27.63	7.19	538.0	1,614.00	64.08	25.19	2.10	14.56	1.21
C299	166	247	10.35	148.13	26.5	17.88	39.00	6.98	754.0	2,262.00	90.96	24.87	2.07	14.98	1.25
969	173	218	9.52	112.77	20.6	18.26	46.30	8.44	574.0	1,722.00	80.28	21.45	1.79	12.40	1.03
2852	156	116	4.57	113.94	19.0	16.67	24.04	4.01	580.0	1,740.00	42.72	40.73	3.39	26.11	2.18
40014	244	740	45.60	363.00	80.4	22.15	56.72	12.56	1846.0	5,538.00	272.52	20.32	1.69	8.33	0.69
2365	259	820	53.63	429.00	94.0	21.90	57.05	12.50	2182.0	6,546.00	301.98	21.68	1.81	8.37	0.70
875	252	40	2.55	208.00	31.0	14.90	8.23	1.22	1058.8	3,176.40	14.73	215.64	17.97	85.57	7.13
2768	272	107	7.35	170.40	31.0	18.19	23.70	4.30	867.4	2,602.20	39.40	66.04	5.50	24.78	2.02
2528	224	68	3.85	144.30	24.0	16.63	16.04	2.67	734.6	2,203.80	25.04	88.01	7.33	39.29	3.27
2278	304	1060	81.37	589.39	141.0	23.92	57.71	13.81	3000.0	9,000.00	390.36	23.06	1.92	7.59	0.63
1999	310	1140	89.24	565.82	147.0	25.98	60.71	15.77	2880.0	8,640.00	419.82	20.58	1.72	6.64	0.55
40066	225	770	43.75	363.00	81.0	22.31	54.01	12.05	1846.0	5,538.00	283.57	19.53	1.63	8.68	0.72
4666	320	810	65.45	505.00	95.0	18.81	68.89	12.96	2572.0	7,716.00	298.30	25.87	2.16	8.08	0.67
398	298	770	57.94	416.00	100.0	24.04	57.94	13.93	2118.0	6,354.00	283.57	22.41	1.87	7.52	0.63
118	193	380	18.52	191.00	38.5	20.16	48.10	9.70	973.0	2,919.00	139.94	20.86	1.74	10.81	0.90
2136	190	410	19.67	189.00	44.0	23.28	44.70	10.41	964.0	2,892.00	150.99	19.15	1.60	10.08	0.84
3552	183	185	8.55	224.00	38.0	16.96	22.50	3.82	1142.0	3,426.00	68.13	50.29	4.19	27.48	2.29
5519	195	75	3.69	163.00	21.3	13.07	17.32	2.26	828.0	2,484.00	27.62	89.93	7.49	46.12	3.84
3379	187	135	6.38	177.00	33.0	18.64	19.33	3.60	900.0	2,700.00	49.72	54.30	4.52	29.04	2.42
1365	125	630	19.88	214.00	38.8	18.13	51.23	9.28	1090.0	3,270.00	232.01	14.09	1.17	11.27	0.94
540	105	750	19.89	221.00	38.0	17.19	52.34	9.00	1125.0	3,375.00	276.20	12.22	1.02	11.64	0.97
1695	389	480	47.15	336.79	79.0	23.46	59.68	14.00	1714.0	5,142.00	176.77	29.09	2.42	7.48	0.62
3	204	167	8.60	147.00	27.0	18.37	31.85	5.90	750.0	2,250.00	61.50	36.59	3.05	17.94	1.49
10	348	240	21.09	138.00	38.5	27.90	54.78	15.28	702.8	2,108.40	88.38	23.86	1.99	6.86	0.57
11	344	210	18.24	153.00	40.1	26.20	45.49	11.92	778.0	2,334.00	77.34	30.18	2.51	8.77	0.73
600	333	810	68.11	416.00	106.0	25.48	64.25	16.37	2118.0	6,354.00	298.30	21.30	1.78	6.40	0.53
4662	310	1225	95.90	882.00	169.0	19.10	56.75	10.87	3348.0	10,044.00	451.13	22.26	1.86	7.18	0.60
2316	160	830	33.53	424.36	79.6	18.76	42.12	7.90	2160.0	6,480.00	305.66	21.20	1.77	13.25	1.10
2650	186	870	40.86	427.50	100.0	23.39	40.86	9.55	2176.0	6,528.00	320.39	20.38	1.70	10.96	0.91
42217	202	325	16.58	334.00	52.50	15.70	31.58	4.96	1700.0	5,100.00	119.69	42.61	3.55	21.09	1.76

TABLE 10. (Continued) ENERGY EFFICIENCY DATA ON NATURAL GAS WELLS - HIGH PLAINS UNDERGROUND WATER CONSERVATION NO. 1

Well No.	Total Lift	GPM	Water HP	Input HP	Brake HP	Motor Eff.	Pump Eff.	Overall Eff.	Annual (MCF) Consumption	Annual Fuel Cost	Ac. Ft. Pumped	Cost/ Ac. Ft.	Cost/ Ac. In.	Cost/Ac. Ft./ 100 Ft. Lift	Cost/Ac. In./ 100 Ft. Lift
1	225	415	23.60	301.00	79.5	26.70	29.69	7.84	1532.0	4,596.00	152.83	30.07	2.51	13.36	1.11
2366	230	830	48.21	354.00	80.3	22.68	60.00	13.62	1800.0	5,400.00	305.66	17.67	1.47	7.68	0.64
40013	220	720	40.00	488.00	72.5	14.86	55.17	8.20	2482.0	7,446.00	265.15	28.08	2.34	12.76	1.06
1039	222	815	45.69	442.00	93.0	21.00	49.13	10.34	2250.0	6,750.00	300.14	22.49	1.87	10.13	0.84
32	228	725	41.74	301.00	75.0	24.92	55.65	13.87	1532.0	4,596.00	266.99	17.21	1.43	7.55	0.63
2361	201	800	40.61	404.00	92.5	22.90	43.90	10.05	2058.0	6,174.00	294.61	20.96	1.75	10.43	0.87
40126	212	890	47.65	429.00	101.0	23.54	47.18	11.11	2182.0	6,546.00	327.76	19.97	1.66	9.42	0.78
1395	239	530	31.99	393.00	78.8	20.05	40.60	8.14	2000.0	6,000.00	195.18	30.74	2.56	12.86	1.07
40124	238	960	57.70	442.00	81.2	18.37	71.10	13.05	2250.0	6,750.00	353.54	19.09	1.59	8.02	0.67
6572	161	70	2.85	85.26	12.3	14.42	23.13	3.33	434.0	1,302.00	25.78	50.50	4.21	31.37	2.61
2	281	510	36.19	307.50	56.2	18.27	64.39	11.76	1565.2	4,695.60	187.82	25.00	2.08	8.90	0.74
1	277	610	42.66	363.00	58.0	15.97	73.55	11.75	1846.0	5,538.00	224.64	24.65	2.05	8.90	0.74
4	185	740	34.57	456.00	80.0	17.54	43.21	7.58	2322.0	6,966.00	272.52	25.56	2.13	13.82	1.15
5	165	215	8.96	154.00	24.3	15.78	36.87	5.82	782.0	2,346.00	79.18	29.63	2.47	17.96	1.50
6	330	460	38.33	308.00	61.5	19.80	62.32	12.44	1566.0	4,698.00	169.40	27.73	2.31	8.40	0.70
7	307	470	36.43	283.00	70.0	24.73	52.04	12.87	1440.0	4,320.00	173.09	24.96	2.08	8.13	0.68
12	192	240	11.63	141.00	24.5	17.37	47.47	8.24	720.0	2,160.00	88.38	24.44	2.04	12.73	1.06
3	284	520	37.29	228.29	51.2	22.42	72.83	16.33	1162.0	3,486.00	191.50	18.20	1.52	6.41	0.53
4093	252	680	43.27	308.00	87.2	28.31	49.62	14.04	1566.0	4,698.00	250.42	18.76	1.56	7.44	0.62
1001	261	470	30.98	363.00	87.0	23.96	35.61	8.53	1850.0	5,550.00	173.09	32.06	2.67	12.28	1.02
3508	265	410	27.43	261.00	53.0	20.30	51.75	10.50	1328.0	3,984.00	150.99	26.39	2.20	9.96	0.83
1705	265	675	45.17	472.00	105.7	22.39	42.73	9.57	2400.0	7,200.00	248.58	28.96	2.41	10.93	0.91
2419	258	430	28.02	448.00	65.0	14.51	43.10	6.25	2280.0	6,840.00	158.35	43.19	3.60	16.74	1.40
3560	230	370	21.49	307.70	83.3	27.07	25.80	7.00	1566.0	4,698.00	136.26	34.48	2.87	14.99	1.25
2773	227	1020	58.47	405.89	88.0	21.68	66.44	14.40	2066.0	6,198.00	375.63	16.50	1.38	7.27	0.61
1129	232	880	51.55	446.36	83.2	18.63	61.95	11.54	2272.0	6,816.00	324.07	21.03	1.75	9.06	0.76
40163	230	315	18.29	365.42	75.0	20.52	24.38	5.00	1860.0	5,580.00	116.00	48.10	4.01	20.91	1.74
3401	237	880	52.66	458.54	89.0	19.40	59.16	11.48	2334.0	7,002.00	324.07	21.61	1.80	9.12	0.76
1800	208	660	34.67	345.00	76.0	22.03	45.62	10.05	1756.0	5,268.00	243.06	21.67	1.81	10.42	0.87
1037	212	750	40.15	449.00	83.5	18.60	48.08	8.90	2286.0	6,858.00	276.20	24.83	2.07	11.71	0.98
1	193	719	35.00	257.17	78.0	30.33	44.80	13.60	1309.0	3,927.00	264.78	14.83	1.24	7.68	0.64
2	146	355	13.08	176.80	49.0	27.71	26.69	7.40	900.0	2,700.00	130.73	20.65	1.72	14.14	1.18
2835	235	950	56.37	442.00	111.0	25.11	50.78	12.75	2250.0	6,750.00	349.85	19.29	1.61	8.21	0.68
3541	230	490	28.46	470.33	102.0	21.68	27.90	6.05	2394.0	7,182.00	180.45	39.80	3.32	17.30	1.44
3017	171	350	15.11	226.00	54.2	23.98	27.87	6.68	1154.0	3,462.00	128.89	26.86	2.24	15.71	1.31
5043	165	590	24.58	211.00	44.6	21.14	55.11	11.65	1074.0	3,222.00	217.28	14.83	1.24	8.99	0.75
413	193	500	24.37	215.00	48.5	22.56	50.25	11.33	1093.0	3,279.00	184.13	17.81	1.48	9.23	0.77
2446	256	585	37.82	314.34	54.4	17.31	69.52	12.03	1600.0	4,800.00	215.44	22.28	1.86	8.70	0.73

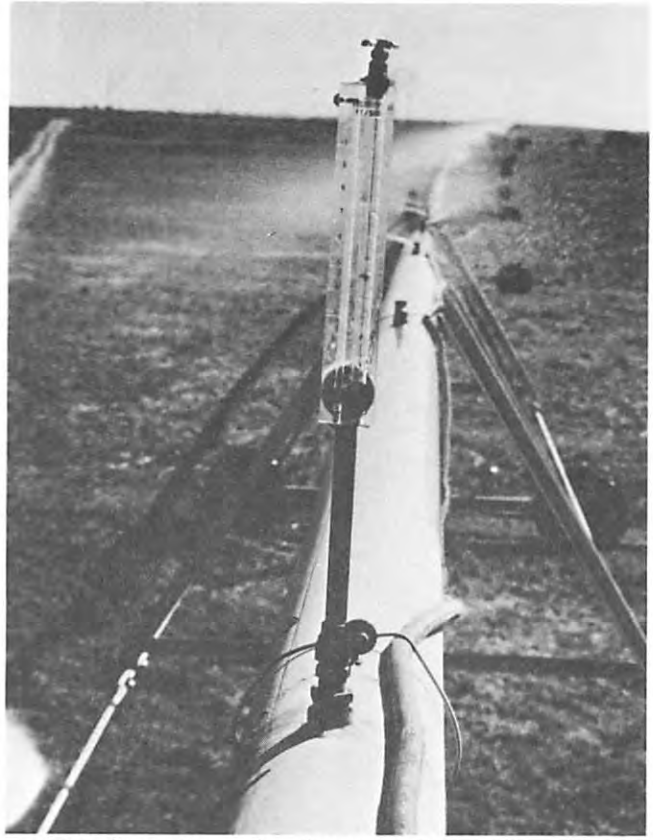
TABLE 10. (Continued) ENERGY EFFICIENCY DATA ON NATURAL GAS WELLS - HIGH PLAINS UNDERGROUND WATER CONSERVATION NO. 1

Well No.	Total Lift	GPM	Water HP	Input HP	Brake HP	Engine Eff.	Pump Eff.	Overall Eff.	Annual (MCF) Consumption	Annual Fuel Cost	Ac. Ft. Pumped	Cost/ Ac. Ft.	Cost/ Ac. In.	Cost/ Ac. Ft./100 Ft. Lift	Cost/ Ac. In./100 Ft. Lift
5583	280	250	17.68	302.0	43	14.20	41.10	5.85	1538.4	4615.20	92.10	50.10	4.18	17.89	1.49
5272	320	497	40.16	351.7	72	20.40	55.78	11.42	1790.0	4475.00	183.00	29.34	2.45	9.17	0.76
1481	255	484	31.17	298.8	63	21.10	49.52	10.44	1521.0	4563.00	178.24	25.59	2.13	10.04	0.84
40102	185	195	9.11	151.0	21	13.90	43.38	6.00	770.0	2310.00	71.81	32.19	2.68	17.40	1.45
41273	165	530	22.10	292.0	46	15.75	48.00	7.57	1488.0	4464.00	195.18	22.86	1.91	13.85	1.15
1131	248	460	28.80	262.5	46	17.50	62.60	10.97	1336.0	4008.00	169.4	23.67	1.97	9.54	0.80
3214	244	265	41.60	372.0	112	30.10	37.14	11.18	1894.0	5682.00	248.57	22.86	1.90	9.37	0.78
1614	247	526	32.80	377.0	111	29.44	29.50	8.70	1920.0	5760.00	193.70	29.74	2.48	12.04	1.00
4317	255	480	30.90	430.64	88	20.43	35.11	7.17	2192.0	6576.00	176.77	37.20	3.10	14.59	1.22
3229	232	635	37.20	321.0	70.3	21.90	52.91	11.58	1636.0	4908.00	233.85	20.99	1.75	9.05	0.75
3840	289	750	54.73	376.0	84	22.34	65.15	14.55	1916.0	5748.00	276.20	20.81	1.73	7.20	0.60
40224	226	770	43.94	301.0	70.3	23.35	62.50	14.59	1532.0	4596.00	283.57	16.21	1.35	7.17	0.60
3397	233	820	48.24	442.00	84.2	19.05	57.29	10.91	2250.0	6750.00	301.98	22.35	1.86	9.59	0.80
3892	318	816	65.52	436.00	94.0	21.56	69.70	15.02	2222.0	6666.00	300.51	22.18	1.85	6.97	0.58
40002	165	115	4.79	108.81	18.8	17.28	25.49	4.40	553.84	1661.52	42.35	39.23	3.27	23.77	1.98
320	172	160	6.95	126.30	16.8	13.30	41.36	5.14	642.86	1928.58	58.92	32.73	2.73	19.03	1.59
40003	155	240	9.39	133.40	30.0	22.49	31.31	7.04	679.24	2037.72	88.38	23.06	1.92	14.88	1.24
226	151	205	7.82	117.88	23.8	20.19	32.84	6.63	600.00	1800.00	75.49	23.84	1.99	15.79	1.32
TOTAL	20836	47355	2831.83	27693.02	5723.40	1883.48	4212.76	868.59	139,826.14	418583.42	17,349.11	2786.63	232.22	1290.31	107.44
Average	226.48	514.73	30.78	301.01	62.21	20.47	45.79	9.44	1519.85	4549.82	188.58	30.29	2.52	14.03	1.17

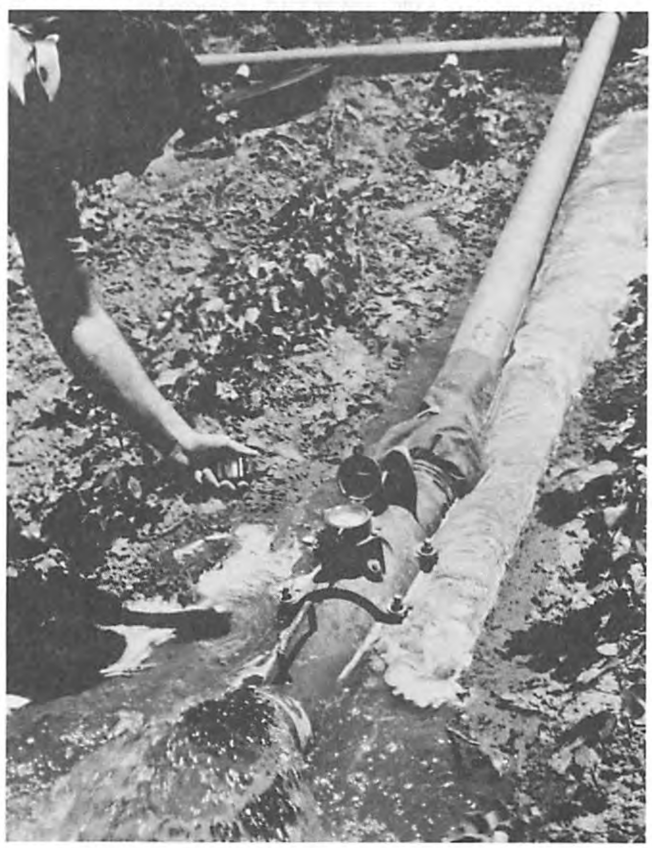
TABLE 11

Summary of Pump Efficiencies of Natural Gas Wells

Pumps	Performance Level Rating
One (1)	tested less than 10 percent efficie
3 or 3.26 percent	ranged between 10 and 20 percent
14 or 15.22 percent	ranged between 20 and 30 percent
9 or 9.78 percent	ranged between 30 and 40 percent
26 or 28.26 percent	ranged between 40 and 50 percent
23 or 25.00 percent	ranged between 50 and 60 percent
13 or 14.13 percent	ranged between 60 and 70 percent
3 or 3.26 percent	ranged between 70 and 80 percent



The Cox Velocity Gage is inserted in the first nozzle opening to meter water on a center pivot sprinkler.



Ken Carver is metering water with a flow meter.

THE ELECTRIC COOPERATIVE'S IRRIGATION PUMPING PLANT TESTING PROGRAM

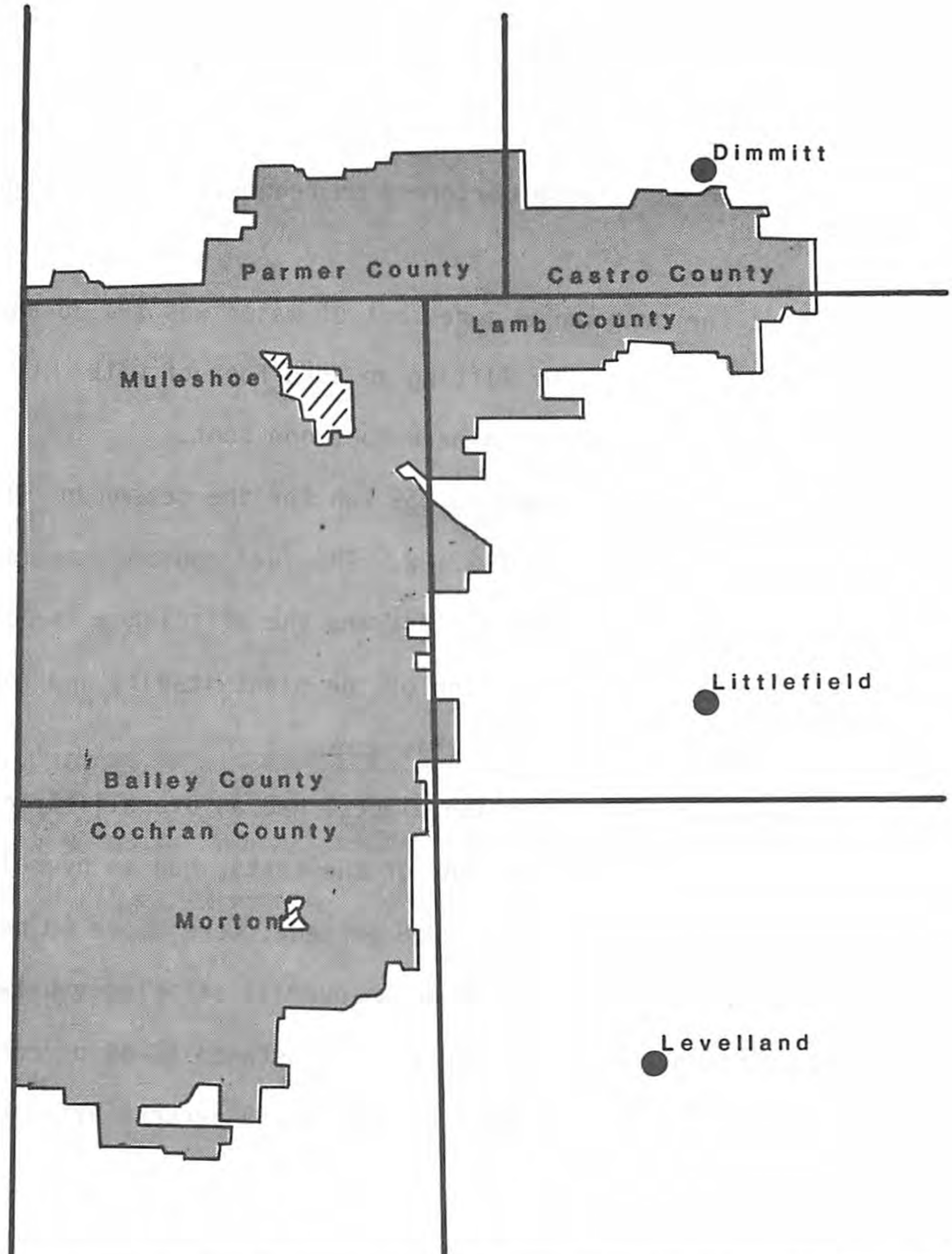


Figure 4. **Service Area Of Bailey County Electric Cooperative Assn. Texas 62 Bailey**

BAILEY COUNTY ELECTRIC COOPERATIVE

The Bailey County Electric Cooperative Association reports the average overall efficiency of pumping plants tested in their service area was 43.2 percent (Table 12). The tests were performed on requests from the owners or operators.

The average cost for pumping an acre-foot of water was $31.35 and $2.61 per acre-inch. The average cost of lifting an acre-foot of water 100 feet was $17.08 (Table 12), or $0.17 to lift an acre-foot one foot.

The average fuel consumption was 76,059 kwh for the season or 38 kwh per hour, resulting in a cost per hour of $2.28. The fuel consumption is determined by the efficiency of the pumping plant and the efficiency is determined by the total head or lift, the production of the plant itself, and the amount of energy the pumping plant uses to do this work.

Four, or 6.2 percent of the pumping plants, had an overall efficiency below 20 percent. Seven, or 10.8 percent of the tests, had an overall efficiency between 20-29 percent and 7, or 10.8 percent, were above 60 percent. Fifteen, or 23.1 percent of the tests, had an overall efficiency between 30 and 39 percent. Eighteen, or 27.7 percent, fell between 40-49 percent efficient. Fourteen, or 21.5 percent, were between 50-59 percent efficient.

TABLE 12. Bailey County Electric Cooperative Association

ENERGY EFFICIENCY DATA ON ELECTRIC WELLS

Total Lift	GPM	Water HP	Input HP	Overall Eff.	Annual (KWH) Consumption	Annual Fuel Cost	Ac. Ft. Pumped	Cost/ Ac. Ft.	Cost/ Ac. In.	Cost/Ac. Ft./100 Ft. Lift	Cost/Ac. In./100 Ft. Lift
121	1,100	33.61	100.90	33.28	150,692	9,041.52	405.09	22.32	1.86	18.45	1.54
175	500	22.09	52.93	41.73	79,000	4,740.00	184.13	25.74	2.15	14.71	1.23
119	700	21.03	57.34	36.68	85,580	5,134.80	257.89	19.91	1.66	16.73	1.39
124	630	19.73	51.59	38.24	77,000	4,620.00	232.01	19.91	1.66	16.06	1.34
120	850	29.75	59.22	50.24	88,380	5,302.80	313.03	16.94	1.41	14.12	1.18
160	500	22.20	58.26	34.67	86,960	5,217.60	184.13	28.34	2.36	17.71	1.48
195	130	6.40	14.88	43.01	22,220	1,333.20	47.87	27.85	2.32	14.28	1.19
140	200	7.07	12.63	55.98	18,850	1,131.00	73.65	15.36	1.28	10.97	0.91
226	395	22.54	45.18	49.89	67,440	4,046.40	145.47	27.82	2.32	12.31	1.03
284	60	4.30	16.84	25.53	25,120	1,507.20	22.10	68.20	5.68	24.01	2.00
186	210	9.86	32.53	30.31	48,560	2,913.60	77.34	37.67	3.14	20.25	1.69
260	700	45.96	74.68	61.54	111,420	6,685.20	257.89	25.92	2.16	9.97	0.83
279	1,040	73.27	94.11	77.86	140,460	8,427.60	383.00	22.00	1.83	7.89	0.66
198	425	21.25	35.85	59.27	53,520	3,211.20	156.51	20.52	1.71	10.36	0.86
173	425	18.57	37.49	49.53	55,960	3,357.60	156.51	21.45	1.79	12.40	1.03
173	1,000	43.69	69.46	62.90	103,680	6,220.80	368.27	16.89	1.41	9.76	0.81
301	350	26.60	46.30	57.45	69,120	4,147.20	128.89	32.18	2.68	10.69	0.89
170	400	17.17	60.20	28.52	89,800	5,388.00	147.31	36.58	3.05	21.52	1.79
240	575	34.85	65.12	53.52	97,200	5,832.00	211.75	27.54	2.30	11.48	0.96
253	285	18.20	39.10	46.55	58,320	3,499.20	104.96	33.34	2.78	13.18	1.10
137	475	16.43	59.22	27.74	88,380	5,302.80	174.93	30.31	2.53	22.12	1.84
254	730	46.82	80.67	58.04	120,400	7,224.00	268.83	26.87	2.24	10.58	0.88
202	500	25.51	54.66	46.67	81,580	4,894.80	184.13	26.58	2.22	13.16	1.10
272	600	41.20	57.79	71.29	86,260	5,175.60	220.95	23.42	1.95	8.61	0.72
157	275	10.90	36.40	29.95	54,400	3,264.00	101.27	32.23	2.69	20.53	1.71
169	310	13.23	32.41	40.82	48,380	2,902.80	114.16	25.43	2.12	15.05	1.25
175	580	25.63	42.75	59.95	63,800	3,828.00	213.59	17.92	1.49	10.24	0.85
150	320	12.12	34.95	34.68	52,160	3,129.60	117.85	26.56	2.21	17.71	1.48
194	150	7.35	26.25	28.00	39,180	2,350.80	55.24	42.56	3.55	21.94	1.83
168	700	28.30	44.80	63.17	66,800	4,008.00	257.89	15.54	1.30	9.25	0.77
173	570	23.70	48.50	48.87	72,400	4,344.00	209.91	20.69	1.72	11.96	1.00
113	94	2.64	44.82	5.89	66,900	4,014.00	34.62	115.94	9.66	102.60	8.55
220	285	15.80	50.95	31.01	76,040	4,562.40	104.96	43.47	3.62	19.76	1.65
181	700	32.00	58.30	54.89	87,000	5,220.00	257.89	20.24	1.69	11.18	0.93
133	250	8.40	17.50	48.00	26,120	1,567.20	92.07	17.02	1.42	12.80	1.07
153	260	10.05	24.50	41.02	36,600	2,196.00	95.75	22.93	1.91	14.99	1.25
155	215	8.40	26.90	31.23	40,140	2,408.40	79.18	30.42	2.53	19.63	1.64

TABLE 12. (Continued) ENERGY EFFICIENCY DATA ON ELECTRIC WELLS

	Total Lift	GPM	Water HP	Input HP	Overall Eff.	Annual (KWH) Consumption	Annual Fuel Cost	Ac. Ft. Pumped	Cost/ Ac. Ft.	Cost/ Ac. In.	Cost/Ac. Ft./100 Ft. Lift	Cost/Ac. In./100 Ft. Lift
	156	210	8.30	17.40	47.70	25,920	1,555.20	77.34	20.11	1.68	12.89	1.07
	200	200	10.10	37.49	26.94	55,960	3,357.60	73.65	45.59	3.80	22.80	1.90
	190	200	9.60	31.12	30.84	46,440	2,786.40	73.65	37.83	3.15	19.91	1.66
	273	550	37.92	68.34	55.48	102,000	6,120.00	202.55	30.21	2.52	11.07	0.92
	123	310	9.63	22.78	42.27	33,980	2,038.80	114.16	17.86	1.49	14.52	1.21
	126	380	12.90	24.52	52.61	36,600	2,196.00	139.94	15.69	1.31	12.45	1.04
	279	730	51.43	120.40	42.72	179,720	10.783.20	268.83	40.11	3.34	14.38	1.20
	116	100	2.93	16.80	17.44	25,080	1,504.80	36.83	40.86	3.40	35.22	2.94
	175	170	7.50	29.60	25.34	44,200	2,652.00	62.61	42.36	3.53	24.21	2.02
	130	360	11.80	27.80	42.45	41,400	2,484.00	132.58	18.74	1.56	14.42	1.20
	227	300	17.20	45.55	37.76	67,980	4,078.80	110.48	36.92	3.08	16.26	1.36
	120	290	8.80	28.70	30.66	42,900	2,574.00	106.80	24.10	2.01	20.08	1.67
	141	170	6.05	15.44	39.18	23,040	1,382.40	62.61	22.08	1.84	15.66	1.30
	137	150	5.19	14.60	35.55	21,800	1,308.00	55.24	23.68	1.97	17.28	1.44
	220	247	13.70	31.90	42.95	47,600	2,856.00	90.96	31.40	2.62	14.27	1.19
	225	600	34.09	53.77	63.40	80,260	4,815.60	220.96	21.79	1.82	9.68	0.81
	222	400	22.42	54.16	41.40	80,840	4,850.40	147.30	32.93	2.74	14.83	1.24
	209	365	19.26	47.76	40.33	71,280	4,276.80	134.42	31.82	2.65	15.22	1.27
	265	900	60.23	104.76	57.49	156,360	9,381.60	331.44	28.31	2.36	10.68	0.89
	324	740	60.55	101.90	59.42	152,060	9,123.60	272.52	33.48	2.79	10.33	0.86
	165	300	12.50	83.36	15.00	120,420	7,225.20	110.48	65.40	5.45	39.64	3.30
	281	820	58.19	112.04	51.94	167,220	10,033.20	301.98	33.22	2.77	11.82	0.99
	280	660	46.67	101.88	45.81	152,060	9,123.60	243.06	37.54	3.13	13.41	1.12
	345	840	73.18	116.52	62.80	173,920	10,435.20	309.34	33.73	2.81	9.78	0.81
	348	800	70.30	118.43	59.35	176,760	10,605.60	294.60	36.00	3.00	10.34	0.86
	226	100	5.70	29.21	19.51	43,600	2,616.00	36.83	71.03	5.92	31.43	2.62
	149	320	12.04	36.44	33.04	54,380	3,262.80	117.85	27.69	2.31	18.58	1.55
	264	260	17.33	56.44	30.71	84,240	5,054.40	95.75	52.79	4.40	20.00	1.67
TOTAL	12,819	28,961	1,550.13	3,315.09	2,808.01	4,943,842	296,630.52	10,665.78	2,037.88	169.85	1,110.12	92.54
AVERAGE	197.22	445.55	23.85	51.00	43.20	76,059.11	4,563.55	164.09	31.35	2.61	17.08	1.42

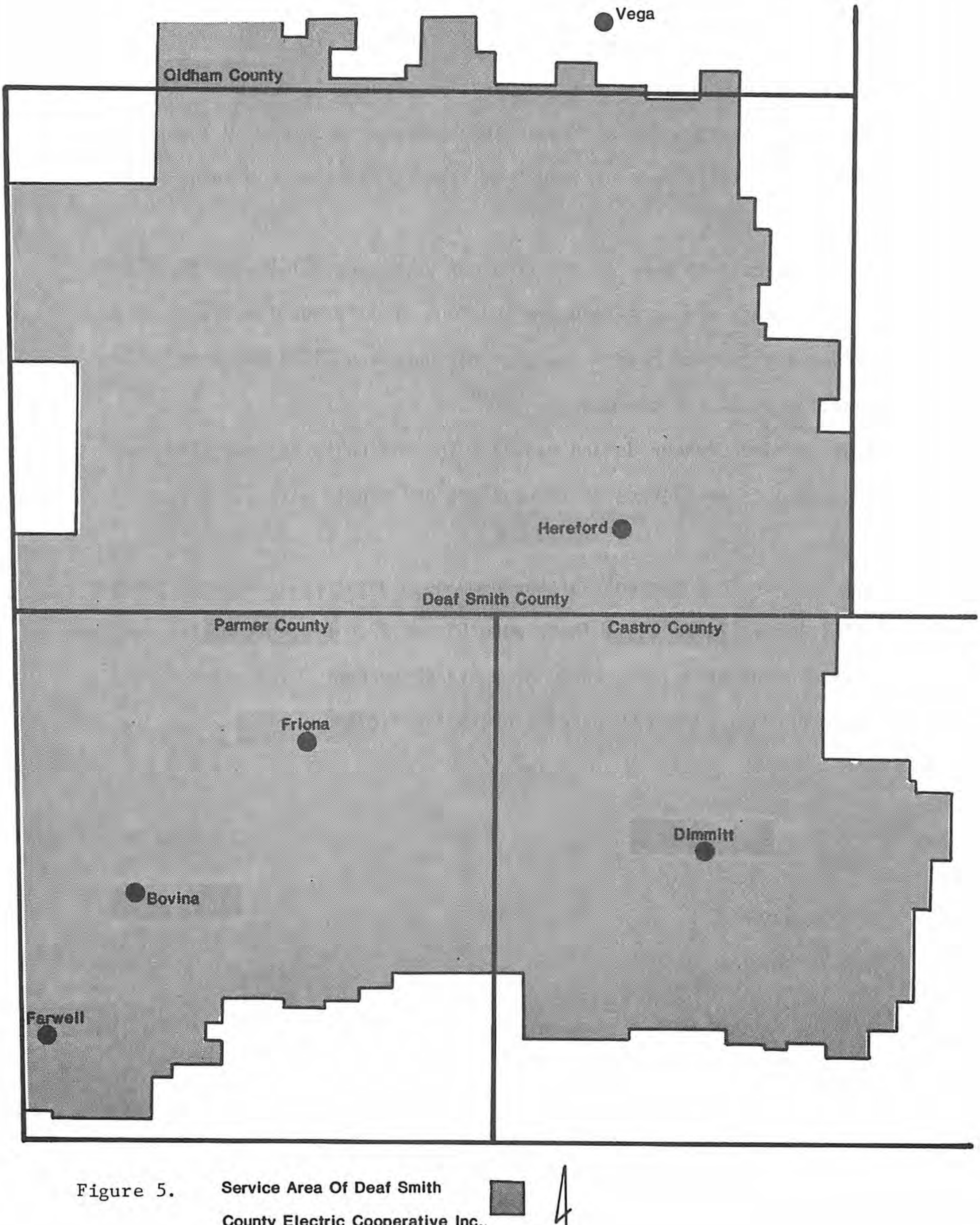


Figure 5. **Service Area Of Deaf Smith County Electric Cooperative Inc.**

DEAF SMITH COUNTY ELECTRIC COOPERATIVE

The Deaf Smith County Electric Cooperative Incorporated reports the overall efficiency of the pumping plants in their service area was 39.3 percent (Table 13). The results were derived from testing 233 electric powered pumping plants.

The average cost to pump an acre-foot of water was $51.15 and $4.26 per acre-inch. The cost per acre-foot per 100 foot of lift was $19.57, or $0.20 per acre-foot per foot of head. The cost per hour was $1.44 based on an average consumption of 24 kwh per hour.

The average horsepower demand was 32.1 for the units tested. This was required to produce an average of 193 gallons per minute with 269.6 feet of lift.

Sixty-two, or 26.6 percent, of the pumping plants' fell below 30 percent overall efficiency (Table 14). There were 55, or 23.6 percent, of the pumping plants in the upper efficiency range of above 50 percent. The other 48.8 percent were between 30 and 50 percent overall efficiency.

TABLE 13. Deaf Smith Electric Cooperative Inc.

ENERGY EFFICIENCY DATA ON ELECTRIC WELLS

Total Lift	GPM	Water HP	Input HP	Overall Eff.	Annual (KWH) Consumption	Annual Fuel Cost	Ac. Ft. Pumped	Cost/ Ac. Ft.	Cost/ Ac. In.	Cost/Ac. Ft./100 Ft. Lift	Cost/Ac. In./100 Ft. Lift
245	115	7.11	17.81	39.92	26580	1,594.80	42.35	37.66	3.14	15.37	1.28
250	75	4.73	18.98	24.92	28320	1,699.20	27.62	61.52	5.13	24.61	2.05
250	65	4.10	11.93	34.37	17800	1,068.00	23.94	44.61	3.72	17.84	1.49
250	195	12.31	26.21	46.97	39120	2,347.20	71.81	32.69	2.72	13.08	1.09
250	65	4.10	10.69	38.35	15960	957.60	23.94	40.00	3.33	16.00	1.33
343	145	12.56	25.26	49.72	37700	2,262.00	53.40	42.36	3.53	12.35	1.03
287	245	17.76	36.56	48.60	54560	3,273.60	90.22	36.28	3.02	12.64	1.05
320	135	10.91	39.14	36.36	58420	3,505.20	49.72	70.50	5.87	22.03	1.84
219	60	3.32	7.20	46.10	10800	648.00	22.10	29.32	2.44	13.39	1.12
207	180	9.41	24.80	37.90	37000	2,220.00	66.29	33.49	2.79	16.18	1.35
239	200	12.07	28.90	41.80	43200	2,592.00	73.65	35.19	2.93	14.72	1.23
213	85	4.57	11.60	39.40	17200	1,032.00	31.30	32.97	2.75	15.48	1.29
233	245	14.41	25.70	56.07	38400	2,304.00	90.22	25.54	2.13	10.96	0.91
276	205	14.27	30.07	47.45	44880	2,692.80	75.49	35.67	2.97	12.92	1.08
211	220	11.70	19.82	59.03	23400	1,404.00	81.02	17.33	1.44	8.21	0.68
229	110	6.35	22.10	28.73	32980	1,978.80	40.51	48.85	4.07	21.33	1.78
231	310	18.10	38.17	47.42	56960	3,417.60	114.16	29.94	2.49	12.96	1.08
238	315	18.93	41.68	45.42	62200	3,732.00	116.00	32.17	2.68	13.52	1.13
234	295	17.42	45.51	38.28	67920	4,075.20	108.64	37.51	3.13	16.03	1.34
246	105	6.52	12.75	51.14	19020	1,141.20	38.67	29.51	2.46	12.00	1.00
250	100	6.31	12.63	49.96	18860	1,131.60	36.83	30.72	2.56	12.29	1.02
257	60	3.89	5.99	64.94	8940	536.40	22.10	24.27	2.02	9.44	0.79
257	60	3.89	8.91	43.66	13300	798.00	22.10	36.11	3.01	14.05	1.17
255	120	7.73	20.89	37.00	31180	1,870.80	44.20	42.33	3.53	16.60	1.38
253	130	8.29	23.16	35.79	34560	2,073.60	47.87	43.32	3.61	17.12	1.43
247	305	18.99	34.30	55.36	51200	3,072.00	112.32	27.35	2.28	11.07	0.92
423	250	26.70	50.52	52.85	75400	4,524.00	92.07	49.14	4.09	11.62	0.97
372	230	21.61	42.75	50.55	63800	3,828.00	84.70	45.19	3.77	12.15	1.01
373	265	24.93	52.93	47.10	79000	4,740.00	97.59	48.57	4.05	13.02	1.09
370	160	14.94	38.33	38.98	57200	3,432.00	58.92	58.25	4.85	15.74	1.31
367	150	13.89	39.69	35.00	59240	3,554.40	55.24	64.34	5.36	17.53	1.46
323	190	15.48	40.15	38.56	59940	3,596.40	69.97	51.40	4.28	15.91	1.33
330	185	15.40	48.75	31.59	72760	4,365.60	68.13	64.08	5.34	19.42	1.62
302	100	7.60	66.54	11.42	99320	5,959.20	36.83	161.80	13.48	53.58	4.46
343	170	14.73	25.26	58.31	37700	2,262.00	62.61	36.13	3.01	10.53	0.88
253	410	26.22	52.18	50.25	77852	4,671.15	150.99	30.94	2.58	12.23	1.02
302	125	9.52	24.37	39.06	36380	2,182.80	46.03	47.42	3.95	15.70	1.31

TABLE 13. (Continued) Deaf Smith Electric Cooperative Inc.

ENERGY EFFICIENCY DATA ON ELECTRIC WELLS

Total Lift	GPM	Water HP	Input HP	Overall Eff.	Annual (KWH) Consumption	Annual Fuel Cost	Ac. Ft. Pumped	Cost/ Ac. Ft.	Cost/ Ac. In.	Cost/Ac. Ft./100 Ft. Lift	Cost/Ac. In./100 Ft. Lift
164	55	2.27	6.85	33.14	10220	613.20	20.25	30.28	2.52	18.46	1.54
190	51	2.45	8.70	28.16	13000	780.00	18.78	41.53	3.46	21.86	1.82
196	47	2.30	8.22	27.98	12200	732.00	17.31	42.29	3.52	21.58	1.80
178	130	5.80	12.00	48.33	18000	1,080.00	47.87	22.56	1.88	12.67	1.06
151	92	3.50	6.50	53.85	9600	576.00	33.88	17.00	1.42	11.26	0.94
172	65	2.80	6.10	45.90	9200	552.00	23.94	23.06	1.92	13.41	1.12
172	30	1.30	5.80	22.41	8600	516.00	11.05	46.70	3.89	27.15	2.26
195	140	6.90	13.10	52.67	19600	1,176.00	51.56	22.81	1.90	11.70	0.97
192	305	14.80	29.10	50.86	43400	2,604.00	112.32	23.18	1.93	12.07	1.01
174	50	2.20	12.90	17.05	19200	1,152.00	18.41	62.57	5.21	35.96	3.00
174	22	1.00	7.70	12.99	11600	696.00	8.10	85.93	7.16	49.39	4.12
172	46	2.00	5.90	33.90	8800	528.00	16.94	31.17	2.60	18.12	1.51
170	40	1.70	4.40	38.64	6600	396.00	14.73	26.88	2.24	15.81	1.32
235	70	4.20	25.70	16.34	38400	2,304.00	25.78	89.37	7.45	38.03	3.17
217	435	23.80	37.40	63.64	55800	3,348.00	160.20	20.90	1.74	9.63	0.80
257	220	14.30	31.60	45.25	47200	2,832.00	81.02	34.95	2.91	13.60	1.13
235	200	11.90	19.10	62.30	28600	1,716.00	73.65	23.30	1.94	9.91	0.83
265	300	20.10	36.90	54.47	55000	3,300.00	110.48	29.87	2.49	11.27	0.94
270	290	19.80	41.50	47.71	62000	3,720.00	106.80	34.83	2.90	12.90	1.08
298	308	23.20	42.70	54.33	63800	3,828.00	113.43	33.75	2.81	11.33	0.94
253	540	34.50	60.10	57.40	89800	5,388.00	198.86	27.09	2.26	10.71	0.89
301	250	19.00	29.70	63.97	44400	2,664.00	92.07	28.93	2.41	9.61	0.80
138	43	1.50	5.03	29.82	7500	450.00	15.84	28.41	2.37	20.59	1.72
135	63	2.20	7.30	30.14	10940	656.40	23.20	28.29	2.36	20.96	1.75
136	67	2.30	7.40	31.08	11000	660.00	24.67	26.75	2.23	19.67	1.64
164	35	1.50	6.40	23.44	9600	576.00	12.89	44.69	3.72	27.25	2.27
163	45	1.80	6.80	26.47	10200	612.00	16.57	36.93	3.08	22.66	1.89
163	58	2.40	12.90	18.60	19200	1,152.00	21.36	53.93	4.49	33.09	2.76
163	54	2.20	7.20	30.56	10800	648.00	19.89	32.58	2.71	19.99	1.67
249	112	7.00	19.50	35.90	29000	1,740.00	41.25	42.18	3.52	16.94	1.41
218	105	5.80	29.90	19.40	44600	2,676.00	38.67	69.20	5.77	31.74	2.65
280	135	9.60	30.20	31.79	45000	2,700.00	49.72	54.30	4.53	19.39	1.62
270	93	6.40	22.40	28.57	33600	2,016.00	34.25	58.86	4.91	21.80	1.82
225	300	17.10	38.60	44.30	57600	3,456.00	110.48	31.28	2.61	13.90	1.16
322	290	23.60	38.06	62.01	56820	3,409.20	106.80	31.92	2.66	9.91	0.83
307	140	10.80	25.49	42.37	38040	2,282.40	51.56	44.27	3.69	14.42	1.20
239	20	1.20	17.10	7.02	25540	1,532.40	7.37	207.92	17.33	87.00	7.25

TABLE 13. (Continued) Deaf Smith Electric Cooperative Inc.

ENERGY EFFICIENCY DATA ON ELECTRIC WELLS

Total Lift	GPM	Water HP	Input HP	Overall Eff.	Annual (KWH) Consumption	Annual Fuel Cost	Ac. Ft. Pumped	Cost/ Ac. Ft.	Cost/ Ac. In.	Cost/Ac. Ft./100 Ft. Lift	Cost/Ac. In./100 Ft. Lift
195	33	1.60	5.20	30.77	7800	468.00	12.15	38.52	3.21	19.75	1.65
183	58	2.70	11.20	24.11	16600	996.00	21.36	46.63	3.89	25.48	2.12
197	99	4.90	14.10	34.75	21000	1,260.00	36.46	34.56	2.88	17.54	1.46
208	122	6.40	13.50	47.41	20200	1,212.00	44.93	26.98	2.25	12.97	1.08
210	59	3.10	8.40	36.90	12600	756.00	21.73	34.79	2.90	16.57	1.38
207	22	1.20	7.20	16.67	10760	645.60	8.10	79.70	6.64	38.50	3.21
353	82	7.30	30.50	23.93	45600	2,736.00	30.19	90.63	7.55	25.67	2.14
284	73	7.10	20.10	35.32	30000	1,800.00	26.88	66.96	5.58	23.58	1.96
330	120	10.00	30.20	33.11	45000	2,700.00	44.19	61.10	5.09	18.52	1.54
218	50	2.80	5.70	49.12	8400	504.00	18.41	27.38	2.28	12.56	1.05
214	50	2.70	5.90	45.76	8800	528.00	18.41	28.68	2.39	13.40	1.12
207	60	3.10	6.50	47.69	9600	576.00	22.10	26.06	2.17	12.59	1.05
214	30	1.60	7.60	21.05	11400	684.00	11.05	61.90	5.16	28.93	2.41
183	45	2.10	19.60	10.71	29200	1,752.00	16.58	105.67	8.81	57.74	4.81
219	80	4.40	18.00	24.44	27000	1,620.00	29.46	54.99	4.58	25.11	2.09
176	30	1.30	10.70	12.15	16000	960.00	11.05	86.88	7.24	49.36	4.11
244	35	2.20	8.00	27.50	12000	720.00	12.89	55.86	4.65	22.89	1.91
233	61	3.60	8.50	42.36	12600	756.00	22.46	33.66	2.80	14.45	1.20
246	31	1.90	6.23	30.50	9300	558.00	11.42	48.86	4.07	19.86	1.66
247	70	4.40	12.90	34.11	19200	1,152.00	25.78	44.69	3.72	18.09	1.51
257	36	2.30	10.40	22.12	15400	924.00	13.26	69.68	5.81	27.11	2.26
262	37	2.40	6.30	38.10	9400	564.00	13.63	41.38	3.45	15.79	1.32
237	23	1.38	5.52	25.00	8200	492.00	8.47	58.09	4.84	24.51	2.04
255	45	2.90	9.00	32.22	13400	804.00	16.57	48.52	4.04	19.03	1.59
255	33	2.10	11.50	18.26	17200	1,032.00	12.15	84.94	7.08	33.31	2.78
359	330	29.90	58.00	51.55	86600	5,196.00	121.53	42.75	3.56	11.91	0.99
297	182	13.65	25.20	54.17	37600	2,256.00	67.02	33.66	2.81	11.33	0.94
240	185	11.90	20.20	58.91	30200	1,812.00	68.13	26.60	2.22	11.08	0.92
240	195	11.80	22.00	53.64	32800	1,968.00	71.81	27.41	2.28	11.42	0.95
240	195	11.80	20.10	58.71	30000	1,800.00	71.81	25.07	2.09	10.45	0.87
230	100	5.80	18.70	31.02	28000	1,680.00	36.83	45.61	3.80	19.83	1.65
217	908	44.70	93.20	47.96	139200	8,352.00	334.39	24.98	2.08	11.51	0.96
214	40	2.20	8.10	27.16	12000	720.00	14.73	48.88	4.07	22.84	1.90
254	35	2.30	13.40	17.16	20000	1,200.00	12.89	93.10	7.76	36.65	3.05
175	15	0.70	15.30	4.58	22800	1,368.00	5.53	247.38	20.61	141.36	11.78
230	40	2.30	16.80	13.69	25000	1,500.00	14.73	101.83	8.49	44.27	3.69
216	55	3.00	18.50	16.22	27600	1,656.00	20.25	81.78	6.81	37.86	3.16

TABLE 13. (Continued) Deaf Smith Electric Cooperative Inc.

ENERGY EFFICIENCY DATA ON ELECTRIC WELLS

Total Lift	GPM	Water HP	Input HP	Overall Eff.	Annual (KWH) Consumption	Annual Fuel Cost	Ac. Ft. Pumped	Cost/ Ac. Ft.	Cost/ Ac. In.	Cost/Ac. Ft./100 Ft. Lift	Cost/Ac. In./100 Ft. Lift
284	170	12.2	32.20	36.34	48000	2,820.00	62.61	45.04	3.75	15.86	1.32
364	340	31.2	57.20	54.55	85400	5,124.00	125.21	40.92	3.41	11.24	0.94
332	330	27.63	60.40	45.75	90160	5,409.60	121.53	44.51	3.71	13.41	1.12
334	280	23.64	52.83	44.75	78840	4,730.40	103.11	45.88	3.82	13.74	1.14
316	220	17.57	65.50	26.82	97820	5,869.20	81.02	72.44	6.04	22.92	1.91
289	230	16.80	35.16	47.16	53160	3,189.60	84.70	37.66	3.14	13.03	1.09
276	365	25.46	49.80	51.12	74320	4,459.20	134.42	33.17	2.76	12.02	1.00
293	305	22.57	54.70	41.26	81640	4,898.40	112.32	43.61	3.63	14.88	1.24
305	125	9.64	40.15	24.01	59940	3,596.40	46.03	78.13	6.51	25.62	2.13
319	335	26.95	51.08	52.76	76240	4,574.40	123.37	37.08	3.09	11.62	0.97
307	41	3.17	6.81	46.55	10160	609.60	15.10	40.37	3.36	13.15	1.10
251	42	2.66	12.19	21.82	18180	1,090.80	15.47	70.51	5.88	28.09	2.34
312	132	10.39	21.28	48.83	31760	1,905.60	48.61	39.20	3.27	12.56	1.05
207	435	22.72	43.42	52.33	64800	3,888.00	160.20	24.27	2.02	11.72	0.98
222	535	30.02	51.46	58.34	76800	4,608.00	197.02	23.39	1.95	10.54	0.88
218	550	30.22	49.62	60.90	74060	4,443.60	202.55	21.94	1.83	10.06	0.84
211	425	22.62	39.69	56.99	59240	3,554.40	156.51	22.71	1.89	10.76	0.90
234	550	32.56	65.53	49.69	97820	5,869.20	202.55	28.98	2.41	12.38	1.03
231	125	7.29	15.79	46.17	23560	1,413.60	46.03	30.71	2.56	13.29	1.11
244	440	27.09	45.93	58.98	68540	4,112.40	162.04	25.38	2.11	10.40	0.87
247	870	54.35	99.24	54.77	148120	8,887.20	320.39	27.84	2.31	11.27	0.94
219	270	14.93	34.05	43.85	50820	3,049.20	99.43	30.67	2.56	14.00	1.17
182	30	1.38	5.10	27.06	7620	457.20	11.05	41.38	3.45	22.74	1.89
196	60	2.97	8.02	37.03	11960	717.60	22.10	32.47	2.71	16.57	1.38
194	70	3.43	11.11	30.87	16580	994.80	25.78	38.59	3.22	19.89	1.66
188	135	6.41	14.94	42.90	22300	1,338.00	49.72	26.91	2.24	14.31	1.19
202	125	6.38	15.02	42.48	22420	1,345.20	46.03	29.22	2.44	14.47	1.21
205	45	2.33	8.42	27.67	12560	753.60	16.57	45.48	3.79	22.19	1.85
186	14	0.66	5.08	12.99	7580	454.80	5.16	88.14	7.34	47.39	3.95
250	55	3.47	7.12	48.74	10640	638.40	20.25	31.53	2.63	12.61	1.05
246	105	6.50	17.75	36.62	26500	1,590.00	38.67	41.12	3.43	16.72	1.39
255	60	3.86	19.07	20.24	28460	1,707.60	22.10	77.27	6.44	30.30	2.53
202	325	16.60	26.60	62.41	39720	2,383.20	119.69	19.91	1.66	9.86	0.82
187	100	4.30	11.90	36.13	17800	1,068.00	36.83	29.00	2.42	15.51	1.29
222	55	3.10	6.90	44.93	10360	621.60	20.25	30.70	2.56	13.83	1.15
221	80	4.50	19.30	23.32	28800	1,728.00	29.46	58.66	4.89	26.54	2.21
205	115	6.00	24.80	24.19	37000	2,220.00	42.35	52.42	4.37	25.57	2.13

TABLE 13. (Continued) Deaf Smith Electric Cooperative Inc.

ENERGY EFFICIENCY DATA ON ELECTRIC WELLS

Total Lift	GPM	Water HP	Input HP	Overall Eff.	Annual (KWH) Consumption	Annual Fuel Cost	Ac. Ft. Pumped	Cost/ Ac. Ft.	Cost/ Ac. In.	Cost/Ac. Ft./100 Ft. Lift	Cost/Ac. In./100 Ft. Lift
266	45	3.00	13.70	21.90	20400	1,224.00	16.58	73.82	6.15	27.75	2.31
250	90	5.70	12.50	45.60	18800	1,128.00	33.15	34.03	2.84	13.61	1.13
255	66	4.20	11.10	37.84	16600	996.00	24.31	40.97	3.41	16.07	1.34
260	116	7.60	13.50	56.30	20200	1,212.00	42.72	28.37	2.36	10.91	0.91
250	71	4.50	11.40	39.47	17000	1,020.00	26.15	39.01	3.25	15.60	1.30
255	180	11.60	19.00	61.05	28400	1,704.00	66.29	25.71	2.14	10.08	0.84
239	114	6.90	11.20	61.61	16600	996.00	41.98	23.73	1.98	9.93	0.83
288	120	8.70	27.20	31.99	40600	2,436.00	44.20	55.11	4.59	19.14	1.59
356	225	20.20	45.80	44.10	68400	4,104.00	82.86	49.53	4.13	13.91	1.16
307	68	5.30	24.80	21.37	37000	2,220.00	25.04	88.66	7.39	28.88	2.41
316	70	5.60	29.50	18.98	44000	2,640.00	25.78	102.40	8.53	32.41	2.70
281	235	16.70	29.70	56.23	44400	2,664.00	86.54	30.78	2.57	10.95	0.91
281	125	8.90	30.80	28.90	46000	2,760.00	46.03	59.96	5.00	21.34	1.78
239	205	12.40	26.40	46.97	39400	2,364.00	75.49	31.32	2.61	13.10	1.09
281	235	16.70	48.90	34.15	73000	4,380.00	86.54	50.61	4.22	18.01	1.50
354	870	77.80	129.20	60.22	192800	11,568.00	320.39	36.11	3.01	10.20	0.85
332	970	81.30	137.60	59.08	205400	12,324.00	357.22	34.50	2.87	10.39	0.87
330	195	16.20	35.60	45.51	53200	3,192.00	71.81	44.45	3.70	13.47	1.12
333	95	8.00	21.30	37.56	31800	1,908.00	34.99	54.53	4.54	16.38	1.36
308	85	6.60	22.80	28.95	34000	2,040.00	31.30	65.18	5.43	21.16	1.76
304	120	9.22	31.58	29.20	47120	2,827.20	44.19	63.98	5.33	21.05	1.75
319	940	75.80	106.87	70.93	159500	9,570.00	346.17	27.65	2.30	8.67	0.72
303	740	56.62	126.30	44.83	188500	11,310.00	272.51	41.50	3.46	13.70	1.14
293	360	26.67	74.10	35.99	110600	6,636.00	132.58	50.05	4.17	17.08	1.42
291	40	2.94	31.01	9.48	46280	2,776.80	14.73	188.51	15.71	64.78	5.40
423	390	41.62	83.95	49.58	125300	7,518.00	143.62	52.35	4.36	12.38	1.03
424	545	58.30	102.91	56.65	153600	9,216.00	200.70	45.92	3.83	10.83	0.90
313	460	36.31	82.94	43.78	123800	7,428.00	169.40	43.85	3.65	14.01	1.17
276	630	43.96	88.21	49.84	131660	7,899.60	232.00	34.05	2.84	12.34	1.03
289	575	42.01	81.72	51.41	121980	7,318.60	211.75	34.56	2.88	11.96	1.00
330	46	3.80	13.62	27.90	20320	1,219.20	16.94	71.97	6.00	21.81	1.82
313	435	34.38	103.17	33.32	153980	9,238.80	160.20	57.67	4.81	18.42	1.54
315	420	33.43	74.49	44.88	111180	6,670.80	154.67	43.13	3.59	13.69	1.14
327	795	65.61	113.41	57.85	169280	10,156.80	292.77	34.69	2.89	10.61	0.88
324	670	54.80	91.70	59.76	136880	8,212.80	246.74	33.29	2.77	10.27	0.86
325	625	51.33	89.63	57.27	133780	8,026.80	230.17	34.87	2.91	10.73	0.89
300	115	8.71	39.47	22.07	58900	3,534.00	42.35	83.45	6.95	27.82	2.32

TABLE 13. (Continued) Deaf Smith Electric Cooperative Inc.

ENERGY EFFICIENCY DATA ON ELECTRIC WELLS

Total Lift	GPM	Water HP	Input HP	Overall Eff.	Annual (KWH) Consumption	Annual Fuel Cost	Ac. Ft. Pumped	Cost/ Ac. Ft.	Cost/ Ac. In.	Cost/Ac. Ft./100 Ft. Lift	Cost/Ac. In./100 Ft. Lift
289	135	9.87	53.44	33.95	79760	4,785.60	49.72	96.25	8.02	33.30	2.78
290	175	12.83	30.87	41.56	46080	2,764.80	64.45	42.90	3.57	14.79	1.23
283	75	5.36	31.58	37.72	47120	2,827.20	27.62	102.36	8.53	36.17	3.01
292	90	6.64	22.40	29.64	33440	2,006.40	33.14	60.54	5.05	20.73	1.73
304	70	5.37	17.37	30.92	25920	1,555.20	25.78	60.33	5.03	19.85	1.65
281	165	11.71	20.53	57.04	30640	1,838.40	60.76	30.26	2.52	10.77	0.90
251	330	20.92	55.13	37.95	82280	4,936.80	121.53	40.62	3.39	16.81	1.35
294	100	7.42	18.52	40.06	27640	1,658.40	36.83	45.03	3.75	15.32	1.28
288	170	12.36	22.78	54.26	34000	2,040.00	62.61	32.58	2.72	11.31	0.94
282	70	4.98	19.30	25.80	28800	1,728.00	25.78	67.03	5.59	23.77	1.98
170	60	2.58	13.24	19.49	19760	1,185.60	22.10	53.65	4.47	31.56	2.63
165	45	1.88	13.30	14.14	19840	1,190.40	16.57	71.84	5.99	43.54	3.63
200	115	5.80	19.30	30.05	28800	1,728.00	42.35	40.80	3.40	20.40	1.70
200	80	4.04	21.00	19.24	31400	1,884.00	29.46	63.95	5.33	31.98	2.66
329	180	14.90	30.40	49.01	45400	2,724.00	66.29	41.09	3.42	12.49	1.04
347	175	15.40	39.50	38.99	59000	3,540.00	64.45	54.93	4.58	15.83	1.32
317	90	7.20	20.90	34.45	31200	1,872.00	33.14	56.49	4.71	17.82	1.49
364	465	42.70	76.00	56.18	113400	6,804.00	171.24	39.73	3.31	10.91	0.91
422	82	8.70	25.50	34.12	38200	2,292.00	30.20	75.89	6.32	17.98	1.50
318	75	6.00	21.60	27.78	32200	1,932.00	27.62	69.95	5.83	22.00	1.83
411	157	16.30	33.90	48.08	50600	3,036.00	57.82	52.51	4.38	12.78	1.06
383	138	13.30	31.50	42.22	47000	2,820.00	50.82	55.49	4.62	14.49	1.21
416	65	6.80	24.60	27.64	36600	2,196.00	23.94	91.73	7.64	22.05	1.84
388	88	8.60	22.70	37.89	34000	2,040.00	32.41	62.94	5.25	16.22	1.35
324	25	2.00	23.00	8.70	34400	2,064.00	9.21	224.10	18.68	69.17	5.76
385	340	33.10	66.50	49.74	99200	5,952.00	125.21	47.54	3.96	12.35	1.03
405	430	44.00	108.50	40.55	162000	9,720.00	158.35	61.38	5.12	15.16	1.26
385	270	26.30	49.60	53.02	74000	4,440.00	99.43	44.65	3.72	11.60	0.97
385	345	33.60	63.40	53.00	94600	5,676.00	127.05	44.68	3.72	11.61	0.97
355	190	17.10	31.30	54.63	46800	2,808.00	69.97	40.13	3.34	11.30	0.94
333	355	29.90	65.80	45.44	98200	5,892.00	130.73	45.06	3.76	13.53	1.13
382	300	29.00	62.30	46.55	93000	5,580.00	110.48	50.51	4.21	13.22	1.10
382	305	29.40	67.80	43.36	101200	6,072.00	112.32	54.06	4.50	14.15	1.18
337	680	57.90	97.80	59.20	146000	8,760.00	250.42	34.98	2.92	10.38	0.86

TABLE 13. (Continued) Deaf Smith Electric Cooperative Inc.

ENERGY EFFICIENCY DATA ON ELECTRIC WELLS

	Total Lift	GPM	Water HP	Input HP	Overall Eff.	Annual (KWH) Consumption	Annual Fuel Cost	Ac. Ft. Pumped	Cost/ Ac. Ft.	Cost/ Ac. In.	Cost/Ac. Ft./100 Ft. Lift	Cost/Ac. In./100 Ft. Lift
	286	180	12.98	25.17	51.57	37560	2,253.60	66.29	34.00	2.83	11.89	0.99
	340	590	50.60	93.87	53.90	140100	8,406.00	217.28	38.69	3.22	11.38	0.95
	371	100	9.36	37.55	24.93	56040	3,362.40	36.83	91.30	7.61	24.61	2.05
	386	100	9.74	20.58	47.33	30720	1,843.20	36.83	50.05	4.17	12.97	1.08
	417	90	9.48	24.37	38.90	36380	2,182.80	33.14	65.87	5.49	15.80	1.32
	419	65	6.88	20.52	33.53	30620	1,837.20	23.94	76.74	6.40	18.32	1.53
	389	25	2.44	18.57	13.14	27720	1,663.20	9.21	180.59	15.05	46.42	3.87
	393	18	1.79	20.64	8.67	30820	1,849.20	6.63	278.91	23.24	70.97	5.91
	315	590	46.93	97.15	48.31	145000	8,700.00	217.28	40.04	3.34	12.71	1.06
	253	480	30.69	62.44	49.15	93200	5,592.00	176.77	31.63	2.64	12.50	1.04
	251	55	3.48	15.87	21.97	23680	1,420.80	20.25	70.16	5.85	27.95	2.33
	278	116	8.14	21.40	38.04	31920	1,915.20	42.72	44.83	3.74	16.12	1.34
	277	140	9.80	21.05	46.56	31420	1,885.20	51.56	36.56	3.05	13.20	1.10
	281	160	11.35	29.41	38.59	43920	2,635.20	58.92	44.73	3.73	15.92	1.33
TOTAL	62,816	45,009	3,276.12	7,482.92	9,151.72	11087032	669,773.35	16,575.37	11,918.65	993.19	4,559.78	379.98
AVERAGE	269.59	193.17	14.06	32.12	39.28	47584	2,874.56	71.14	51.15	4.26	19.57	1.63

TABLE 14

Deaf Smith Electric Cooperative, Inc.
Summary of Overall Efficiency Ranges

Pumping Plants Tested	Efficiency Range
24 or 10.3 percent	Below 20 percent
38 or 16.3 percent	20-29 percent
57 or 24.5 percent	30-39 percent
59 or 25.3 percent	40-49 percent
44 or 18.9 percent	50-59 percent
11 or 4.7 percent	Above 60 percent

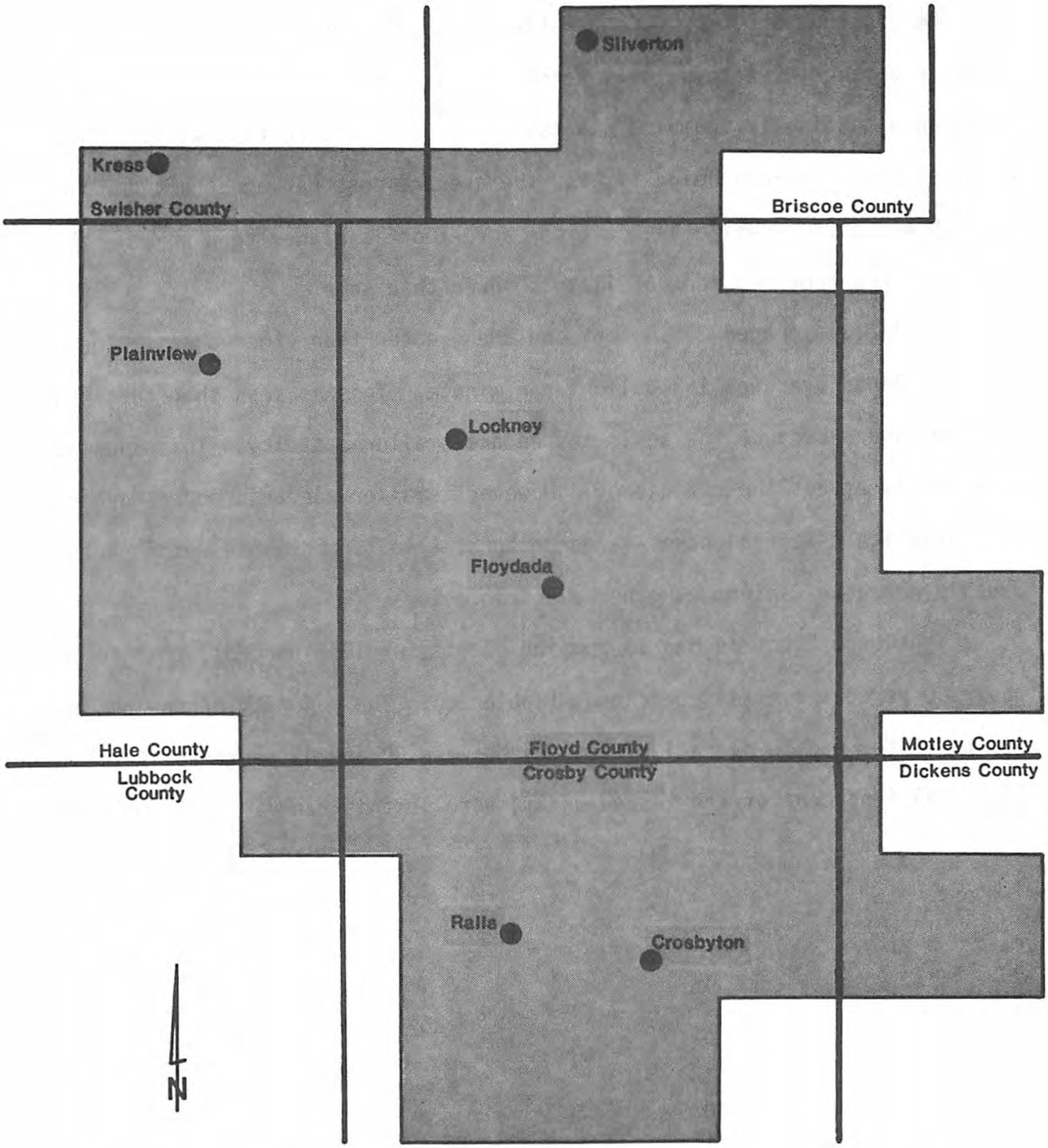


Figure 6. **Service Area Of Lighthouse Electric Cooperative, Inc**

LIGHTHOUSE ELECTRIC COOPERATIVE

The Lighthouse Electric Cooperative found the average overall efficiency in their service area to be 38.9 percent (Table 15). The efficiencies were based upon testing 127 pumping plants. The cost per acre-foot was $53.01 with the cost per acre-inch being $4.42. The average cost per acre-foot per foot of lift was $0.20. While the cost per acre-foot is higher than normal, the cost per acre-foot per foot of lift is lower than some.

The lifts averaged 272.6 feet and are greater than other areas. The pumping plants averaged 155 gallons per minute. This is less than that found in other areas because the wells tested are smaller capacity. This does not necessarily affect the efficiency. However, smaller electric motors generally are not quite as efficient as larger motors. Also, submersible motors are usually not as efficient as other electric motors.

Lighthouse Electric had 13 pumping plants, or 10.2 percent, that tested above 60 percent overall efficiency (Table 16). The majority of the pumping plants tested had an overall efficiency between 30 and 49 percent. A total of 68, or 53.6 percent of the tested units, were in this range.

TABLE 15. Lighthouse Electric Cooperative Inc.
ENERGY EFFICIENCY DATA ON ELECTRIC WELLS

Type Pump	H. P. Rating	Operation Head/Ft.	GPM	Water H.P.	H.P. Input	Overall Eff.	Ac. Ft./ 24 Hours	Kwh/ Ac. Ft.	Cost/ 24 Hours	Cost/ Ac. Ft.	Cost/ Ac. In.	Cost/Ac. Ft./ Ft. Lift
S	20	269	223	15.1	27.6	54.8%	.991	502	$29.82	$30.12	$ 2.51	$ .11
S	20	263	248	16.5	27.5	60	1.102	449	29.70	26.94	2.45	.10
S	20	393	91.7	9.1	22.2	41	.407	981	23.94	58.86	4.91	.15
S	20	399	127	12.8	39.4	32.5	.564	1259	42.60	75.54	6.30	.19
T	75	374	194	18.3	48.6	37.7	.862	1020	52.74	61.20	5.10	.16
T	50	431	112	12.2	44.3	27.8	.497	1600	47.70	96.00	8.00	.22
T	25	320	75.8	6.13	20.1	30.5	.337	1070	21.66	64.20	5.35	.20
S	7.5	267	36.1	2.43	5.73	42.5	.160	645	6.18	38.70	3.23	.14
S	10	292	37.8	2.79	9.45	29.5	.168	1010	10.20	60.60	5.05	.21
S	10	317	23	1.84	16.8	10.9	.102	2970	18.18	178.20	14.85	.56
S	20	317	74.5	5.96	19.2	31.1	.331	1040	20.64	62.40	5.20	.20
T	7.5	178	17.9	.805	9.19	8.76	.079	2080	9.84	124.80	10.40	.70
S	5	182	24	1.10	6.50	17	.106	1100	7.02	66.00	5.50	.36
T	7.5	140	29.8	1.05	5.65	18.7	.132	768	6.06	46.08	3.84	.33
S	7.5	192	40.3	1.95	6.55	29.8	.179	659	7.08	39.54	3.30	.21
S	5	216	68.2	3.72	5.79	64.2	.303	344	6.24	20.64	1.72	.10
T	60	248	543	34.1	60.1	56.5	2.41	449	64.93	26.94	2.25	.11
T	50	223	242	13.6	36.9	37	1.07	617	39.60	37.02	3.09	.17
T	60	233	310	18.2	56.5	32.2	1.37	739	60.75	44.34	3.70	.19
T	40	232	265	15.5	42.1	36.9	1.17	644	45.18	38.64	3.22	.17
S	20	218	194	10.7	23.5	45.5	.862	490	25.32	29.40	2.45	.13
S	20	321	39	3.16	22.9	13.8	.173	2383	24.72	142.98	11.92	.45
S	25	290	146	10.7	27.2	39.2	.649	757	29.46	45.42	3.79	.16
S	7.5	301	63	4.79	13.44	35.6	.280	866	14.52	51.96	4.33	.14
S	25	303	130	9.95	32.42	30.69	.577	1011	34.98	60.66	5.06	.20
S	30	307	185	14.34	40.33	35.5	.822	874	43.08	52.44	4.37	.17
S	30	292	250	18.43	37.05	48.6	1.11	615	40.98	36.90	3.08	.13
S	25	290	185	13.55	39.37	34.4	.888	863	45.96	51.78	4.32	.18
T	30	206	85	4.42	17.08	26	.377	811	18.36	48.66	4.06	.24
T	50	178	260	11.68	32.42	36.03	1.15	505.9	34.92	30.35	2.53	.17
T	40	177	145	6.48	28.94	22.39	.644	809.5	31.26	48.57	4.05	.27
T	50	185	80	3.74	32.8	11.4	.355	1662	35.40	99.72	8.31	.54
T	50	362	55	5.03	40.33	12.47	.244	2973	43.50	178.38	14.87	.49
T	50	352	150	13.33	36.44	36.6	.666	984.8	39.36	59.09	4.92	.17
T	25	292	100	7.37	25.46	29	.444	1031	27.48	61.86	5.16	.21
T	40	283	130	9.29	33.77	27.5	.578	1061	36.78	63.66	5.31	.22
T	40	282	180	12.82	26.05	49.2	.800	587	28.20	35.22	2.94	.12
S	30	291	215	15.80	24.37	64.8	.955	460	26.34	27.60	2.30	.09
T	50	201	185	9.39	24.64	38	.822	542	26.76	32.52	2.71	.16
T	30	212	185	9.9	27.33	36.24	.822	599	29.52	35.94	3.00	.17

TABLE 15. (Continued) Lighthouse Electric Cooperative Inc.
ENERGY EFFICIENCY DATA ON ELECTRIC WELLS

Type Pump	H. P. Rating	Operation Head/Ft.	GPM	Water H.P.	H.P. Input	Overall Eff.	Ac. Ft./ 24 Hours	Kwh/ Ac. Ft.	Cost/ 24 Hours	Cost/ Ac. Ft.	Cost/ Ac. In.	Cost/Ac. Ft./ Ft. Lift
S	20	311	70	5.50	23.15	23.7	.311	344	6.42	20.64	1.72	.07
T	40	302	190	14.49	44.81	32.34	.844	956	48.42	57.36	4.78	.19
T	40	282	180	12.82	37.67	34.03	.800	847.5	40.68	50.85	4.24	.18
S	20	286	200	14.44	26.89	50.14	.888	584.5	31.14	35.07	2.92	.12
S	20	283	210	15	29.88	50.02	.933	579	32.40	34.74	2.90	.12
T	40	282	210	14.95	39.35	38	.933	760	42.54	45.60	3.80	.16
S	20	227	200	11.46	23.15	49.5	.888	469.6	25.02	28.18	2.35	.12
S	10	282	70	4.98	12.40	40.2	.311	718	13.38	43.08	3.59	.15
S	25	296	100	7.47	8.68	86	.444	352.4	9.36	21.14	1.76	.07
S	10	336	25	2.12	9.24	22	.111	1408	9.38	84.48	7.04	.25
S	30	335	125	10.57	30.06	35	.555	980	32.63	58.80	4.90	.18
S	30	335	150	12.69	41.67	30	.666	1120	44.76	67.20	5.60	.20
S	10	230	74	4.30	13.4	32	.320	736	14.16	44.16	3.68	.19
T	50	308	200	15.6	55.5	28	.889	1130	60.30	67.80	5.65	.22
S	20	249	155	9.75	20.2	48	.689	578	23.88	34.68	2.89	.14
S	30	331	269	22.5	47.1	47.8	1.20	709	51.06	42.54	3.55	.13
S	25	330	207	17.3	37.5	46.1	.920	733	40.44	43.98	3.67	.13
T	30	164	585	24.2	52	46.6	2.6	360	56.16	21.60	1.80	.13
T	15	184	60	2.79	16	17.4	.267	1083	17.34	64.98	5.42	.35
S	10	216	123	6.71	14.2	47.2	.546	469	15.36	28.14	2.36	.13
T	20	282	26	1.87	14.9	12.5	.116	2310	16.08	138.60	11.55	.49
S	15	323	96	7.85	22	35.7	.428	926	23.76	55.56	4.63	.17
T	30	319	118	9.51	28.6	33.2	.524	984	30.96	59.04	4.92	.19
S	15	316	145	11.6	16.7	69.5	.644	466	18.00	27.96	2.33	.09
S	7.5	239	69	4.16	11.6	35.8	.307	685	12.60	41.10	3.43	.17
S	7.5	184	51.5	2.39	7.05	33.9	.224	556	7.50	33.36	2.78	.18
S	15	172	8.57	.372	3.13	11.9	.0381	1480	3.38	88.80	7.40	.52
S	20	137	174	6.02	31.5	19.1	.733	734	32.28	44.40	3.67	.32
S	30	334	340	28.7	43.3	66.3	1.511	516	46.80	30.96	2.58	.09
T	10	132	64.2	2.14	6.25	34.2	.285	395	6.78	23.70	1.98	.18
T	20	142	150	5.38	14.4	37.4	.666	389	15.54	23.34	1.95	.16
T	30	142	317	11.4	26	48.8	1.40	298	25.02	17.88	1.49	.13
T	20	365	135	12.4	20.6	60.2	.600	621	22.38	37.26	3.11	.10
S	20	411	175	18.2	27.2	66.9	.777	629	29.34	37.74	3.15	.09
S	15	349	100	8.81	22.5	39.2	.444	911	24.24	54.66	4.56	.16
S	25	381	90	8.66	21.5	40.2	.400	970	9.30	58.20	4.85	.15
S	25	317	85	6.81	20.7	32.8	.377	988	22.32	59.28	4.94	.19
S	10	353	42.6	3.80	3.91	42.7	.189	847	9.60	50.82	4.24	.14
S	20	366	163	15.1	28.2	53.5	.724	701	30.48	42.06	3651	.11

TABLE 15. (Continued) Lighthouse Electric Cooperative Inc.
ENERGY EFFICIENCY DATA ON ELECTRIC WELLS

Type Pump	H. P. Rating	Operation Head/Ft.	GPM	Water H.P.	H.P. Input	Overall Eff.	Ac. Ft./ 24 Hours	Kwh/ Ac. Ft.	Cost/ 24 Hours	Cost/ Ac. Ft.	Cost/ Ac. In.	Cost/Ac. Ft./ Ft. Lift
S	15	297	37.5	2.81	16.4	17.1	.166	1780	17.70	106.80	8.90	.36
S	7.5	269	10	.679	15.7	4.3	.044	6380	16.86	382.80	31.90	1.42
S	15	287	142	10.3	19.3	53.3	.631	551	20.88	33.06	2.76	.12
S	15	344	143	12.4	20.3	61.1	.635	576	21.96	34.56	2.88	.10
S	10	210	115	6.10	6.61	92.3	.511	233	7.14	13.98	1.17	.07
S	10	339	61	5.22	12.1	43.2	.271	804	13.08	48.24	4.02	.14
S	10	292	43	3.17	13.4	23.7	.191	1260	14.46	75.60	6.30	.26
S	25	460	90	10.5	26.8	39	.400	1210	29.04	72.60	6.05	.16
S	25	285	63	4.53	26.1	17.4	.280	1680	28.20	100.80	8.40	.35
S	15	193	136	6.63	24.1	27.5	.604	719	26.04	43.14	3.60	.22
T	25	340	111	9.53	22.5	42.4	.493	821	24.30	49.26	4.11	.14
T	25	354	160	14.3	26.7	53.6	.711	676	28.86	40.56	3.38	.11
T	25	212	250	13.4	106	12.6	1.11	1720	114.54	103.20	8.60	.49
T	5	141	50	1.78	4.43	40.2	.222	359	4.80	21.54	1.80	.15
S	10	316	33.3	2.66	8.88	30	.148	1080	9.60	64.80	5.40	.21
S	10	306	74.1	5.73	14.7	39	.329	804	15.90	48.24	4.02	.16
S	10	308	35.9	2.79	9.09	30.7	.159	1030	9.84	61.80	5.15	.20
S	15	307	131	10.2	22.9	44.3	.582	710	24.78	42.60	3.55	.14
S	10	321	60.6	4.91	12.4	39.6	.269	830	13.38	49.80	4.15	.16
S	10	327	79.7	6.58	10.1	65.2	.354	513	10.92	30.78	2.57	.09
S	15	349	137	12.1	24.1	50.1	.608	713	26.04	42.78	3.57	.12
S	15	259	102	6.67	21.1	31.68	.453	839	22.80	50.34	4.20	.19
S	10	233	102	6.00	12.0	50.0	.453	477	12.96	28.62	2.39	.12
S	15	339	76.1	6.51	17.5	37.2	.338	933	18.90	55.98	4.67	.17
T	60	313	381	30.1	59.8	50.4	1.69	636	64.50	38.16	3.18	.12
T	60	288	205	14.9	43.2	34.5	.911	855	46.74	51.30	4.28	.18
T	50	288	188	13.7	40.4	33.8	.835	872	43.68	52.32	4.36	.18
T	50	283	284	20.3	41.1	49.4	1.26	586	44.28	35.16	2.93	.12
T	50	295	256	19.1	25	76.3	1.137	396	27.00	23.76	1.98	.08
T	50	272	279	19.2	47.6	40.4	1.24	689	51.24	41.34	3.45	.15
T	50	293	260	19.2	43.3	44.4	1.15	676	46.62	40.56	3.38	.14
T	50	232	387	22.7	44.5	50.9	1.72	467	48.18	28.02	2.34	.12
T	40	218	350	19.3	45.1	42.7	1.55	523	48.66	31.38	2.62	.14
T	100	243	939	57.6	111	51.8	4.17	480	120.12	28.80	2.40	.12
T	50	219	451	24.9	48.4	51.5	2.00	435	52.20	26.10	2.18	.12
T	50	200	706	35.7	57.9	61.6	3.13	332	62.34	19.92	1.66	.10
T	50	196	445	22	40.4	54.5	1.97	368	43.50	22.08	1.84	.11
S	15	287	111	8.04	18.8	42.8	.493	687	20.34	41.22	3.44	.14
S	75	248	41.4	2.59	10.7	24.3	.184	1050	11.58	63.00	5.25	.25
S	10	276	39.3	2.74	13.0	21	.174	1350	14.01	81.00	6.75	.29

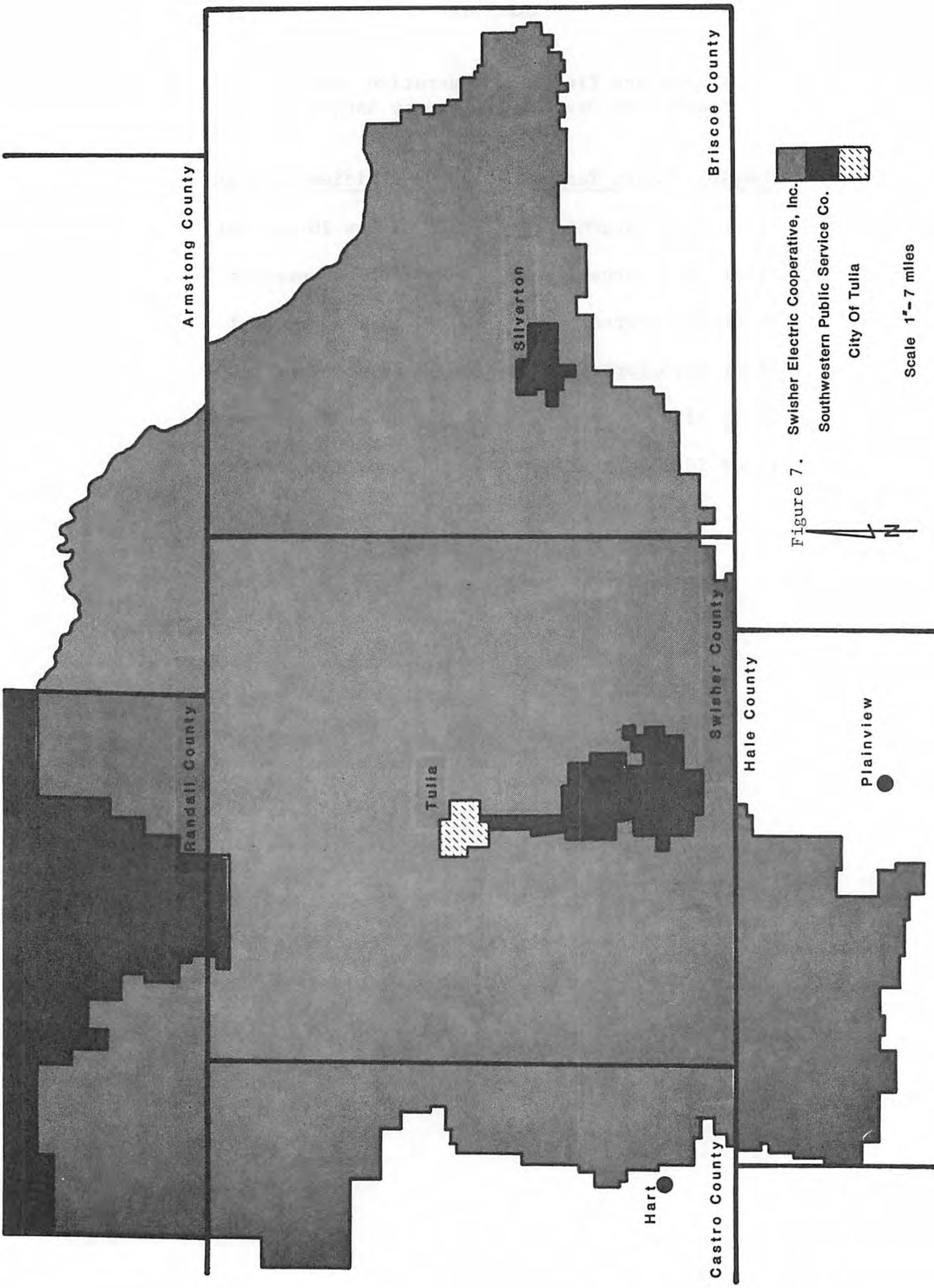
TABLE 15. (continued) Lighthouse Electric Cooperative Inc.
ENERGY EFFICIENCY DATA ON ELECTRIC WELLS

Type Pump	H. P. Rating	Operation Head/Ft.	GPM	Water H.P.	H.P. Input	Overall Eff.	Ac. Ft./ 24 Hours	Kwh/ Ac. Ft.	Cost/ 24 Hours	Cost/ Ac. Ft.	Cost/ Ac. In.	Cost/Ac. Ft./ Ft. Lift
T	30	202	103	5.25	29.9	17.6	.457	1180	32.34	70.80	5.90	.35
S	5	130	78.4	2.57	5.57	46.2	.348	288	6.00	17.28	1.44	.13
S	7.5	200	69	3.48	9.07	38.4	.306	533	9.78	31.98	2.67	.16
S	10	198	69	3.45	10.4	33.2	.306	610	11.22	36.60	3.05	.18
S	10	262	75	4.96	9.15	54.2	.333	495	9.90	29.70	2.48	.11
T	15	214	122	6.59	14.8	44.4	.542	493	16.02	29.58	2.47	.14
S	7.5	245	75	4.64	9.05	51.3	.333	489	9.78	29.34	2.45	.12
S	10	275	74.1	5.15	15.8	32.6	.329	863	17.04	51.78	4.32	.19
TOTAL	3290	34627	19729.4	1316.5	3336.0	4943.7	87.59	109947.8	3578.20	6732.67	561.50	25.24
AVG.	25.9	272.6	155.3	10.4	26.3	38.9	0.69	865.7	28.17	53.01	4.42	0.20

TABLE 16

Lighthouse Electric Cooperative, Inc.
Summary of Overall Efficiency Ranges

Pumping Plants Tested	Efficiency Range
16 or 12.6 Percent	Below 20 percent
14 or 11.0 Percent	20 - 29 percent
42 or 33.1 Percent	30 - 39 percent
26 or 20.5 Percent	40 - 49 percent
16 or 12.6 Percent	50 - 59 percent
13 or 10.2 Percent	Above 60 percent


Armstong County
Briscoe County
Silverton
Randall County
Swisher County
Tulia
Hale County
Plainview
Castro County
Hart
Swisher Electric Cooperative, Inc.
Southwestern Public Service Co.
City Of Tulia
Scale 1"= 7 miles
N
Figure 7.

SWISHER COUNTY ELECTRIC COOPERATIVE

The average overall efficiency for wells tested by the Swisher Electric Cooperative was 35.6 percent (Table 17). The lowest overall efficiency was 13 percent compared to the highest efficiency of 69 percent. The 13 percent efficiency was a well producing only 35 GPM. For wells producing below 100 GPM, the average overall efficiency was 21.5 percent. This is very low and would seem to be uneconomical to pump. Wells producing more than a 100 GPM had an overall efficiency of 48.6 percent.

The average cost to pump an acre-foot of water was $43.22. The average cost for wells pumping less than 100 GPM was $57.24 per acre-foot and for wells pumping more than 100 GPM the average was $30.37 per acre-foot. The less than 100 GPM capacity pumps had a cost per acre-foot per foot of lift of $0.30 compared to the average of $0.22. The greater than 100 GPM capacity pumps had a cost of $0.15 per acre-foot per foot of lift.

Both Well Number 1 and Well Number 7 (Table 17) had a pumping cost of $40.00 an acre-foot of water. Well Number 1 has an overall efficiency of 52 percent while Well Number 7 has 31 percent overall efficiency. We find that Well Number 1 has a lift of 341 feet while Well Number 7 has a lift of only 192 feet. Therefore, when the cost per acre-foot per foot of lift is compared, Well Number 1 costs $0.12 and Well Number 7 costs $0.21. Now the real effect of pumping plant efficiency can be visualized. Swisher Electric reported that only one pumping plant, or 4.4 percent, tested above 60 percent overall efficiency (Table 18).

TABLE 17. SUMMARY OF 23 PUMP EFFICIENCY TESTS PERFORMED BY SWISHER ELECTRIC COOPERATIVE, INC.

Well No.	Total Lift	GPM	Water HP	Input HP	Overall Eff.	KWH per Hour	Annual (KWH) Consumption	Annual Fuel Cost	Ac. Ft. Pumped	Cost/ Ac. Ft.	Cost/ Ac. In.	Cost/ Ac. Ft. Ft. Lift
1	341	225	19.4	37.0	52%	27.6	55200	3312.00	82.8	40.00	3.33	.12
2	217	175	9.6	20.4	47%	15.2	30400	1824.00	64.4	28.32	2.36	.30
3	218	235	12.9	26.7	48%	19.9	39800	2386.00	86.5	27.58	2.30	.13
4	190	45	2.2	8.9	25%	6.6	13200	792.00	16.6	47.71	3.98	.25
5	185	50	2.3	10.7	21%	8.0	16000	960.00	18.4	52.17	4.35	.28
6	180	40	1.8	8.4	21%	6.3	12600	756.00	14.7	51.43	4.29	.29
7	192	35	1.8	5.8	31%	4.3	8600	516.00	12.9	40.00	3.33	.21
8	206	35	1.8	9.9	17%	7.4	14800	888.00	12.9	68.84	5.74	.33
9	210	450	23.9	48.6	49%	36.3	72600	4356.00	165.7	26.29	2.19	.13
10	300	400	30.3	44.0	69%	32.8	65600	3936.00	147.3	26.72	2.23	.09
11	200	375	18.9	41.7	45%	31.1	62200	3732.00	138.1	27.02	2.25	.14
12	200	425	21.5	67.2	32%	50.1	100200	6012.00	156.5	38.42	3.20	.19
13	216	135	7.4	21.8	33%	16.3	32600	1956.00	49.7	39.36	3.28	.18
14	175	85	3.8	17.9	21%	13.4	26800	1608.00	31.3	51.37	4.28	.29
15	215	75	4.1	17.1	24%	12.8	25600	1536.00	27.6	55.65	4.64	.26
16	160	35	1.4	10.9	13%	8.1	16200	972.00	12.9	75.35	6.28	.47
17	200	50	2.5	14.7	17%	11.0	22000	1320.00	18.4	71.74	5.98	.36
18	200	55	2.8	9.8	29%	7.3	14600	876.00	20.3	43.15	3.60	.22
19	200	60	3.0	17.8	17%	13.3	26600	1596.00	22.1	72.22	6.02	.36
20	212	350	18.7	45.4	41%	33.9	67800	4068.00	128.9	31.56	2.63	.15
21	250	600	37.9	78.7	54%	58.7	117400	7044.00	220.9	31.89	2.66	.13
22	219	1050	58.1	101.9	57%	76.0	152000	9120.00	386.7	23.58	1.97	.11
23	215	300	16.3	29.2	56%	21.8	43600	2616.00	110.5	23.67	1.97	.11
Total	4901	5285	302.3	694.5	819%	518.2	460200	62182.00	1946.1	994.04	82.86	5.10
Avg.	213	230	13.1	30.2	35.6	22.5	20009	2703.57	84.6	43.22	3.60	0.22

TABLE 18

Swisher Electric Cooperative, Inc.
Summary of Overall Efficiency Ranges

Pumping Plants Tested	Efficiency Range
4 or 17.4 Percent	Below 20 Percent
6 or 26.1 Percent	20 - 29 Percent
3 or 13.0 Percent	30 - 39 Percent
5 or 21.7 Percent	40 - 49 Percent
4 or 17.4 Percent	50 - 59 Percent
1 or 4.4 Percent	Above 60 Percent

TABLE 19

Natural Gas Units
Hourly Pumping Cost Pumping 500 Gallons Per Minute
At Different Lifts & Pump Efficiencies

	Efficiency							
Lift (Feet)	10%	20%	30%	40%	50%	60%	70%	80%
100	$ 4.02	$2.01	$1.34	$1.00	$0.80	$0.67	$0.57	$0.50
150	6.02	3.01	2.01	1.51	1.20	1.00	0.86	0.75
200	8.03	4.02	2.68	2.01	1.61	1.34	1.15	1.00
250	10.04	5.02	3.35	2.51	2.01	1.67	1.43	1.26
300	12.05	6.03	4.02	3.01	2.41	2.01	1.72	1.51
350	14.06	7.03	3.01	3.52	2.81	2.34	2.01	1.76
400	16.07	8.04	5.36	4.02	3.21	2.68	2.30	2.01
450	18.08	9.04	6.03	4.52	3.62	3.01	2.58	2.26

Natural Gas Price: $3.00 per MCF

Motor Efficiency: 24 Percent

TABLE 20

Electric Powered Units
Hourly Pumping Cost Pumping 500 Gallons Per Minute
At Different Lifts & Pump Efficiencies

	Efficiency							
Lift (Feet)	10%	20%	30%	40%	50%	60%	70%	80%
100	$ 6.30	$ 3.15	$2.10	$1.58	$1.26	$1.05	$0.90	$0.79
150	9.42	4.71	3.14	2.36	1.88	1.57	1.35	1.18
200	12.54	6.27	4.18	3.14	2.51	2.09	1.79	1.57
250	15.72	7.86	5.24	3.93	3.14	2.25	2.62	1.97
300	18.84	9.42	6.28	4.71	3.77	3.14	2.69	2.36
350	21.96	10.98	7.32	5.49	4.39	3.66	3.14	2.75
400	25.14	12.57	8.38	6.29	5.03	4.19	3.59	3.14
450	28.26	14.13	9.42	7.07	5.65	4.71	4.04	3.53

Electricity Price Based on $0.06 per Kilowatt Hour

Electric Motor Efficiency at 90 Percent