TEXAS IRRIGATION
PUMPING PLANT EFFICIENCY TESTING PROGRAM

Final Report
submitted to the
State Energy Conservation Office

April 7, 1995

by

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Executive Summary

This report details an irrigation pumping plant testing program conducted by the Texas Agricultural Extension Service (TAEX) from May 1992 through December, 1994. The project was funded through a grant from the State Energy Conservation Office (formerly the Governor's Energy Office) for $119,500 and cost sharing by TAEX in excess of $100,000.

During this period, TAEX tested approximately 359 irrigation pumping plants throughout Texas. This report details the testing program and the results of 244 tests conducted by Byron Neal and Guy Fipps under this grant. These were performed in 25 counties in Central, South and West Texas in the attached map. The average overall efficiencies found in each region are shown in the following three charts. We found that in most areas the actual efficiencies were well below the industry standards, indicating excessive energy use. Assuming an average 2000 hours of operation per year, the potential energy savings with improvements in these pumps and engines (i.e. bringing them up to the standard efficiencies) could equal each year:

150,383 gallons of diesel,

51,908 Mcf of natural gas, and

3,449,623 kwh of electricity.

Assuming the cost of fuel shown on the fifth chart, this energy has a value of $507,923 per year.

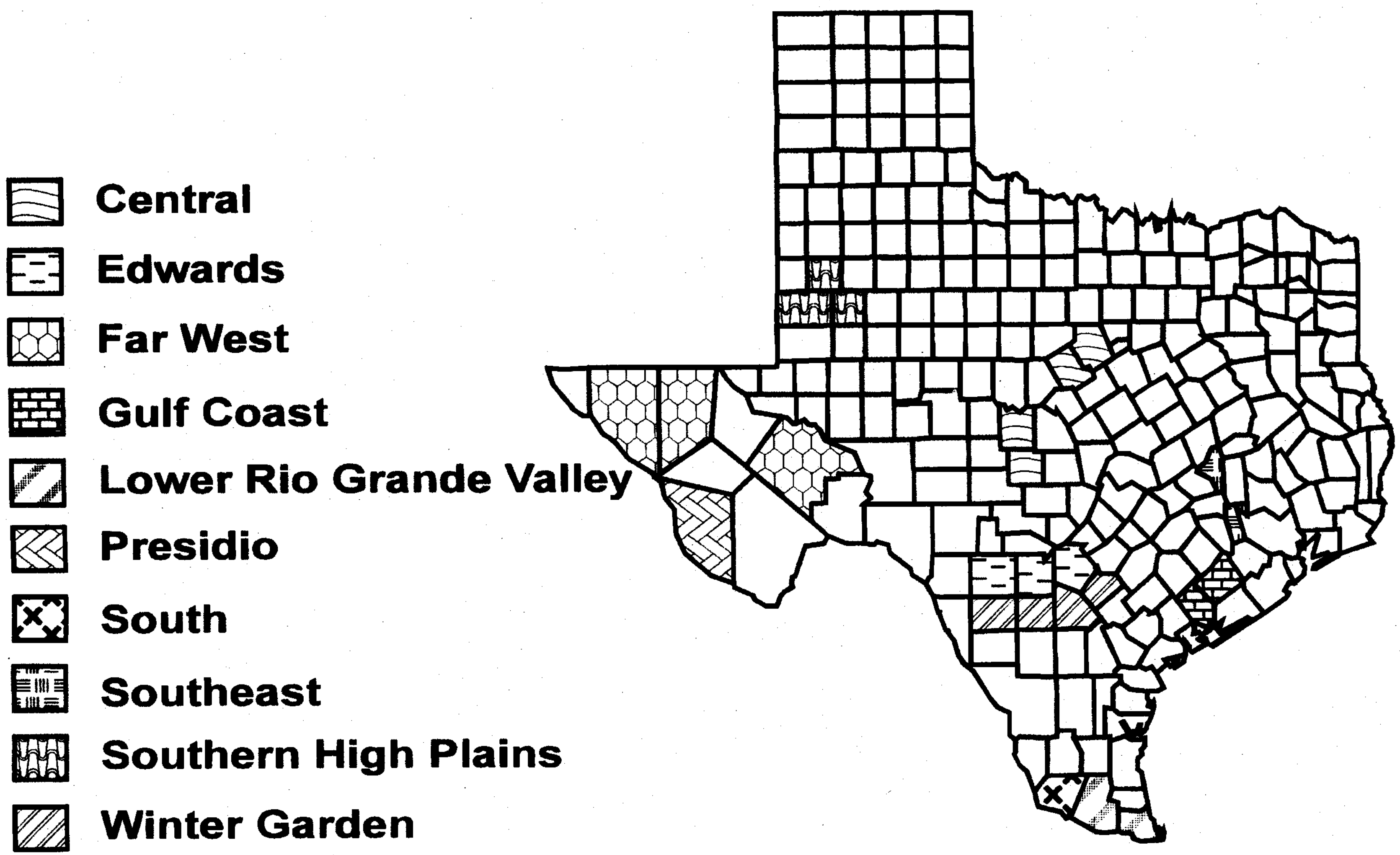
Information was also collected on conditions which may pose a serious safety hazard to pump operators and to preserving groundwater quality (by improper well head protection). The last two charts in this Executive Summary summarize these conditions. Over half of all pump installations surveyed lacked adequate guards and covers. All engines produced

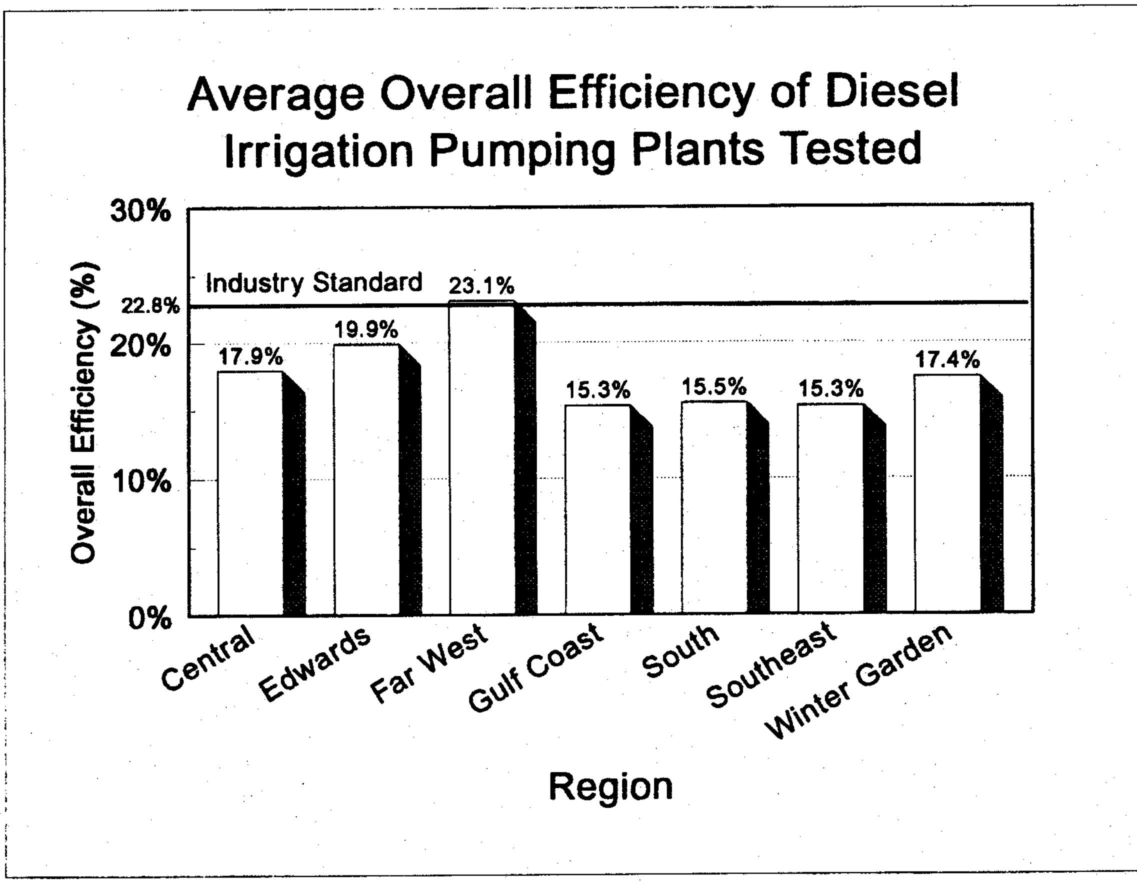
dangerous noise levels. On the positive side, we found that most pump installations meet current Texas well head construction regulations.

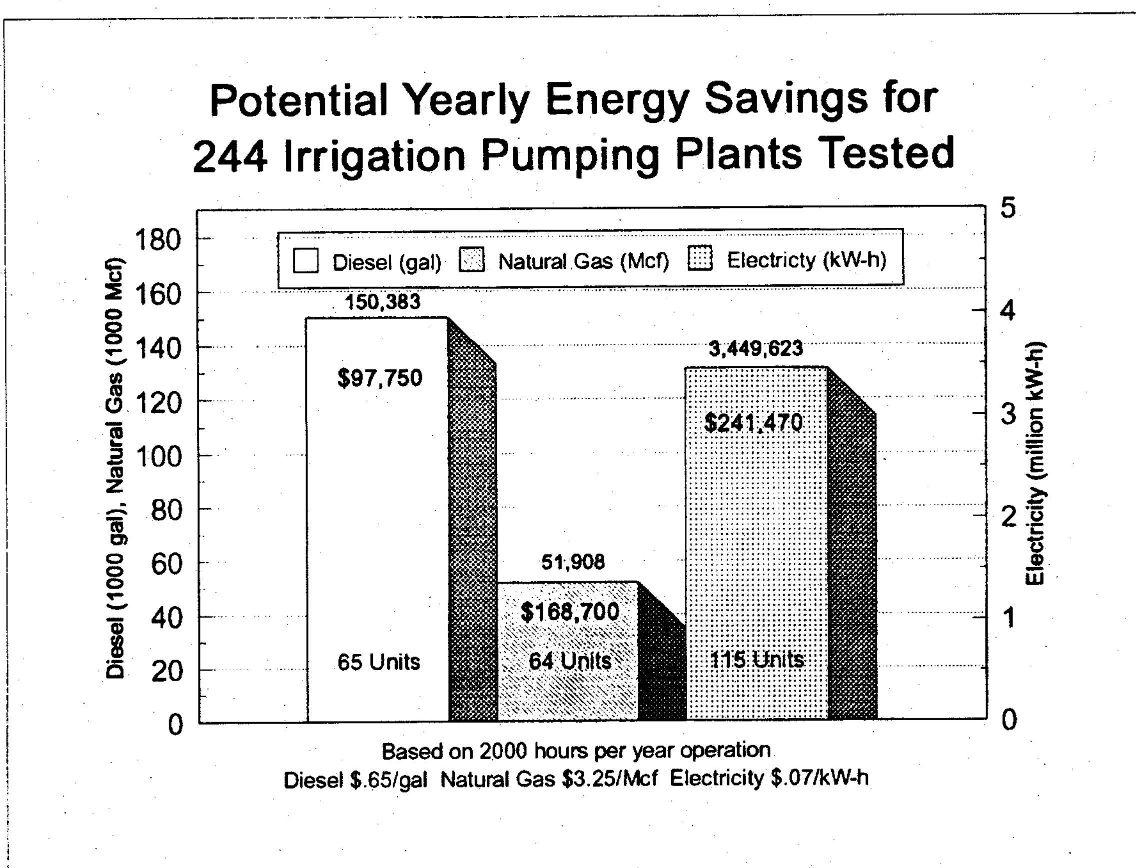
Among the many accomplishments of the project are the following:

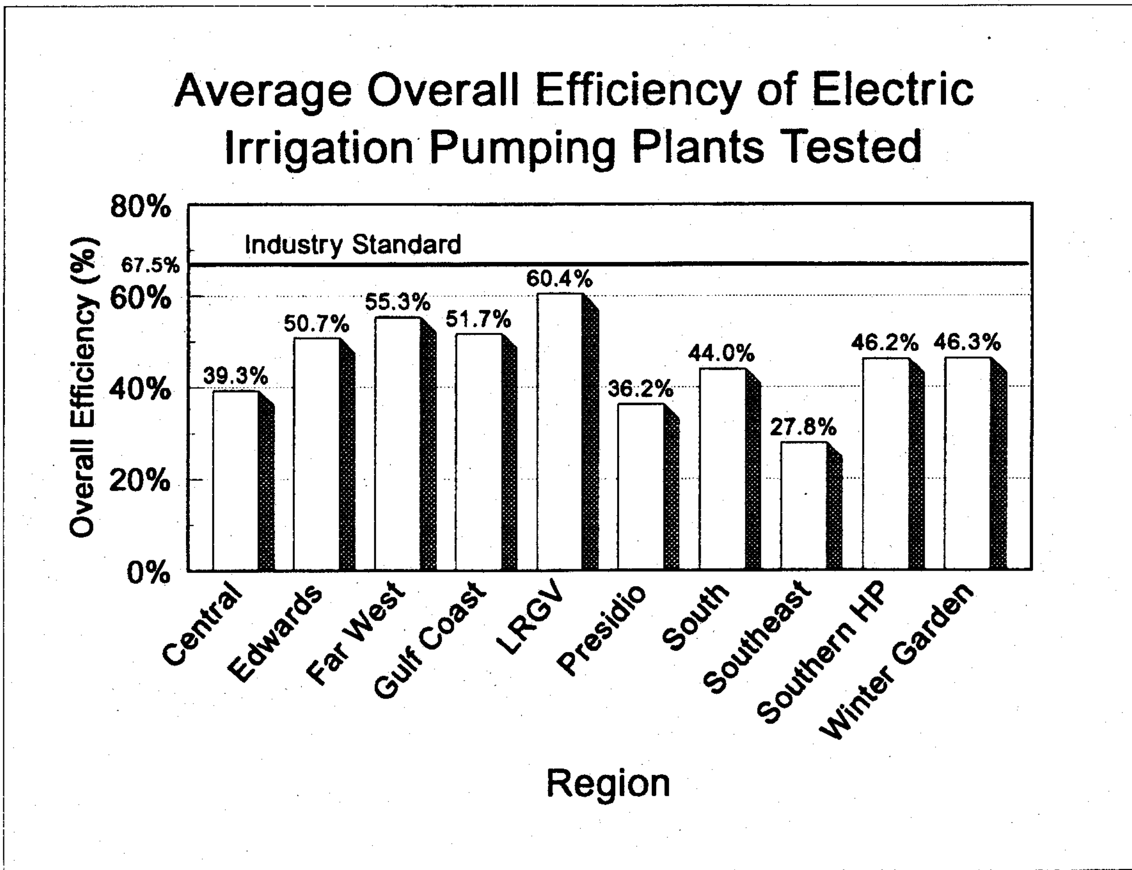
1. Development of the Texas Irrigation Pumping Plant Evaluation Software (TIPPES);
2. Tests conducted in 25 counties throughout Central, South, and West Texas, the first time this service has been available in most of these areas;
3. Cooperative testing programs were established with 6 groundwater districts, 6 irrigation districts, 2 major utilities, and two USDA multi-agency projects;
4. Numerous improvements in testing equipment and analysis procedures;
5. Creation of a data base to allow for energy and water policy analysis, including information on areas where no previous data is available;
6. Technical assistance and education for individuals, district, and agency personnel on the relationship between energy sue, water conservation and economic competitiveness;
7. Three publications and 12 news releases and articles on the results and benefits of the testing program;
8. Development of a safety check list to educate irrigators on operator and environmental safety hazards of their pump installations;
9. Identification of actual safety hazards in nearly all of the installations tested; and
10. A benefit-cost ration of about 5 to 1 (potential energy saving sin units tested per year/cost of the project per year). This benefit-cost ratio would be increased significantly if this testing program was continued.

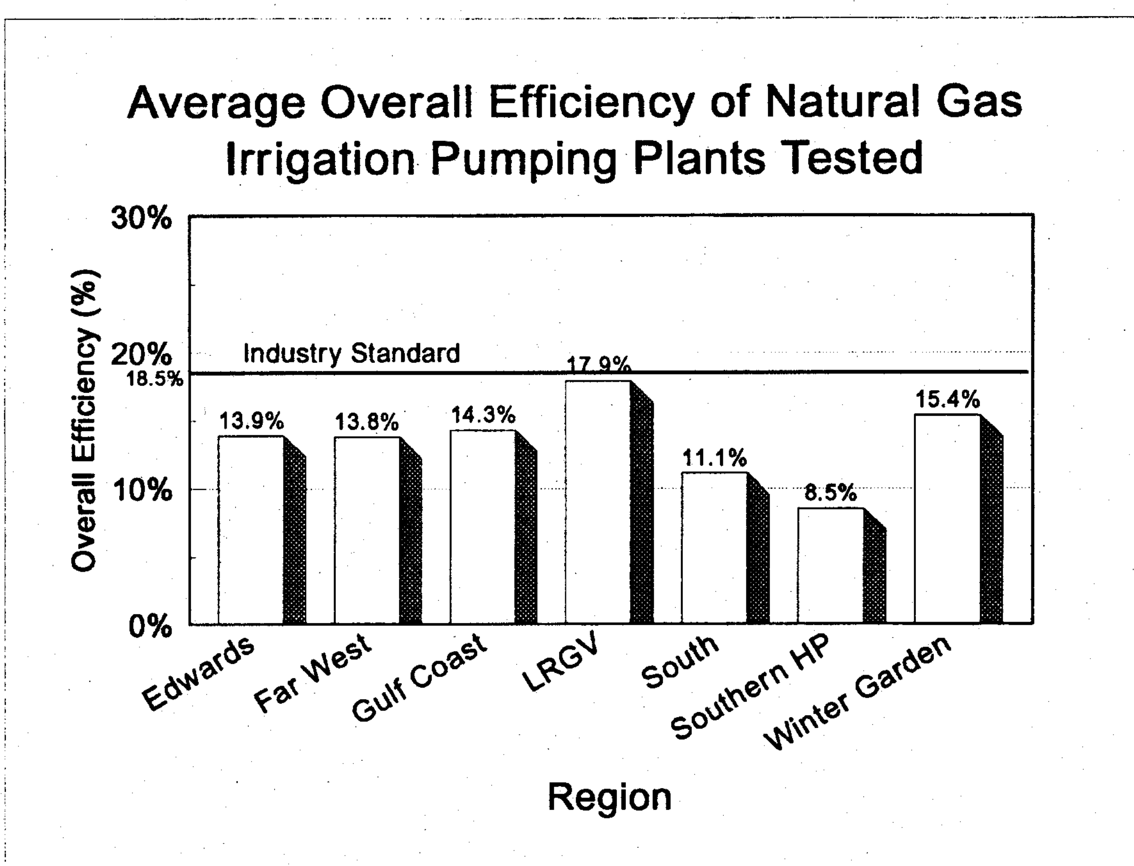
This testing program was originally approved as a four year project by the Governor and the U.S. Department of Energy. In October of 1994, TAEX requested funding from SECO for the remaining two years of the project, to which we have not received a reply. A copy of this proposal is included in Appendix H.


Central
Edwards
Far West
Gulf Coast
Lower Rio Grande Valley
Presidio
South
Southeast
Southern High Plains
Winter Garden


Average Overall Efficiency of Diesel Irrigation Pumping Plants Tested
30%
20%
10%
0%
22.8%
Overall Efficiency (%)
Industry Standard
17.9%
19.9%
23.1%
15.3%
15.5%
15.3%
17.4%
Central
Edwards
Far West
Gulf Coast
South
Southeast
Winter Garden
Region

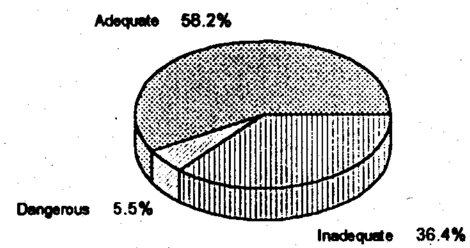

Potential Yearly Energy Savings for 244 Irrigation Pumping Plants Tested
Diesel (gal)
Natural Gas (Mcf)
Electricty (kW-h)
180
160
140
120
100
80
60
40
20
0
Diesel (1000 gal), Natural Gas (1000 Mcf)
5
4
3
2
1
0
Electricity (million kW-h)
150,383
$97,750
65 Units
51,908
$168,700
64 Units
3,449,623
$241,470
115 Units
Based on 2000 hours per year operation
Diesel $.65/gal Natural Gas $3.25/Mcf Electricity $.07/kW-h


Average Overall Efficiency of Electric Irrigation Pumping Plants Tested
Overall Efficiency (%)
80%
67.5%
60%
40%
20%
0%
Industry Standard
39.3%
50.7%
55.3%
51.7%
60.4%
36.2%
44.0%
27.8%
46.2%
46.3%
Central
Edwards
Far West
Gulf Coast
LRGV
Presidio
South
Southeast
Southern HP
Winter Garden
Region

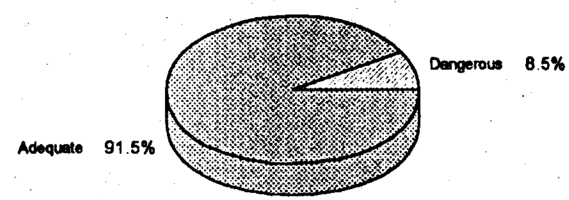

Average Overall Efficiency of Natural Gas Irrigation Pumping Plants Tested
Overall Efficiency (%)
30%
20%
18.5%
10%
0%
Industry Standard
13.9%
13.8%
14.3%
17.9%
11.1%
8.5%
15.4%
Edwards
Far West
Gulf Coast
LRGV
South
Southern HP
Winter Garden
Region

Safety Summaries
Wellhead Protection

Concrete Slab Conditions

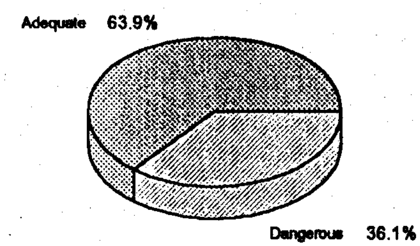


Pump Base Conditions

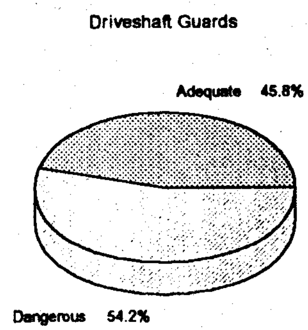


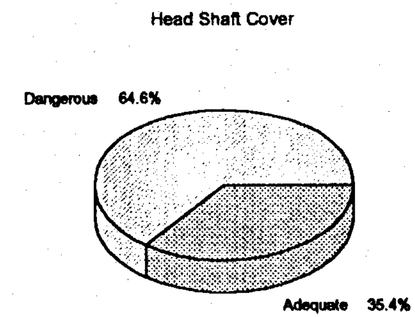
	Adequate	Inadequate	Dangerous
Concrete Slab	32	20	3
Pump Base	60	5	0
Check Valve	45	0	26

Check Valve Conditions

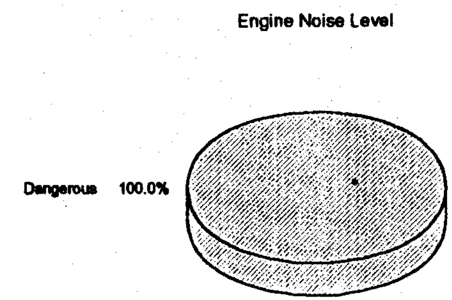


Safety Summaries
General Operator Safety





	Adequate	Inadequate	Dangerous
Driveshaft	27	0	32
Head Shaft Cover	42	0	23
Noise Level	0	0	61



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I. Background and Literature Review

This section provides a review of the results from previous irrigation pumping plant testing programs and presents the Nebraska performance standards for evaluating pumping plant efficiency.

A. Economic Considerations

Irrigation pumping plant efficiency testing provides growers with information for making decisions on repair or replacement of pumping plant components. New (1986) reported that a decrease in engine efficiency of 5% can result in a 25% increase in fuel use. Additionally a 33% decrease in pump efficiency can increase fuel costs by 50%, and a 67% decrease in pump efficiency would increase pumping costs 200%. New reported that the primary reasons for lower engine efficiencies and, thus, higher fuel consumption are wear, improper tuning and partial loading of the engine.

B. Standards

In 1986, Leon New (Extension Agricultural Engineer, Texas A&M University System) published the fact sheet "Pumping Plant Efficiency and Irrigation Costs" (New, 1986) in which he discussed in detail the factors which affect irrigation pumping plant efficiency. He presented standards and defined "attainable" efficiency for individual pieces of equipment (Table 1). New also presented the concept of the <u>fuel-cost analysis</u> for analyzing pumping plant efficiency and the <u>fuel-cost analysis per 100 foot of head</u> to compare units under different operating condition (Table 2).

Table 1. Attainable Irrigation Pumping Equipment Efficiencies. (New, 1986).

Equipment	Attainable efficiency percent
Pumps (centrifugal, turbine)	75-82
Right angle pump drive (gear head)	95
Automotive-type engines	20-26
Industrial engines	
Diesel	25-37
Natural Gas	24-27
Electric motors	
Small	75-85
Large	85-92

New and Schnieder (1988) discussed that the Nebraska performance criteria which are generally accepted as the maximum practical efficiencies for irrigation pumping equipment. These criteria are shown in Table 3. The Nebraska overall efficiencies are based on the assumptions of 75% efficiency for a turbine pump in a deep-well and 95% efficiency for right angle gear drives (usually used with internal combustion, engine pumping plants).

Table 2. Average Power Unit and Pump Efficiencies, Fuel Consumption, and Specific Fuel Cost for Natural Gas, Electric and Diesel Pumping Plants from Pumping Plant Efficiency Tests, 1975-85 (New, 1986).

		Electricity		
	Natural Gas	VHS	Submersible	Diesel
1. Number of tests	455	91	38	35
2. Power unit				
a. Horsepower, HP	87	81	20	108
b. Fuel per Hp,*	12.3	-	-	.062
c. Efficiency, %	20	90	79	30
3. Pump				
a. Flow rate, GPM	574	594	136	688
b. Pumping lift, ft	300	267	248	289
c. Discharge head, psi	14	20	12	40
d. Efficiency, %	58	58	51	66
4. Overall efficiency, %	11.6	52	40	19.3
5. Specific fuel consumption */acre-inch/100 ft head	272	17.3	22.9	1.16
6. Fuel cost @ *				
a. $ Per acre-inch	3.45	4.28	4.98	4.15
b. Specific water cost, $/acre-inch/100 ft. head	1.08	1.45	1.83	1.10

* Natural gas-cubic feet @ $4.00 MCF
Electricity-KWH @ $.08 KWH
Diesel-gallon @ $.95 gallon

Table 3. Nebraska Irrigation Pumping Plant Efficiency Criteria (New and Schneider, 1988).

Type	Power Unit Efficiency	Overall Efficiency
Electric	88%	66%
Diesel	33%	24%
Natural Gas	24%	17%

C. Previous Testing Programs and Results

While irrigation pumping plant testing programs have been conducted by numerous organizations in the U.S., only a few have been reported in the literature. The Agricultural Engineering Department at Texas Tech University (1968) reported the average overall efficiency of 134 pumps was 52.2%, and the average thermal efficiency of 46 natural gas engines was 19.8%. Abernathy, et al (1978) found that the pump and engine efficiencies of 52 natural gas pumping plants in New Mexico were 52% and 22%, respectively.

New and Schneider (1988) reported the results of 500 tests performed from 1975 through 1985. They found an average pump efficiency of 59%, with large geographic variations in efficiencies. Natural gas and diesel engine efficiencies averaged 21% and 31%, respectively; and the average overall efficiency of electric pumping plants was 47%. They also found that the average efficiencies of different types of electric pumping plants varied significantly. Vertical hollow shaft, submersible, and horizontal motors connected to right angle drives with V-belts were 52.9%, 40.9% and 35.4% respectively. New and Schnieder also reported an average efficiency of 43% in tests of 249 pumps conducted by the High Plains Underground Water Conservation District #1 (HPUWCD), with the average thermal efficiency of 21%.

Central Power and Light Company began a short-lived testing program in the early 1990's (Darcy, 1992). Due to limitations in their testing equipment (small torque meter), they were not able to test large internal combustion irrigation engines in the Winter Garden and other areas of South Texas. Except for overall efficiency testing of electric pumping plants by the Texas Water Development Board and some local offices of the Natural Resources Conservation Service, no other testing program has been attempted in the vast region of South Texas.

II. Project History and Accomplishments

The major emphasis in this project was to test irrigation pumping plants in areas where such testing is unavailable or limited, to performed detailed analysis of test results, to work with local water management districts and other organizations, to determine the need for a continuing testing program, and to collect additional data for evaluating pumping plant efficiency standards.

A. Project History

The history of this project is given in Table 4. Our proposal was originally approved for funding as a 4-year project by the Governor's Office in December 1990. We were later asked to submit a two-year budget and provide additional cost-sharing (while providing the same amount of service). We finally began work on the project in Fall of 1992. We encountered numerous delays and were only able conduct about 13 months of full-time testing as discussed below.

B. Explanation on the Number of Units Tested

During this project, the Texas Agricultural Extension Service (TAEX) tested approximately 359 irrigation pumping plants. This includes 244 by the College Station Unit and about 115 pumping plants tested by Leon New who is located at the Texas A&M Center in Amarillo. There are several reasons we were not able to reach our goal of 300 tests per year. These are discussed below.

We began work on the project in the Fall of 1992. However, we were not able to begin testing until June 1993 due to unexpected and uncontrollable delays. These included

Table 4. History of the Irrigation Pumping Plant Testing Program conducted by the Texas Agricultural Extension Service (TAEX) in cooperation with the State Energy Conservation Office (SECO).

Activity and Time Period
Original Proposal Submitted to the Governor's Energy Office: 1990
Contract between the Governor's Energy Office and TAEX signed: May 1992
Equipment specification review and purchase: November 1992 to May 1993
Trail testing to establish testing procedures and eliminate equipment problems: June 1993 to August 1993
Full-scale testing throughout the state: September 1993 to November 1994
Request for continued funding submitted to the SECO, October 1994
Data analysis and final reporting: December 1994 to March 1995
Audit by State Energy Conservation Office: February 1995

specifications review and bidding delays in the State Purchasing Office for the torque meter and drive shaft test kit, and then a 6-month wait for delivery of the torque meter from the manufacturer. The drive shaft test kit had to be built after the torque meter was delivered in order to ensure flange compatibility.

Our equipment specifications and set-up were based on that used on the Texas High Plains for the last 15 years. We found that numerous changes had to be made during the first three months of testing (June-August 1993) due to the significant differences in pumping plant installations and conditions in South Texas. Over the next year, we continued to run into unexpected problems and unconventional testing conditions which caused further delays and modifications.

During our first full year of testing (September 1993 - August 1994), we evaluated a total of 256 pumping plants. This is slightly lower than the average of 300 per year, but is within an acceptable range for the first year of testing during which time procedures and equipment modifications were constantly required and cooperative programs were being developed. We believe an average of 300 test a year would have been achieved if the project was continued for the full 4 years as originally approved.

C. Accomplishments

In this report we detail the many accomplishments of the project. Even though the testing program only lasted one-half the proposed duration, we were still able to meet the most important goals of the project. These include:

1. Development of the Texas Irrigation Pumping Plant Evaluation Software (TIPPES);
2. Tests conducted in 25 counties throughout Central, South, and West Texas, the first time this service has been available in most of these areas;
3. Cooperative programs were established with 6 groundwater districts, 6 irrigation districts, 2 major utilities, and two USDA multi-agency projects;
4. Numerous improvements in testing equipment and analysis procedures;
5. Creation of a data base to allow for energy and water policy analysis, including information on areas where no previous data is available. The data base includes new information on:

    a. fuel costs and usage in various locations around the state;

    b. energy (BTU) value of diesel fuel and natural gas by locations;

    c. potential fuel savings possible with repair or replacement of components;

6. Technical assistance and education for individuals, district, and agency personnel on the relationship between energy use, water conservation and economic competitiveness;
7. Three publications and 12 news releases and articles on the results and benefits of the testing program;
8. Development of a safety check list to educated irrigators on operator and environmental safety hazards of their pump installations;
9. Identification of actual safety hazards and nearly all of the installations tested; and
10. Achieved a benefit-cost ratio of about 5 to 1 (potential energy savings in units tested per year/cost of the project per year). This benefit-cost ratio would be increased significantly if this testing program was continued.

III. Equipment Specifications[1]

This sections provides information and specifications for the equipment used in the irrigation pumping plant efficiency testing program.

A. Torque Meter

A torque meter is used to measure the torque and speed (in revolutions per minute, rpm) produced by an engine. A *Lebow 1641-50K*, flange drive, non-contact rotary transformer coupled torque meter was chosen for use in this project. Specifications for this torque cell are as follows:

torque range: 0 to 50,000 in-lb,

speed rating: 0 to 4,000 Rpm,

torque overload range: 150,000 in-lb,

shipping weight: 85 lb,

speed pickup: 120 pulses per revolution,

electronic readout: 5 Digit display with decimal capable of displaying torque, speed and horsepower.

This torque meter provides a measurement range of 0 to 3,000 horsepower (hp) with ±1% hp accuracy.

[1]Trade names are provided for informational purposes only and does not imply endorsement by the Texas Agricultural Extension Service or the Texas A&M University System.

B. Torque Meter Mount and Support

We designed and constructed a support stand (Fig. 1) to support the torque meter during installation and to keep the torque meter from rotating during testing. We also constructed a test mount to aid in the installation of the torque meter during testing (Fig. 2) . The support stand also removes some of the weight load of the torque meter from the gear head. Each leg of the support is fully adjustable in height.

C. Drive Shaft Kit

A special test drive shaft connects the torque meter to the engine and the gear head. Various test drive shafts lengths, flange series and adapter plates are needed due to the variation of equipment commonly found in irrigation pumping plants installations. These components are referred to as the drive shaft kit. The drive shaft kit for this project was constructed by *Cargo Machine & Welding* in Amarillo, TX. Specifications for the kit is as follows:

one (1) 1410 series drive shaft for 24" test hookup,

one (1) 1410 series drive shaft for 36" test hookup,

one (1) 1410 series drive shaft for 48" test hookup,

one (1) 1610 series drive shaft for 36" test hookup,

one (1) 1610 drive shaft for 48" test hookup,

one (12) adapter plates for accommodating 1310 to 1710 series flanges.

We estimate that this kit is compatible with 80% of the pumping plant units in Texas.

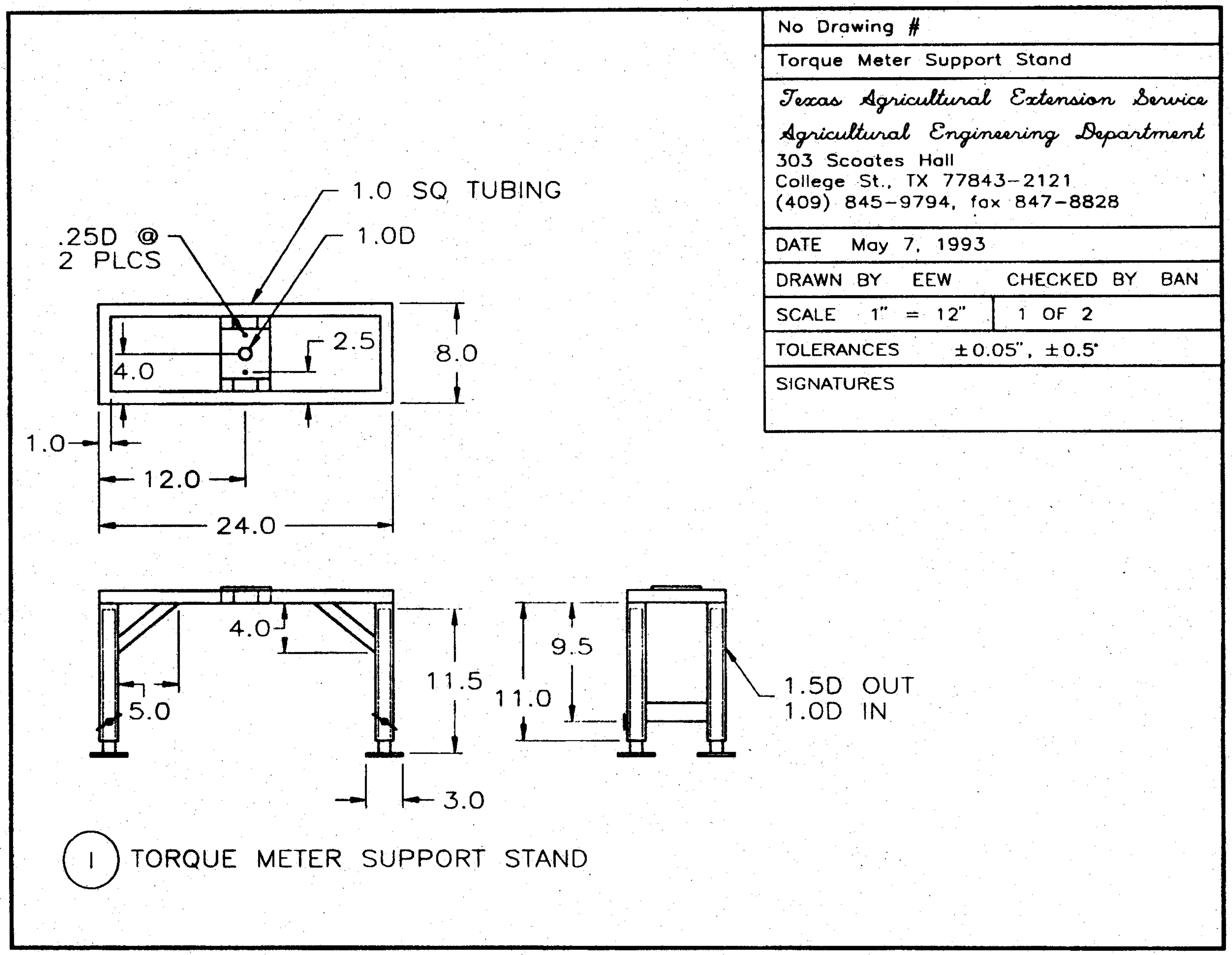

Figure 1. Drawing of the torque meter support stand.

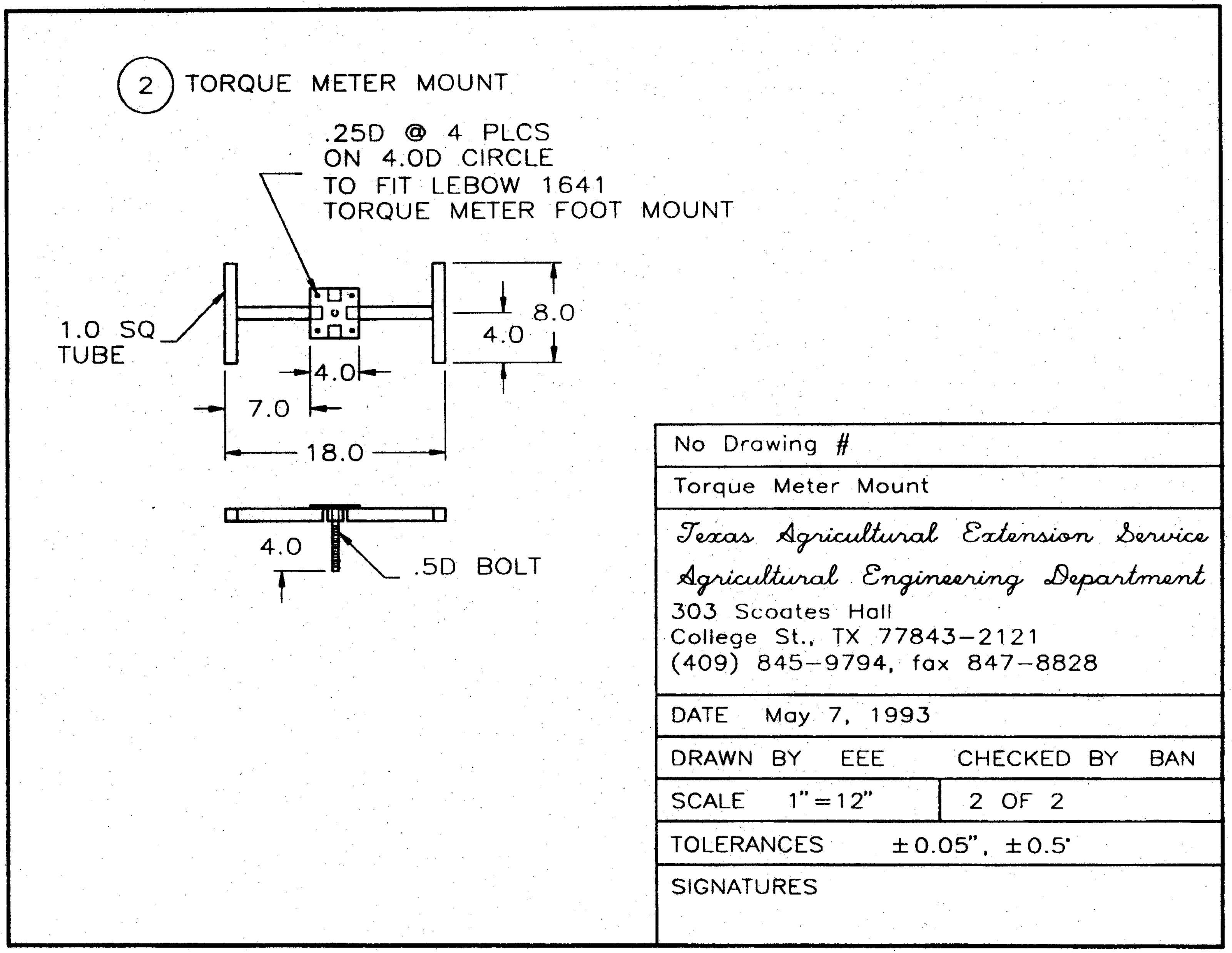

Figure 2. Drawing of the torque meter test mount.

D. Dial Indicator

In cases where the existing flanges are damaged or warped, excessive vibrations may be produced during testing in the test drive shaft and torque meter. Such vibrations can lead to failure of the installation and pose a serious hazard to equipment and personnel. A dial indicator with a magnetic mount was used to measure the maximum deviation from the perpendicular of the gear head flange's axis of rotation prior to testing. The dial indicator has a maximum measurement range of 1 inch and divisions of 0.001 inches. We found that if the flange deviated more than about 0.03 inches, excessive vibrations are likely.

E. Engine Fuel Consumption Measuring Devices

Engine fuel consumption is measured and used in calculating the efficiency of the engine and the overall efficiency. The most common fuel used in irrigation pumping plants are natural gas and diesel.

1. Natural Gas Meter and Connections

A standard gas supply meter was donated (anonymously) to the project for measuring natural gas consumption during testing. The meter has a pressure monitoring port and 4 ounce drive-pressure. Flexible rubber hoses were used to connect the gas meter to the natural gas supply line and to the intake port of the engine. The three most commons sizes of gas supply lines in Texas are 0.75, 1.0 and 1.25 inch. Connections were made to these lines with flexible rubber tubing of 1, 1.25 and 1.5 inch secured by hose clamps.

2. Diesel Fuel Meter

The equipment set-up for measuring diesel fuel consumption is illustrated in Fig. 3. We constructed a small test fuel tank (2.5 feet height, 6 inches in diameter with an approximate

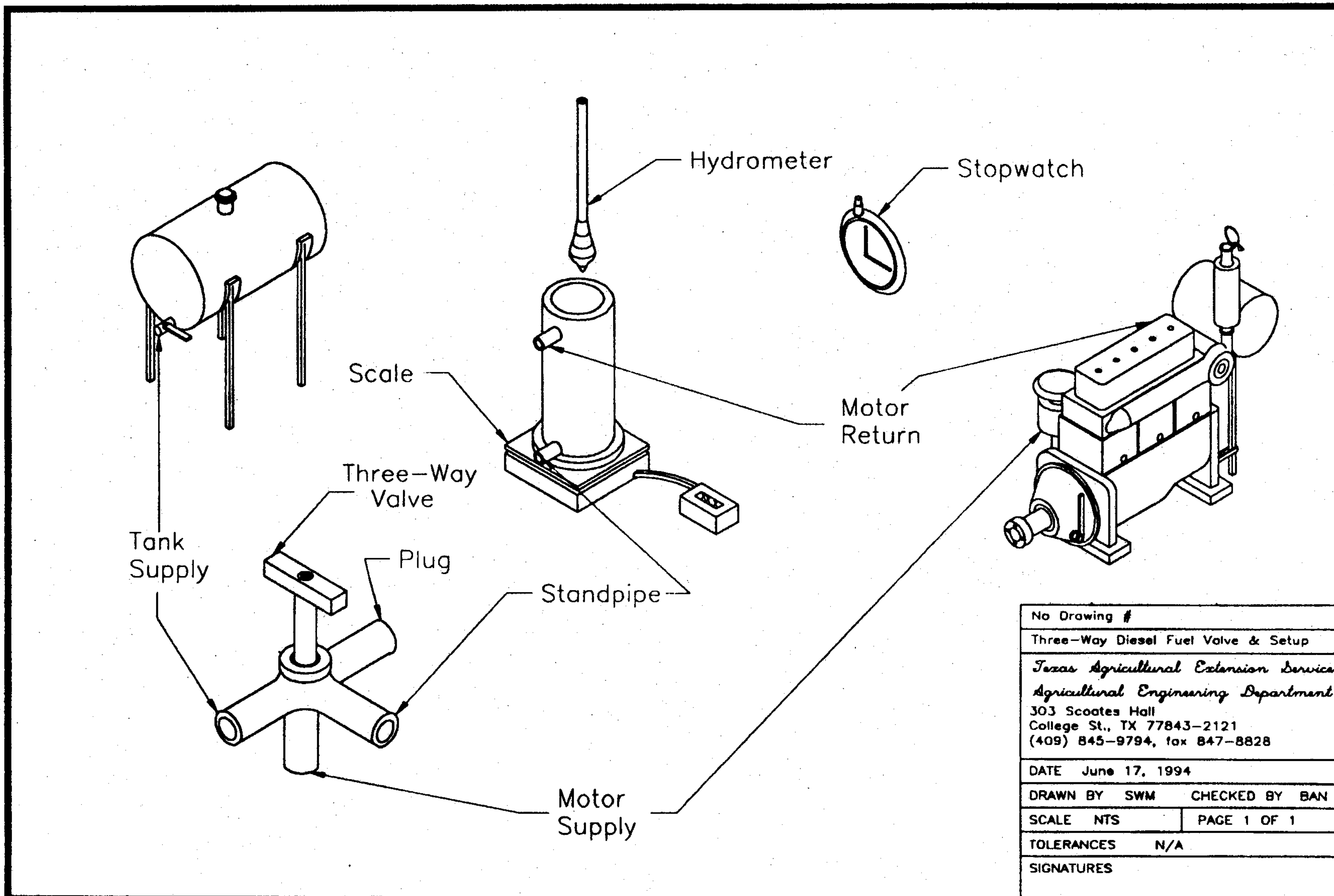

Figure 3. Schematic of equipment used for measuring diesel fuel consumption (not to scale).

capacity of 2.5 gallons) out of PVC pipe (schedule 40) and a square sheet of ¼ inch plexiglass. These materials were selected due to their availability and resistance to diesel fuel. During testing, the fuel tank is placed on a rechargeable digital scale, and the total weight of fuel consumed by the engine during testing is recorded. The scale has a capacity of 100 lbs and a resolution of 0.05 lbs.

A three-way diesel fuel valve and standard fuel line hoses connects the test fuel tank to the engine and to the main diesel supply tank. The valve was connected in such a way to allow the engine to obtain fuel from either the diesel supply tank, the fuel tank, or both (Fig. 3). The density of the fuel was measured with a light fluid hydrometer (with a range of 0.6 to 1.0). The temperature of the fuel was also measured and used to convert the fuel weight to volume.

F. Water Flow Meter

During testing, the water flow rate produced by the pumping plant is measured in the discharge pipe at a location as close as practical to the pump. A *Panametrics model PT868* portable ultra-sonic transit-time flow meter was purchased for non-intrusive flow measurement. The meter was equipped with an integrated pipe wall thickness measurement device and with both magnetic and chain mounting fixtures. This flow meter has the following specifications:

accuracy: ±1%,

measurable velocity range: 0.1 to 40 ft/sec,

repeatability: ±0.2% to 0.5%,

operation time per battery charge: 8 to 10 hours, operating temperature range: 14° to 122°F,

30-key tactile feedback membrane keypad,

64 x 128 pixel LCD graphic display,

able to measure flow through most standard metal and plastic pipe materials,

pipe wall thickness range: 0.05 to 3",

pipe size capability (outside diameter): 0.5 to 200".

G. Well Sounding Cables

Powers well sounders were used to measure static water level and pumping lift. Pumping lift is defined as the vertical distance between the water level in a well (or surface water source) and the centerline of the pump discharge during pumping. Static water level is the distance to the water table before pumping. The pump testing unit was equipped with 300 and 500 foot-long well sounders (with two wire electrodes, 5 foot graduations, and analog readout). Occasionally, the line will hang-up in the well casing or pump. In such instances, the line must be cut and tied off. The *Powers* well sounder was selected because it can differentiate between the water level in the well and the cascading water in the well column, and due to the ease of replacing damaged components.

H. Clamp Around Power Probe

A *Fluke* 80ikw "clamp around" power probe was used to measure the power consumption of electric motors. The power probe has the following specifications:

useable on any conductor up to 3" in diameter,

single or three phase power measurement capability,

A/C or D/C amps measurement capability,

useable on up to 660 volts A/C and up to 1000 volts D/C,

350 kw A/C or D/C power measurement capability.

I. Pressure Gauges

Three pressure gauges were purchased with the following ranges: 0 to 30 ounces per square inch, 0 to 100 psi, 0 to 200 psi. A vacuum and pressure gauge with a range of 35 inches of vacuum to 15 psi of pressure was also purchased. These gauges were used to measure the pressure in the discharge pipe of the pump, the pressure of the natural gas in the gas meter, and air line pressure (if needed).

J. Portable Gasoline A/C Generator

The torque cell requires AC power. A standard portable 1.8 kilowatt gasoline generator was used to provide AC power at 110 volts.

K. Hand Tools

Standard hand tools were purchased for installation and maintenance of the testing equipment. Tools include combination wrenches, adjustable wrenches, pipe wrenches, ratchets and sockets, and standard and philip screw drivers.

L. Equipment Trailer

We designed and constructed a trailer to hold and transport all of the required testing equipment (Fig 4). The trailer was equipped with 8 doors to provide convenient access to the testing equipment located on two internal shelves. An open door warning light was installed for the rear two doors and located such that it was visible in the rear view mirror.

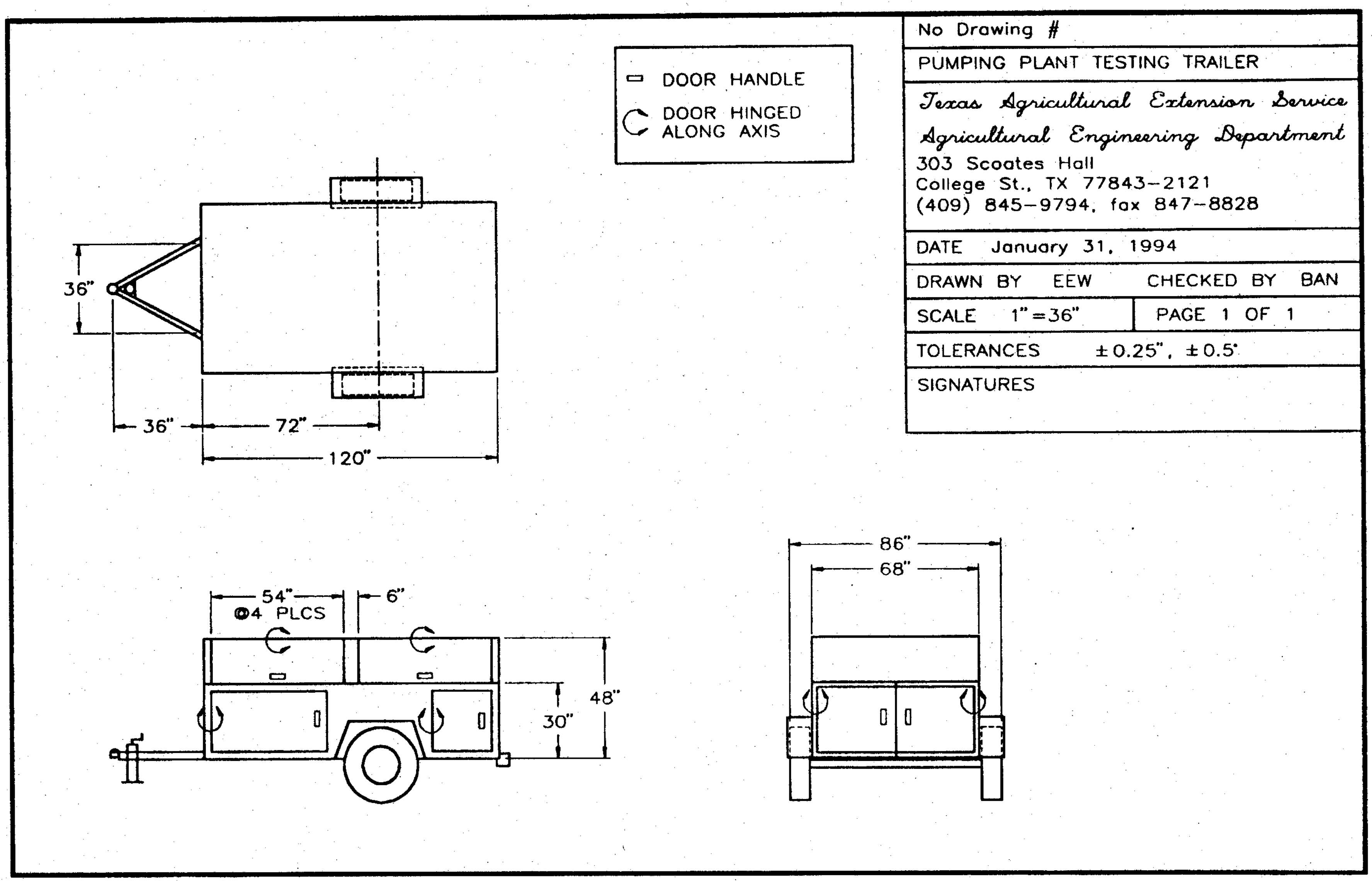

Figure 4. Drawing of custom designed trailer for storing and transporting testing equipment.

The trailer's specifications are as follows:

3,600 lb axle,

20 gauge sheet steel skin,

1" square tubing frame,

weather proof,

locking doors, and

2" locking ball coupler,

1,000 lb ram jack.

M. Laptop Computer

A laptop personal computer and portable ink-jet printer were used to perform pumping plant efficiency analysis in the field and to print out the results. The specifications of this computer are:

80386 25 MHz processor,

120 MB hard drive,

256 grey scale VGA display,

integrated track ball mouse,

4 MB RAM, and

3.25" internal floppy disk drive.

The specifications of the portable ink-jet printer are:

paper supply speed: 6.7 seconds/sheet,

size: 15.4" wide, 2.1" long, 8.5" high,

weight: 1.8 lbs.

IV. Testing Procedures

Testing procedures for internal combustion and electric pumping plants are discussed in this section, as well as some common problems encountered.

A. Testing Procedure for Internal Combustion Engine Power Units

The testing procedure for all internal combustion engines (natural gas, diesel or dual fuel) is similar.

1. Torque Meter Installation

The torque meter measures the power output of the engine. Installation of the torque meter is as follows:

a. The operating drive shaft between the engine and gear head is removed.

b. The dial indicator is positioned on the face of the gear head flange. The flange is then slowly rotated to measure the maximum deviation. If the maximum deviation is more than 0.03 inches, the torque cell is installed with a shim to try to obtain safe and smooth operation.

c. The torque cell is installed on the gear head flange.

d. The adapter drive shaft is installed between the engine flange and the torque cell.

2. Engine Fuel Use

For **natural gas engines,** we install our gas meter between the supply pipeline and the intake of the carburetor using flexible rubber hoses (for accuracy, the gas meter must have a pressure monitoring port and a known drive pressure). If the existing gas meter is used, the gas company must be contacted to obtain the correction factor for that particular meter.

For **diesel engines**, the test fuel tank is installed between the main supply tank and the fuel intake port of the engine. A three-way valve selects the source of fuel supply. Since most diesel engines return excess fuel to the main supply tank, the return line must also be connected to the test fuel tank. A scale measures the weight of fuel consumed by the engine during testing. The weight of fuel is converted to volume with the fuel's density measured with a hydrometer. For dual-fuel engines (operating on natural gas and diesel simultaneously) both the natural gas and the diesel fuel connections are used.

3. Static and Pumping Water Level

The well sounder is inserted into the well bore through an access port usually found in the pump base. If missing, an access hole is drilled where possible. After testing, the newly drilled access hole must be plugged.

4. Discharge Pressure

A pressure gauge is installed on the discharge pipe as close to the pump as feasible. If a suitable port is not available, a port is drilled where possible.

5. Flow Rate

The ultra-sonic flow meter is attached to the outside of the discharge pipe as close to the pump as feasible. When this is not practical (due to such situations as too short of a straight run, too much turbulence, or excessive pipe corrosion) flow is measured at another point in the water distribution system or at a discharge point with an inline flowmeter.

6. Warm-Up

After all equipment is installed, the motor is started and brought up to normal operating temperature. The pump is then engaged and brought up to normal operating speed. The system is allowed to operate until all air is flushed out of the discharge pipe lines and normal operating pressures are achieved.

7. Testing

Engine torque, engine speed (rpm), engine output horsepower, water flow rate, discharge pressure, pumping lift, and fuel consumption are recorded on the appropriate field data sheet (see Appendix A). The test data is collected during 3 to 5 repetitions. Following testing, the pumping plant is shut-down, the testing equipment is removed, and the unit is restored to its original status.

8. Data Analysis

The data collected during testing is entered into TIPPES (Texas Irrigation Pumping Plant Efficiency Software) on the laptop computer. The software performs all necessary calculations and prints a report with the portable ink-jet printer. Included in the report are:

1. the measured efficiency of the engine,
2. the measured efficiency of the pump,
3. the overall efficiency of the pumping plant,
4. the operational costs based on the actual fuel prices, and
5. projected savings with improvements to the pumping plant (to bring the unit up to standard efficiency).

B. Testing Procedure for Electric Power Units

Testing electric pumping plants is simpler and takes less time than internal combustion units. Most electric power units are coupled directly to the pump, so that it is impossible to install a torque meter.

1. Motor Efficiency

Since most electric pumping plants do not use drive shafts, the efficiency of the motor is estimated based on *Motor Master*. *Motor Master* is a software package containing efficiency data on most grades of electric motors. *Motor Master* is distributed by the Washington State Energy Office.

2. Static and Pumping Water Level

The well sounder is inserted into the well bore through an access port usually found in the pump base. If missing, an access hole is drilled where possible. After testing, the newly drilled access hole must be plugged.

3. Discharge Pressure

A pressure gauge is installed on the discharge pipe as close to the pump as feasible. If a suitable port is not available, a port is drilled where possible.

4. Flow Rate

The ultra-sonic flow meter is attached to the outside of the discharge pipe as close to the pump as feasible. When this is not practical (due to situations such as too short of a straight run, too much turbulence, or excessive pipe corrosion) flow is measured at another point in the water distribution system.

5. Electric Power Consumption

The motor control box is opened, and the electrical leads and contacts are inspected to determine if the power probe can be safely used. In some cases, there is not sufficient clearance between the leads, fuse assembly, starter relay, and the control box. With the motor operating, the power probe is clamped around the electric leads and a second connection is made on the line of the phase being measured. The probe measures the amps and kilowatt load of each phase of the motor. The kilowatt load of each phase are added together to determine the electrical power consumption of the motor.

Wherever feasible, the power probe measurement is used instead of an existing meter. This is because with an existing meter it is often difficult to obtain an accurate power consumption in a reasonable length of time. If the pumping plant draws more than 660 volts, connection of the power probe is not recommended by the probe's manufacturer. In these cases, a dedicated electric meter from the power supplier must be used to measure the electrical power consumption.

6. Pre-test

The pump is engaged and brought up to normal operating speed. The system is allowed to operate until all air is flushed out of the discharge pipe lines and normal operating pressures are achieved.

7. Testing

The flow rate, discharge pressure, input power and pumping lift are recorded on the field data sheet (Appendix A). The appropriate data is collected during 3 to 5 test repetitions. When all data has been collected, the equipment is removed and the control box is closed.

8. Data Analysis

The data collected during testing is entered into TIPPES (Texas Irrigation Pumping Plant Efficiency Software) on the laptop computer. The software performs all necessary calculations and prints a report with the portable ink-jet printer. Included in the report are:

1. the estimated efficiency of the engine (from the *Motor Master* software package),

2. the overall efficiency of the pumping plant,
3. the operational costs based on the current fuel prices, and
4. projected savings with improvements to the pumping plant to bring the unit up to standard efficiency.

C. Common Problems

About one quarter of the pumping plants we encountered did not have well bore access ports. In some cases, an access port can be drilled in the pump base support or in the well casing. This port is plugged after the testing is completed. If an access hole cannot be installed, the pumping lift must be estimated using the water level in a nearby well or by other means.

Another problem frequently encountered was warped flanges on the gear head. Our torque meter is about 14" long and weighs over 100 pounds. Excessive vibration of the torque meter could potentially cause a failure of the gear head. Sometime inserting shims between the torque meter and the gear head flange reduced the vibration to an acceptable level. We had success with shims made from pieces of aluminum cans. If shims do not reduce the vibration, the torque meter is immediately removed and the test is completed without it. However, without the torque meter, the engine efficiency and the pump efficiency cannot be separated from the overall efficiency of the pumping plant.

V. TIPPES

TIPPES (Texas Irrigation Pumping Plant Evaluation Software) was developed in this project and performs all necessary calculations for determination and reporting of pumping plant efficiency test results. The software is written in *Visual Basic for DOS* and considers four types of power units: diesel, natural gas, electric, and dual-fuel (diesel and natural gas). The software calculates efficiencies, fuel or power consumption, average flow rate, total head and the potential savings, stores the test data, and generates a printed report. Appendix C contains a complete summary of the equations used in TIPPES. The TIPPES users guide is in Appendix G and a copy of the software is included on a diskette with this report. David Smith and Ed Wilson assisted in the design of the software and in programming.

VI. Data Base

A data base containing all pumping plant efficiency test results was created in *dBase*. The data base contains 15 fields of data as follows:

1. test identification number,
2. irrigation method,
3. engine model,
4. engine rpm,
5. engine horsepower,
6. engine fuel consumption,
7. engine efficiency,
8. volumetric water flow rate,
9. pumping lift,
10. discharge pressure,
11. pump efficiency,
12. overall efficiency,
13. pumping cost per hour,
14. pumping cost per acre-inch, and
15. pumping cost per acre-inch per 100′ of head.

A print out of the data base can be found in Appendix D and a diskette containing the data is included with this report.

VII. Cooperators

Cooperating organizations in testing areas are indispensable. Local organizations such as water conservation districts, public utilities, and irrigation districts help by identifying and contacting growers interested in having a test performed and by scheduling efficiency tests. Whenever possible, we allowed the cooperating organization to determine the local testing schedule. We requested these organizations provide personnel to assist with the installation of test equipment.

The following is a list of agencies and organizations that cooperated with us in this project.

Bay View Irrigation District #11

Cameron County Irrigation District #2

Central Power and Light Co

Evergreen Underground Water Conservation District

Hickory Underground Water Conservation District

Hidalgo County Irrigation District #1

Hidalgo County Irrigation District #2

Hidalgo County Irrigation District #6

Medina County Underground Water Conservation District

Mesa Underground Water Conservation District

Santa Cruz Irrigation District #15

Seco Creek Water Quality Demonstration Project

South Plains Underground Water Conservation District

Texas Water Development Board

TU Electric Co.

United Irrigation District

Upper North Bosque River Hydrologic Unit Project

Uvalde County Underground Water Conservation District

VIII. County Test Results

We tested irrigation pumping plants in 25 counties throughout Central, South and West Texas as shown in Fig. 5. In Tables 5, 6, and 7, the test results are summarized for each county. Information is provided on the number of units tested in each county, the average overall efficiency, fuel use, and water costs. Water costs are given in terms of the cost of fuel to produce an acre-inch of water, and the fuel costs to produce an acre-inch with 100 ft head. This standardized cost is useful in comparing units operating at different loads.

Table 5 lists the averages from 65 diesel pumping plant efficiency results in 14 counties. Overall efficiencies ranged from a low of 10.9% in Brazos County to a high of 23.1% in Culberson County. The mean overall efficiency of 18.1% is slightly lower than the 19.3% reported by New (1986).

The overall efficiencies from the natural gas tests (Table 6) show a range from 7.5% in Terry County to 17.9% in Hidalgo County. The mean overall efficiency of 13.1% is higher than the 11.6% reported by New (1986), primarily due to the larger power units in our tests.

The overall efficiencies of the electric power units (Table 7) varied significantly form 27.8% in Waller County to 63.4% in Hidalgo County. Generally, the larger the power unit (in kw-h), the more efficient the pumping plant.

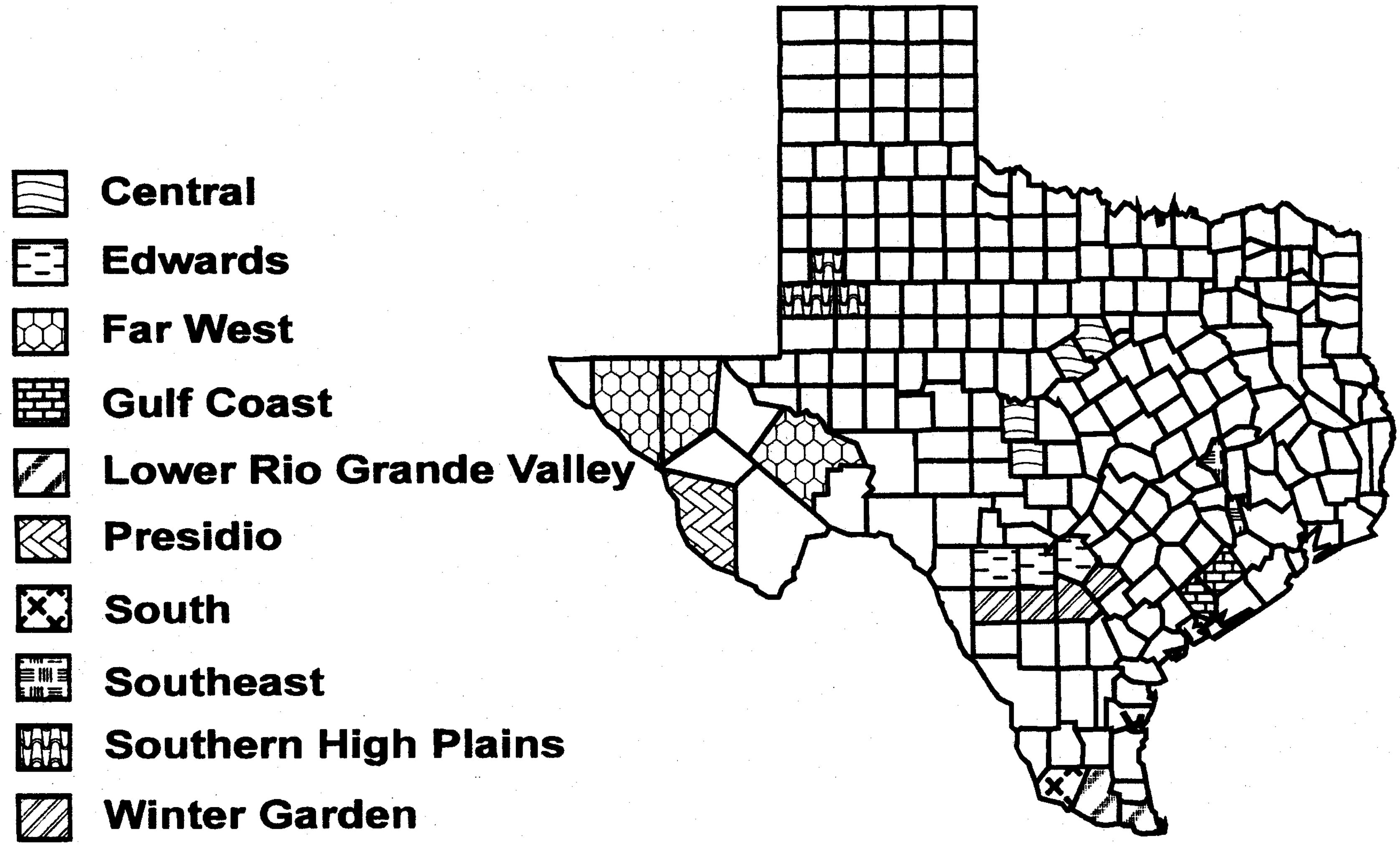

Figure 5. Counties and Test Regions where irrigation pumping plant efficiency testing took place.

Table 5. Diesel Pumping Plant Test Results by County.					
County	Number Tested	Average Overall Efficiency	Average Fuel Use (gal/hr)	Average Cost ($/Ac-in)	Standardized Cost ($/Ac-in)
Atascosa	5	15.8%	3.4	$1.69	$1.75
Bexar	6	12.2%	3.8	$1.01	$0.80
Brazos	1	10.9%	1.2	$0.57	$0.61
Culberson	2	23.1%	8.5	$1.72	$1.95
Frio	4	18.9%	11.3	$3.62	$3.67
Jackson	4	15.3%	9.3	$1.30	$1.30
Mason	2	17.6%	5.8	$4.17	$2.68
McCulloch	1	18.5%	3.2	$2.27	$3.35
Medina	24	24.1%	8.1	$1.51	$1.43
Starr	4	15.5%	5.0	$0.81	$1.04
Uvalde	7	13.9%	5.4	$1.28	$1.21
Waller	3	19.7%	4.3	$1.03	$1.22
Wilson	1	23.9%	2.5	$0.43	$0.39
Zavala	1	12.5%	1.6	$1.21	$1.27
Mean		18.1%	6.5	$1.21	$0.83
Standard Deviation		0.064%	3.8	$2.55	$2.50
Total	65				

Standardized costs based on $0.65/gallon

Table 6. Natural Gas Pumping Plant Test Results by County.					
County	Number Tested	Average Overall Efficiency	Average Fuel Use (Ccf/hr)	Average Cost ($/Ac-in)	Standardized Cost ($/Ac-in)
Bexar	1	14.1%	911	$0.90	$0.53
Dawson	1	11.5%	544	$1.73	$1.79
Frio	4	17.3%	1445	$2.10	$2.53
Hidalgo	6	17.9%	3652	$0.20	$0.17
Hudspeth	7	11.4%	1314	$0.55	$0.96
Jackson	7	14.3%	1170	$1.04	$0.93
Medina	2	16.2%	1525	$1.56	$1.26
Pecos	26	14.3%	1675	$1.06	$1.71
Starr	4	11.1%	1044	$0.84	$1.11
Terry	3	7.5%	343	$1.05	$1.61
Uvalde	1	9.2%	462	$0.44	$0.50
Zavala	2	12.6%	1537	$2.58	$2.64
Mean		13.1%	1592	$1.39	$0.76
Standard Deviation		0.035%	958	$3.92	$3.11
Total	64				

Standardized cost based on $3.25/Mcf

Table 7. Electric Pumping Plant Test Results by County.					
County	Number Tested	Average Overall Efficiency	Average Fuel Use (kw-h)	Average Cost ($/Ac-in)	Standardized Cost ($/Ac-in)
Atascosa	3	42.9%	33.9	$2.64	$3.04
Cameron	8	52.6%	32.5	$0.14	$0.14
Comanche	7	46.4%	8.7	$3.41	$1.79
Culberson	1	48.2%	41.0	$5.49	$4.70
Dawson	5	52.6%	24.7	$1.64	$2.31
Erath	16	35.8%	5.6	$1.99	$2.09
Gaines	11	44.4%	17.8	$2.19	$2.47
Hidalgo	21	63.4%	238.5	$0.29	$0.29
Hudspeth	2	58.8%	35.0	$0.65	$1.01
Jackson	1	51.7%	56.6	$1.02	$1.19
McCulloch	1	45.0%	56.3	$3.23	$2.85
Medina	10	58.3%	125.3	$2.04	$2.30
Presidio	5	36.2%	24.4	$0.54	$0.43
Starr	6	44.0%	59.8	$0.93	$0.94
Terry	6	44.2%	17.3	$3.05	$2.50
Uvalde	8	42.2%	69.4	$1.36	$1.63
Waller	1	27.8%	116.8	$2.85	$3.26
Zavala	3	49.8%	91.3	$2.18	$2.07
Mean		42.6%	76.9	$1.94	$1.49
Standard Deviation		0.155%	92.2	$6.03	$6.45
Total	115				

Standardized cost based on $0.07/kw-h

IX. Regional Descriptions and Testing Results

We grouped the 25 counties where testing was performed into 10 Test Regions as illustrated in Fig 5. These test regions are similar in the types and sizes of power units, pumping lifts and flow rates. The test results are shown for each power unit by test region in Tables 8, 9, 10, 11 and 12. In this section, each test region is described, including information on water supplies, water quality, pumping conditions and measured overall efficiency.

A. Central Test Region

The Central Test Region includes Comanche, Erath, Mason and McCulloch Counties. The main source of irrigation water in Comanche and Erath Counties is the Trinity Aquifer, a mainly shallow sand formation. The TDS (total dissolved solids) of the groundwater ranges from less than 500 to 3,000 ppm (parts per million; source: TWC, 1989). Most of the wells in Comanche and Erath counties are less than 6″ in diameter with small electrical submersible pumps. The average measured pumping lift (from wells) was 115 feet with an average measured pumping rate of 47 gpm (gallons per minute).

To maintain an ample irrigation water supply, many irrigators pump from their wells into small reservoirs. When irrigating, they pump out of these small reservoirs into their distribution systems. Well yields tend to fall off significantly toward the end of the pumping season. To compensate, many irrigators increase the back pressure on the pumps to avoid cavitation.

Our testing was performed late in the pumping season after a long dry period.

Table 8. Average Diesel Testing Results by Test Region.

	Engine				Pump						Cost		
Region	RPM	Horsepower	Fuel (gal/hr)	Efficiency (%)	Flow Rate (gpm)	Pumping Lift (ft)	Discharge Pressure (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Per Hour ($/hr)	Per Acre-inch ($/Ac-in)	Acre-inch per 100' of Head ($/Ac-in/100')
Central	2012		4.9		512	271	37	357.5		17.9	3.53	3.22	0.88
Edwards	1730	147	6.8	34.2	1543	134	31	205.7	71.0	20.3	4.59	1.39	0.87
Far West	1650		8.5		1270	275	22	325.8		23.1	4.92	1.72	0.54
Gulf Coast	1424	199	9.3	32.1	2093	146	1	148.6	55.2	15.3	6.01	1.30	0.93
South	1492	62	5.0	29.4	1880	35	24	82.8	80.9	15.5	3.32	0.81	1.05
Southeast	1690		3.5		918	138	2	141.5		17.5	1.96	0.92	0.75
Winter Garden	1482	118	6.0	32.1	786	203	37	288.8	57.5	17.4	3.83	2.24	0.82
Average	1661	141	6.5	33.5	1375	151	28	215.4	67.4	19.0	4.27	1.56	0.86

Table 9. Average Natural Gas Testing Results by Region.

	Engine				Pump						Cost		
Region	RPM	Horsepower	Fuel (Ccf/hr)	Efficiency (%)	Flow Rate (gpm)	Pumping Lift (ft)	Discharge Pressure (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Per Hour ($/hr)	Per Acre-inch ($/Ac-in)	Acre-inch per 100' of Head ($/Ac-in/100')
Edwards	1845	190	1106	22.1	1844	142	4	151.8	53.4	13.9	4.67	1.12	0.86
Far West	1488	164	1598	25.1	1553	197	13	226.2	56.8	13.7	3.14	0.95	0.45
Gulf Coast	918	96	1170	23.7	1839	135	0	135.1	57.4	14.3	4.16	1.04	0.75
South	1200	68	1044	15.6	1926	30	29	96.4	72.3	11.1	3.40	0.84	0.86
Southern HP	1790	45	581	17.7	421	93	45	196.0	63.2	9.7	1.83	2.11	1.10
Winter Garden	1015	168	1476	26.2	841	375	32	448.2	66.1	15.7	4.26	2.26	0.53
Average	1325	144	1391	24.1	1482	185	16	220.1	61.3	13.5	3.41	1.36	0.60

Table 10. Average Electrical Testing Results by Region.

	Motor				Pump						Cost		
Region	Rated Horsepower	Electricity (Kw-h)	Input Horsepower	Estimated Efficiency (%)	Flow Rate (gpm)	Pumping Lift (ft)	Discharge Pressure (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Per Hour ($/hr)	Per Acre-inch ($/Ac-in)	Acre-inch per 100' of Head ($/Ac-in/100')
Central	11	8.6	11.6	84.0	127	92	36	174	47.1	39.3	0.61	2.46	2.15
Edwards	129	100.4	134.6	92.0	1548	138	17	176.6	55.5	51.1	6.09	1.74	1.05
Far West	43	37.0	49.5	90.0	822	164	15	197.9	61.3	55.3	2.39	2.26	0.98
Gulf Coast	75	56.6	75.8	91.0	1494	104	0	104.0	56.8	51.7	3.40	1.02	0.98
Presidio	36	24.4	32.8	91.0	1796	22	2	27.0	39.8	36.2	2.14	0.54	2.19
South	78	59.8	80.1	90.0	1997	29	17	68.7	48.6	44.0	3.86	0.93	1.32
Southeast	125	116.8	156.5	85.0	1130	150	1	152.3	32.7	27.8	7.15	2.85	1.87
Southern HP	25	19.2	25.8	90.0	249	108	36	190.9	52.4	46.2	1.17	2.30	1.23
Winter Garden	86	62.6	83.9	89.0	872	158	22	208.6	51.9	46.3	4.12	2.41	1.26
Average	56	41.6	55.7	87.0	787	126	26	165.2	50.6	44.7	2.63	2.03	1.51

Table 11. Average for Large Natural Gas Testing Results by Region.

	Engine				Pump						Cost		
Region	RPM	Horsepower	Fuel (Ccf/hr)	Efficiency (%)	Flow Rate (gpm)	Pumping Lift (ft)	Discharge Pressure (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Per Hour ($/hr)	Per Acre-inch ($/Ac-in)	Acre-inch per 100' of Head ($/Ac-in/100')
LRGV	1106		3652		32277	8	10	30.3		17.9	14.61	2.38	0.79

Table 12. Average for Large Electric Testing Results by Region.

	Engine				Pump						Cost		
Region	Rated Horsepower	Electricity (Kw-h)	Input Horsepower	Estimated Efficiency (%)	Flow Rate (gpm)	Pumping Lift (ft)	Discharge Pressure (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Per Hour ($/hr)	Per Acre-inch ($/Ac-in)	Acre-inch per 100' of Head ($/Ac-in/100')
LRGV	274	181.7	243.4	92.0	20568	22	2	25.5	67.1	60.4	11.88	2.99	1.17

Damage from cavitation, wear from pumping sand, and operational points outside the high efficiency envelope resulted in measured overall efficiencies in these counties to be very low, averaging only 39.1%.

The Hickory Aquifer serves as the major water source for Mason and McCulloch Counties. The Hickory aquifer is comprised mainly of sand and sandstone. The TDS of water from the Hickory aquifer in the test region ranges from less than 500 to greater than 10,000 ppm (TWC, 1989). These counties have average lifts of 254 feet and average yields of 512 gpm.

Overall efficiencies in Mason and McCulloch Counties were below standards of 22.8% overall efficiency for diesel and 67% overall efficiency for electric units. The measured overall efficiencies were 17.9% for diesel units and 45.0% for electric units.

In the Central Region we tested 24 electric and 3 diesel pumping plants. Regional summaries can be found in Appendix F. The average overall efficiency of diesel plants was 17.9%, and the average overall efficiency of electric plants was 39.9%.

B. Edwards Test Region

The Edwards Test Region consists of Bexar, Medina, and Uvalde counties. The Edwards Aquifer was the water supply for the pumping plants tested in these three counties. The Edwards Aquifer is a consolidated limestone formation. The Edwards Aquifer TDS levels range from less than 500 to 1,000 ppm (TWC, 1989). The pumping lift varies from flowing artisan in Bexar County to pumping lifts as high as 330 feet in Medina County, with a regional average of 144 feet. The well yields in this region are very high, up to 4,414 gpm. The average pumping rate is about 1,600 gpm.

The average measured overall efficiency of the 37 diesel plants tested was 21.4%, only slightly below the standard. Average overall efficiency of the 18 electric plants tested was 51.1%. The average overall efficiency of the 4 natural gas plants tested was 13.9%.

C. Far West Test Region

The Far West Test Region includes Culberson, Hudspeth and Pecos Counties. The mainly sand and gravel West Texas Bolsons Aquifers are the main sources of water for Culberson County. The TDS of these aquifers range from 1000 to 3000 ppm (TWC, 1989). The average pumping lift is 275 feet and average pumping rate is 1,122 gpm. Hudspeth County's main irrigation water supply is the Bone Spring-Victorio Peak Aquifer. The TDS of this aquifer is less than 500 ppm. Hudspeth County has an averaged pumping lift of 109 feet, and flow rates average 1,803 gpm. The Edwards-Trinity Aquifer is the main water supply for Pecos County. TDS for this aquifer ranges from 1,000 to 3,000 ppm (TWC, 1989). Average pumping lift is 219 feet, and average pumping rate is 1,432 gpm.

Average measured overall efficiencies of the 2 diesel plants tested was 23.1%. Average overall efficiency of the 3 electric plants tested was 55.3%. The average efficiency of the 33 natural gas plants tested was 13.7%. With the exception of Hudspeth County, the water is clean but corrosive. Low efficiencies are most likely due to corrosion of the pumps.

D. Gulf Coast Test Region

The Gulf Coast Test Region consists of Jackson and Wharton counties. The Gulf Coast Aquifer was the source of water for all pumping plants tested in this region. The Aquifer is a sand and gravel formation. The TDS of the Gulf Coast Aquifer ranges from less than 500 to 1,000 ppm (TWC, 1989). The average pumping lift was 136 feet, and average flow rate was 1,895 gpm.

The average overall efficiency of the 4 diesel plants tested was 15.3%. The efficiency of the only electric plant tested was 51.7%. The average efficiency of the 7 natural gas plants tested was 14.3%. Wear from pumping sand is the likely reason for pumping plant efficiencies to be below the standards.

E. Lower Rio Grande Valley Test Region

Cameron and Hidalgo Counties comprise the Lower Rio Grande Test Region. The Rio Grande River is the water source for this region. The TDS of the river in this region averages about 664 ppm (TWC, 1992). The average pumping lift was 20 feet, and the average flow rate was 22,575 gpm. Most of the pumping plants in this region are owned and operated by irrigation districts. These districts use very large pumping plants to lift water from the Rio Grande River into distribution canals where, in most cases, water flows by gravity to fields. However, in the eastern and western parts of the region, smaller secondary lift pump are required. Pumping plants tend to have been properly designed and are well maintained.

The average overall efficiency of the 29 electric plants tested was 60.4%, only slightly below the standard. Average overall efficiency of the 6 natural gas plants tested was 17.9%, also only slightly below the standard.

F. Presidio Test Region

The Presidio Region consist of Presidio County. The Rio Grande River was the water source for units tested in this region. The TDS of the river in this region ranges from 580 to 1500 ppm (TWC, 1992). Average pumping lift in this region was 22 feet, with an average flow rate of 1,796 gpm.

The average overall efficiency of the 5 electric plants tested was 36.2%, well below the standard. Aging pumping plants and corrosive water most likely are the cause of efficiencies being below the standard.

G. South Test Region

The South Region is Starr County. Individual farms or irrigators pump water from the Rio Grande River for irrigation purposes. TDS of the river in this region is 500 to 1,000 ppm (TWC, 1992). Average pumping lift was 36 feet, and the average flow rate was 1,943 gpm. The average measured overall efficiency of the 4 diesel plants tested was 15.5%.
The average overall efficiency of the 6 electric plants tested was 44.0%. The average overall efficiency of the 4 natural gas plants tested was 11.1%. Corrosive water is the most probable cause for the efficiencies being below the standards.

H. Southeast Test Region

The Southeast Test Region includes Brazos and Waller Counties. Most irrigation water in Brazos County is pumped from the alluvial formation along the Brazos River. The TDS of the water from these wells ranges from 1,000 to 3,000 ppm (TWC, 1989). In Waller County, irrigation water is pumped from the Gulf Coast Aquifer. The average pumping lift was 140 feet, with a flow rate of 960 gpm.

The average overall efficiency of the 4 diesel plants tested was 17.5%. The overall efficiency of the single electric plant tested was 27.8%. One of the diesel plants was small and the other two pumps (diesel and electric) were probably worn from sand. The electric motor on the electric unit produced a lot of heat and was very noisy, which could be a signs of a problem.

I. Southern High Plains Test Region

Dawson, Gaines and Terry Counties comprise the Southern High Plains Test Region. All irrigation water is pumped from the Ogallala aquifer. The TDS of the Ogallala aquifer in this region ranges from 500 to 3,000 ppm (TWC, 1989). The average pumping lift was 106 feet, and the average flow rate was 275 gpm.

Average overall pumping plant efficiency of the 22 electric plants tested was 46.2%. The average overall efficiency of the 4 natural gas plants tested was 9.7%. The most likely reasons for the efficiencies being well below the standards is wear from pumping sand and damage caused by cavitation.

J. Winter Garden Test Region

The Winter Garden Test Region is made up of Atascosa, Frio, Wilson, and Zavala Counties. The Carrizo-Wilcox Aquifer is the main water source for irrigation in this region. The TDS of the Carrizo-Wilcox aquifer in this region ranges from less than 500 to 1,000 ppm (TWC, 1989). This portion of the Carrizo-Wilcox is geothermal and groundwater temperatures range from 95° to 120° F. Pumping plants in this region had average pumping lifts of 236 feet and average flow rate of 823 gpm.

The average measured overall efficiency of the 11 diesel plants tested was 17.4%. The average overall efficiency of the 6 electric plants tested was 46.3%. The average overall efficiency of the 6 natural gas plants tested was 15.7%. Possible reasons for efficiencies being below the standards are wear from pumping sand and wear from overheating of the components that are exposed to the high temperature of the ground water.

X. Potential Savings

A. Potential Energy Savings of Individual Pumping Plants

The potential energy savings for individual pumping plants was calculated with TIPPES (Texas Irrigation Pumping Plant Evaluation Software). This saving is based on the difference between the measured efficiency of the pumping plant and the standard efficiency. This savings represents the potential fuel-cost savings if the pumping plant is brought up to the standard (by repair or replacement). Fuel costs savings are calculated separately for the engine and pump where possible. These values are included in Appendix D. Potential savings range from $0.00 to $16,820 a year.

B. Potential Savings of 244 Pumping Plants

The potential savings with improvements in 244 of the pumping plants tested is illustrated in Fig 6. The 65 diesel pumping plants could potentially save a total of 150,383 gallons of fuel a year, the 64 natural gas could potentially save a total of 51,908 Mcf a year, and the 115 electric could potentially save a total of 3,449,623 kwh of electricity per year. Assuming costs of $0.65 for diesel, $3.25 Mcf for natural gas, and $0.7 kwh, the potential energy savings has a value of $507,920 per year.

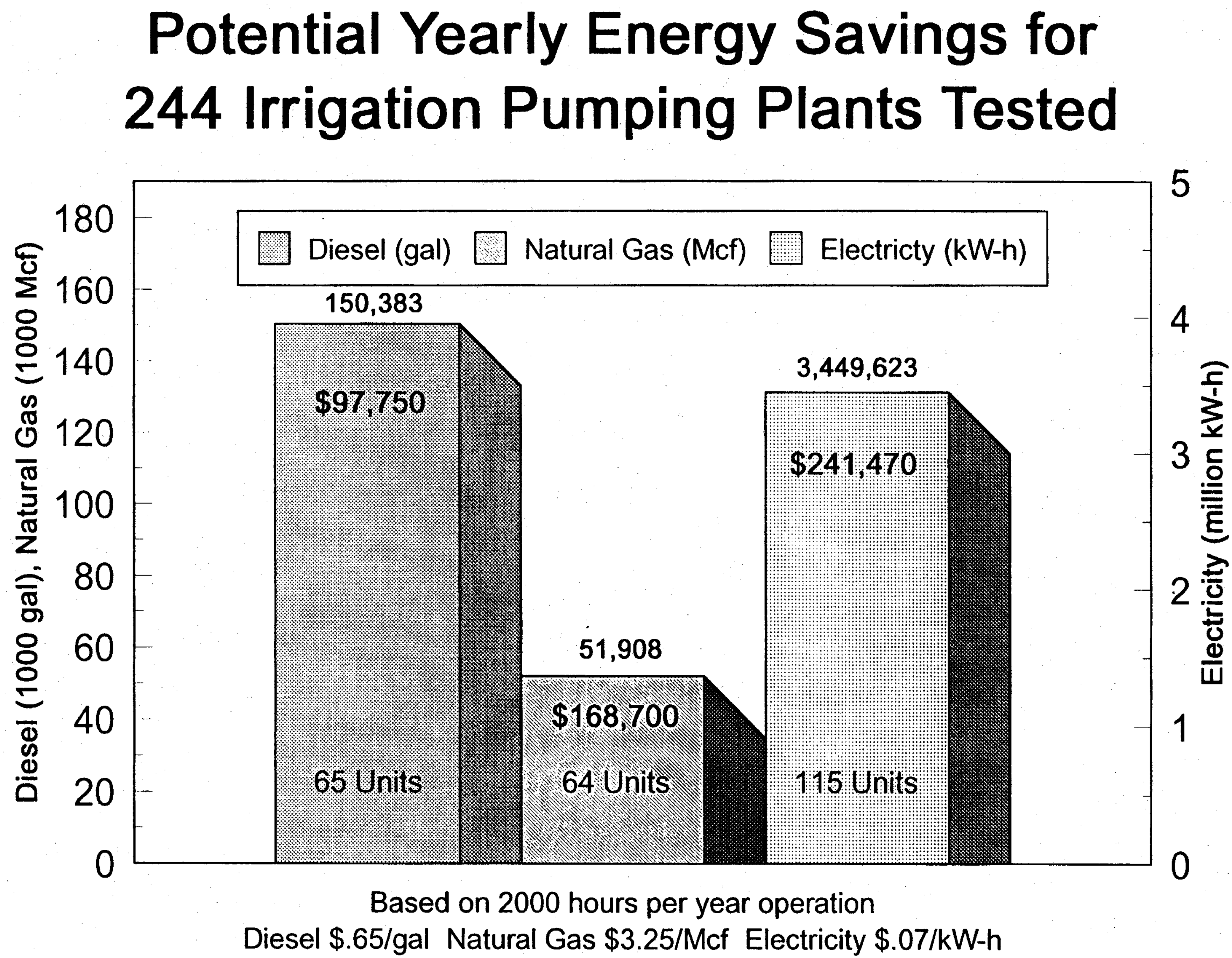

Figure 6. Potential savings for all 244 pumping plants tested.

XI. Safety Check Lists

A safety check list (Appendix A) was completed for 71 irrigation pumping plants. The safety check identifies potential hazards in and around the pumping plant. The check-list identifies safety hazards related to the protection of the operator and well head protection (Table 13). We observed that 54% of drive shafts lacked guards, 65% lacked head shaft covers, and all engines produced dangerous noise levels (defined as sound pressure greater than 90 dBA measured head level at the engine control panel). We observed that 42% of all well installations did not meet current construction standards for well head protection. Additionally, about 1/3 of all pumps lacked a backflow prevention device (check valve).

Table 13. Safety Check-list Summary			
	Adequate	**Inadequate**	**Dangerous**
Wellhead Protection			
Concrete Slab	32	20	3
Pump Base	60	5	0
Check Valve	45	0	26
Driveshaft			
Guards	27	0	32
Bolts	61	0	0
U-joints	59	0	1
Barrel	60	0	0
Slip Spline	57	3	0
Flanges	55	6	0
Environment	61	0	0
Gear Head			
Head Shaft Cover	42	0	23
Ratchet Pins	47	1	0
Housing Condition	57	0	0
Pump Base Condition	57	0	0
Internal Combustion Engine			
Emergency Kill Switches	59	2	0
Position of Motor Controls	61	0	0
Position of Clutch Controls	52	0	0
Fuel Line Condition & Position	60	0	1
Noise Level	0	0	61
Electric Motor			
Control Box Condition	10	0	0
Proper Grounding	10	0	0
Conduit to Motor	8	0	2

XII. Energy Value of Diesel Fuel

In calculating the energy supplied to a diesel engine, a diesel fuel energy content of 136,000 BTU/gallon is assumed (Barger, et al 1963). During the project, 10 samples of diesel fuel were taken at random and analyzed for BTU content in a *Parr Instrument Company* adiabatic bomb calorimeter using a standard combustion heat test. The results are shown in Fig. 7. The energy value ranged from a low of 133,603 BTU/gallon to a high of 139,147 BTU/gallon. The average energy content was 136,600 BTU per gallon. We used 136,000 BTU/gallon for the calculations reported here, which lead to a margin of error of ±2%.

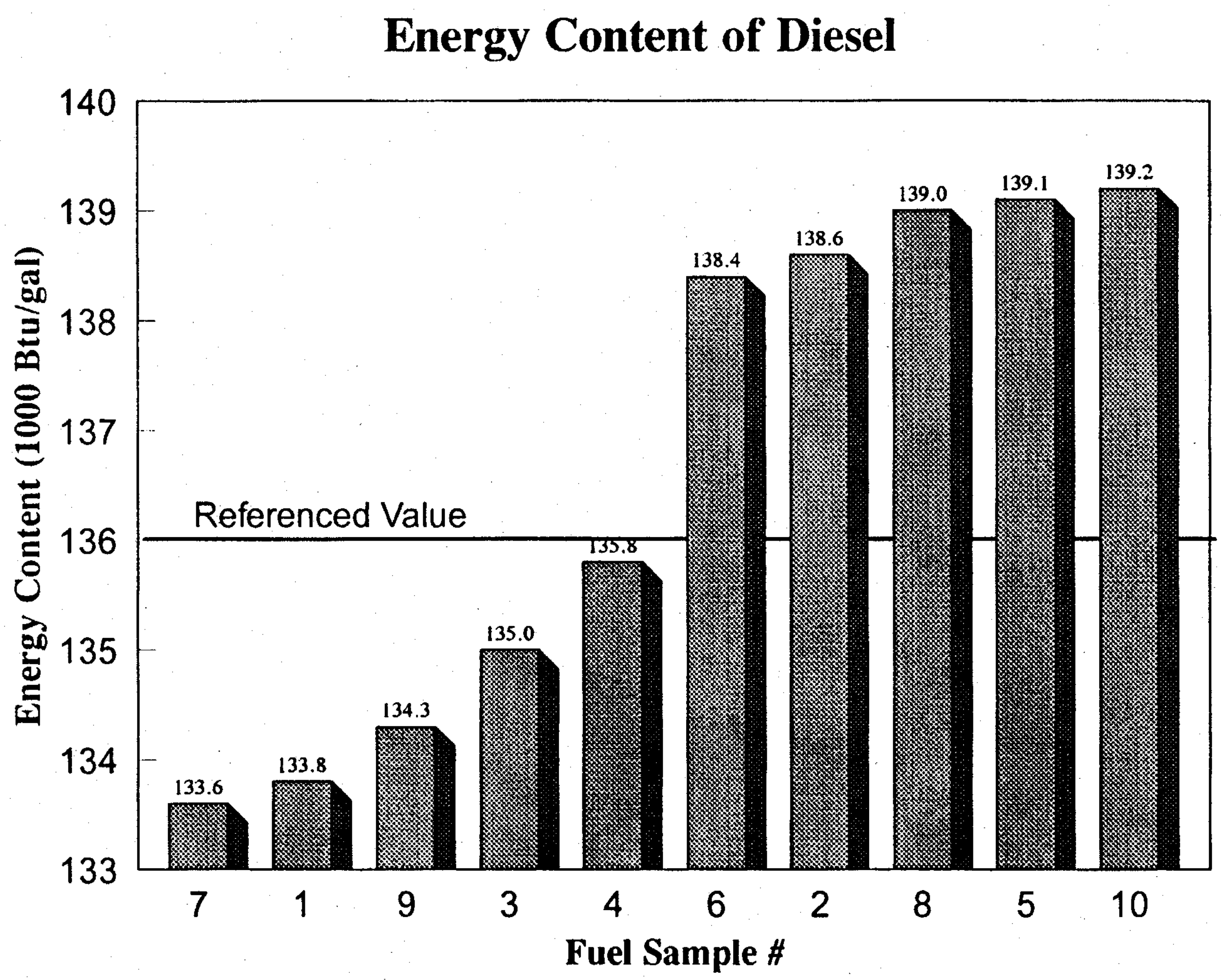

Figure 7. Analysis for energy content of diesel fuel samples.

XIII. Personal Observations by Byron Neal

Over the past two years and from prior experience, my impressions are that irrigators do not think about their pumping plants until something goes wrong. As long as the pumping plant provides enough water at the right pressure, irrigators do not take any measurements or make any adjustments to improve pumping plant performance. When something does go wrong, they solve the problem in the least expensive way, either by buying a used pump or by buying a surplus motor. The least expensive could turn out to be very expensive.

Purchasing a surplus motor may result in a grossly over-sized power plant which consumes excessive amounts of fuel, although providing the pump with the needed power. A motor that is properly matched to the power requirements of the pump should use less fuel and last longer that an oversized motor.

Purchasing a used pump may result in a pump that will provide the volume of water at the pressure that the irrigator wants, but it might do it at low efficiency. The pump will often require more power and the motor will use more fuel to provide that extra power, thus making it cost more to irrigate.

Irrigators want and need to know the information that pumping plant efficiency testing provides. Moreover, they need the first-hand involvement in their system in the presence of an objective professional engineer, or an energy or safety technician. Pumping plant efficiency testing provides irrigators with another management tool. This tool can be used to reduce energy use and lower the cost of producing agricultural products and keep them in business.

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Appendixes

A. Data Sheets

B. List of Terms and Units

C. Equations

D. Data Base Print Out

E. Regional Summaries

F. State Summary

G. Irrigation Pumping Plant Efficiency Test Program - User's Guide

H. Request for Continued Funding, Proposal to the State Energy Office

TEXAS AGRICULTURAL EXTENSION SERVICE
IRRIGATION PUMPING PLANT EFFICIENCY TESTS
DIESEL POWER UNITS

Owner ____________________ Date ______________
Location ______________________ Irrigation Method ______________
County ___________________ Tested by ______________

Average Annual Operation Time ________hr/yr Diesel Cost $______/gal

ENGINE DATA:
Brand ____________________ Cylinders ___________ Turbo ____
Model ____________________ Other _________________________

PUMP DATA:
Brand _________ Size _______ RPM _______ Ratio ______(H:V)

DIESEL DATA: Temp ___________(°F) Density ___________(γ)

MEASUREMENTS:
Output Power:

Torque	RPM	Horsepower
1. ______________	1. ______________	1. ______________
2. ______________	2. ______________	2. ______________
3. ______________	3. ______________	3. ______________
4. ______________	4. ______________	4. ______________
5. ______________	5. ______________	5. ______________

Fuel:

Pounds	Seconds
1. ______________	1. ______________
2. ______________	2. ______________
3. ______________	3. ______________
4. ______________	4. ______________
5. ______________	5. ______________

Static Water Level _______(ft) Pumping Water Level _______(ft)
Discharge Pressure _______(psi) * 2.31 = _______(ft)
Total Head _______(ft) Water Temp _______(°F)
Flow Rate _______, _______, _______, _______, _______, _______(GPM)
Engine Noise Level _______(dBA)
COMMENTS:

TEXAS AGRICULTURAL EXTENSION SERVICE
IRRIGATION PUMPING PLANT EFFICIENCY TESTS
NATURAL GAS POWER UNITS

Owner ____________________ Date _______________
Location ____________________ Irrigation Method _______________
County ____________________ Tested by _______________

Average Annual Operation Time _______hr/yr Natural Gas Cost $_______/Mcf

ENGINE DATA:
Brand ____________________ Cylinders ___________ Turbo _____
Model ____________________ Other ________________________

PUMP DATA:
Brand ___________ Size _________ RPM _______ Ratio _______(H:V)

MEASUREMENTS:
Output Power:

Torque	RPM	Horsepower
1. ____________	1. ____________	1. ____________
2. ____________	2. ____________	2. ____________
3. ____________	3. ____________	3. ____________
4. ____________	4. ____________	4. ____________
5. ____________	5. ____________	5. ____________

Fuel:

Metered Cubic Feet	Seconds	Meter Pressure
1. ____________	1. ____________	1. ____________(psi/oz.)
2. ____________	2. ____________	2. ____________(psi/oz.)
3. ____________	3. ____________	3. ____________(psi/oz.)
4. ____________	4. ____________	4. ____________(psi/oz.)
5. ____________	5. ____________	5. ____________(psi/oz.)

Static Water Level _______(ft) Pumping Water Level _______(ft)
Discharge Pressure ________(psi) * 2.31 = _______(ft)
Total Head _______(ft) Water Temp _______(°F)
Flow Rate ________, _______, _______, _______, _______(GPM)
Engine Noise Level _______(dBA)

COMMENTS:

TEXAS AGRICULTURAL EXTENSION SERVICE
IRRIGATION PUMPING PLANT EFFICIENCY TESTS
ELECTRIC POWER UNITS

Owner ________________ Date ____________
Location ________________ Irrigation Method ____________
County ________________ Tested by ____________

Average Annual Operation Time _____hr/yr Electric Cost $______/Kw-h

MOTOR DATA:
Brand _________ Type _________ Horsepower______ Serial No. _________
Voltage _______ Amperes ______ Phase ______ RPM ______ S.F. ________
Estimated Efficiency ______(%)

PUMP DATA:
Centrifugal ___ Propeller ___ Turbine ___ Pump Setting _____(ft) No. Stages ______
Brand _________ Model _________ Size _____ Impeller Size _____(in) Type ______
Nameplate: GPM ______ Head ______ RPM ______ Measured RPM ______

MEASUREMENTS:
Electricity Input:

Kw-h (Disc Method):
$Mm*(Rev*3.6*k_h)/Sec$ = ___________ (KW Input)

Kw-h (Instrument Method):

Line:	KW's	Amps	Volts
AB	___________	___________	___________
BC	___________	___________	___________
CA	___________	___________	___________

Static Water Level ______(ft) Pumping Water Level ______(ft)
Discharge Pressure _____(psi) * 2.31 = _____(ft)
Total Head ______(ft) Water Temp ______(°F)
Flow Rate ______, ______, ______, ______, ______(GPM)

COMMENTS:

TEXAS AGRICULTURAL EXTENSION SERVICE
IRRIGATION PUMPING PLANT EFFICIENCY TESTS
DUAL FUEL POWER UNITS

Owner ________________
Location ________________
County ________________

Date ____________
Irrigation Method ____________
Tested by ______________

Average Annual Operation Time ______hr/yr

Diesel Cost $______/gal
Gas Cost $______/Mcf

ENGINE DATA:
Brand ________________ Cylinders _________ Turbo ___
Model ________________ Other ____________________

PUMP DATA:
Brand _______ Size ______ RPM ______ Ratio ______(H:V)

DIESEL DATA: Temp _________(°F) Density _________(γ)

MEASUREMENTS:
Output Power:

Torque	RPM	Horsepower
1. ________	1. ________	1. ________
2. ________	2. ________	2. ________
3. ________	3. ________	3. ________
4. ________	4. ________	4. ________
5. ________	5. ________	5. ________

Fuel:
Diesel

Pounds	Seconds
1. ________	1. ________
2. ________	2. ________
3. ________	3. ________
4. ________	4. ________
5. ________	5. ________

Natural Gas

Metered Cubic Feet	Seconds	Meter Pressure
1. ________	1. ________	1. ________(psi/oz.)
2. ________	2. ________	2. ________(psi/oz.)
3. ________	3. ________	3. ________(psi/oz.)
4. ________	4. ________	4. ________(psi/oz.)
5. ________	5. ________	5. ________(psi/oz.)

Static Water Level ______(ft) Pumping Water Level ______(ft)
Discharge Pressure ______(psi) * 2.31 = ______(ft)
Total Head ______(ft) Water Temp ______(°F)
Flow Rate ______, ______, ______, ______, ______, ______(GPM)
Engine Noise Level ______(dBA)
COMMENTS:

LIST OF TERMS AND UNITS

A. List of Terms

Shaft hp	=output horsepower of motor
Fuel Consumption	= diesel-(gallons/hour), natural gas-(cubic feet/hour)
input hp	= input horsepower to the motor
engine efficiency	= (%)
T	= torque (inch-pounds)
rpm	= engine speed (revolutions/minute)
pounds	= weight of diesel consumed in "sec"
γ	= specific gravity of diesel
density	= density of diesel (pounds/cubic foot)
FHV	= fuel heat value; diesel-(BTU/gallon), natural gas-(BTU/cubic foot)
pumping lift	= (feet)
discharge pressure	= (psi)
total head	= (feet)
0.95	= gear head efficiency (decimal)
gpm	= flow rate of water from pumping plant (gallons/minute)
annual operation	= (hours)
fuel cost	= diesel in/gallon, natural gas-in/MCF
elecost	= electricity cost ($/KW-hr)
conversion	= pressure conversion to standard pressure
meterpress	= meter pressure (psi or ounces)
atmo	= atmospheric pressure (psi or ounces)

meterdrive	=	meter drive = 0.25
rev	=	revolutions of the meter dial in "sec"
metercoeff	=	meter factor
standard cost per hour	=	($/hr)
SEE	=	standard engine efficiency (decimal)
		diesel, 0.32
		natural gas, 0.26
		electric, 0.90
		dual fuel, 0.27
CEE	=	current engine efficiency (decimal)
SEP	=	standard efficiency of the pump (decimal), 0.75
Savings	=	($/hr)
3 Year Savings	=	($)

B. Conversion Factors

33,000 foot-pounds	=	1 hp-minute
12 inches	=	1 foot
600 seconds	=	1 hour
7.481 gallons	=	1 cubic foot
2545 BTU	=	1 hp-hour
2.31 feet of water (head)	=	1 psi
3960 gallon-foot	=	1 hp-minute
450 gpm-hr	=	1 acre-inch
1.34 hp	=	1 kw
1000 cubic feet	=	1 MCF

EQUATIONS

A. Efficiency

1. Diesel

$$\text{shaft hp} = \frac{T \times rpm}{63025} \qquad D(1)$$

$$\text{fuel consumption} = \frac{\text{pounds} \times 3600 \times 7.481}{\text{sec} \times \gamma \times \text{density temp adjust}} \qquad D(2)$$

$$\text{input hp} = \text{fuel consumption} \times \frac{FHV}{2545} \qquad D(3)$$

$$\text{engine efficiency} = \frac{\text{shaft hp}}{\text{input hp}} \times 100\% \qquad D(4)$$

$$\text{total head} = \text{pumping lift} + \text{discharge pressure} \times 2.31 \qquad D(5)$$

$$\text{pump efficiency} = \frac{GPM \times \text{total head}}{3960 \times \text{shaft hp} \times .95} \times 100\% \qquad D(6)$$

$$\text{overall efficiency} = \frac{GPM \times \text{total head}}{3960 \times \text{input hp}} \times 100\% \qquad D(7)$$

$$\text{fuel cost per hour} = \text{fuel consumption} \times \text{fuel cost} \qquad D(8)$$

$$\text{fuel cost per acre-inch} = \frac{\text{fuel cost per hour} \times 450}{GPM} \qquad D(9)$$

$$\begin{array}{c}\text{fuel cost per acre-inch} \\ \text{per 100 foot of head}\end{array} = \frac{\text{fuel cost per acre-inch}}{\text{total head}} \times 100 \qquad D(10)$$

$$\text{annual operating cost} = \text{fuel cost per hour} \times \text{annual operation} \qquad D(11)$$

2. Natural Gas

$$\text{shaft hp} = \frac{T \times rpm}{63025} \qquad N(1)$$

$$\text{fuel consumption} = \frac{\text{cubic feet} \times 3600 \times \text{conversion}}{\text{sec}} \qquad N(2)$$

$$\text{conversion} = \frac{\text{meterpress} + \text{atmo}}{\text{atmo} + \text{meterdrive}} \qquad N(3)$$

$$\text{input hp} = \text{fuel consumption} \times \frac{FHV}{2545} \qquad N(4)$$

$$\text{engine efficiency} = \frac{\text{shaft hp}}{\text{input hp}} \times 100\% \qquad N(5)$$

$$\text{total head} = \text{pumping lift} + \text{discharge pressure} \times 2.31 \qquad N(6)$$

$$\text{pump efficiency} = \frac{\text{gpm} \times \text{total head}}{3960 \times \text{shaft hp} \times .95} \times 100\% \qquad N(7)$$

$$\text{overall efficiency} = \frac{\text{gpm} \times \text{total head}}{3960 \times \text{input hp}} \times 100\% \qquad N(8)$$

$$\text{fuel cost per hour} = \text{fuel consumption} \times \text{fuel cost} \qquad N(9)$$

$$\text{fuel cost per acre-inch} = \frac{\text{fuel cost per hour} \times 450}{\text{gpm}} \qquad N(10)$$

$$\begin{array}{c}\text{fuel cost per acre-inch}\\ \text{per 100 foot of head}\end{array} = \frac{\text{fuel cost per acre-inch}}{\text{total head}} \times 100 \qquad N(11)$$

$$\text{annual operating cost} = \text{fuel cost per hour} \times \text{annual operation} \qquad N(12)$$

3. Electric

a. Using the "instrument method"

$$\text{input hp} = \text{KW} \times 1.34 \qquad \text{E(1)}$$

b. Using the "disc method"

$$\text{input hp} = \frac{\text{rev} \times 3.6 \times \text{metercoeff} \times 1.34}{\text{sec}} \times \text{metermult} \qquad \text{E(2)}$$

$$\text{engine efficiency} = \text{input by user} \qquad \text{E(3)}$$

$$\text{shaft hp} = \frac{\text{input hp} \times \text{engine efficiency}}{100} \qquad \text{E(4)}$$

$$\text{total head} = \text{pumping lift} + \text{discharge pressure} \times 2.31 \qquad \text{E(5)}$$

$$\text{pump efficiency} = \frac{\text{gpm} \times \text{total head}}{3960 \times \text{input hp} \times \text{engine efficiency}} \times 100\% \qquad \text{E(6)}$$

$$\text{overall efficiency} = \frac{\text{gpm} \times \text{total head}}{3960 \times \text{input hp}} \times 100\% \qquad \text{E(7)}$$

$$\text{fuel cost per hour} = \text{KW} \times \text{elecost} \qquad \text{E(8)}$$

$$\text{fuel cost per acre-inch} = \frac{\text{fuel cost per hour} \times 450}{\text{gpm}} \qquad \text{E(9)}$$

$$\begin{array}{c}\text{fuel cost per acre-inch} \\ \text{per 100 foot of head}\end{array} = \frac{\text{fuel cost per acre-inch}}{\text{total head}} \times 100 \qquad \text{E(10)}$$

$$\text{annual operating cost} = \text{fuel cost per hour} \times \text{annual operation} \qquad \text{E(11)}$$

4. Dual Fuel

$$\text{shaft hp} = \frac{T \times rpm}{63025} \qquad DF(1)$$

$$\text{fuel consumption (diesel)} = \frac{\text{pounds} \times 3600 \times 7.481}{\text{sec} \times \gamma \times \text{density temp adjustment}} \qquad DF(2)$$

$$\text{fuel consumption (natural gas)} = \frac{\text{cubic feet} \times 3600 \times \text{conversion}}{\text{sec}} \qquad DF(3)$$

$$\text{conversion} = \frac{\text{meterpress} + \text{atmo}}{\text{atmo} + \text{meterdrive}} \qquad DF(4)$$

$$\text{input hp} = \frac{\text{fuel consumption (diesel)} \times FHV}{2545} + \frac{\text{fuel consumption (natural gas)} \times FHV}{2545} \qquad DF(5)$$

$$\text{engine efficiency} = \frac{\text{shaft hp}}{\text{input hp}} \times 100 \qquad DF(6)$$

$$\text{total head} = \text{pumping lift} + (\text{discharge pressure} \times 2.31) \qquad DF(7)$$

$$\text{pump efficiency} = \frac{\text{gpm} \times \text{total head}}{3960 \times \text{shaft hp} \times 0.95} \times 100 \qquad DF(8)$$

$$\text{overall efficiency} = \frac{\text{gpm} \times \text{total head}}{3960} \text{ input hp} \times 100 \qquad DF(9)$$

$$\text{fuel cost per hour} = (\text{diesel fuel consumption} \times \text{diesel fuel cost}) + (\text{natural gas fuel consumption} \times \text{natural gas fuel cost}) \qquad DF(10)$$

$$\text{fuel cost per acre-inch} = \frac{\text{fuel cost per hour}}{\text{gpm}} \times 450 \qquad DF(11)$$

$$\text{fuel cost per acre-inch per 100 foot} = \frac{\text{fuel cost per acre-inch}}{\text{total head}} \times 100 \quad \text{DF(12)}$$

$$\text{annual operating cost} = \text{fuel cost per hour} \times \text{annual operation} \quad \text{DF(13)}$$

B. Potential Savings of Improving Motor and Pump Efficiencies

1. Diesel

Improving motor efficiency only:

$$\text{standard cost per hour} = \frac{\text{shaft hp} \times 2545 \times \text{fuel cost}}{\text{SEE} \times \text{FHV}} \quad \text{D(1)}$$

Improving pump efficiency only:

$$\text{standard cost per hour} = \frac{\text{gpm} \times \text{total head} \times 2545 \times \text{fuel cost}}{3960 \times 0.95 \times \text{SEP} \times \text{CEE} \times \text{FHV}} \quad \text{D(2)}$$

Improving motor and pump efficiences:

$$\text{standard cost per hour} = \frac{\text{gpm} \times \text{total head} \times 2545 \times \text{fuel cost}}{3960 \times 0.95 \times \text{SEP} \times \text{SEE} \times \text{FHV}} \quad \text{D(3)}$$

$$\text{savings (\$/hr)} = \text{fuel cost per hour} - \text{standard cost per hour} \quad \text{D(4)}$$

$$\text{3 year savings (\$)} = (\text{fuel cost per hour} - \text{standard cost per hour}) \times 3 \times \text{annual operation} \quad \text{D(5)}$$

2. Natural Gas

Improving motor efficiency only:

$$\text{standard cost per hour} = \frac{\text{shaft hp} \times 2545 \times \text{fuel cost}}{\text{SEE} \times \text{FHV} \times 1000} \quad \text{NG(1)}$$

Improving pump efficiency only:

$$\text{standard cost per hour} = \frac{\text{gpm} \times \text{total head} \times 2545 \times \text{fuel cost}}{3960 \times 0.95 \times \text{SEP} \times \text{CEE} \times \text{FHV} \times 1000} \quad \text{NG(2)}$$

Improving motor and pump efficiencies:

$$\text{standard cost per hour} = \frac{\text{gpm x total head x 2545 x fuel cost}}{\text{3960 x 0.95 SEP x SEE x FHV x 1000}} \qquad \text{NG(3)}$$

$$\text{Savings (\$/hr)} = \text{fuel cost per hour} - \text{standard cost per hour} \qquad \text{NG(4)}$$

$$\text{3 year savings (\$)} = \text{(fuel cost per hour - standard cost per hour) x 3 x annual operation} \qquad \text{NG(5)}$$

<u>3. Electric</u>

Improving motor efficiency only:

$$\text{standard cost per hour} = \frac{\text{shaft hp x elecost}}{\text{SEE}} \qquad \text{EE(1)}$$

Improving pump efficiency only:

$$\text{standard cost per hour} = \frac{\text{gpm x total head x elecost}}{\text{3960 x SEP x CEE x 1.34}} \qquad \text{EE(2)}$$

Improving motor and pump efficiencies:

$$\text{standard cost per hour} = \frac{\text{gpm x total head x elecost}}{\text{3960 x SEP x SEE x 1.34}} \qquad \text{EE(3)}$$

$$\text{Savings (\$hr)} = \text{Fuel cost per hour} - \text{standard cost per hour} \qquad \text{EE(4)}$$

$$\text{3 Year Savings (\$)} = \text{fuel cost per hour - standard cost per hour x 3 x annual operation} \qquad \text{EE(5)}$$

4. Dual Fuel

$$IHP_d = \text{input horsepower by diesel} = \frac{\text{diesel fuel consumption x } FHV_d}{2545} \qquad DF(1)$$

$$IHP_{ng} = \text{input horsepower by natural gas}$$
$$= \frac{\text{natural gas fuel consumption x } FHV_{ng}}{2545} \qquad DF(2)$$

$$\text{percentd} = \text{\% of total input horsepower contributed by diesel}$$
$$= \frac{IHP_d}{IHP_d + IHP_{ng}} \qquad DF(3)$$

$$\text{percentng} = \text{\% of total input horsepower contributed by natural gas}$$
$$= \frac{IHP_{ng}}{IHP_{ng} + IHP_d} \qquad DF(4)$$

$$\text{BTU required} = \frac{\text{shaft hp x 2545}}{\text{SEE}} \qquad DF(5)$$

Improving motor efficiency only:

$$\text{Standard diesel consumption per hour} = \frac{\text{BTU required x percentd}}{FHV_d} \qquad DF(6)$$

$$\text{Standard natural gas consumption per hour} = \frac{\text{BTU required x percentd}}{FHV_{ng}} \qquad DF(7)$$

$$\text{Standard dual fuel cost per hour} = (\text{fuel cost}_d \text{ x standard diesel consumption per hour}) + (\text{fuel cost}_{ng} \text{ x standard natural gas consumption per hour}) \qquad DF(8)$$

Improving pump efficiency only:

$$\text{Standard input BTU} = \frac{\text{gpm x total head x 2545}}{\text{3960 x 0.95 x SEP x CEE}} \qquad \text{DF(9)}$$

$$\text{Standard diesel cost} = \frac{\text{Standard input BTU x percentd x fuel cost}_d}{\text{FHV}_d} \qquad \text{DF(10)}$$

$$\text{Standard natural gas cost} = \frac{\text{Standard input BTU x percentng x 1000}}{\text{FHV}_{ng}} \text{ x fuel cost}_{ng} \qquad \text{DF(11)}$$

Standard cost per hour = Standard diesel cost + Standard natural gas cost DF(12)

Savings ($/hr) = fuel cost per hour - standard cost per hour DF(13)

3 Year Savings ($) = (fuel cost per hour - standard cost per hour) x 3 x annual operation DF(14)

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LOCATION	COUNTY	METHOD	MODEL	RPM	HP	FUEL	E EFF	FLOW	LIFT	PRESS	T HEAD	P EFF	O EFF	$/HR	$/AC-IN	$/AC-IN @ 100' HEAD
D93001-1	Medina	Pivot	Cum 360	1,765	220	10.3	40.0%	1,770	230	60	368.6	79.0%	30.0%	$6.92	$1.76	$0.48
D93001-2	Medina	Pivot	Cum 360	1,720	205	10.5	37.0%	1,810	225	52	345.1	81.0%	28.0%	$7.00	$1.74	$0.50
D93002-1	Medina	Pivot	Cum 903	1,430	80	4.7	32.0%	1,715	35	52	155.1	88.0%	27.0%	$2.94	$0.77	$0.50
D93002-2	Medina	Pivot	Cum 903	1,725	135	7.7	33.0%	2,420	45	55	172.1	82.0%	26.0%	$4.86	$0.90	$0.52
D93003	Frio	LEPA	Cum 350	1,625	143	7.9	34.0%	635	390	34	468.5	55.0%	18.0%	$5.54	$3.92	$0.84
D93004	Frio	Pivot	Cat 353	1,020	170	10.0	32.0%	810	330	44	431.6	55.0%	17.0%	$6.01	$3.34	$0.77
D93005	Medina	Furrow	Cat 3406	1,785	265	16.9	29.0%	2,200	250	2	254.6	56.0%	16.0%	$11.82	$2.42	$0.95
D93006	Medina	Pivot	Deere 6466			2.1		2,866	125	7	141.2		16.0%	$8.19	$1.29	$0.91
D93007	Medina	Reservoir	Det 471			6.6		1,000	58	86	256.7		19.0%	$4.60	$2.07	$0.81
D93008-1	Waller	Flood	Int 466	1,750		5.1		1,152	174	1	176.3		19.0%	$2.81	$1.10	$0.62
D93008-2	Waller	Flood	Int 466	1,560		3.6		921	168	1	170.3		21.0%	$1.98	$0.97	$0.57
D93008-3	Waller	Flood	Int 466	1,650		4.2		1,017	170	1	172.3		20.0%	$2.31	$1.02	$0.59
D93009	Medina	Furrow	Cum ?	1,910	240	12.5	36.0%	1,710	280	10	303.1	57.0%	20.0%	$8.50	$2.24	$0.74
D93010	Medina	Furrow	Volvo TDHPP12	1,745	230	11.6	37.0%	2,300	262	15	296.7	79.0%	28.0%	$7.89	$1.54	$0.52
D93011	Medina	Furrow	Cat 334	1,655	160	9.1	33.0%	2,020	200	5	210.4	71.0%	22.0%	$6.34	$1.41	$0.67
D93012	Medina	Pivot	Cum 360	1,665	190	9.5	37.0%	2,270	250	-10	226.9	72.0%	26.0%	$6.65	$1.32	$0.58
D93013	Medina	Pivot	Deere 6404	1,320	30	2.1	27.0%	1,130	70	2	73.5	74.0%	19.0%	$1.47	$0.59	$0.80
D93014	Bexar	Furrow	Deere 6359	2,250		6.6		3,205	35	10	58.1		13.0%	$4.62	$0.65	$1.12
D93015	Bexar	Furrow	Deere 4039	2,000		5.6		2,100	20	38	107.8		19.0%	$3.92	$0.84	$0.78
D93016	Bexar	Reservoir	Perkins			0.9		210	25	8	43.5		5.0%	$0.70	$1.49	$3.43
D93017	Jackson	Flood	Catapillar	1,785	266	17.2	29.0%	2,196	250	2	254.6	56.0%	15.0%	$10.98	$2.25	$0.88
D94001	Bexar	Side Roll	Deere 1385	1,200		1.9		560	50	2	54.6		8.0%	$1.07	$0.86	$1.58
D94002	Bexar	Side Roll	Deutz 6L	1,700		2.3		1,100	14	15	48.7		11.0%	$1.72	$0.70	$1.44
D94003-1	Medina	Pivot	Cum 360	1,735	200	9.0	42.0%	1,540	220	80	404.8	83.0%	33.0%	$5.85	$1.71	$0.42
D94003-2	Medina	Pivot	Cum 360	1,585	155	8.0	36.0%	1,390	230	52	350.1	84.0%	29.0%	$5.20	$1.68	$0.48
D94003-3	Medina	Pivot	Cum 360	1,670	180	9.1	37.0%	1,540	240	60	378.6	86.0%	30.0%	$5.92	$1.73	$0.46
D94004	McCulloch	Side Roll	Ford 401	2,000		3.2		279	350	45	453.9		19.0%	$2.27	$3.66	$0.81
D94005	Mason	Furrow	Deere 6059	1,875		3.2		638	215	3	221.9		21.0%	$2.21	$1.56	$0.70
D94006	Mason	Side Roll	Int A170	2,160		8.3		619	249	64	396.8		14.0%	$6.12	$4.45	$1.12
D94007	Medina	Furrow	Cat 3406	1,890		15.1		4,414	180	18	221.6		31.0%	$7.83	$0.80	$0.36
D94008-1	Medina	Big Gun	Cat 3208	1,640	65	3.5	34.0%	447	125	105	367.6	69.0%	22.0%	$2.25	$2.27	$0.62
D94008-2	Medina	Reservoir	Cat 3208	2,265	190	10.4	35.0%	1,376	250	20	296.2	56.0%	19.0%	$6.67	$2.18	$0.74
D94009	Culberson	Drip	Deere 6076			10.5		1,620	275	40	367.4		27.0%	$5.99	$1.66	$0.45
D94010	Culberson	Drip	Deere 6076	1,650		6.4		920	275	4	284.2		19.0%	$3.65	$1.78	$0.63
D94011	Brazos	Furrow	Deere 4039	1,800		1.2		580	40	3	46.9		11.0%	$0.74	$0.57	$1.22
D94012	Starr	Furrow	Deere 6466	1,500	62	3.9	29.0%	2,200	30	24	85.4	81.0%	23.0%	$2.51	$0.51	$0.60
D94013	Jackson	Reservoir	Deutz BF6L	1,820	132	7.0	35.0%	1,454	186	0	186.0	55.0%	18.0%	$4.08	$1.26	$0.68
D94014-1	Jackson	Linear Move	Cat D342	1,120		8.4		2,754	78	2	82.6		13.0%	$5.86	$0.96	$1.16
D94014-2	Jackson	Linear Move	Cat D342	970		4.5		1,967	69	1	71.3		15.0%	$3.11	$0.71	$1.00
D94015	Frio	Pivot	Deere 6619	1,930	297	15.4	36.0%	1,243	416	63	561.5	63.0%	22.0%	$10.75	$3.89	$0.69
D94016	Wilson	Pivot	Cum NHC4	1,160	30	1.6	35.0%	374	92	10	115.1	38.0%	13.0%	$1.01	$1.21	$1.05
D94017	Bexar	Pivot	Detroit 471			5.4		1,108	15	70	176.7		17.0%	$3.69	$1.50	$0.85
D94018	Atascosa	Resivior	Detroit 471	1,240	64	3.8	32.0%	523	175	9	195.8	42.0%	13.0%	$2.11	$1.82	$0.93
D94019	Atascosa	Pivot	Deere 4039	1,500		1.7		540	7	45	111.0		17.0%	$0.95	$0.79	$0.71
D94020	Atascosa	Pivot	Detroit 641	1,450		3.1		615	5	42	102.0		10.0%	$1.73	$1.26	$1.24
D94021	Frio	Pivot	Cat 353	1,650		11.7		900	400	40	492.4		18.0%	$6.69	$3.34	$0.68

LOCATION	COUNTY	METHOD	MODEL	RPM	HP	FUEL	E_EFF	FLOW	LIFT	PRESS	T_HEAD	P_EFF	O_EFF	$/HR	$/AC-IN	@ 100' HEAD
D94022-1	Atascosa	Side Roll	Detroit 471	1,475	44	3.0	27.0%	364	200	56	329.4	73.0%	19.0%	$2.04	$2.52	$0.77
D94022-2	Atascosa	Side Roll	Detroit 471	1,770	81	5.3	29.0%	777	200	44	301.6	77.0%	21.0%	$3.57	$2.07	$0.69
D94023	Medina	Drip	Int 501	1,935	76	4.2	34.0%	552	151	65	301.2	58.0%	19.0%	$2.62	$2.14	$0.71
D94024	Medina	Reservior	Cum 5.9P	1,770	68	3.8	32.0%	766	200	0	200.0	60.0%	18.0%	$2.39	$1.40	$0.70
D94025-1	Medina	Reservior	Detroit 671	1,550		5.3		1,105	175	0	175.0		17.0%	$3.15	$0.13	$0.73
D94025-2	Medina	Reservior	Detroit 671	1,750		6.8		1,174	175	0	175.0		14.0%	$4.00	$1.53	$0.88
D94026-1	Medina	Pivot	Volvo TD71	1,540	108	5.6	36.0%	1,087	200	44	301.6	80.0%	28.0%	$3.32	$1.37	$0.46
D94026-2	Medina	Pivot	Volvo TD71	1,580	117	5.9	37.0%	1,163	200	44	301.6	80.0%	28.0%	$3.50	$1.35	$0.45
D94027	Zavala	Furrow	Deere 4039			2.5		1,870	15	23	68.1		24.0%	$1.78	$0.43	$0.63
D94028	Uvalde	Pivot	Detroit V671	1,725	147	8.3	33.0%	2,125	80	52	200.0	77.0%	24.0%	$5.39	$1.14	$0.57
D94029	Uvalde	Pivot	Detroit 671	1,830	119	8.4	27.0%	920	50	54	174.7	37.0%	9.0%	$5.44	$2.66	$1.52
D94030	Uvalde	Furrow	Detroit 371	1,680		4.9		1,180	35	10	58.1		7.0%	$3.17	$1.21	$2.08
D94031	Uvalde	Reservoir	Detroit 471	1,600		4.7		1,280	33	30	102.3		13.0%	$3.03	$1.07	$1.04
D94032	Uvalde	Pivot	Detroit 371	1,700		2.4		560	33	31	104.6		11.0%	$1.58	$1.27	$1.21
D94033	Uvalde	Furrow	Cat D333	1,600		5.7		1,810	110	5	120.4		18.0%	$3.36	$0.84	$0.69
D94034	Uvalde	Furrow	Deere 6369	2,160	50	3.2	29.0%	1,180	75	5	85.4	54.0%	15.0%	$2.10	$0.80	$0.94
D94035	Starr	Reservoir	Deutz BF62	1,900		7.8		2,235	60	32	103.9		14.0%	$5.13	$1.03	$0.99
D94036	Starr	Drip	Deutz DF62	1,267		4.7		1,872	25	28	89.7		17.0%	$3.12	$0.75	$0.84
D94037	Starr	Furrow	Detroit 471	1,300		3.6		1,211	25	12	52.2		8.0%	$2.53	$0.94	$1.78

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LOCATION	COUNTY	METHOD	MODEL	RPM	HP	FUEL	E_EFF	FLOW	LIFT	PRESS	T_HEAD	P_EFF	O_EFF	$/HR	$/AC-IN	$/AC-IN @ 100' HEAD
G93001-1	Jackson	Flood	Cat 342	895	80.0	800	25.0%	1580	142	0.4	142.9	73.0%	17.0%	$4.20	$1.20	$0.84
G93001-2	Jackson	Flood	Cat 342	1030	125.0	1153	27.0%	2100	157	0.4	157.9	69.0%	18.0%	$6.05	$1.30	$0.82
G93001-3	Jackson	Flood	Cat 342	820	60.0	619	25.0%	1140	132	0.4	132.9	67.0%	16.0%	$3.25	$1.28	$0.97
G93002-1	Frio	Pivot	Cat 353	1025	177.0	1548	26.0%	905	390	53.0	512.4	70.0%	17.0%	$4.03	$2.00	$0.39
G93002-2	Frio	Pivot	Cat 353	1005	167.0	1458	26.0%	870	390	49.0	503.2	70.0%	17.0%	$3.79	$1.96	$0.39
G93003	Frio	Pivot	Cat 353	985	164.0	1381	27.0%	720	400	33.0	476.2	53.0%	13.0%	$3.59	$2.24	$0.47
G93004	Frio	Pivot	Cat 353	1045	163.0	1394	26.0%	850	400	52.0	520.1	72.0%	18.0%	$4.18	$2.21	$0.43
G93005	Medina	Furrow	Waukesha			1112		1320	300	2.0	304.6		21.0%	$4.50	$1.53	$0.50
G93006	Medina	Furrow	Cat 342	1110	190.0	1938	22.0%	2225	160	5.0	171.6	53.0%	11.0%	$7.84	$1.59	$0.92
G94001	Bexar	Furrow	Int 501			911		2492	75	4.0	84.2		14.0%	$5.01	$0.90	$1.07
G94002	Terry	Pivot	Chevy 292	1790	45.0	625	18.0%	446	112	52.0	232.1	63.0%	11.0%	$1.97	$1.99	$0.86
G94003	Terry	Pivot	Chrysler 318			405		492	60	40.0	152.4		12.0%	$1.27	$1.17	$0.77
G94004	Dawson	Pivot	Ford 300			544		445	75	62.0	218.2		12.0%	$1.71	$1.73	$0.79
G94005	Terry	Pivot	Chevy 292			750		299	126	24.0	181.4		5.0%	$2.37	$3.55	$1.96
G94006	Zavala	Reservoir	Waukesha			2015		980	360	0.0	360.0		11.0%	$6.55	$3.01	$0.84
G94007	Zavala	Reservoir	Crysler 440			1059		720	308	4.0	317.2		14.0%	$3.44	$2.15	$0.68
G94008	Starr	Furrow	Waukesha	1100	68.0	1107	16.0%	1814	30	31.0	101.6	72.0%	11.0%	$3.60	$0.89	$0.88
G94009	Starr	Furrow	Waukesha	1000		1120		1774	30	30.0	99.3		10.0%	$3.64	$0.92	$0.93
G94010	Starr	Furrow	Catapillar	1400		1015		2715	30	21.0	78.5		14.0%	$3.30	$0.55	$0.70
G94011	Starr	Furrow	Catapillar	1300		935		1400	30	33.0	106.2		10.0%	$3.04	$0.98	$0.92
G94012	Jackson	Flood	Waukesha	780	118.0	1609	18.0%	1807	150	0.0	150.0	61.0%	10.0%	$5.63	$1.40	$0.93
G94013	Jackson	Flood	Moline 800	1200		664		1470	100	0.0	100.0		14.0%	$1.66	$0.51	$0.51
G94014-1	Jackson	Flood	Waukesha	800		1540		2258	127	0.0	127.0		11.0%	$3.85	$0.77	$0.60
G94014-2	Jackson	Flood	Waukesha	900		1808		2515	135	0.0	135.0		11.0%	$4.52	$0.81	$0.60
G94015	Pecos	Pivot	Cat 342			2495		2089	275	20.0	321.0		18.0%	$4.99	$1.07	$0.33
G94016	Pecos	Pivot	Cat 378	1635	295.0	3125	25.0%	2719	280	19.0	324.0	79.0%	19.0%	$6.25	$1.03	$0.32
G94017	Pecos	Furrow/Basin	Deere 6076	2000		927		950	169	0.0	169.0		11.0%	$1.85	$0.88	$0.52
G94018	Pecos	Furrow/Basin	Moline 850	1700		861		1108	171	0.0	171.0		14.0%	$1.72	$0.70	$0.41
G94019	Pecos	Furrow/Basin	Cum 250	1740		1397		997	111	0.0	111.0		5.0%	$2.79	$1.26	$1.14
G94020	Pecos	Furrow/Basin	Cum 250	1680	93.0	1082	22.0%	1000	230	0.0	230.0	66.0%	14.0%	$2.16	$0.97	$0.42
G94021-1	Pecos	Furrow/Basin	Cat 342	1080	160.0	1621	26.0%	1496	240	1.0	242.0	60.0%	15.0%	$3.24	$0.98	$0.40
G94021-2	Pecos	Furrow/Basin	Cat 342	1165	203.0	1971	27.0%	1516	260	1.0	262.0	52.0%	13.0%	$3.94	$1.17	$0.45
G94022	Pecos	Furrow/Basin	Cat 342	1130		1639		1896	196	6.0	210.0		16.0%	$3.28	$0.78	$0.37
G94023	Pecos	Furrow/Basin	Cat 342	1000		1461		1200	275	0.0	275.0		15.0%	$2.92	$1.10	$0.40
G94024	Pecos	Furrow/Basin	Cat 342	1130		1437		1303	180	2.0	185.0		11.0%	$2.87	$0.99	$0.54
G94025	Pecos	Furrow/Basin	Cat 342			1571		1612	195	8.0	212.0		14.0%	$3.14	$0.88	$0.41
G94026	Pecos	Furrow/Basin	Cat 342	1100		1373		1740	193	0.0	193.0		16.0%	$2.75	$0.71	$0.37
G94027	Pecos	Furrow/Basin	Moline 800			978		1177	147	0.0	147.0		12.0%	$1.96	$0.75	$0.51

LOCATION	COUNTY	METHOD	MODEL	RPM	HP	FUEL	E_EFF	FLOW	LIFT	PRESS	T_HEAD	P_EFF	O_EFF	$/HR	$/AC-IN	@ 100' HEAD
G94028	Pecos	Furrow/Basin	Cum 250			1330		1309	160	0.0	160.0		10.0%	$2.66	$0.91	$0.57
G94029	Pecos	Furrow/Basin	Cum 250	1625	120.0	1197	26.0%	1241	167	4.0	176.0	48.0%	12.0%	$2.39	$0.87	$0.49
G94030	Pecos	Pivot	Cat 342	1050		1309		1176	190	47.0	299.0		18.0%	$2.62	$1.00	$0.34
G94031	Pecos	Furrow/Basin	Cat 342			1324		803	191	41.0	286.0		11.0%	$2.65	$1.48	$0.52
G94032	Pecos	Furrow/Basin	Cat 342			1160		1308	189	5.0	201.0		15.0%	$2.32	$0.80	$0.40
G94033	Pecos	Furrow/Basin	Cat 342			1824		1320	260	40.0	352.0		17.0%	$3.65	$1.24	$0.35
G94034	Pecos	Furrow/Basin	Cat 353			2285		2082	155	50.0	271.0		16.0%	$4.57	$0.99	$0.37
G94035	Pecos	Pivot	Cat 342			2266		1264	300	42.0	397.0		15.0%	$4.53	$1.61	$0.41
G94036	Pecos	Pivot	Cat 378			2856		1615	295	52.0	415.0		15.0%	$5.71	$1.59	$0.38
G94037	Pecos	Furrow/Basin	Cum 250			1538		1100	320	0.0	320.0		15.0%	$3.08	$1.26	$0.39
G94038	Pecos	Furrow/Basin	Cat 342			1489		1373	290	10.0	313.0		19.0%	$2.98	$0.98	$0.31
G94039	Pecos	Pivot	Cum 525	1660	264.0	3024	23.0%	1825	280	55.0	407.0	75.0%	16.0%	$6.05	$1.49	$0.37
G94040	Uvalde	Furrow	Chevy 292	2580		462		1339	34	5.5	46.7		9.0%	$1.32	$0.44	$0.95
G94041-1	Hudspeth	Furrow	Cummins 250	1785	95.0	1075	23.0%	1620	123	0.0	123.0	56.0%	12.0%	$1.94	$0.54	$0.44
G94041-2	Hudspeth	Furrow	Cummins 250	1785	146.0	1427	27.0%	2385	123	0.0	123.0	56.0%	14.0%	$2.57	$0.48	$0.39
G94042	Hudspeth	Furrow	Cat 3306			1326		1466	74	15.0	108.7		8.0%	$2.39	$0.73	$0.67
G94043	Hudspeth	Furrow	Ford 460			1152		2830	86	0.0	86.0		14.0%	$2.07	$0.33	$0.38
G94044	Hudspeth	Furrow	Deere 6076 AF	1650	122.0	1165	27.0%	1830	100	0.0	100.0	40.0%	10.0%	$2.10	$0.52	$0.52
G94045-1	Hudspeth	Basin	Cummins 250	1600	134.8	1399	25.0%	1610	126	2.0	130.6	41.0%	10.0%	$2.52	$0.70	$0.54
G94045-2	Hudspeth	Basin	Cummins 250	1750	172.5	1652	27.0%	2300	141	2.0	145.6	52.0%	13.0%	$2.97	$0.58	$0.40
LG93007	Hidalgo	Canal	Cum 743			765		10260	15	2.0	19.6		17.0%	$3.06	$1.62	$0.14
LG93008	Hidalgo	Canal	Cat 398	1110		4351		45000	7	11.0	32.4		22.0%	$17.40	$2.10	$0.18
LG93009	Hidalgo	Canal	Cat 398	1050		4544		35100	7	11.0	32.4		16.0%	$18.18	$2.81	$0.24
LG93010	Hidalgo	Canal	Cat 398	1096		3530		36000	7	11.0	32.4		21.0%	$14.12	$2.13	$0.18
LG93011	Hidalgo	Canal	Cat 398	1124		4402		34200	7	11.0	32.4		16.0%	$17.61	$2.80	$0.23
LG93012	Hidalgo	Canal	Cat 398	1150		4322		33100	7	11.0	32.4		16.0%	$17.29	$2.84	$0.24

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LOCATION	COUNTY	METHOD	TYPE	RATED HP	kW-h	INPUT HP	M_EFF	FLOW	LIFT	PRESS	T_HEAD	P_EFF	O_EFF	$/HR	$/AC-IN	$/AC-IN @ 100' HEAD
E93001	Erath	Reservoir	Sub	10	9.1	12.2	84.0%	85	187	55.0	314.1	66.0%	55.0%	$0.38	$2.01	$0.64
E93002	Erath	Reservoir	Sub	8	5.3	7.1	83.0%	58	137	34.0	215.5	54.0%	45.0%	$0.22	$1.71	$0.80
E93003	Erath	Reservoir	Sub	10	9.1	12.2	84.0%	131	150	6.0	163.9	53.0%	45.0%	$0.38	$1.30	$0.80
E93004	Erath	Reservoir	Sub	10	10.1	13.5	84.0%	55	144	20.0	190.2	23.0%	20.0%	$0.42	$3.44	$1.81
E93005	Erath	Pivot	Sub	10	9.1	12.2	84.0%	120	140	4.0	149.2	44.0%	37.0%	$0.38	$1.42	$0.95
E93006	Erath	Reservoir	Horiz	8	5.4	7.2	83.0%	250	3	24.0	58.4	61.0%	51.0%	$0.23	$0.41	$0.69
E93007	Erath	Reservoir	Sub		1.8	2.4	84.0%	27	100	34.0	178.5	60.0%	51.0%	$0.08	$1.25	$0.70
E93008	Erath	Reservoir	Sub		3.2	4.3	84.0%	22	121	50.0	236.5	36.0%	31.0%	$0.13	$2.72	$1.15
E93009	Erath	Reservoir	Sub		2.4	3.2	84.0%	22	47	50.0	162.5	34.0%	28.0%	$0.10	$2.05	$1.26
E93010	Erath	Reservoir	Sub		5.1	6.8	84.0%	28	115	26.0	175.1	22.0%	18.0%	$0.21	$3.41	$1.95
E93011	Erath	Pivot	Horiz	20	18.5	24.8	84.0%	440	8	34.0	86.5	52.0%	39.0%	$0.87	$0.85	$0.74
E93012	Erath	Reservoir	Sub	3	1.7	2.3	82.0%	22	83	33.0	159.2	47.0%	39.0%	$0.07	$1.45	$0.91
E93013	Erath	Reservoir	Sub	3	1.8	2.4	82.0%	9	105	36.0	188.2	22.0%	18.0%	$0.08	$3.75	$1.99
E93014	Erath	Reservoir	Sub	3	2.4	3.2	82.0%	25	95	24.0	150.4	36.0%	30.0%	$0.10	$1.80	$1.20
E93015	Erath	Reservoir	Sub	3	2.3	3.1	82.0%	45	90	21.0	138.5	62.0%	51.0%	$0.10	$0.96	$0.69
E93016	Erath	Reservoir	Sub	3	2.3	3.1	82.0%	13	95	30.0	164.3	21.0%	18.0%	$0.10	$3.32	$20.20
E93017	Atascosa	Pivot	VHS	125	86.7	116.2	90.0%	820	250	36.0	333.2	48.0%	44.0%	$5.60	$3.07	$0.92
E93023	Atascosa	Reservoir	Sub	5	5.5	7.4	84.0%	130	89	1.0	91.3	48.0%	40.0%	$0.45	$1.55	$1.70
E93024	Atascosa	Reservoir	Sub	10	9.4	12.6	85.0%	104	40	77.0	217.9	53.0%	45.0%	$0.76	$3.31	$1.52
E93025	Comanche	Sprinkler	Horiz	15	11.2	15.0	88.0%	300	8	42.0	105.0	60.0%	53.0%	$1.18	$1.76	$1.68
E93026	Comanche	Sprinkler	Horiz	5	3.3	4.4	82.0%	73	2	50.0	117.5	60.0%	49.0%	$0.35	$2.14	$1.82
E93027	Comanche	Reservoir	Sub	3	2.7	3.6	81.0%	29	107	54.0	231.7	58.0%	47.0%	$0.28	$4.40	$1.90
E93028	Comanche	Reservoir	Sub	8	5.1	6.8	84.0%	55	130	51.0	247.8	60.0%	50.0%	$0.54	$4.38	$1.77
E93029	Comanche	Reservoir	Sub	5	5.0	6.7	81.0%	45	110	57.0	241.7	52.0%	42.0%	$0.53	$5.14	$2.13
E93030	Comanche	Side Roll	Horiz	10	9.1	12.2	84.0%	125	7	70.0	168.7	52.0%	44.0%	$0.96	$3.44	$2.04
E93031	Comanche	Side Roll	Horiz	30	24.8	33.2	86.0%	450	15	44.0	116.6	46.0%	40.0%	$2.60	$2.60	$2.23
E93032	Medina	Reservoir	VHS	250	191.0	255.9	94.0%	1955	330	3.0	336.9	69.0%	65.0%	$11.46	$2.64	$0.78
E93033	Medina	Reservoir	VHS	125	108.5	145.4	92.0%	2260	123	3.0	129.9	55.0%	51.0%	$6.51	$1.30	$1.00
E93034	Uvalde	Furrow	VHS	50	37.5	50.3	90.0%	965	49	5.0	60.6	33.0%	29.0%	$2.10	$0.98	$1.61
E93035	Uvalde	Furrow	VHS	100	78.2	104.8	91.0%	2040	90	6.0	103.9	56.0%	51.0%	$4.37	$0.96	$0.93
E93036	Uvalde	Furrow	VHS	125	93.6	125.4	92.0%	1580	94	5.0	105.6	37.0%	34.0%	$5.23	$1.49	$1.41
E93039	Waller	Reservoir	VHS	125	116.8	156.5	85.0%	1130	150	1.0	152.3	33.0%	28.0%	$7.15	$2.85	$1.87
E93040	Uvalde	Furrow	VHS	125	84.8	113.6	93.0%	1620	125	4.0	133.1	52.0%	48.0%	$4.30	$1.19	$0.90

LOCATION	COUNTY	METHOD	TYPE	HP	kW-h	HP	M_EFF	FLOW	LIFT	PRESS	T_HEAD	P_EFF	O_EFF	$/HR	$/AC-IN	@ 100' HEAD
E93041	Medina	Pivot	VHS	150	124.6	167.0	93.0%	1300	100	84.0	294.0	62.0%	58.0%	$6.31	$2.18	$0.74
E93042	Medina	Pivot	VHS	50	35.6	47.7	91.0%	700	80	34.0	158.5	65.0%	59.0%	$1.80	$1.16	$0.73
E93043	Medina	Pivot	VHS	200	157.9	211.6	93.0%	1478	200	38.0	287.7	55.0%	51.0%	$9.47	$2.88	$1.00
E93044	Medina	Reservoir	VHS	125	103.4	138.6	92.0%	1985	146	2.0	149.5	59.0%	54.0%	$6.20	$1.41	$0.94
E94001	McCulloch	Side Roll	VHS	60	56.3	75.4	91.0%	622	200	7.0	216.2	50.0%	45.0%	$4.46	$3.23	$1.49
E94002	Medina	Furrow	VHS	100	81.4	109.1	92.0%	1421	200	2.5	205.8	74.0%	68.0%	$5.70	$1.80	$0.88
E94003	Medina	Furrow	VHS	125	88.1	118.1	92.0%	1247	200	6.0	213.9	62.0%	57.0%	$6.17	$2.23	$1.04
E94004-1	Medina	Furrow	VHS	250	182.0	243.9	94.0%	2562	200	5.0	211.6	60.0%	56.0%	$12.74	$2.24	$1.06
E94004-2	Medina	Pivot	VHS	250	180.2	241.5	94.0%	2213	200	35.0	280.9	69.0%	65.0%	$12.61	$2.56	$0.91
E94005	Terry	Pivot	Horiz	25	19.3	25.7	90.0%	107	118	22.0	168.8	25.0%	18.0%	$1.45	$6.08	$3.60
E94006	Terry	Pivot	Horiz	40	22.2	31.0	90.0%	211	150	54.0	274.7	58.0%	47.0%	$1.73	$3.70	$1.35
E94007	Terry	Pivot	Horiz	20	17.1	23.0	90.0%	274	74	36.0	157.2	55.0%	47.0%	$1.29	$2.12	$1.35
E94008	Terry	Pivot	Horiz	20	11.3	15.1	90.0%	218	62	20.0	108.2	46.0%	39.0%	$0.85	$1.75	$1.62
E94009	Terry	Pivot	Horiz	20	13.9	18.6	90.0%	197	59	54.0	183.7	57.0%	49.0%	$1.04	$2.38	$1.30
E94010	Terry	Pivot	Horiz	25	19.7	26.4	90.0%	297	52	76.0	227.6	76.0%	65.0%	$1.48	$2.24	$0.98
E94011	Dawson	Pivot	Sub	20	14.5	19.4	90.0%	270	84	31.0	155.6	61.0%	55.0%	$0.73	$1.21	$0.78
E94012	Dawson	Pivot	VHS	50	39.1	52.4	91.0%	488	104	45.0	208.0	54.0%	49.0%	$1.96	$1.80	$0.87
E94013	Dawson	Pivot	Sub	20	17.5	23.5	90.0%	246	80	52.0	200.1	59.0%	53.0%	$0.88	$1.60	$0.80
E94014	Dawson	Pivot	Sub	40	27.8	37.3	90.0%	414	116	40.0	208.4	65.0%	58.0%	$1.39	$1.51	$0.72
E94015	Dawson	Pivot	Sub	30	24.5	32.8	90.0%	268	123	48.0	233.9	54.0%	48.0%	$1.23	$2.06	$0.88
E94016	Gaines	Pivot	Sub	20	17.7	23.7	90.0%	218	137	30.0	206.3	53.0%	48.0%	$1.06	$2.19	$1.06
E94017	Gaines	Pivot	Horiz	30	19.8	26.5	90.0%	260	84	35.0	164.9	48.0%	41.0%	$1.19	$2.05	$1.25
E94018	Gaines	Pivot	Sub	25	21.5	28.8	90.0%	285	101	32.0	174.9	49.0%	44.0%	$1.29	$2.04	$1.17
E94019	Gaines	Pivot	Sub	25	23.2	31.1	90.0%	289	154	26.0	214.1	56.0%	50.0%	$1.39	$2.17	$1.01
E94020	Gaines	Pivot	Sub	25	20.4	27.3	90.0%	234	95	35.0	175.9	42.0%	38.0%	$1.22	$2.36	$1.34
E94021	Gaines	Pivot	Sub	30	22.7	30.4	90.0%	361	150	20.0	196.2	65.0%	59.0%	$1.36	$1.70	$0.87
E94022	Gaines	Pivot	Sub	25	18.8	25.2	90.0%	230	94	35.0	174.9	45.0%	40.0%	$1.13	$2.21	$1.26
E94023	Gaines	Pivot	Sub	15	11.3	15.1	90.0%	122	84	35.0	164.9	37.0%	34.0%	$0.68	$2.50	$1.52
E94024	Gaines	Pivot	Sub	20	10.7	14.3	90.0%	139	120	20.0	166.2	45.0%	41.0%	$0.64	$2.07	$1.25
E94025	Gaines	Pivot	Sub	25	19.7	26.4	90.0%	253	163	22.0	213.8	57.0%	52.0%	$1.18	$2.10	$0.98
E94026	Gaines	Pivot	Sub	8	9.7	13.0	90.0%	99	170	22.0	220.8	47.0%	42.0%	$0.58	$2.65	$1.20
E94027	Culberson	Side Roll	Sub	40	41.0	54.9	91.0%	275	284	42.0	381.0	53.0%	48.0%	$3.64	$5.49	$1.56
E94028	Presidio	Furrow	Horiz	25	20.0	26.8	90.0%	1695	17	0.0	17.0	30.0%	27.0%	$1.75	$0.46	$2.73
E94029	Presidio	Furrow	Horiz	25	20.3	27.2	90.0%	1280	35	0.0	35.0	46.0%	42.0%	$1.77	$0.62	$1.78
E94030	Presidio	Furrow	Horiz	50	38.2	51.2	92.0%	2200	30	0.0	30.0	35.0%	33.0%	$3.34	$0.68	$2.28
E94031	Presidio	Furrow	Horiz	50	27.6	37.0	92.0%	2625	15	0.0	15.0	29.0%	27.0%	$2.41	$0.41	$2.76
E94032	Presidio	Furrow	Horiz	30	16.1	21.6	91.0%	1180	15	10.0	38.1	58.0%	53.0%	$1.41	$0.54	$1.41

LOCATION	COUNTY	METHOD	TYPE	HP	kW-h	HP	M_EFF	FLOW	LIFT	PRESS	T_HEAD	P_EFF	O_EFF	$/HR	$/AC-IN	@ 100' HEAD
E94033	Zavala	Reservoir	VHS	150	116.0	155.4	93.0%	953	360	0.0	360.0	60.0%	56.0%	$7.59	$3.58	$1.00
E94034	Zavala	Reservoir	VHS	150	99.6	133.5	92.0%	2165	100	10.0	123.1	55.0%	50.0%	$6.52	$1.35	$1.10
E94035	Zavala	Furrow	VHS	75	58.4	78.3	91.0%	1060	110	7.0	126.2	47.0%	43.0%	$3.82	$1.62	$1.29
E94036	Starr	Furrow	VHS	75	52.8	70.8	91.0%	2126	30	13.0	60.0	50.0%	46.0%	$3.45	$0.73	$1.22
E94037	Jackson	Flood	VHS	75	56.6	75.8	91.0%	1494	104	0.0	104.0	57.0%	52.0%	$3.40	$1.02	$0.98
E94038	Uvalde	Furrow	VHS	75	80.9	108.4	91.0%	1330	110	0.0	110.0	37.0%	34.0%	$5.22	$1.77	$1.61
E94039	Uvalde	Furrow	VHS	100	88.7	118.9	92.0%	800	133	10.0	156.1	29.0%	27.0%	$4.83	$2.72	$1.74
E94040	Uvalde	Pivot	VHS	50	48.3	64.7	90.0%	1084	35	55.0	162.1	76.0%	69.0%	$2.41	$1.00	$0.62
E94041	Uvalde	Furrow	VHS	75	43.0	57.6	90.0%	1330	76	1.5	79.5	51.0%	46.0%	$2.15	$0.73	$0.92
E94042	Hudspeth	Furrow	Sub	40	33.6	44.9	90.0%	765	128	0.0	128.0	61.0%	55.0%	$0.63	$0.37	$0.29
E94043	Hudspeth	Furrow	VHS	50	36.3	48.6	90.0%	1425	80	2.0	84.6	70.0%	63.0%	$2.90	$0.92	$1.08
E94044	Starr	Drip	Horiz	65	38.1	51.0	90.0%	1068	4	40.0	96.4	57.0%	51.0%	$2.46	$1.04	$1.07
E94045	Starr	Canal	VHS	100	86.4	115.6	90.0%	1840	30	20.0	76.2	34.0%	31.0%	$5.57	$1.36	$1.79
E94046	Starr	Furrow/Drip	VHS	100	84.7	113.5	90.0%	1850	30	20.0	76.2	34.0%	31.0%	$5.46	$1.33	$1.74
E94047	Starr	Furrow	Horiz	75	59.7	80.1	91.0%	2768	30	10.0	53.1	51.0%	46.0%	$3.85	$0.63	$1.18
E94048	Starr	Canal	Horiz	50	37.1	49.7	90.0%	2332	50	0.0	50.0	66.0%	59.0%	$2.39	$0.49	$0.92
LE93018	Cameron	Canal	VHS	250	169.2	226.7	94.0%	40500	12	1.0	14.3	92.0%	86.0%	$11.07	$1.48	$0.12
LE93019	Cameron	Canal	VHS	20	11.6	15.5	89.0%	3600	8	1.0	10.3	91.0%	81.0%	$0.76	$1.14	$0.10
LE93020	Cameron	Canal	Horiz	20	16.1	21.6	85.0%	3000	8	1.0	10.3	57.0%	49.0%	$1.05	$1.91	$0.16
LE93021	Cameron	Canal	Horiz	25	14.2	19.0	89.0%	2600	10	2.0	14.6	76.0%	68.0%	$0.93	$1.94	$0.16
LE93022	Cameron	Canal	Horiz	25	13.7	18.4	89.0%	2700	10	2.0	14.6	82.0%	73.0%	$0.90	$1.80	$0.15
LE93037	Hidalgo	Canal	VHS	350	219.1	293.6	95.0%	29250	15	5.0	26.6	70.0%	67.0%	$14.33	$2.66	$0.22
LE93038	Hidalgo	Canal	Horiz	500	361.7	484.7	95.0%	42200	7	9.0	27.8	86.0%	82.0%	$23.66	$3.05	$0.25
LE94001	Hidalgo	Canal	VHS	400	271.9	364.4	93.0%	27720	32	3.0	38.9	80.0%	75.0%	$17.79	$3.48	$0.29
LE94002	Hidalgo	Canal	VHS	150	91.5	122.6	92.0%	6700	32	3.0	38.9	58.0%	54.0%	$5.99	$4.85	$0.41
LE94003	Hidalgo	Canal	VHS	200	182.2			11600	10	3.0	16.3		20.0%	$11.92	$5.58	$0.47
LE94004	Hidalgo	Canal	VHS	400	269.0	360.5	94.0%	31050	30	2.0	34.6	80.0%	75.0%	$17.60	$3.08	$0.26
LE94005	Hidalgo	Canal	VHS	400	274.1	367.3	94.0%	29250	30	2.0	34.6	74.0%	69.0%	$17.93	$3.33	$0.28
LE94006	Hidalgo	Canal	VHS	400	289.9	388.5	94.0%	23400	30	2.0	34.6	56.0%	53.0%	$18.96	$4.40	$0.37
LE94007	Hidalgo	Canal	VHS	400	264.7	354.7	94.0%	29700	30	2.0	34.6	78.0%	73.0%	$17.32	$3.17	$0.27
LE94008	Hidalgo	Canal	VHS	400	289.5	387.9	94.0%	31950	30	2.0	34.6	76.0%	72.0%	$18.94	$3.22	$0.27
LE94009	Hidalgo	Canal	VHS	400	261.2	350.0	94.0%	30150	30	2.0	34.6	80.0%	75.0%	$17.09	$3.08	$0.26
LE94010	Hidalgo	Canal	VHS	400	208.4	279.3	94.0%	20250	30	2.0	34.6	67.0%	63.0%	$13.63	$3.66	$0.31
LE94011	Hidalgo	Canal	VHS	400	259.9	348.3	94.0%	32400	30	2.0	34.6	86.0%	81.0%	$17.00	$2.85	$0.24
LE94012	Hidalgo	Canal	VHS	400	221.9	297.3	94.0%	18900	30	2.0	34.6	59.0%	55.0%	$14.52	$4.17	$0.35
LE94013	Hidalgo	Canal	Horiz	400	267.8	358.8	94.0%	27377	26	0.0	26.0	54.0%	50.0%	$17.52	$3.48	$0.29
LE94014	Hidalgo	Canal	VHS	150	93.1	124.7	92.0%	10800	28	0.0	28.0	67.0%	61.0%	$6.09	$3.06	$0.26

LOCATION	COUNTY	METHOD	TYPE	HP	kW-h	HP	M_EFF	FLOW	LIFT	PRESS	T_HEAD	P_EFF	O_EFF	$/HR	$/AC-IN	@ 100' HEAD
LE94015	Hidalgo	Canal	VHS	450	315.2	422.4	94.0%	40000	28	0.0	28.0	71.0%	67.0%	$20.62	$2.80	$0.23
LE94016	Hidalgo	Canal	VHS	450	322.9	432.7	94.0%	36100	28	0.0	28.0	63.0%	59.0%	$21.12	$3.18	$0.27
LE94017	Hidalgo	Canal	VHS	300	193.7	259.5	93.0%	19423	30	0.0	29.5	60.0%	56.0%	$12.67	$3.54	$0.30
LE94018	Hidalgo	Canal	VHS	400	239.3	320.6	93.0%	25955	30	0.0	29.5	65.0%	60.0%	$15.65	$3.27	$0.27
LE94019	Hidalgo	Canal	VHS	200	111.3	149.1	92.0%	12800	30	0.0	29.5	70.0%	64.0%	$7.28	$3.09	$0.26
LE94020	Cameron	Canal	VHS	40	23.3	31.2	90.0%	4950	6	0.0	6.0	27.0%	24.0%	$1.50	$1.65	$0.14
LE94021	Cameron	Canal	VHS	10	5.0	6.6	80.0%	800	6	0.0	6.0	26.0%	18.0%	$0.32	$2.17	$0.18
LE94022	Cameron	Canal	VHS	15	6.8	8.1	80.0%	1356	6	0.0	6.0	28.0%	23.0%	$0.44	$1.76	$0.15

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Central Region Diesel Power Unit Summary

Location	County	Irrigation Method	Model	Engine Rpm	Engine Hp	Engine Fuel (Gal/hr)	Engine Efficiency (%)	Flow Rate (GPM)	Pumping Lift (ft)	Pump Discharge Head (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Cost Per Hour ($/Hr)	Cost Per Ac-In ($/Ac-In)	Cost Ac-In per 100' Head ($/Ac-In/100')
D94004	McCulloch	Side Roll	Ford 401	2000		3.2		279	350	45	453.9		18.5%	$2.27	$3.66	$0.81
D94005	Mason	Furrow	Deere 6059	1875		3.2		638	215	3	221.9		21.2%	$2.21	$1.56	$0.70
D94006	Mason	Side Roll	Int A170	2160		8.3		619	249	64	396.8		14.0%	$6.12	$4.45	$1.12
			Average	2012		4.9		512	271	37	357.5		17.9%	$3.53	$3.22	$0.88

Central Region Electric Power Unit Summary

Location	County	Irrigation Method	Type	Motor Rated Hp	Motor Electricity (kW-h)	Motor Input Hp	Motor Estimated Efficiency (%)	Flow Rate (GPM)	Pumping Lift (ft)	Pump Discharge Head (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Cost Per Hour ($/Hr)	Cost Per Ac-In ($/Ac-In)	Cost Ac-In per 100' Head ($/Ac-In/100')
E93001	Erath	Reservoir	Sub	10	9.1	12.2	84%	85	187	55	314.1	65.8%	55.3%	$0.38	$2.01	$0.64
E93002	Erath	Reservoir	Sub	7.5	5.3	7.1	83%	58	137	34	215.5	53.6%	44.5%	$0.22	$1.71	$0.80
E93003	Erath	Reservoir	Sub	10	9.1	12.2	84%	131	150	6	163.9	53.0%	44.5%	$0.38	$1.30	$0.80
E93004	Erath	Reservoir	Sub	10	10.1	13.5	84%	55	144	20	190.2	23.2%	19.5%	$0.42	$3.44	$1.81
E93005	Erath	Pivot	Sub	10	9.1	12.2	84%	120	140	4	149.2	44.2%	37.1%	$0.38	$1.42	$0.95
E93006	Erath	Reservoir	Horiz	7.5	5.4	7.2	83%	250	3	24	58.4	61.4%	51.0%	$0.23	$0.41	$0.69
E93007	Erath	Reservoir	Sub		1.8	2.4	84%	27	100	34	178.5	60.1%	50.5%	$0.08	$1.25	$0.70
E93008	Erath	Reservoir	Sub		3.2	4.3	84%	22	121	50	236.5	36.4%	30.6%	$0.13	$2.72	$1.15
E93009	Erath	Reservoir	Sub		2.4	3.2	84%	22	47	50	162.5	33.5%	28.1%	$0.10	$2.05	$1.26
E93010	Erath	Reservoir	Sub		5.1	6.8	84%	28	115	26	175.1	21.5%	18.1%	$0.21	$3.41	$1.95
E93011	Erath	Pivot	Horiz	20	18.5	24.8	84%	440	8	34	86.5	52.1%	38.8%	$0.87	$0.85	$0.74
E93012	Erath	Reservoir	Sub	3	1.7	2.3	82%	22	83	33	159.2	47.3%	38.8%	$0.07	$1.45	$0.91
E93013	Erath	Reservoir	Sub	3	1.8	2.4	82%	9	105	36	188.2	21.6%	17.7%	$0.08	$3.75	$1.99
E93014	Erath	Reservoir	Sub	3	2.4	3.2	82%	25	95	24	150.4	36.0%	29.5%	$0.10	$1.80	$1.20
E93015	Erath	Reservoir	Sub	3	2.3	3.1	82%	45	90	21	138.5	62.3%	51.1%	$0.10	$0.96	$0.69
E93016	Erath	Reservoir	Sub	3	2.3	3.1	82%	13	95	30	164.3	21.3%	17.5%	$0.10	$3.32	$20.20
E93025	Comanche	Sprinkler	Horiz	15	11.2	15.0	88%	300	8	42	105.0	60.2%	53.0%	$1.18	$1.76	$1.68
E93026	Comanche	Sprinkler	Horiz	5	3.3	4.4	82%	73	2	50	117.5	59.7%	49.0%	$0.35	$2.14	$1.82
E93027	Comanche	Reservoir	Sub	3	2.7	3.6	81%	29	107	54	231.7	57.9%	46.9%	$0.28	$4.40	$1.90
E93028	Comanche	Reservoir	Sub	7.5	5.1	6.8	84%	55	130	51	247.8	60.0%	50.4%	$0.54	$4.38	$1.77
E93029	Comanche	Reservoir	Sub	5	5	6.7	81%	45	110	57	241.7	51.7%	41.9%	$0.53	$5.14	$2.13
E93030	Comanche	Side Roll	Horiz	10	9.1	12.2	84%	125	7	70	168.7	52.0%	43.7%	$0.96	$3.44	$2.04
E93031	Comanche	Side Roll	Horiz	30	24.8	33.2	86%	450	15	44	116.6	46.4%	39.9%	$2.60	$2.60	$2.23
E94001	McCulloch	Side Roll	VHS	60	56.3	75.4	91%	622	200	7	216.2	49.5%	45.0%	$4.46	$3.23	$1.49
			Average	11	8.6	11.6	84%	127	92	36	174.0	47.1%	39.3%	$0.61	$2.46	$2.15

Edwards Region Diesel Power Unit Summary

Location	County	Irrigation Method	Model	Engine Rpm	Engine Hp	Engine Fuel (Gal/hr)	Engine Efficiency (%)	Flow Rate (GPM)	Pumping Lift (ft)	Pump Discharge Head (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Cost Per Hour ($/Hr)	Cost Per Ac-In ($/Ac-In)	Cost Ac-In per 100' Head ($/Ac-In/100')
D93001-1	Medina	Pivot	Cum 360	1765	220	10.3	39.8%	1770	230	60	368.6	79.0%	29.8%	$6.92	$1.76	$0.48
D93002-1	Medina	Pivot	Cum 903	1430	80	4.7	32.1%	1715	35	52	155.1	88.4%	27.0%	$2.94	$0.77	$0.50
D93002-2	Medina	Pivot	Cum 903	1725	135	7.7	32.8%	2420	45	55	172.1	82.0%	25.6%	$4.86	$0.90	$0.52
D93005	Medina	Furrow	Cat 3406	1785	265	16.9	29.4%	2200	250	2	254.6	56.2%	15.7%	$11.82	$2.42	$0.95
D93006	Medina	Pivot	Deere 6466			2.1		2866	125	7	141.2		16.3%	$8.19	$1.29	$0.91
D93007	Medina	Reservoir	Det 471			6.6		1000	58	86	256.7		18.5%	$4.60	$2.07	$0.81
D93001-2	Medina	Pivot	Cum 360	1720	205	10.5	36.7%	1810	225	52	345.1	81.0%	28.2%	$7.00	$1.74	$0.50
D93009	Medina	Furrow	Cum ?	1910	240	12.5	35.9%	1710	280	10	303.1	57.4%	19.6%	$8.50	$2.24	$0.74
D93010	Medina	Furrow	Volvo TDHPP12	1745	230	11.6	37.1%	2300	262	15	296.7	78.9%	27.8%	$7.89	$1.54	$0.52
D93011	Medina	Furrow	Cat 334	1655	160	9.1	33.1%	2020	200	5	210.4	70.6%	22.2%	$6.34	$1.41	$0.67
D93012	Medina	Pivot	Cum 360	1665	190	9.5	37.4%	2270	250	-10	226.9	72.1%	25.7%	$6.65	$1.32	$0.58
D93013	Medina	Pivot	Deere 6404	1320	30	2.1	26.7%	1130	70	2	73.5	73.6%	18.7%	$1.47	$0.59	$0.80
D93014	Bexar	Furrow	Deere 6359	2250		6.6		3205	35	10	58.1		13.3%	$4.62	$0.65	$1.12
D93015	Bexar	Furrow	Deere 4039	2000		5.6		2100	20	38	107.8		19.1%	$3.92	$0.84	$0.78
D93016	Bexar	Reservoir	Perkins			0.9		210	25	8	43.5		5.0%	$0.70	$1.49	$3.43
D94001	Bexar	Side Roll	Deere 1385	1200		1.9		560	50	2	54.6		7.8%	$1.07	$0.86	$1.58
D94002	Bexar	Side Roll	Deutz 6L	1700		2.3		1100	14	15	48.7		10.9%	$1.72	$0.70	$1.44
D94003-1	Medina	Pivot	Cum 360	1735	200	9.0	41.6%	1540	220	80	404.8	82.9%	32.8%	$5.85	$1.71	$0.42
D94003-2	Medina	Pivot	Cum 360	1585	155	8.0	36.3%	1390	230	52	350.1	83.5%	28.8%	$5.20	$1.68	$0.48
D94003-3	Medina	Pivot	Cum 360	1670	180	9.1	37.0%	1540	240	60	378.6	86.1%	30.3%	$5.92	$1.73	$0.46
D94007	Medina	Furrow	Cat 3406	1890		15.1		4414	180	18	221.6		30.7%	$7.83	$0.80	$0.36
D94008-1	Medina	Big Gun	Cat 3208	1640	65	3.5	33.8%	447	125	105	367.6	68.7%	22.0%	$2.25	$2.27	$0.62
D94008-2	Medina	Reservoir	Cat 3208	2265	190	10.4	34.6%	1376	250	20	296.2	56.2%	18.5%	$6.67	$2.18	$0.74
D94017	Bexar	Pivot	Detroit 471			5.4		1108	15	70	176.7		17.0%	$3.69	$1.50	$0.85
D94023	Medina	Drip	Int 501	1935	76	4.2	33.6%	552	151	65	301.2	58.2%	18.6%	$2.62	$2.14	$0.71
D94024	Medina	Reservior	Cum 5.9P	1770	68	3.8	31.7%	766	200	0	200	59.5%	17.9%	$2.39	$1.40	$0.70
D94025-1	Medina	Reservior	Detroit 671	1550		5.3		1105	175	0	175.0		17.2%	$3.15	$0.13	$0.73
D94025-2	Medina	Reservior	Detroit 671	1750		6.8		1174	175	0	175.0		14.3%	$4.00	$1.53	$0.88
D94026-1	Medina	Pivot	Volvo TD71	1540	108	5.6	36.1%	1087	200	44	301.6	80.3%	27.5%	$3.32	$1.37	$0.46
D94026-2	Medina	Pivot	Volvo TD71	1580	117	5.9	36.8%	1163	200	44	301.6	80.0%	28.0%	$3.50	$1.35	$0.45
D94028	Uvalde	Pivot	Detroit V671	1725	147	8.3	33.2%	2125	80	52	200.0	76.8%	24.2%	$5.39	$1.14	$0.57
D94029	Uvalde	Pivot	Detroit 671	1830	119	8.4	26.7%	920	50	54	174.7	36.8%	9.1%	$5.44	$2.66	$1.52
D94030	Uvalde	Furrow	Detroit 371	1680		4.9		1180	35	10	58.1		6.6%	$3.17	$1.21	$2.08
D94031	Uvalde	Reservoir	Detroit 471	1600		4.7		1280	33	30	102.3		13.2%	$3.03	$1.07	$1.04
D94032	Uvalde	Pivot	Detroit 371	1700		2.4		560	33	31	104.6		11.4%	$1.58	$1.27	$1.21
D94033	Uvalde	Furrow	Cat D333	1600		5.7		1810	110	4.5	120.4		18.1%	$3.36	$0.84	$0.69
D94034	Uvalde	Furrow	Deere 6369	2160	50	3.2	29.3%	1180	75	4.5	85.4	53.8%	14.9%	$2.10	$0.80	$0.94
			Average	1726	151	7.2	34.4%	1597	146	34	223.2	71.8%	20.9%	$4.89	$1.44	$0.82

Edwards Region Electric Power Unit Summary

				Motor					Pump						Cost		
Location	County	Irrigation Method	Type	Rated Hp	Electricity (kW-h)	Input Hp	Estimated Efficiency (%)	Flow Rate (GPM)	Pumping Lift (ft)	Discharge Head (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Per Hour ($/Hr)	Per Ac-In ($/Ac-In)	Ac-In per 100' Head ($/Ac-In/10')
E93032	Medina	Reservoir	VHS	250	191.0	255.9	94%	1955	330	3	336.9	69.1%	65.0%	$11.46	$2.64	$0.78
E93033	Medina	Reservoir	VHS	125	108.5	145.4	92%	2260	123	3	129.9	55.4%	51.0%	$6.51	$1.30	$1.00
E93034	Uvalde	Furrow	VHS	50	37.5	50.3	90%	965	49	5	60.6	32.7%	29.4%	$2.10	$0.98	$1.61
E93035	Uvalde	Furrow	VHS	100	78.2	104.8	91%	2040	90	6	103.9	56.1%	51.1%	$4.37	$0.96	$0.93
E93036	Uvalde	Furrow	VHS	125	93.6	125.4	92%	1580	94	5	105.6	36.5%	33.6%	$5.23	$1.49	$1.41
E93040	Uvalde	Furrow	VHS	125	84.8	113.6	93%	1620	125	4	133.1	51.5%	47.9%	$4.30	$1.19	$0.90
E93041	Medina	Pivot	VHS	150	124.6	167.0	93%	1300	100	84	294.0	62.2%	57.8%	$6.31	$2.18	$0.74
E93042	Medina	Pivot	VHS	50	35.6	47.7	91%	700	80	34	158.5	64.5%	58.7%	$1.80	$1.16	$0.73
E93043	Medina	Pivot	VHS	200	157.9	211.6	93%	1478	200	38	287.7	54.6%	50.8%	$9.47	$2.88	$1.00
E93044	Medina	Reservoir	VHS	125	103.4	138.6	92%	1985	146	2	149.5	58.8%	54.1%	$6.20	$1.41	$0.94
E94002	Medina	Furrow	VHS	100	81.4	109.1	92%	1421	200	2.5	205.8	73.6%	67.7%	$5.70	$1.80	$0.88
E94003	Medina	Furrow	VHS	125	88.1	118.1	92%	1247	200	6	213.9	62.0%	57.1%	$6.17	$2.23	$1.04
E94004-1	Medina	Furrow	VHS	250	182.0	243.9	94%	2562	200	5	211.6	59.7%	56.1%	$12.74	$2.24	$1.06
E94004-2	Medina	Pivot	VHS	250	180.2	241.5	94%	2213	200	35	280.9	69.2%	65.0%	$12.61	$2.56	$0.91
E94038	Uvalde	Furrow	VHS	75	80.9	108.4	91%	1330	110	0	110.0	37.5%	34.1%	$5.22	$1.77	$1.61
E94039	Uvalde	Furrow	VHS	100	88.7	118.9	92%	800	133	10	156.1	28.8%	26.5%	$4.83	$2.72	$1.74
E94040	Uvalde	Pivot	VHS	50	48.3	64.7	90%	1084	35	55	162.1	76.2%	68.5%	$2.41	$1.00	$0.62
E94041	Uvalde	Furrow	VHS	75	43.0	57.6	90%	1330	76	1.5	79.5	51.5%	46.3%	$2.15	$0.73	$0.92
			Average	129	100.4	134.6	92%	1548	138	17	176.6	55.5%	51.2%	$6.09	$1.74	$1.05

Edwards Region Natural Gas Power Unit Summary

				Engine					Pump						Cost		
Location	County	Irrigation Method	Model	Rpm	Hp	Fuel (cf/hr)	Efficiency (%)	Flow Rate (GPM)	Pumping Lift (ft)	Discharge Head (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Per Hour ($/Hr)	Per Ac-In ($/Ac-In)	Ac-In per 100' Head ($/Ac-In/100')
G93005	Medina	Furrow	Waukesha			1112		1320	300	2	304.6		20.6%	$4.50	$1.53	$0.50
G93006	Medina	Furrow	Cat 342	1110	190	1938	22.1%	2225	160	5	171.6	53.4%	11.2%	$7.84	$1.59	$0.92
G94001	Bexar	Furrow	Int 501			911		2492	75	4	84.2		14.1%	$5.01	$0.90	$1.07
G94040	Uvalde	Furrow	Chevy 292	2580		462		1339	34	5.5	46.7		9.2%	$1.32	$0.44	$0.95
			Average	1845	190	1106	22.1%	1844	142	4	151.8	53.4%	13.8%	$4.67	$1.12	$0.86

Far West Region Diesel Power Unit Summary

Location	County	Irrigation Method	Model	Engine Rpm	Engine Hp	Engine Fuel (Gal/hr)	Engine Efficiency (%)	Flow Rate (GPM)	Pumping Lift (ft)	Pump Discharge Head (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Cost Per Hour ($/Hr)	Cost Per Ac-In ($/Ac-In)	Cost Ac-In per 100' Head ($/Ac-In/100')
D94009	Culberson	Drip	Deere 6076			10.5		1620	275	40	367.4		26.8%	$5.99	$1.66	$0.45
D94010	Culberson	Drip	Deere 6076	1650		6.4		920	275	4	284.2		19.3%	$3.65	$1.78	$0.63
			Average	1650		8.5		1270	275	22	325.8		23.1%	$4.82	$1.72	$0.54

Far West Region Electric Power Unit Summary

Location	County	Irrigation Method	Type	Motor Rated Hp	Motor Electricity (kW-h)	Motor Input Hp	Motor Estimated Efficiency (%)	Flow Rate (GPM)	Pumping Lift (ft)	Pump Discharge Head (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Cost Per Hour ($/Hr)	Cost Per Ac-In ($/Ac-In)	Cost Ac-In per 100' Head ($/Ac-In/100')
E94027	Culberson	Side Roll	Sub	40	41.0	54.9	91%	275	284	42	381.0	53.0%	48.2%	$3.64	$5.49	$1.56
E94042	Hudspeth	Furrow	Sub	40	33.6	44.9	90%	765	128	0	128.0	61.2%	55.1%	$0.63	$0.37	$0.29
E94043	Hudspeth	Furrow	VHS	50	36.3	48.6	90%	1425	80	2	84.6	69.6%	62.6%	$2.90	$0.92	$1.08
			Average	43	37.0	49.5	90%	822	164	15	197.9	61.3%	55.3%	$2.39	$2.26	$0.98

Far West Region Natural Gas Power Unit Summary

Location	County	Irrigation Method	Model	Engine Rpm	Engine Hp	Engine Fuel (cf/hr)	Engine Efficiency (%)	Flow Rate (GPM)	Pumping Lift (ft)	Pump Discharge Head (psi)	Total Head (ft)	Pump Efficiency (%)	Overall Efficiency (%)	Per Hour ($/Hr)	Cost Per Ac-In ($/Ac-In)	Ac-In per 100' Head ($/Ac-In/100')
G94015	Pecos	Pivot	Cat 342			2495		2089	275	20	321		17.6%	$4.99	$1.07	$0.33
G94016	Pecos	Pivot	Cat 378	1635	295	3125	24.6%	2719	280	19	324	79.2%	18.5%	$6.25	$1.03	$0.32
G94017	Pecos	Furrow/Basin	Deere 6076	2000		927		950	169	0	169		11.4%	$1.85	$0.88	$0.52
G94018	Pecos	Furrow/Basin	Moline 850	1700		861		1108	171	0	171		14.4%	$1.72	$0.70	$0.41
G94019	Pecos	Furrow/Basin	Cum 250	1740		1397		997	111	0	111		5.2%	$2.79	$1.26	$1.14
G94020	Pecos	Furrow/Basin	Cum 250	1680	93	1082	22.3%	1000	230	0	230	65.8%	13.9%	$2.16	$0.97	$0.42
G94021-1	Pecos	Furrow/Basin	Cat 342	1080	160	1621	25.6%	1496	240	1	242	60.3%	14.7%	$3.24	$0.98	$0.40
G94021-2	Pecos	Furrow/Basin	Cat 342	1165	203	1971	26.7%	1516	260	1	262	52.1%	13.2%	$3.94	$1.17	$0.45
G94022	Pecos	Furrow/Basin	Cat 342	1130		1639		1896	196	6	210		15.9%	$3.28	$0.78	$0.37
G94023	Pecos	Furrow/Basin	Cat 342	1000		1461		1200	275	0	275		14.8%	$2.92	$1.10	$0.40
G94024	Pecos	Furrow/Basin	Cat 342	1130		1437		1303	180	2	185		11.0%	$2.87	$0.99	$0.54
G94025	Pecos	Furrow/Basin	Cat 342			1571		1612	195	8	212		14.3%	$3.14	$0.88	$0.41
G94026	Pecos	Furrow/Basin	Cat 342	1100		1373		1740	193	0	193		16.1%	$2.75	$0.71	$0.37
G94027	Pecos	Furrow/Basin	Moline 800			978		1177	147	0	147		11.6%	$1.96	$0.75	$0.51
G94028	Pecos	Furrow/Basin	Cum 250			1330		1309	160	0	160		10.3%	$2.66	$0.91	$0.57
G94029	Pecos	Furrow/Basin	Cum 250	1625	120	1197	26.1%	1241	167	4	176	48.4%	12.0%	$2.39	$0.87	$0.49
G94030	Pecos	Pivot	Cat 342	1050		1309		1176	190	47	299		17.6%	$2.62	$1.00	$0.34
G94031	Pecos	Furrow/Basin	Cat 342			1324		803	191	41	286		11.4%	$2.65	$1.48	$0.52
G94032	Pecos	Furrow/Basin	Cat 342			1160		1308	189	5	201		14.8%	$2.32	$0.80	$0.40
G94033	Pecos	Furrow/Basin	Cat 342			1824		1320	260	40	352		16.7%	$3.65	$1.24	$0.35
G94034	Pecos	Furrow/Basin	Cat 353			2285		2082	155	50	271		16.2%	$4.57	$0.99	$0.37
G94035	Pecos	Pivot	Cat 342			2266		1264	300	42	397		14.5%	$4.53	$1.61	$0.41
G94036	Pecos	Pivot	Cat 378			2856		1615	295	52	415		15.4%	$5.71	$1.59	$0.38
G94037	Pecos	Furrow/Basin	Cum 250			1538		1100	320	0	320		15.0%	$3.08	$1.26	$0.39
G94038	Pecos	Furrow/Basin	Cat 342			1489		1373	290	10	313		18.9%	$2.98	$0.98	$0.31
G94039	Pecos	Pivot	Cum 525	1660	264	3024	22.7%	1825	280	55	407	74.8%	16.1%	$6.05	$1.49	$0.37
G94041-1	Hudspeth	Furrow	Cummins 250	1785	95	1075	22.5%	1620	123	0	123	55.6%	11.9%	$1.94	$0.54	$0.44
G94041-2	Hudspeth	Furrow	Cummins 250	1785	146	1427	27.5%	2385	123	0	123	55.6%	13.9%	$2.57	$0.48	$0.39
G94042	Hudspeth	Furrow	Cat 3306			1326		1466	74	15	109		7.7%	$2.39	$0.73	$0.67
G94043	Hudspeth	Furrow	Ford 460			1152		2830	86	0	86		13.6%	$2.07	$0.33	$0.38
G94044	Hudspeth	Furrow	Deere 6076 AF	1650	122	1165	26.7%	1830	100	0	100	39.9%	10.1%	$2.10	$0.52	$0.52
G94045-1	Hudspeth	Basin	Cummins 250	1600	135	1399	24.5%	1610	126	2	131	41.5%	9.7%	$2.52	$0.70	$0.54
G94045-2	Hudspeth	Basin	Cummins 250	1750	173	1652	26.6%	2300	141	2	146	51.6%	13.0%	$2.97	$0.58	$0.40
			Average	1488	164	1598	25.1%	1553	197	13	226.2	56.8%	13.7%	$3.14	$0.95	$0.45

Gulf Coast Region Diesel Power Unit Summary

Location	County	Irrigation Method	Model	Engine Rpm	Hp	Fuel (Gal/hr)	Efficiency (%)	Pump Flow Rate (GPM)	Pumping Lift (ft)	Pump Discharge Head (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Per Hour ($/Hr)	Per Ac-in ($/Ac-in)	Ac-in per 100' Head ($/Ac-in/100')
D93017	Jackson	Flood	Catapillar	1785	266	17.2	29.0%	2196	250	2	254.6	55.9%	15.4%	$10.98	$2.25	$0.88
D94013	Jackson	Reservoir	Deutz BF6L	1820	132	7.0	35.1%	1454	186	0	186.0	54.5%	18.2%	$4.08	$1.26	$0.68
D94014-1	Jackson	Linear Move	Cat D342	1120		8.4		2754	78	2	82.6		12.8%	$5.86	$0.96	$1.16
D94014-2	Jackson	Linear Move	Cat D343	970		4.5		1967	69	1	71.3		14.9%	$3.11	$0.71	$1.00
			Average	1424	199	9.3	32.1%	2093	146	1	148.6	55.2%	15.3%	$6.01	$1.30	$0.93

Gulf Coast Region Electric Power Unit Summary

Location	County	Irrigation Method	Motor Type	Rated HP	Electricity (kW-h)	Input Hp	Estimated Efficiency (%)	Pump Flow Rate (GPM)	Pumping Lift (ft)	Discharge Head (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Cost Per Hour ($/Hr)	Per Ac-in ($/Ac-in)	Ac-in per 100' Head ($/Ac-in/100')
E94037	Jackson	Flood	VHS	75	56.6	75.8	91.0%	1494	104	0	104.0	56.8%	51.7%	$3.40	$1.02	$0.96
			Average	75	56.6	75.8	91.0%	1494	104	0	104.0	56.8%	51.7%	$3.40	$1.02	$0.96

Gulf Coast Region Natural Gas Power Unit Summary

Location	County	Irrigation Method	Engine Model	Rpm	Hp	Fuel (cf/hr)	Efficiency (%)	Pump Flow Rate (GPM)	Pumping Lift (ft)	Discharge Head (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Cost Per Hour ($/Hr)	Per Ac-In ($/Ac-In)	Ac-In per 100' Head ($/Ac-In/100')
G93001-1	Jackson	Flood	Cat 342	895	80	800	25.2%	1580	142	0.4	142.9	72.7%	17.4%	$4.20	$1.20	$0.84
G93001-2	Jackson	Flood	Cat 342	1030	125	1153	27.3%	2100	157	0.4	157.9	68.8%	17.9%	$6.05	$1.30	$0.82
G93001-3	Jackson	Flood	Cat 342	820	60	619	24.5%	1140	132	0.4	132.9	66.9%	15.6%	$3.25	$1.28	$0.97
G94012	Jackson	Flood	Waukesha	780	118	1609	17.8%	1807	150	0	150.0	61.1%	10.3%	$5.63	$1.40	$0.93
G94013	Jackson	Flood	Moline 800	1200		664		1470	100	0	100.0		13.6%	$1.66	$0.51	$0.51
G94014-1	Jackson	Flood	Waukesha	800		1540		2258	127	0	127.0		11.4%	$3.85	$0.77	$0.60
G94014-2	Jackson	Flood	Waukesha	900		1808		2515	135	0	135.0		11.5%	$4.52	$0.81	$0.60
			Average	918	96	1170	23.7%	1839	135	0	135.1	67.4%	13.9%	$4.17	$1.04	$0.75

Presidio Region Electric Power Unit Summary

			Motor					Pump						Cost		
		Irrigation			Electricity	Input	Estimated Efficiency	Flow Rate	Pumping Lift	Discharge Head	Total Head	Efficiency	Overall Efficiency	Per Hour	Per Ac-in	Ac-in per 100' Head
Location	County	Method	Type	Rated HP	(kW-h)	Hp	(%)	(GPM)	(ft)	(psi)	(ft)	(%)	(%)	($/Hr)	($/Ac-in)	($/Ac-in/100')
E94028	Presidio	Furrow	Horiz	25	20.0	26.8	90.0%	1695	17	0	17.0	30.2%	27.2%	$1.75	$0.46	$2.73
E94029	Presidio	Furrow	Horiz	25	20.3	27.2	90.0%	1280	35	0	35.0	46.2%	41.6%	$1.77	$0.62	$1.78
E94030	Presidio	Furrow	Horiz	50	38.2	51.2	92.0%	2200	30	0	30.0	35.4%	32.5%	$3.34	$0.68	$2.28
E94031	Presidio	Furrow	Horiz	50	27.6	37.0	92.0%	2625	15	0	15.0	29.2%	26.9%	$2.41	$0.41	$2.76
E94032	Presidio	Furrow	Horiz	30	16.1	21.6	91.0%	1180	15	10	38.1	57.8%	52.6%	$1.41	$0.54	$1.41
			Average	36	24.4	32.8	91.0%	1796	22	2	27.0	39.8%	36.2%	$2.14	$0.54	$2.19

South Region Diesel Power Unit Summary

Location	County	Irrigation Method	Model	Engine Rpm	Engine Hp	Engine Fuel (Gal/hr)	Engine Efficiency (%)	Flow Rate (GPM)	Pumping Lift (ft)	Pump Discharge Head (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Per Hour ($/Hr)	Per Ac-in ($/Ac-in)	Ac-in per 100' Head ($/Ac-in/100')
D94012	Starr	Furrow	Deere 6466	1500	62	3.9	29.4%	2200	30	24	85.4	80.9%	22.6%	$2.51	$0.51	$0.60
D94035	Starr	Reservoir	Deutz BF62	1900		7.8		2235	60	32	103.9		14.1%	$5.13	$1.04	$0.99
D94036	Starr	Drip	Deutz DF63	1267		4.7		1872	25	28	89.7		16.8%	$3.12	$0.75	$0.84
D94037	Starr	Furrow	Detroit 471	1300		3.6		1211	25	12	52.2		8.4%	$2.53	$0.94	$1.78
			Average	1492	62	5.0	29.4%	1880	35	24	82.8	80.9%	15.5%	$3.32	$0.81	$1.05

South Region Electric Power Unit Summary

Location	County	Irrigation Method	Motor Type	Rated HP	Electricity (kW-h)	Input Hp	Estimated Efficiency (%)	Pump Flow Rate (GPM)	Pumping Lift (ft)	Discharge Head (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Cost Per Hour ($/Hr)	Per Ac-in ($/Ac-in)	Ac-in per 100' Head ($/Ac-in/100')
E94036	Starr	Furrow	VHS	75	52.8	70.8	91.0%	2126	30	13	60.0	50.0%	45.5%	$3.45	$0.73	$1.22
E94044	Starr	Drip	Horiz	65	38.1	51.0	90.0%	1068	4	40	96.4	56.6%	50.9%	$2.46	$1.04	$1.07
E94045	Starr	Canal	VHS	100	86.4	115.6	90.0%	1840	30	20	76.2	33.7%	30.6%	$5.57	$1.36	$1.79
E94046	Starr	Furrow/Drip	VHS	100	84.7	113.5	90.0%	1850	30	20	76.2	34.5%	31.4%	$5.46	$1.33	$1.74
E94047	Starr	Furrow	Horiz	75	59.7	80.1	91.0%	2768	30	10	53.1	50.9%	46.4%	$3.85	$0.63	$1.18
E94048	Starr	Canal	Horiz	50	37.1	49.7	90.0%	2332	50	0	50.0	65.8%	59.2%	$2.39	$0.49	$0.92
			Average	78	59.8	80.1	90.3%	1997	29	17	68.7	48.6%	44.0%	$3.86	$0.93	$1.32

South Region Natural Gas Power Unit Summary

Location	County	Irrigation Method	Model	Engine Rpm	Engine Hp	Engine Fuel (Gal/hr)	Engine Efficiency (%)	Flow Rate (GPM)	Pumping Lift (ft)	Pump Discharge Head (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Per Hour ($/Hr)	Per Ac-in ($/Ac-in)	Ac-in per 100' Head ($/Ac-in/100')
G94008	Starr	Furrow	Waukesha	1100	68	1107	15.6%	1814	30	31	101.6	72.3%	10.7%	$3.60	$0.89	$0.88
G94009	Starr	Furrow	Waukesha	1000		1120		1774	30	30	99.3		10.1%	$3.64	$0.92	$0.93
G94010	Starr	Furrow	Catapillar	1400		1015		2715	30	21	78.5		13.5%	$3.30	$0.55	$0.70
G94011	Starr	Furrow	Catapillar	1300		935		1400	30	33	106.2		10.2%	$3.04	$0.98	$0.92
			Average	1200	68	1044	15.6%	1926	30	29	96.4	72.3%	11.1%	$3.40	$0.84	$0.86

Southeast Region Diesel Power Unit Summary

			Engine						Pump							
Location	County	Irrigation Method	Model	Rpm	Hp	Fuel (Gal/hr)	Efficiency (%)	Flow Rate (GPM)	Pumping Lift (ft)	Pump Discharge Head (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Per Hour ($/Hr)	Per Ac-in ($/Ac-in)	Ac-in per 100' Head ($/Ac-in/100')
D93008-1	Waller	Flood	Int 466	1750		5.1		1152	174	1	176.3		18.8%	$2.81	$1.10	$0.62
D93008-2	Waller	Flood	Int 467	1560		3.6		921	168	1	170.3		20.6%	$1.98	$0.97	$0.57
D93008-3	Waller	Flood	Int 468	1650		4.2		1017	170	1	172.3		19.7%	$2.31	$1.02	$0.59
D94011	Brazos	Furrow	Deere 4039	1800		1.2		580	40	3	46.9		10.9%	$0.74	$0.57	$1.22
			Average	1690		3.5		918	138	2	141.5		17.5%	$1.96	$0.92	$0.75

Southeast Region Electric Power Unit Summary

			Motor					Pump						Cost		
Location	County	Irrigation Method	Type	Rated HP	Electricity (kW-h)	Input Hp	Estimated Efficiency (%)	Flow Rate (GPM)	Pumping Lift (ft)	Discharge Head (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Per Hour ($/Hr)	Per Ac-in ($/Ac-in)	Ac-in per 100' Head ($/Ac-in/100')
E93039	Waller	Reservoir	VHS	125	116.8	156.5	85.0%	1130	150	1	152.3	32.7%	27.8%	$7.15	$2.85	$1.87
			Average	125	116.8	156.5	85.0%	1130	150	1	152.3	32.7%	27.8%	$7.15	$2.85	$1.87

Southern High Plains Region Electric Power Unit Summary

Location	County	Irrigation Method	Motor Type	Rated HP	Electricity (kW-h)	Input Hp	Estimated Efficiency (%)	Pump Flow Rate (GPM)	Pumping Lift (ft)	Discharge Head (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Per Hour ($/Hr)	Per Ac-in ($/Ac-in)	Ac-in per 100' Head ($/Ac-in/100')
E94005	Terry	Pivot	Horiz	25	19.3	25.7	90.0%	107	118	22	168.8	24.6%	17.7%	$1.45	$6.08	$3.60
E94006	Terry	Pivot	Horiz	40	22.2	31.0	90.0%	211	150	54	274.7	57.5%	47.3%	$1.73	$3.70	$1.35
E94007	Terry	Pivot	Horiz	20	17.1	23.0	90.0%	274	74	36	157.2	55.2%	47.2%	$1.29	$2.12	$1.35
E94008	Terry	Pivot	Horiz	20	11.3	15.1	90.0%	218	62	20	108.2	45.9%	39.3%	$0.85	$1.75	$1.62
E94009	Terry	Pivot	Horiz	20	13.9	18.6	90.0%	197	59	54	183.7	57.3%	49.0%	$1.04	$2.38	$1.30
E94010	Terry	Pivot	Horiz	25	19.7	26.4	90.0%	297	52	76	227.6	75.6%	64.7%	$1.48	$2.24	$0.98
E94011	Dawson	Pivot	Sub	20	14.5	19.4	90.0%	270	84	31	155.6	60.8%	54.7%	$0.73	$1.21	$0.78
E94012	Dawson	Pivot	VHS	50	39.1	52.4	91.0%	488	104	45	208.0	53.7%	48.9%	$1.96	$1.80	$0.87
E94013	Dawson	Pivot	Sub	20	17.5	23.5	90.0%	246	80	52	200.1	58.8%	53.0%	$0.88	$1.60	$0.80
E94014	Dawson	Pivot	Sub	40	27.8	37.3	90.0%	414	116	40	208.4	65.0%	58.5%	$1.39	$1.51	$0.72
E94015	Dawson	Pivot	Sub	30	24.5	32.8	90.0%	268	123	48	233.9	53.5%	48.2%	$1.23	$2.08	$0.88
E94016	Gaines	Pivot	Sub	20	17.7	23.7	90.0%	218	137	30	206.3	53.2%	47.9%	$1.06	$2.19	$1.06
E94017	Gaines	Pivot	Horiz	30	19.8	26.5	90.0%	260	84	35	164.9	47.7%	40.8%	$1.19	$2.05	$1.25
E94018	Gaines	Pivot	Sub	25	21.5	28.8	90.0%	285	101	32	174.9	48.5%	43.7%	$1.29	$2.04	$1.17
E94019	Gaines	Pivot	Sub	25	23.2	31.1	90.0%	289	154	26	214.1	55.8%	50.3%	$1.39	$2.17	$1.01
E94020	Gaines	Pivot	Sub	25	20.4	27.3	90.0%	234	95	35	175.9	42.2%	38.0%	$1.22	$2.36	$1.34
E94021	Gaines	Pivot	Sub	30	22.7	30.4	90.0%	361	150	20	196.2	65.3%	58.8%	$1.36	$1.70	$0.87
E94022	Gaines	Pivot	Sub	25	18.8	25.2	90.0%	230	94	35	174.9	44.7%	40.2%	$1.13	$2.21	$1.26
E94023	Gaines	Pivot	Sub	15	11.3	15.1	90.0%	122	84	35	164.9	37.3%	33.5%	$0.68	$2.50	$1.52
E94024	Gaines	Pivot	Sub	20	10.7	14.3	90.0%	139	120	20	166.2	45.3%	40.8%	$0.64	$2.07	$1.25
E94025	Gaines	Pivot	Sub	25	19.7	26.4	90.0%	253	163	22	213.8	57.5%	51.7%	$1.18	$2.10	$0.98
E94026	Gaines	Pivot	Sub	7.5	9.7	13.0	90.0%	99	170	22	220.8	47.2%	42.5%	$0.58	$2.65	$1.20
			Average	25	19.2	25.8	90.0%	249	108	36	190.9	52.4%	46.2%	$1.17	$2.30	$1.23

Southern High Plains Region Natural Gas Power Unit Summary

Location	County	Irrigation Method	Engine Model	Rpm	Hp	Fuel (Gal/hr)	Efficiency (%)	Flow Rate (GPM)	Pumping Lift (ft)	Pump Discharge Head (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Per Hour ($/Hr)	Per Ac-in ($/Ac-in)	Ac-in per 100' Head ($/Ac-in/100')
G94002	Terry	Pivot	Chevy 292	1790	45	625	17.7%	466	112	52	232.1	63.2%	10.6%	$1.97	$1.99	$0.86
G94003	Terry	Pivot	Chrysler 318			405		192	60	40	152.4		11.9%	$1.27	$1.17	$0.77
G94004	Dawson	Pivot	Food 300			544		445	75	62	218.2		11.5%	$1.71	$1.73	$0.79
G94005	Terry	Pivot	Chevy 292			750		299	126	24	181.4		4.7%	$2.37	$3.55	$1.96
			Average	1790	45	581	17.7%	351	93	45	196.0	63.2%	9.7%	$1.83	$2.11	$1.10

Winter Garden Region Diesel Power Unit Summary

Location	County	Irrigation Method	Model	Engine Rpm	Hp	Fuel (Gal/hr)	Efficiency (%)	Flow Rate (GPM)	Pumping Lift (ft)	Pump Discharge Head (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Per Hour ($/Hr)	Per Ac-in ($/Ac-in)	Ac-in per 100' Head ($/Ac-in/100')
D93003	Frio	LEPA	Cum 350	1625	143	7.9	33.9%	635	390	34	468.5	55.3%	18.7%	$5.54	$3.92	$0.84
D93004	Frio	Pivot	Cat 353	1020	170	10.0	31.8%	810	330	44	431.6	54.7%	17.4%	$6.01	$3.34	$0.77
D94015	Frio	Pivot	Deere 6619	1930	297	15.4	36.2%	1243	416	63	561.5	62.5%	21.5%	$10.75	$3.89	$0.69
D94016	Wilson	Pivot	Cum NHC4	1160	30	1.6	34.9%	374	92	10	115.1	37.8%	12.5%	$1.01	$1.21	$1.05
D94018	Atascosa	Reservoir	Detroit 471	1240	64	3.8	31.8%	523	175	9	195.8	42.4%	12.8%	$2.11	$1.82	$0.93
D94019	Atascosa	Pivot	Deere 4039	1500		1.7		540	7	45	111.0		16.7%	$0.95	$0.79	$0.71
D94020	Atascosa	Pivot	Detroit 641	1450		3.1		615	5	42	102.0		9.6%	$1.73	$1.26	$1.24
D94021	Frio	Pivot	Cat 353	1650		11.7		900	400	40	492.4		17.8%	$6.69	$3.34	$0.68
D94022-1	Atascosa	Side Roll	Detroit 471	1475		3.0	27.3%	364	200	56	329.4	72.8%	18.9%	$2.04	$2.52	$0.77
D94022-2	Atascosa	Side Roll	Detroit 471	1770	44	5.3	28.8%	777	200	44	301.6	77.1%	21.1%	$3.57	$2.07	$0.69
D94027	Zavala	Furrow	Deere 4039		81	2.5		1870	15	23	68.1		23.9%	$1.78	$0.43	$0.63
			Average	1482	118	6.0	32.1%	786	203	37	288.8	57.5%	17.4%	$3.83	$2.24	$0.82

Winter Garden Region Electric Power Unit Summary

Location	County	Irrigation Method	Motor Type	Rated HP	Electricity (kW-h)	Input Hp	Estimated Efficiency (%)	Pump Flow Rate (GPM)	Pumping Lift (ft)	Discharge Head (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Per Hour ($/Hr)	Per Ac-in ($/Ac-in)	Ac-in per 100' Head ($/Ac-in/100')
E93017	Atascosa	Pivot	VHS	125	86.7	116.2	90.0%	820	250	36	333.2	48.3%	43.5%	$5.60	$3.07	$0.92
E93023	Atascosa	Reservoir	Sub	5	5.5	7.4	84.0%	130	89	1	91.3	47.5%	39.9%	$0.45	$1.55	$1.70
E93024	Atascosa	Reservoir	Sub	10	9.4	12.6	85.0%	104	40	77	217.9	53.3%	45.3%	$0.76	$3.31	$1.52
E94033	Zavala	Reservoir	VHS	150	116.0	155.4	93.0%	953	360	0	360.0	59.9%	55.7%	$7.59	$3.58	$1.00
E94034	Zavala	Reservoir	VHS	150	99.6	133.5	92.0%	2165	100	10	123.1	54.8%	50.4%	$6.52	$1.35	$1.10
E94035	Zavala	Furrow	VHS	75.0	58.4	78.3	91.0%	1060	110	7	126.2	47.4%	43.2%	$3.82	$1.62	$1.29
			Average	86	62.6	83.9	89.2%	872	158	22	208.6	51.9%	46.3%	$4.12	$2.41	$1.26

Winter Garden Region Natural Gas Power Unit Summary

				Engine					Pump							
Location	County	Irrigation Method	Model	Rpm	Hp	Fuel (Gal/hr)	Efficiency (%)	Flow Rate (GPM)	Pumping Lift (ft)	Discharge Head (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Per Hour ($/Hr)	Per Ac-in ($/Ac-in)	Ac-in per 100' Head ($/Ac-in/100')
G93002-1	Frio	Pivot	Cat 353	1025	177	1548	25.8%	905	390	53	512.4	69.6%	18.0%	$4.03	$2.00	$0.39
G93002-2	Frio	Pivot	Cat 354	1005	167	1458	25.8%	870	390	49	503.2	69.7%	18.0%	$3.79	$1.96	$0.39
G93003	Frio	Pivot	Cat 355	985	164	1381	26.8%	720	400	33	476.2	52.8%	14.2%	$3.59	$2.24	$0.47
G93004	Frio	Pivot	Cat 356	1045	163	1394	26.4%	850	400	52	520.1	72.1%	19.0%	$4.18	$2.21	$0.43
G94006	Zavala	Reservoir	Waukesha			2015		980	360	0	360.0		11.3%	$6.55	$3.01	$0.84
G94007	Zavala	Reservoir	Crysler 440			1059		720	308	4	317.2		13.9%	$3.44	$2.15	$0.68
			Average	1015	168	1476	26.2%	841	375	32	448.2	66.1%	15.7%	$4.26	$2.26	$0.53

Electric Power Unit Summary for Large Pumping Plants

			Motor					Pump									
Location	County	Irrigation Method	Type	Rated HP	Electricity (kW-h)	Input Hp	Estimated Efficiency (%)	Flow Rate (GPM)	Pumping Lift (ft)	Discharge Head (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Per Hour ($/Hr)	Per Ac-foot ($/Ac-ft)	Per Million Cubic Feet ($/Mcf)	Per Million Cubic Feet per 10' of Head ($/Mcf/10')
LE93018	Cameron	Canal	VHS	250	169.2	226.7	94.0%	40500	12	1	14.3	91.8%	86.3%	$11.07	$1.48	$34.16	$23.89
LE93019	Cameron	Canal	VHS	20	11.6	15.5	89.0%	3600	8	1	10.3	90.5%	80.5%	$0.76	$1.14	$26.35	$25.58
LE93020	Cameron	Canal	Horiz	20	16.1	21.6	85.0%	3000	8	1	10.3	57.2%	48.6%	$1.05	$1.91	$43.88	$42.61
LE93021	Cameron	Canal	Horiz	25	14.2	19.0	89.0%	2600	10	2	14.6	76.0%	67.6%	$0.93	$1.94	$44.66	$30.59
LE93022	Cameron	Canal	Horiz	25	13.7	18.4	89.0%	2700	10	2	14.6	81.5%	72.5%	$0.90	$1.80	$41.49	$28.42
LE93037	Hidalgo	Canal	VHS	350	219.1	293.6	95.0%	29250	15	5	26.6	70.1%	66.6%	$14.33	$2.66	$61.25	$23.03
LE93038	Hidalgo	Canal	Horiz	500	361.7	484.7	98.5%	42200	7	9	27.8	86.0%	81.7%	$23.66	$3.05	$70.09	$25.21
LE94001	Hidalgo	Canal	VHS	400	271.9	364.4	93.0%	27720	32	3	38.9	80.4%	74.8%	$17.79	$3.48	$80.21	$20.62
LE94002	Hidalgo	Canal	VHS	150	91.5	122.6	92.0%	6700	32	3	38.9	58.4%	53.7%	$5.99	$4.85	$111.67	$28.71
LE94003	Hidalgo	Canal	VHS	200	182.2			11600	10	3	16.3		20.3%	$11.92	$5.58	$128.44	$78.80
LE94004	Hidalgo	Canal	VHS	400	269.0	360.5	94.0%	31050	30	2	34.6	79.9%	75.1%	$17.60	$3.08	$70.84	$20.47
LE94005	Hidalgo	Canal	VHS	400	274.1	367.3	94.0%	29250	30	2	34.6	73.9%	69.4%	$17.93	$3.33	$76.63	$22.15
LE94006	Hidalgo	Canal	VHS	400	289.9	388.5	94.0%	23400	30	2	34.6	55.9%	52.5%	$18.96	$4.40	$101.31	$29.28
LE94007	Hidalgo	Canal	VHS	400	264.7	354.7	94.0%	29700	30	2	34.6	77.7%	73.0%	$17.32	$3.17	$72.88	$21.06
LE94008	Hidalgo	Canal	VHS	400	289.5	387.9	94.0%	31950	30	2	34.6	76.4%	71.8%	$18.94	$3.22	$74.09	$21.41
LE94009	Hidalgo	Canal	VHS	400	261.2	350.0	94.0%	30150	30	2	34.6	79.9%	75.1%	$17.09	$3.08	$70.84	$20.47
LE94010	Hidalgo	Canal	VHS	400	208.4	279.3	94.0%	20250	30	2	34.6	67.3%	63.2%	$13.63	$3.66	$84.15	$24.32
LE94011	Hidalgo	Canal	VHS	400	259.9	348.3	94.0%	32400	30	2	34.6	86.3%	81.1%	$17.00	$2.85	$65.59	$18.96
LE94012	Hidalgo	Canal	VHS	400	221.9	297.3	94.0%	18900	30	2	34.6	59.0%	55.4%	$14.52	$4.17	$96.01	$27.75
LE94013	Hidalgo	Canal	Horiz	400	267.8	358.8	94.0%	27377	26	0	26.0	53.9%	50.1%	$17.52	$3.48	$79.99	$30.76
LE94014	Hidalgo	Canal	VHS	150	93.1	124.7	92.0%	10800	28	0	28.0	66.5%	61.2%	$6.09	$3.06	$70.48	$25.17
LE94015	Hidalgo	Canal	VHS	450	315.2	422.4	94.0%	40000	28	0	28.0	71.2%	67.0%	$20.62	$2.80	$64.44	$23.01
LE94016	Hidalgo	Canal	VHS	450	322.9	432.7	94.0%	36100	28	0	28.0	62.8%	59.0%	$21.12	$3.18	$73.15	$26.12
LE94017	Hidalgo	Canal	VHS	300	193.7	259.5	93.0%	19423	29.5	0	29.5	60.0%	55.8%	$12.67	$3.54	$81.54	$27.64
LE94018	Hidalgo	Canal	VHS	400	239.3	320.6	93.0%	25955	29.5	0	29.5	64.9%	60.3%	$15.65	$3.27	$75.38	$25.55
LE94019	Hidalgo	Canal	VHS	200	111.3	149.1	92.0%	12800	29.5	0	29.5	69.5%	64.0%	$7.28	$3.09	$71.08	$24.10
LE94020	Cameron	Canal	VHS	40	23.3	31.2	90.0%	4950	6	0	6.0	26.7%	24.0%	$1.50	$1.65	$37.88	$63.13
LE94021	Cameron	Canal	VHS	10	5.0	6.6	80.0%	800	6	0	6.0	26.1%	18.5%	$0.32	$2.17	$50.00	$83.33
LE94022	Cameron	Canal	VHS	15.0	6.8	8.1	80.0%	1356	6	0	6.0	28.2%	22.6%	$0.44	$1.76	$40.56	$67.60
			Average	274	181.7	243.4	91.9%	20568	22	2	25.5	67.1%	60.4%	$11.88	$2.99	$68.93	$32.06

Natural Gas Power Unit Summary for Large Pumping Plants

				Engine					Pump								
Location	County	Irrigation Method	Model	Rpm	Hp	Fuel (Gal/hr)	Efficiency (%)	Flow Rate (GPM)	Pumping Lift (ft)	Discharge Head (psi)	Total Head (ft)	Efficiency (%)	Overall Efficiency (%)	Per Hour ($/Hr)	Per Ac-foot ($/Ac-ft)	Per Million Cubic Feet ($/Mcf)	Per Million Cubic Feet per 10' of Head ($/Mcf/10')
LG93007	Hidalgo	Canal	Cum 743			765		10260	15	2	19.6		16.9%	$3.06	$1.62	$37.28	$19.00
LG93008	Hidalgo	Canal	Cat 398	1110		4351		45000	7	11	32.4		21.5%	$17.40	$2.10	$48.33	$14.92
LG93009	Hidalgo	Canal	Cat 399	1050		4544		35100	7	11	32.4		16.0%	$18.18	$2.81	$64.74	$19.98
LG93010	Hidalgo	Canal	Cat 400	1096		3530		36000	7	11	32.4		21.2%	$14.12	$2.13	$49.03	$15.13
LG93011	Hidalgo	Canal	Cat 401	1124		4402		34200	7	11	32.4		16.1%	$17.61	$2.80	$64.36	$19.87
LG93012	Hidalgo	Canal	Cat 402	1150		4322		33100	7	11	32.4		15.9%	$17.29	$2.84	$65.29	$20.15
			Average	1106		3652		32277	8	10	30.3		17.9%	$14.61	$2.38	$54.84	$18.18

State Irrigation Pumping Plant Testing Results

	Diesel	Electric	Natural Gas		Large Electric	Large Natural Gas
# Tested	65	86	58		29	6
Max Engine Efficiency	41.6%	94.0%	27.5%		95.0%	
Min Engine Efficiency	26.7%	81.0%	15.6%		80.0%	
Avg Engine Efficiency	31.9%	88.8%	21.7%		91.8%	
Standard Engine Efficiency	32.0%	90.0%	26.0%		90.0%	26.0%
Max Pump Efficiency	88.4%	76.2%	79.2%		91.8%	
Min Pump Efficiency	36.8%	21.3%	39.9%		26.1%	
Avg Pump Efficiency	66.2%	47.9%	63.2%		67.2%	
Standard Pump Efficiency	75.0%	75.0%	75.0%		75.0%	75.0%
Max Overall Efficiency	34.5%	68.5%	20.6%		86.3%	21.5%
Min Overall Efficiency	5.0%	17.5%	4.7%		18.5%	15.9%
Avg Overall Efficiency	18.1%	42.6%	13.1%		60.6%	17.9%
Standard Overall Efficiency	22.8%	67.5%	18.5%		67.5%	18.5%
Max Cost per Acre-inch	$4.45	$6.08	$3.55	Max Cost per Acre-foot	$5.58	$2.84
Min Cost per Acre-inch	$0.13	$0.37	$0.33	Min Cost per Acre-foot	$1.14	$1.62
Avg Cost per Acre-inch	$1.66	$1.94	$1.39	Avg Cost per Acre-foot	$3.00	$2.38
Max Cost per Acre-inch @100' Head	$3.43	$20.20	$1.96	Max Cost per Acre-inch @10' Head	$83.33	$20.15
Min Cost per Acre-inch @100' Head	$0.36	$0.29	$0.31	Min Cost per Acre-inch @10' Head	$18.96	$14.92
Avg Cost per Acre-inch @100' Head	$0.83	$1.49	$0.76	Avg Cost per Acre-inch @10' Head	$31.91	$18.18
				Max Cost per Million Cubic Feet	$128.44	$65.29
				Min Cost per Million Cubic Feet	$26.35	$37.28
				Avg Cost per Million Cubic Feet	$69.03	$54.84

IRRIGATION PUMPING PLANT EFFICIENCY TEST PROGRAM - USER'S GUIDE

Introduction

The *Irrigation Pumping Plant Efficiency Test Program* enables the user to evaluate the performance of diesel, natural gas, electric, and dual fuel powered irrigation pumping plants. An economic analysis giving the potential savings of improving motor and pump efficiencies to standard efficiencies is also provided.

Installation

To install the Irrigation Pumping Plant Efficiency Test Program insert the disk in drive A or B. Type "**INSTALLA**" when using drive A and "**INSTALLB**" when using drive B. This will create the directories C:\PUMP and C:\PUMP\EPD. The files **PUMP.EXE, PRINTPL.BI** and **PRINTIT.EXE** will be loaded into C:\PUMP. Printer driver files, ***.EPD,** will be loaded into the C:\PUMP\EPD directory.

Execution

To run the executable program, type "pump" at the DOS prompt. An introductory or title screen will appear introducing the program. Press <ENTER> to forward to the "Main Menu". The main menu gives the user a choice to enter input data for a new test, to retrieve a file already containing input data, or to exit the program. The Up/Down keys enable the user to change the focus from one option button to another. Simply "click" using the mouse or press <ENTER> on the desired option button to proceed.

The first screen enables the user to enter site information and to choose the engine type to evaluate. The mouse, <TAB>, and <ENTER> keys can all be used to move from field to field throughout the program. Following is a list of the required input data for each screen according to engine type. This data **must** be entered before a performance evaluation can be computed.

Input

Diesel

Engine Data: Diesel cost ($/gallon)

Specific gravity of diesel

Diesel temperature (degrees Fahrenheit)

Annual operation (hours)

Heating value of diesel (BTU/gallon)

Noise level of the engine (decibels)

Torque (inch-pounds) - first entry box required for "Complete Efficiency Test"

RPM - first entry box required for "Complete Efficiency Test"

Pounds (of diesel) - first entry box required

Seconds - first entry box required

Pump Data: Pumping lift (feet)

Discharge pressure (psi)

GPM - first entry box required

Natural Gas

Engine Data: Natural gas cost ($/Mcf)

Meter pressure (psi or ounces)

Noise level (decibels)

Heating value of natural gas (BTU/cubic foot)

Atmospheric pressure (psi or ounces)

Annual operation (hours)

Torque (inch-pounds) - first entry box required for "Complete Efficiency Test"

RPM - first entry box required for "Complete Efficiency Test"

Cubic feet - first entry box required

Seconds - first entry box required

Pump Data: Pumping lift (feet)

Discharge pressure (psi)

GPM - first entry box required

Electric

Motor efficiency (%)

Pumping lift (feet)

Discharge pressure (psi)

Flow rate (GPM)

Electricity cost ($/KW-hr)

Annual operation (hours)

Using "Disc Method":

Revolutions

Seconds

Meter constant

Using "Instrument Method":

KW's - all entries boxes required

Amperes - all entries boxes required

Volts - all entries boxes required

Dual Fuel

Engine Data:

- Diesel cost ($/gallon)
- Heating value of diesel (BTU/gallon)
- Specific gravity of diesel
- Diesel temperature (degrees Fahrenheit)
- Noise level of engine (decibels)
- Natural gas cost ($/MCF)
- Heating value of natural gas (BTU/cubic foot)
- Meter pressure (psi or ounces)
- Atmospheric pressure (psi or ounces)
- Annual operation (hours)
- Torque (inch-pounds) - first entry box required for "Complete Efficiency Test"
- RPM - first entry box required for "Complete Efficiency Test"
- Diesel: Pounds
  - Seconds
- Natural gas: Cubic feet
  - Seconds

Pump Data:

- Pumping lift (feet)
- Discharge pressure (psi)
- GPM - first entry box required

Output

After entering all necessary input data, select **<Alt-C Calculations>** to view results. Before the output summary is shown, the user is given the opportunity to save all input data to a file. The filename must not exceed eight characters in length. An extension is added to the filename according to the engine type (diesel - ***.DSL**, natural gas - ***.NGS**, electric - ***.ELC**, dual fuel -***.DUL**). These files are stored under the C:\PUMP directory and can be retrieved from the main menu. After calculations are made, an output summary is shown. Following lists the calculated parameters according to engine type.

Diesel

Input horsepower

Output horsepower - N/A when "Overall Efficiency Test Only" was selected

Total head (feet)

Noise level (decibels)

Fuel consumption (gallons/hour)

Engine efficiency (%) - N/A when "Overall Efficiency Test Only" was selected

Pump efficiency (%) - N/A when "Overall Efficiency Test Only" was selected

Overall efficiency (%)

Fuel cost per hour ($)

Fuel cost per acre-inch ($)

Fuel cost per acre-inch per 100 foot ($)

Natural Gas

Input horsepower

Output horsepower - N/A when "Overall Efficiency Test Only" was selected

Total head (feet)

Noise level (decibels)

Fuel consumption (cubic feet/hour)

Engine efficiency (%) - N/A when "Overall Efficiency Test Only" was selected

Pump efficiency (%) - N/A when "Overall Efficiency Test Only" was selected

Overall efficiency (%)

Fuel cost per hour ($)

Fuel cost per acre-inch ($)

Fuel cost per acre-inch per 100 foot ($)

Electric

Input horsepower

Output horsepower

Total head (feet)

Noise level (decibels)

Engine efficiency (%)

Pump efficiency (%)

Overall efficiency (%)

Fuel cost per hour ($)

Fuel cost per acre-inch ($)

Fuel cost per acre-inch per 100 foot ($)

Dual Fuel

Input horsepower

Output horsepower - N/A when "Overall Efficiency Test Only" was selected

Total head (feet)

Noise level (decibels)

Percent input horsepower

Diesel

Natural gas

Fuel consumption

Diesel (gallons/hour)

Natural gas (cubic feet/hour)

Engine efficiency (%) - N/A when "Overall Efficiency Test Only" was selected

Pump efficiency (%) - N/A when "Overall Efficiency Test Only" was selected

Overall efficiency (%)

Fuel cost per hour ($)

Fuel cost per acre-inch ($)

Fuel cost per acre-inch per 100 foot ($)

Immediately following the output summary, a screen showing the potential savings of improving motor, pump, and motor and pump efficiencies to standard efficiencies for the particular irrigation pumping plant is displayed. Standard efficiencies are based on average attainable efficiencies for pumping plant equipment.

Pump - 75%

Diesel engine - 32%

Natural gas engine - 26%

Electric motor - 90%

Dual fuel engine - 27%

When the actual motor or pump efficiency is greater than the standard value, "No Savings" will be reported. If an "Overall Efficiency Test Only" is being conducted on diesel, natural gas, or dual fuel engines, "N/A" is reported for "Motor only" and "Pump only" savings.

Printing

To obtain a hard copy of the results, choose **<Alt-P Print to File>** to write the results to a temporary file named "**FPRINT.PRT**". This file is stored under the C:\PUMP directory. Return to the main menu and exit the program. To print the report contained in "**FPRINT.PRT**", type "**PRINTIT**". A screen will display a list of available printers determined by the *.EPD files loaded into the C:\PUMP\EPD directory. Choose the appropriate printer to obtain the printed results. ***Note: "FPRINT.PRT" will contain the same values until a new test is performed and a new "FPRINT.PRT" file is made.***

"Printer Disk 1" and "Printer Disk 2" contain ***.EPD** driver files which can be loaded into the C:\PUMP\EPD directory. Refer to the list of available printers and their corresponding printer files at the end of the manual. Following is a list of available printers stored on "Printer Disk 1" and "Printer Disk 2".

Printer Disk 1

AEG	ALQ	AST
Acer	Alps	Anadex
Brother	Businessland	C
CIE	Cannon	Centronics
Citizen	Cordata	Corona
CrystalPrint	DEC	Diablo
Epson	Fujitsu	Generic
Genicom	HP	IBM
ImageWriter	JDL	Kodak
Laserline	Mannesmann	Matra
NCR	NEC	OkiLaser
Okidata	Olivetti	Pacemark
Panasonic		

Printer Disk 2

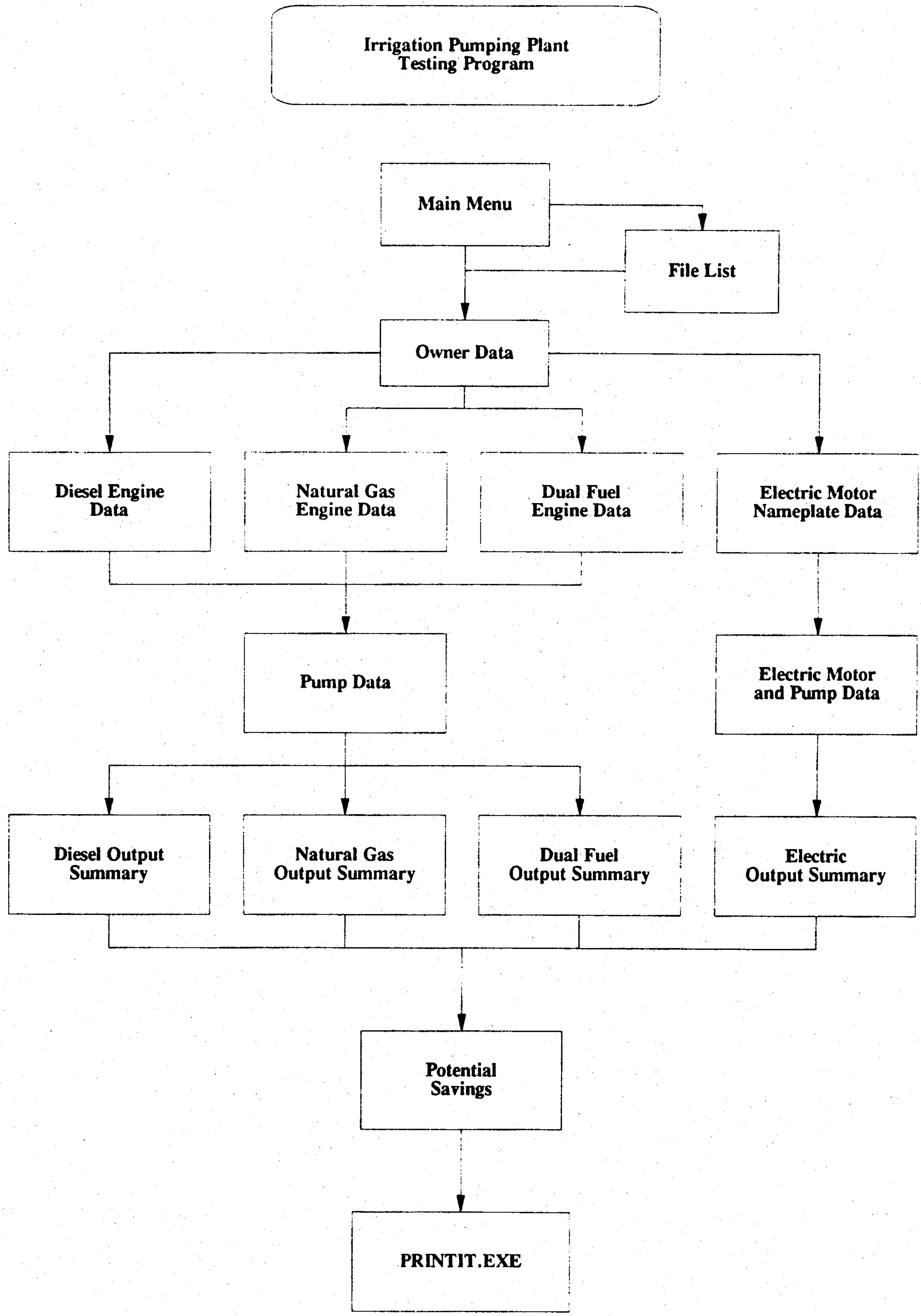
PostScript	ProWriter	QMS
Qume	Ricoh	Seikosha
Silver	Star	Starwriter
Tandy	Texas Instruments	Toshiba
Unisys	Xerox	

Diesel Density as a Function of Temperature

Temperature (degrees F)	Density (pounds/cubic foot)
<= 50	62.422
> 50 and <= 60	62.375
> 60 and <= 70	62.329
> 70 and <= 80	62.251
> 80 and <= 90	62.158
> 90 and <= 100	62.042
> 100 and <= 150	61.531
> 150	60.562

Maximum Exposure as a Function of Noise Level

Noise Level (decibels)	Maximum Exposure (hours)
<= 80	16
> 80 and <= 85	8
> 85 and <= 90	4
> 90 and <= 95	2
> 95 and <= 100	1
> 100 and <= 105	0.5
> 105 and <= 110	0.25
> 115	0


Irrigation Pumping Plant
Testing Program
Main Menu
File List
Owner Data
Diesel Engine Data
Natural Gas Engine Data
Dual Fuel Engine Data
Electric Motor Nameplate Data
Pump Data
Electric Motor and Pump Data
Diesel Output Summary
Natural Gas Output Summary
Dual Fuel Output Summary
Electric Output Summary
Potential Savings
PRINTIT.EXE

REQUEST FOR CONTINUED FUNDING -

IRRIGATION PUMPING PLANT EFFICIENCY TESTING PROGRAM

Proposal to the

State Energy Conservation Office
P.O. Box 13047
Austin, TX 78711-3047

October 21, 1994

Submitted by

Dr. Guy Fipps
Texas Agricultural Extension Service
Texas A&M University System
Agricultural Engineering Department
College Station, TX 77843-2117

Project Description

In this program we test the efficiency of irrigation pumping plants. Where feasible, the efficiency of the pump and engine are determined separately. The results are used to determine energy consumption and potential energy and dollar savings with repair of the unit. Using TIPPES (Texas Irrigation Pumping Plant Evaluation Software), a complete summary of testing results and analysis of the results are provided to the pump owner immediately following the test (TIPPES was developed in this project). A safety checklist is also provided which indicates any hazards including noise levels, lack of guards and well head protection.

Cooperative testing programs are established with ground water and other water management districts and with utilities in areas of the state where no pumping plant testing is available. Cooperators work with local agents of the Texas Agricultural Extension Service (TAEX) to coordinate testing schedules so as to maximize use of equipment and personnel. Cooperative testing also demonstrates the value of such testing to these organizations so as to encourage them to establish similar testing programs. Cooperative testing programs have been conducted with six underground water conservation districts (Medina, Uvalde, Hickory, Evergreen, Mesa, and South Plains), two electric utilities (TU Electric and CP&L), and 4 irrigation districts (Cameron #2, Hidalgo #2 and #6, United and Santa Cruz).

The data collected is incorporated into a central data base to facilitate data analysis. Once enough information is collected, the data will be used to establish baseline performance figures for irrigation pumping plants regionally and state wide. Follow-up testing will be used to determine the actual amount of energy saved as a result of testing.

Program History and Current Status

We submitted the original proposal for this program to the Governor's Energy Office in 1990. During 1991, the project was approved and we were asked to submit a two-year budget. We began work on this project during Fall 1992. The project is scheduled to end on December 31, 1994.

Testing was not begun until June 1993 due to unexpected and uncontrollable delays. These included specifications review and bidding delays in the State Purchasing Office and a long delivery date for the torque cell from the manufacturer. During June, July and August, additional modifications to testing procedures and equipment were necessary due to the differences of pumping plants in South Texas from those on the High Plains.

We completed our first full year of testing during the twelve-month period ending August 1994. A total of 252 units were tested. This is slightly lower than the average of 300 per year as specified in the contract, but is within an acceptable range for the first year of testing during which procedure and equipment modifications were constantly required and cooperative testing programs were being developed. We do not anticipate any problems with obtaining an average of 300 tests a year if the project continues. We have also made good progress on the other objectives of the project as detailed in the Quarterly Reports submitted to the State Energy Conservation Office (SECO).

Justification for Continuation of Funding

The Irrigation Pumping Efficiency Plant Testing Program was originally approved as a four-year project by both the Texas Governor's Office and the U.S. Department of Energy. The project must be conducted for a full four years in order to meet the project objectives.

Significant investment in the program has been made financially by the SECO, and in terms of personnel, time, funds and other resources by TAEX. Much of the long-term value of the program will be lost if it is terminated early.

We have just begun to educate water management districts and utilities about the value of pumping plant testing. Additional cooperative testing programs will likely lead to the establishment of ongoing testing programs supported by these organizations. The problem is that most of these water management districts are small and, individually, do not generate much income. Educating farmers and district board members is also a slow process.

Project Objectives:

With continuing funding, the project objectives will be to:

1. Organize and conduct an Irrigation Pumping Plant Efficiency Testing Training Course which will provide instruction in safe testing procedures, analytical methods and use of TIPPES. This course will also serve as the vehicle to transfer improved procedures and analytical tools developed in this project to other organizations already conducting pumping plant testing.

2. Continue efficiency testing with a goal of testing 300 pumping plants per year. Additional testing in each Test Region will provide a representative sample for energy analyses. Conducting re-testing and surveying will be used to determine actual energy savings resulting from repairs and replacement of defective equipment.

3. Continue expansion of the central data base of test results. Conduct a complete analysis of test results to determine baseline performance figures and potential and actual savings obtainable for irrigation pumping plants in each Test Region and statewide.

4. Produce and disseminate educational publications and interactive computer software concerning energy use and savings potential through efficiency improvement in irrigation pumping.

5. Demonstrate the value of irrigation pumping plant efficiency testing to water management districts and utilities in order to encourage the establishment of similar testing programs. Actively work with these organizations to help them establish partnerships to finance joint testing programs.

6. Expand the TIPPES software to include an analysis of additional energy savings possible with conversion to more efficient irrigation technologies.

Duration of Funding Requested:

We propose continuing the project through August 1997. This duration would ensure that all the objectives of the project are achieved as approved originally by the Governor's Office and the U.S. Department of Energy. Our funding request is broken into two periods: (1) January - August 1995; (2) September 1995 - December 1996.

Budget

Funding Requirements: Period I: 1/1/95 - 8/31/95

		SECO	TAEX
PERSONNEL			
Professional Project Team		$15,000	
Technician:	wages	19,340	
	benefits	5,030	
Graduate Assistant:	wages	8,000	
	benefits	2,080	
student worker		3,270	
TRAVEL		6,000	
EQUIPMENT			
smaller torque cell		7,500	
drive shaft kit accessory		500	
hearing protection		500	
diesel fuel measuring kit		500	
dremel tool and accessory		200	
tachometer		500	
OTHER DIRECT COSTS			
Supplies		1,500	
Operating expenses		2,000	
Publications			1,000
INDIRECT COST (24.5%)			17,866
TOTAL SECO		**56,920**	
TOTAL TAEX			**33,865**

Funding Requirements: Period II: 9/1/ 95 - 12/31/96

		SECO	TAEX
PERSONNEL			
Professional Project Team			$32,000
Technician:	wages	42,670	
	benefits	10,100	
Graduate Assistant:	wages	16,000	
	benefits	4,160	
student worker		7,000	
TRAVEL		10,000	
replacement parts		2,000	
OTHER DIRECT COSTS			
Supplies		2,000	
Operating expenses		2,500	
Publications			1,500
INDIRECT COST (24.5%)			31,833
TOTAL SECO		**96,430**	
TOTAL TAEX			**65,333**

Total Funding Requirements for Periods I and II.

SECO: $153,350 **TAEX: $99,198**