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# /ECONOMIC ANALYSIS OF IRRIGATION PUMPING PLANTS/

by



Gary John Dvorak

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Approved by:

Harry L. Manges
Major Professor

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## INTRODUCTION

With the rising cost of energy and the falling water table in the Ogallala aquifer, irrigators need to become more efficient. A computer model, (VICE) Variable Irrigation Cost Estimator, for estimating variable irrigation costs was developed by Williams et al. (1983), and has been revised and expanded to improve the methods of estimating the annual operating costs. It also shows irrigators some possible ways of cutting irrigation costs.

The revised model is called "Irrigation Cost Estimator and System Evaluator" (ICEASE). The model was developed for use on a micro-computer. It is designed to be user friendly and is written in a common computer language, Basic. This allows the model to be used and updated easily.

The annual operating costs are calculated in much the same manner as the Williams et al. (1983) model, but the maintenance cost estimations have been revised (Etzold et al., 1985). This model, like the Williams et al. (1983) model, doesn't evaluate systems with gasoline power units. Systems with gasoline power units aren't evaluated because they aren't used extensively.

In addition to calculating the annual operating costs, the ICEASE model has five options that can be used to conduct evaluations on an irrigator's pumping plant. The options are:

1. Evaluation of pump repair or replacement.
2. Evaluation of switching power units from one power source to another.
3. Estimate of operation cost changes caused by a falling water table and/or a pump efficiency decline.
4. Estimate of operation cost for different levels of water application.

5. Estimate of operation costs under selected fuel inflation rates.

This report covers development of that portion of the ICEASE model, which uses the first three options.

Before using the computer model, a pump test must be completed on the system that is being evaluated. Before a pump test is conducted, it is suggested the power unit should be in top operating condition so the majority of the pumping plant inefficiencies may be attributed to the pump. The reason for doing this is because a significant number of pump tests don't differentiate between power unit and pump efficiency. Because of this, the program doesn't differentiate between them either. By assuming the majority of the pumping plant inefficiency lies with the pump, the user will get a better idea of where improvements may be made within the system.

Evaluating pump repair or replacement is rather complex. When a pump is repaired or replaced, a higher flow rate is expected and this is hard to predict. The most accurate method to predict the flow rate is by reading the pump curve for the system in question. Since a pump curve may not be available, a procedure to estimate the flow rate for all turbine pumps is used in the model, along with equations to estimate turbine pump repair or replacement cost.

The evaluation procedure to switch power units assumes most operating conditions will remain the same. The fuel cost for the new power unit will be different because of the different fuel type. The fuel consumption is converted to the new fuel type, assuming the same rate of fuel consumption as the old power unit. Power unit labor and maintenance costs may also change. All of these factors are taken into consideration, along with the additional costs associated with switching power units, such as the cost of the new power unit.

The model assumes the pump efficiency with the new power unit will be the same as with the old power unit. The power unit efficiency is assumed to be at the Nebraska Standard Efficiency. If the pumping plant has a poor pump efficiency, the switching of power units may not be the best economic decision. It may be more economical to repair or replace the pump to decrease irrigation costs. To get an estimate of the rated horsepower requirements of the pumping plant, the model assumes the power unit is operating at the Nebraska Standard Efficiency (Schroeder, 1982). The estimate of the pumping plant's rated horsepower requirements is used to estimate the cost of a new power unit.

The third evaluation will allow the user to estimate operating costs and how they will increase as the water table falls and/or pump efficiency declines. An estimate of the annual water table drop and pump efficiency decline is entered by the user of the model.

Proper use of the model will give the irrigator a good estimate of what it is costing to operate the pumping plant. The model will also give reasonable estimates of the costs associated with possible changes to the pumping plant. For a better estimate of the cost to make improvements to the pumping plant, an irrigator should contact an irrigation dealer and use that estimate to make improvements in the model. With this information, the irrigator should be able to decide if it is economically feasible to make changes or improvements in the pumping plant to reduce irrigation costs over what they may otherwise be without adjustments.

## REVIEW OF LITERATURE

There has been a limited amount of work done in the area of repair or replacement cost estimation for irrigation pumping plants. The work that has been done has been very useful and much of it has been incorporated into the model to do an economic analysis of an irrigation pumping plant.

The model developed by Williams et al. (1983) estimates the annual operating costs of an irrigation pumping plant. The information Williams et al. (1983) used to make the cost estimates are based on the Nebraska performance criteria for pumping plants. The model also assumes the pumping plant is properly designed and maintained. Williams et al. (1983) estimated the annual operating costs by calculating the following:

1. Annual pumping hours (PH).

$$PH = \frac{A \times I}{GPM/450} \qquad [1]$$

where A = acres irrigated

I = inches of water applied per year

GPM = flow rate in gallons per minute

Acres irrigated is assumed to be 130 acres for center pivot or 160 acres for gated pipe systems.

2. Water horsepower (WHP).

$$WHP = \frac{((PSI \times 2.31) + PWL) \times GPM}{3960} \qquad [2]$$

where PSI = operating pressure

PWL = pumping water level

3. Brake horsepower (BHP).

$$BHP = \frac{WHP}{Ep \times R} \qquad [3]$$

where Ep = pump efficiency (decimal)

R = drive efficiency (decimal)

4. Fuel cost (FC).

$$FC = \frac{BHP \times PH \times F}{FCON/0.75} \qquad [4]$$

For natural gas

$$FC = \frac{BHP \times PH \times F}{(FCON \times BTU \times 0.001)/0.75} \qquad [5]$$

where F = fuel cost per unit

BTU = btu content of natural gas

FCON = fuel consumption in whp-h/unit of fuel

5. Oil cost for engine (OC).

$$OC = \frac{BHP \times PH \times O}{OCON/0.75} \qquad [6]$$

where O = oil cost per gallon

OCON = oil consumption in whp-h/gallon

For electric motors OC = 0.0

6. Oil for electric motor or gear drive (EMO).

$$EMO = \frac{BHP \times PH \times O}{4000/0.75} \qquad [7]$$

7. Repair and maintenance cost for the power unit (PUM).

PUM = Operator estimate or (BHP x $/BHP factor) [8]

8. Repair and maintenance cost for the irrigation system (DSRM).

DSRM(gated pipe) = Operator estimate or (A x $/Factor) [9]

DSRM(center pivot) = Operator estimate or (Factor x $\sqrt{A}$ x PH) [10]

where A = acres irrigated

Factor = estimate of repair cost/unit

9. Labor costs for maintaining the power unit (PULC).

$$PULC = L \times PH \times WR \qquad [11]$$

where L = labor required per hour of operation

WR = wage rate per hour

10. Annual labor costs for setup, take down and operating system (DSLC).

$$DSLC = DSWR \times (((L/T \times A \times C/U)) + S) \qquad [12]$$

where DSWR = wage rate per hour for the distribution system

L = labor hours per irrigation

T = 150 acres for gated pipe or 130 acres for center pivot

A = acres irrigated, assumed the same as "T"

C = total inches of water applied

U = inches of water applied per irrigation

S = setup and take down hours

11. Reuse system for gated pipe or center pivot drive cost (RS).

$$RS = \frac{3 \times PH \times F}{FCON} \qquad [13]$$

12. Total cost (TC).

$$TC = FC + OC + EMO + PUM + DSRM + PULC + DSLC + RS \qquad [14]$$

13. Cost per acre (CA).

$$CA = \frac{TC}{A} \qquad [15]$$

14. Cost per hour (CH).

$$CH = \frac{TC}{PH} \qquad [16]$$

The procedures used to estimate repair and maintenance costs in the Williams et al. (1983) model are based on Nebraska's Agnet "PUMP" program by Thompson et al. (1981). In the "PUMP" program, repair and maintenance cost estimates on the power unit are based on a cost/brake horsepower. The distribution systems costs are based on a cost/acre. The annual cost estimates for the power unit used by Williams et al. (1983) are:

1. Natural Gas $2.35 - $4.70/BHP
2. L.P. $2.35 - $4.70/BHP
3. Diesel $2.90 - $5.80/BHP

4. Electric $0.62 - $1.24/BHP

For the distribution system the repair and maintenance costs are estimated with the following information:

1. Center Pivot 0.08 - 0.16 $/116 feet of C.P. pipe.
2. Gated Pipe 1.00 - 2.00 $/acre

In both cases, the user of the model entered the repair cost estimate per unit using the given ranges for a guide.

Labor hours for the power unit and the distribution system, used in the Williams et al. (1983) model, came from Nebraska's Agnet "PUMP" program (Thompson et al., 1981). The oil consumption figures are also from the "PUMP" program. The amount of labor required to operate the power unit and distribution system is estimated as follows:

1. Power unit.
   a. Internal combustion engines = 0.04 hrs/hr of operation.
   b. Electric motors = 0.02 hrs/hr of operation.
2. Distribution system.
   a. Gated pipe = 18 labor hours/irrigation.
   b. Center pivot = 4 labor hours/irrigation.

To estimate oil consumption, including oil changes, the "PUMP" program from Thompson et al. (1981) uses the following which is based on whp-h/gallon of oil:

1. Diesel = 700 whp-h/gallon.
2. Other internal combustion engines = 800 whp-h/gallon.
3. Electric motor or gear drive = 4000 whp-h/gallon.

Procedures used to estimate repair and maintenance costs by Etzold et al. (1985) use a mean cost/hr for the power unit maintenance. The maintenance cost estimate is $0.169/hr of operation for natural gas engines and $0.027/hr of operation for electric motors. Data was not available for other internal combustion engines, so the cost estimate for natural gas engines was used for all internal combustion engines. A mean estimate was used because the survey data was not complete enough to develop regression equations to estimate the maintenance costs as a function of technical factors.

The estimates of repair and maintenance costs for the distribution system are based on a cost/acre. The values used are also mean estimates because of insufficient data to completely develop equations to estimate these costs. The estimated values for repair and maintenance costs are $2.47/acre for gated pipe systems and $3.97/acre for center pivot systems.

When a pump is repaired or replaced the flow rate is expected to increase. Pacific Gas and Electric Company of California (1984) uses a pumping plant comparison procedure to predict the flow rate of a pump, assuming it is repaired or replaced. This procedure may also be used to estimate flow rate when the water table and pump efficiency drop.

The procedure Pacific Gas and Electric Company uses is designed primarily for use with electric pumping plants. To allow the procedure to be used for all power units, it will be modified in the ICEASE model. To use the procedure to predict flow rate, the following information is required:

1. Standing water level (SWL).
2. Yield of well (GPM/foot of draw down).
3. Motor Size (present or expected).

4. Expected overall plant efficiency.

5. Discharge level expected.

The pumping plant comparison procedure, used to predict the flow rate of an electric pumping plant assuming the pump is repaired or replaced, goes through the following steps. Calculate:

1. Horsepower input (HPI).

$$HPI = \frac{BHP \times LF \text{ (generally 100 percent)}}{EM \text{ (assumed)}} \qquad [17]$$

where BHP = motor size

LF = motor load

EM = motor efficiency

2. Projected work horsepower (WHP).

$$WHP = HPI \times EOE \qquad [18]$$

where EOE = expected overall pumping plant efficiency

3. Pumping water level (PWL).

$$PWL = \frac{(SWL - DL) + \sqrt{(SWL - DL)^2 + 4[(SWL \times DL) + (\frac{WHP}{YIELD} \times 3960)]}}{2} \qquad [19]$$

where SWL = static water level

DL = discharge level = operating pressure x 2.31

WHP = projected work horsepower

YIELD = gpm per foot of draw down

4. Projected flow rate (GPM).

$$GPM = (PWL - SWL) \times YIELD \qquad [20]$$

Once the new flow rate is estimated, the operating costs of the pumping plant can be calculated using the new predicted flow rate. The flow rate should be higher than the old system which had a poorer pump efficiency. A higher flow rate will reduce operating hours and total costs, assuming the same amount of water is applied as before the pump is repaired or replaced.

Pacific Gas and Electric (Ngo, 1983) has developed regression equations to estimate the repair or replacement cost of irrigation pumps. This repair cost study used 35 cases and was done to determine the repair costs of vertical turbine pumps. The study developed three equations to be used to estimate pump repair or replacement costs. The estimate from these equations includes labor cost, column pipe repair cost, and bowl refurbishment or replacement cost. The equations are listed below.

The first equation, which is for a pump with four stages or less, assumes the bowls will be replaced. The second, which is for five stages or more, also assumes the bowls will be replaced. The third equation is for any number of stages and assumes the bowls will be refurbished. To use the equations, the following information must be known:

1. NB = Number of bowls.
2. BSD = Bowl setting depth (feet).
3. BD = Pump bowl diameter (inches).

With the previous information, an estimate to repair or replace a pump may be calculated using one of the following equations:

1. Replace pump four stages or less.

$$RRC_1 = 692 \times NB + 0.92 \times BSD + 31 \times BD^2 - 2345 \quad [21]$$

(R-squared = 0.92)

2. Replace pump five stages or more.

$$RRC_2 = 1626 \times NB + 4.6 \times BSD + 2.3 \times BD^2 - 125 \quad [22]$$

(R-squared = 0.65)

3. Repair pump any number of stages.

$$RRC_3 = 538 \times NB + 15.4 \times BSD + 0.86 \times BD^2 - 1145 \qquad [23]$$

(R-squared = 0.91)

Pacific Gas and Electric claims these estimates are accurate to within 20% of the actual repair cost.

Switching irrigation power units can be very expensive. There are many factors that must be taken into account. According to Dorn (1982), some of the main factors to be considered are:

1. Initial purchase price of the power unit and associated items such as a drive mechanism.
2. Expected life of power unit and associated items.
3. Repair and maintenance costs of power unit.
4. Labor requirements to operate and maintain the system.
5. Annual hours of operation.
6. Interest rate on capital investment.
7. Cost of the various energy sources.

Other factors which Dorn (1982) suggests to consider are personal preference or judgemental items such as dealer service reliability and availability, and preference for a certain fuel source.

Dorn (1982) looks at power unit selection on a numeric basis, but reminds the irrigator not to forget about other factors such as dealer service, which can be important.

There are two primary areas Dorn (1982) considers when switching power units. They are the energy source and the cost of money.

When evaluating the energy source, Dorn (1982) uses the Nebraska performance criteria which is listed in Table 1. From this table, Table 2 is derived. Table 2 is an energy equivalent table, used to convert an equivalent amount of one fuel source to another fuel source.

Table 1. Nebraska Performance Criteria for Pumping Plants

| Energy Source | hp.h[a] Unit of Energy | whp.h[b] Unit of Energy[c] | Energy Units |
|---|---|---|---|
| Diesel | 16.66 | 12.5 | gallon |
| Gasoline | 11.5[d] | 8.66 | gallon |
| Propane | 9.20[d] | 6.89 | gallon |
| Natural Gas | 82.2[e] | 61.7 | 1000 $ft^3$ |
| Electricity | 1.18[f] | 0.885[g] | kW.h |

[a] hp.h (horsepower-hours) is the work being accomplished by the power unit with drive losses considered.

[b] whp.h (water horsepower-hours) is the work being accomplished by the pumping plant at the Nebraska Performance Criteria.

[c] Based on 75% pump efficiency.

[d] Taken from Test D of Nebraska Tractor Test Reports. Drive losses are accounted for in the data. Assumes no cooling fan.

[e] Manufacturers' data corrected for 5 percent gear head drive loss with no cooling fan. Assumes natural gas energy content of 925 Btu per cubic foot. At 1000 Btu per cubic foot energy content use a Performance Criteria of 88.9 hp.h/1000 ft for natural gas.

[f] Assumes 88 percent electric motor efficiency.

[g] Direct connection, assumes no drive loss.

Table reproduced from Dorn (1982).

Table 2. Energy Equivalency Table

| Fuel "A" | Fuel "B" Diesel (gal) | Reg Gas (gal) | Propane (gal) | Nat Gas (mcf) | Elec (kw-hr) |
|---|---|---|---|---|---|
| Diesel (gal) | 1.0 | 0.693 | 0.551 | 4.936 | 0.071 |
| Reg Gas (gal) | 1.443 | 1.0 | 0.796 | 7.126 | 0.102 |
| Propane (gal) | 1.814 | 1.257 | 1.0 | 8.955 | 0.128 |
| Nat Gas (mcf) | 0.203 | 0.140 | 0.112 | 1.0 | 0.014 |
| Elec (kw-hr) | 14.124 | 9.785 | 7.785 | 69.718 | 1.0 |

Table reproduced from Dorn (1982).

This table assumes the energy content of natural gas is 925 btu per cubic foot. To use the table locate the alternative power source under fuel "A" and go across the table to the present fuel source "B". This number is a multiplier.

One way Dorn suggests the table be used is, "To compute an equivalent price per unit of fuel "B", simply multiply the price per unit of fuel for "A" by the multiplier." If the fuel price for the system being considered is lower than the equivalent price for the current system, it may be economical to switch power units. However, investment costs must be considered.

The table can also be used to convert the fuel consumption of fuel "A" to an equivalent fuel consumption for fuel "B". To do this, the fuel consumption of fuel "A" must be multiplied by the multiplier. This will give the equivalent number of units of fuel "B".

When looking at the cost of money, Dorn (1982) uses Table 3 to find the cash flow required to pay back $100.00 in a specified number of years at a specified interest rate.

Dorn (1982) calculates the fuel savings that can be expected from switching power units, but other items such as repair and maintenance may not be considered. The value of the extra expenditure to switch power units must be known by the person using the procedure. The extra expenditure value is where all of the pumping plant costs, except fuel costs, must be accounted for if they are going to be considered when switching power units. The extra expenditure value must also include any costs associated with changing power units, such as the new power unit and gear head (if needed) costs.

To determine if the power unit switch is economical, the extra expenditure value is divided by 100 and then multiplied by the cash flow value required for $100.00 from Table 3. This is an estimate of the annual savings needed to make the power unit switch economical. If the calculated fuel savings exceed the cash flow required for one year, the power unit switch is economical.

Table 3. Cash Flow Required to Repay Each $100 Expenditure for Various Loan Periods and Interset Rates

| | | Annual Interest Rate Percent | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| Loan Period (years) | 1 | 110.00 | 111.00 | 112.00 | 113.00 | 114.00 | 115.00 | 116.00 | 117.00 | 118.00 | 119.00 | 120.00 |
| | 2 | 57.62 | 58.39 | 59.17 | 59.95 | 60.73 | 61.51 | 62.30 | 63.08 | 63.87 | 64.66 | 65.45 |
| | 3 | 40.21 | 40.92 | 41.63 | 42.35 | 43.07 | 43.80 | 44.53 | 45.26 | 45.99 | 46.73 | 47.47 |
| | 4 | 31.55 | 32.33 | 32.92 | 33.62 | 34.32 | 35.03 | 35.74 | 36.45 | 37.17 | 37.90 | 38.63 |
| | 5 | 26.38 | 27.06 | 27.74 | 28.43 | 29.13 | 29.83 | 30.54 | 31.26 | 31.98 | 32.71 | 33.44 |
| | 6 | 22.96 | 23.64 | 24.32 | 25.02 | 25.72 | 26.42 | 27.14 | 27.86 | 28.59 | 29.33 | 30.07 |
| | 7 | 20.54 | 21.22 | 21.91 | 22.61 | 23.32 | 24.04 | 24.76 | 25.49 | 26.24 | 26.99 | 27.74 |
| | 8 | 18.74 | 19.43 | 20.13 | 20.84 | 21.56 | 22.29 | 23.02 | 23.77 | 24.52 | 25.29 | 26.06 |
| | 9 | 17.36 | 18.06 | 18.77 | 19.49 | 20.22 | 20.96 | 21.71 | 22.47 | 23.24 | 24.02 | 24.81 |
| | 10 | 16.27 | 16.98 | 17.70 | 18.43 | 19.17 | 19.93 | 20.69 | 21.47 | 22.25 | 23.05 | 23.85 |

Table reproduced from Dorn (1982).

To obtain an estimate of the brake and rated horsepower requirements of the pumping plant the model assumes the power unit is operating at the Nebraska Standard Efficiency. Making this assumption allows the model to estimate the horsepower requirements of the pumping plant from the overall efficiency.

To estimate the overall efficiency of the pumping plant, a comparison of the Nebraska pumping plant performance criteria to the overall efficiency may be used (Schroeder, 1982). To estimate the overall efficiency, Schroeder (1982) calculates the performance rating of the pumping plant and compares it to the standard overall efficiency. To find the pumping plant's performance rating, the following is used:

1. Calculate water horsepower (WHP) as in Equation 2.
2. Pumping plant performance in whp-h/unit of energy (PP).

$$PP = \frac{WHP}{C} \qquad [24]$$

where C = fuel consumption per hour

3. Performance rating (PR).

$$PR = \frac{PP}{PC} \times 100 \qquad [25]$$

where PC = performance criteria in whp-h/unit of energy from Table 4

To obtain an estimate of the overall efficiency, the performance rating is compared to the standard overall efficiency from Table 4.

1. Estimated overall efficiency (EOE).

$$EOE = PR \times SOE \qquad [26]$$

where SOE = standard overall efficiency from Table 4

Table 4. Nebraska Performance Criteria vs. Overall Efficiency

| Energy Type | whp-h/unit(2) of energy | Performance Rating(%) | Overall(1) Efficiency(%) |
|---|---|---|---|
| Diesel | 12.5 | 100 | 23 |
| Propane | 6.89 | 100 | 18 |
| Natural Gas | 61.7(3) | 100 | 17 |
| Electricity | 0.885 | 100 | 66 |
| Gasoline | 8.66 | 100 | 17 |

(1) Based on average BTU energy values.

(2) Whp-h/unit of energy (water horsepower-hours/unit of energy) is the performance for the pumping plant - both engine and pump. Value based on field pump efficiency of 75%.

(3) Assumes natural gas content of 925 BTU per cubic foot. At 1000 BTU per cubic foot energy content use a performance criteria of 66.7 whp-h/unit of energy for natural gas.

Table reproduced from Schroeder (1982).

When sizing an internal combustion engine, the brake horsepower requirements need to be derated to estimate the rated horsepower requirements. A procedure by Hansen et al. (1962) adds the following decreases in efficiency to obtain the derating:

| | | |
|---|---|---|
| 1. | For each 300 m above sea level | 0.03 |
| 2. | For each 3 operating air temperature above 18 C | 0.01 |
| 3. | For accessories, using heat exchangers | 0.05 |
| 4. | Radiator and fan | 0.05 |
| 5. | For continuous load operation | 0.20 |
| 6. | Drive losses | 0.00-0.15 |

To obtain the rated horsepower or continuous brake horsepower requirements, Hansen et al. (1962) used the following procedure:

1. Calculate water horsepower (WHP) as in Equation 2.

2. Brake horsepower (BHP).

$$BHP = \frac{WHP}{Ep} \qquad [27]$$

where Ep = pump efficiency

3. Rated horsepower (RHP).

$$RHP = \frac{BHP}{1 - derating} \qquad [28]$$

Another method to derate internal combustion engines, to be used for continuous duty operation, uses the following procedure by Lane et al. (1982):

1. Calculate water horsepower (WHP) as in Equation 2.

2. Correct for elevation, 3% for each 1000ft of elevation.

   EC = 100% - Correction

3. Correct for temperature, 1% for each 10  above 60 F.

   TC = 100% - Correction

4. Accessories, cooling fan 5%.

   AC = 100% - 5% = .95

5. Drive efficiency, gear head or V-belt 5%.

   DC = 100% - 5% = .95

6. Pump efficiency, (Ep).

7. Add 15% reserve to provide for changes in an engine's performance due to wear or manufacturing tolerances.

   RC = 100% - 15% = .85

To find the continuous brake horsepower or rated horsepower requirements, Lane et al. (1982) uses a different method than Hansen et al. (1962). The rated horsepower(RHP) is calculated as follows:

$$RHP = \frac{WHP}{EC \times TC \times AC \times DC \times Ep \times RC} \qquad [29]$$

where EC = elevation correction

TC = temperature correction

AC = accessory correction

DC = drive correction

Ep = pump efficiency

RC = reserve correction

# INVESTIGATION

## Objective

The main objective of this study is to establish simple, but applicable procedures, which can be used to evaluate irrigation costs under a variety of operating conditions.

Specifically, the model will be able to do the following:

1. Estimate annual operating costs for the current pumping plant conditions.
2. Evaluate possible improvements to the pumping plant, to determine if they are economically feasible.
3. Determine the effect of a falling water table and/or pump efficiency decline on annual operating costs.
4. Develop that portion of the ICEASE model which uses the procedures developed. The model will be user friendly and written in a common computer language, Basic. This will enable the model to be used and updated easily.

## Methods of Procedure

### Estimating Annual Operating Costs

The three procedures covered in this report (pump repair or replacement cost, cost of switching power units from one energy source to another, and the procedure to show how a falling water table and pump efficiency decline will affect operating costs) use the annual costs and operating conditions which are calculated in the first part of the ICEASE model.

The annual operating costs are calculated in much the same manner as the Williams et al. (1983) model. Differences between the ICEASE model and the Williams et al. (1983) model are in the way some of the annual costs are calculated. This model primarily runs off of water horsepower (WHP), where the Williams et al. (1983) model ran primarily off of brake horsepower (BHP). This model also calculates the repair and maintenance costs for the power unit and distribution system, using procedures developed by Etzold et al. (1985). The input information required to use the model is as follows:

Items 2,4,5 and 6 should come from a pump test.

1. Number of acres irrigated.
2. System operating pressure (PSI).
3. Number of inches of water irrigated per acre per season.
4. Pumping water level (PWL).
5. Flow rate in gallons per minute (GPM).
6. Fuel consumption per hour.
7. Fuel price per unit.
8. Oil cost per gallon.
9. Power unit maintenance cost estimate or estimated by model.
10. Distribution system maintenance estimate or estimated by model.
11. Wage rate for power unit repair.
12. Wage rate for operating and checking the system.
13. If applicable - BTU content of natural gas or electric connect charge per rated horsepower.

A brake horsepower requirement is needed to estimate some of the annual operating costs. When switching power units, an estimate of the rated horsepower requirements is also needed to estimate power unit and gear head costs.

To estimate the brake and rated horsepower requirements, the model assumes the power unit is operating at the standard power unit efficiency. The standard power unit efficiencies used are calculated from Table 4, which contains the Nebraska standard overall efficiencies. Nebraska assumes a 75% pump efficiency. Knowing this, the standard power unit efficiencies used in the model can be found in the following way:

$$PUE = \frac{SOE}{Ep} \qquad [30]$$

where PUE = standard power unit efficiency

SOE = standard overall efficiency, from Table 4

Ep = pump efficiency of 75%

Using this equation, the standard power unit efficiencies are calculated. In the model they are as follows:

1. Diesel 30.67%
2. Propane 24.00%
3. Natural Gas 22.67%
4. Electric 88.00%

Pump test data collected by Etzold et al. (1985) shows power unit efficiencies for some natural gas and electric units. Of the fifty-one natural gas units tested, twenty-nine of them had the engine efficiency determined. The mean engine efficiency for the twenty-nine engines was 22.15% with a low value of 12.6% and a high value of 27.8%. Fourteen of the twenty-four electric units had the motor efficiencies determined. The mean efficiency for the fourteen motors was 86.31% with a low value of 73.9% and a high value of

92.4%. After analyzing the data collected by Etzold et al. (1985), it seems reasonable to assume the power unit is operating at the standard efficiency.

To estimate the brake and rated horsepower requirements, the model goes through the following procedure which uses the Nebraska performance criteria (Schroeder, 1982):

1. Determine pumping plant performance (PP) as in Equation 24.
2. Determine performance rating (PR) as in Equation 25.

   For natural gas systems:

$$PR = \frac{PP/PC}{BTU \times 0.001} \times 100 \quad [31]$$

where PC = performance criteria in whp-h/unit from Table 4

For natural gas model uses 66.7 whp-h/mcf.

3. Estimate overall pumping plant efficiency (EOE) as in Equation 26.
4. Estimate pump efficiency (Ep), assuming the power unit is efficient.

$$Ep = \frac{EOE}{PUE} \quad [32]$$

5. Estimate brake horsepower requirements (BHP) as in Equation 27.
6. Estimate rated horsepower requirements (RHP) as in Equation 28.

To find the rated horsepower requirements, the brake horsepower requirements need to be derated. The derating was estimated using the procedure by Hansen et al. (1962). The derating was for western Kansas where the elevation is approximately 3500 feet and the temperature reaches 100 degrees Fahrenheit.

The Hansen et al. (1962) procedure is in metric units. To make the derating simple, the model uses the English units that Lane et al. (1982) used to correct for elevation and temperature. These numbers are very close to the metric numbers converted to English units. Using the Lane et al. (1982) numbers to correct for elevation and temperature, the derating comes out to an even number which is easier to work with than the metric conversion. In this model, the derating is assumed to be as follows:

1. Elevation of 3500 feet = 0.105
2. Temperature of 100 F = 0.04
3. Accessories, using heat exchanger = 0.05
4. Continuous load = 0.2
5. Drive losses = 0.025
6. Total losses = 0.42

Once the brake and rated horsepower requirements of the pumping plant are estimated, the annual operating costs can be estimated. To estimate the annual operating costs, the model goes through the following steps:

1. Calculate annual pumping hours (PH) using Equation 1.
2. Calculate water horsepower (WHP) using Equation 2.
3. Calculate fuel cost (FC).

$$FC = PH \times F \times C \qquad [33]$$

where F = fuel cost per unit

C = fuel consumption per hour

4. Calculate engine oil cost or annual electric connect charge (OC).

For engine oil cost

$$OC = \frac{WHP \times PH \times O}{OCON} \qquad [34]$$

where O = oil cost per gallon

OCON = oil consumption in whp-h/gallon

For diesel OCON = 700 whp-h/gallon

Other engines OCON = 800 whp-h/gallon

For annual electric connect charge

$$OC = BHP \times EC \qquad [35]$$

where BHP = brake horsepower

EC = annual connect charge per rated horsepower

5. Calculate oil cost for electric motor or gear drive (EMO).

$$EMO = \frac{WHP \times PH \times O}{4000} \quad [36]$$

where 4000 is the oil consumption in whp-h/gallon for electric motors or gear drives

6. Calculate maintenance costs for power unit (PUM).

For internal combustion engines

PUM = Operator estimate or ($0.169 x PH) [37]

For electric motors

PUM = Operator estimate or ($0.027 x PH) [38]

7. Calculate repair and maintenance costs for distribution system (DSRM).

For gated pipe systems

DSRM = Operator estimate or ($2.47 x A) [39]

For center pivot systems

DSRM = Operator estimate or ($3.97 x A) [40]

8. Calculate power unit labor cost using Equation 11.
9. Calculate distribution system labor cost using Equation 12, except "A" is variable depending on number of acres irrigated.
10. Calculate reuse system cost for gated pipe or center pivot drive costs using Equation 13.
11. Calculate total cost using Equation 14.
12. Calculate cost per acre using Equation 15.
13. Calculate cost per hour using Equation 16.

Once the annual operating costs are estimated, the model has the option of stopping or continuing with other evaluation procedures. When doing the evaluations, more input information is required. Some information will be the same as in the beginning of the model and some will be new information. This helps assure the correct information is entered by the user.

Evaluating Pump Repair or Replacement

The first evaluation covered is pump repair or replacement. One of the most difficult parts of this evaluation is predicting the flow rate (GPM, gallons per minute) of the well, when the pump is repaired or replaced. The model assumes that the same amount of water will be applied during a year even though the pump efficiency improves as a result of the repair or replacement. If this wasn't assumed, there may not be any savings realized.

To predict the flow rate of a repaired or replaced pump, the model uses the procedure developed by Pacific Gas and Electric Company of California. To use this procedure for all types of systems, some slight modifications were made to the first step, which calculates the input horsepower requirements of the pumping plant.

Original pumping water level, flow rate(GPM) and system operating pressure(PSI) can be used to calculate the original input horsepower requirements of the system. This will give the best estimate of the expected flow rate from the well when the pump is repaired or replaced. If the user of the model does not know this information, they have the option to enter the input horsepower requirement of the pumping plant from a pump test evaluation. Using the input horsepower requirement from a pump test evaluation will give a more conservative estimate of the flow rate that can be expected when the pump is repaired or replaced. In some cases, this may be a better estimate because of changes in well conditions since the pump was first installed.

To estimate the flow rate of the well (assuming the pump is repaired or replaced) the model needs the following information:

1. Original pumping water level.
2. Original flow rate.
3. Original operating pressure.

   or

4. Input horsepower from a pump test.

   and

5. Current static water level (SWL).
6. Current pumping water level (PWL).

To estimate the flow rate of the well assuming the pump is repaired or replaced, the model goes through the following steps:

1. Calculate original Pump input horsepower or use input horsepower from a pump test (HPI).

$$HPI = \frac{EP \times (EN + (2.31 \times EQ))}{3960 \times 0.75} \qquad [41]$$

where EP = original flow rate

EN = original pumping water level

EQ = original operating pressure

0.75 is for a 75% efficient pump

or

HPI = Input horsepower from pump test

2. Calculate projected work horsepower (WHP) using Equation 18.
3. Calculate well yield per foot of draw down (YIELD).

$$YIELD = \frac{GPM}{PWL - SWL} \qquad [42]$$

where GPM = current flow rate

PWL = current pumping water level

SWL = current static water level

4. Calculate discharge level (DL).

$$DL = PSI \times 2.31 \qquad [43]$$

where PSI = current system operating pressure

5. Calculate expected pumping water level (PWL) using Equation 19.

6. Calculate expected flow rate (GPM) using Equation 20.

The model assumes some conditions, such as well yield per foot of draw down and operating pressure, will be the same after the pump is repaired or replaced.

To estimate the new annual operating costs, the model assumes the pump will be seventy-five percent efficient, the power unit will be efficient and the estimated flow rate will be obtained.

The same procedure as in the beginning of the model is used to estimate the new annual operating costs. This assumes the pump is operating at seventy-five percent efficiency. The new pumping hours that are calculated will generally be lower because the new flow rate should be higher.

The new energy cost is calculated in a different manner, using the standard fuel consumption figures for an efficient pumping plant from Table 4. To calculate the new energy cost, one of the following equations is used:

For all power sources except natural gas

$$FC = \frac{WHP \times PH}{PC} \times F \qquad [44]$$

For natural gas

$$FC = \frac{WHP \times PH}{PC/(BTU \times 0.001)} \times F \qquad [45]$$

where FC = new annual fuel cost

WHP = new water horsepower

PH = new pumping hours

PC = performance criteria from Table 4, for natural gas 66.7 whp-h/mcf is used

F = fuel cost per unit

Once the new annual operating costs are calculated, the model can estimate the savings that can be expected. The model asks for an estimate of the annual fuel inflation rate expected over the next ten years before estimating the savings.

To calculate the annual fuel cost with fuel inflation for a ten year period, the model uses the following equations. The first equation calculates the fuel cost, including inflation, on an annual basis for the system before any changes are made. The second equation calculates the annual fuel cost, including inflation, assuming improvements have been made to the pumping plant.

$$FC(X) = FC(X-1) \times (1 + FI) \qquad [46]$$

$$NFC(X) = NFC(X-1) \times (1 + FI) \qquad [47]$$

where FC(X) = old fuel cost year(X)

NFC(X) = new fuel cost year(X)

FI = fuel inflation rate

X = year 2 through year 10

The previous information, along with the annual energy savings including inflation are calculated on an annual basis for a ten year period and printed on the screen. To calculate the energy savings with fuel inflation, the model uses the following equation:

$$ES(X) = FC(X) - NFC(X) \quad [48]$$

where ES(X) = energy savings, year(X)

FC(X) = old fuel cost year(X)

NFC(X) = new fuel cost year(X)

X = year 1 through year 10

The model shows total energy savings with fuel inflation and without fuel inflation. This allows the user to see what effect fuel inflation has on energy cost over a ten year period. The total energy savings with fuel inflation are found by adding the annual fuel savings together. To find the total savings without fuel inflation, the model takes the first year savings and multiplies it by ten.

The total operating cost for the system is estimated annually for a ten year period before any improvements are made and also after improvements have been made. The model estimates the annual total cost using one of the following equations:

$$OTC(X) = TC + FC(X) - FC1 \quad [49]$$

$$NTC(X) = ITC + NFC(X) - NFC1 \quad [50]$$

where OTC(X) = total annual cost before improvements for year(X)

TC = total annual costs before improvements for first year

FC(X) = old fuel cost, year(X)

FC1 = old fuel cost in first year

NTC(X) = total annual cost after improvements for year(X)

ITC = total annual costs after improvements for first year

NFC(X) = new fuel cost, year(X)

NFC1 = new fuel cost in first year

X = year 1 through year 10

Once the annual total costs are calculated, the total savings can be found using the following equation:

$$TS(X) = NTC(X) - OTC(X) \quad [51]$$

where TS(X) = total savings for year(X)

The model calculates the total savings, for a ten year period, by adding the annual savings over the ten years together. Total savings are also shown in the model with no fuel inflation. To estimate total savings with no fuel inflation, the first year total savings are multiplied by ten.

Within the model there are a number of checks to be sure the data is correct. The model will also check the savings that are calculated to see that they are positive. If the savings calculated are negative, the model will stop the evaluation, because it is not economically feasible to make improvements to the pumping plant.

If the savings are positive in the evaluation of pump repair or replacement, the model will continue in the evaluation by asking for an estimate of the cost to repair or replace the pump. If the user doesn't have an estimate, the model can estimate the cost to repair or replace the pump using Equations 21, 22, or 23 developed by Ngo, (1983). In order for the model to use these equations, the user must know the following data:

1. Number of pump bowls.

2. Bowl setting depth.

3. Bowl diameter.

4. Interest rate to finance pump repair or replacement.

If this information is known or the user of the model has an estimate of the cost to repair or replace the pump, the evaluation will continue. When continuing, the present value of the total savings are calculated using the interest rate to finance pump repair or replacement entered by the user. To calculate the present value on an annual basis, the model uses the following:

$$NPV(X) = TS(X) \times \frac{1}{(1 + IR)^{X}} \qquad [52]$$

where NPV(X) = present value of savings in year(X)

TS(X) = total savings from improvements in year(X)

IR = interest rate to finance improvements

X = year 1 through year 10

To find the total discounted savings, the annual discounted savings for each year over a ten year period are added together. If the total discounted savings are less than the estimate to repair or replace the pump, the evaluation is complete. If the savings exceed repair cost, the repair cost is subtracted from the total discounted savings to show the user the net savings that can be expected over a ten year period. The net savings and the number of years required to pay for the repairs is displayed to the user.

Evaluation of Switching Power Units

The evaluation procedure which estimates the cost of switching to an alternative power source uses many of the procedures previously discussed. Since gasoline engines aren't evaluated in the model, they are not listed as an alternative power source to be selected by the user.

When switching power sources, operating conditions associated with the pumping plant are assumed to remain the same. The following information is required to evaluate switching to an alternative power source:

1. Alternate power source.

   User has a choice of

   a. Natural gas

   b. Propane (L.P. gas)

   c. Diesel

   d. Electricity

2. Fuel cost per unit.

3. If evaluating natural gas, BTU content of gas.

4. If evaluating electricity, electric connect charge per rated horsepower.

5. Estimate of average annual fuel inflation over the next 10 years for the current fuel source.

6. Estimate of average annual fuel inflation over the next 10 years for the alternative fuel source.

After the model has this information, it evaluates the differences in total operating costs between the different power sources. The model has an estimate of the operating costs for the current fuel source, so it first estimates operating costs for the alternative fuel source.

Before estimating the operating costs for the alternative power source, the model uses the procedure by Dorn (1982) to convert the fuel consumption of the current power source to an equivalent amount of the fuel for the alternative power source.

Table 2, (taken from Dorn, 1982) was revised using the Nebraska performance criteria from Table 1. The information was put into Table 5. The numbers in Table 5 are used to make the fuel consumption conversion in the model. Table 5 contains more significant digits than Table 1, to give better accuracy when making the fuel conversions.

Table 5. Energy Equivalency Table

| | Fuel "B" | | | |
|---|---|---|---|---|
| Fuel "A" | Diesel (gal) | Propane (gal) | Nat Gas (mcf) | Elec (kw-hr) |
| Diesel (gal) | 1.0 | 0.5519126 | 4.936 | 0.0707679 |
| Propane (gal) | 1.18118811 | 1.0 | 8.9550073 | 0.1282231 |
| Nat Gas (mcf) | 0.2025932 | 0.1116694 | 1.0 | 0.0143436 |
| Elec (kw-hr) | 14.130693 | 7.7989071 | 69.717514 | 1.0 |

Once the fuel consumption is estimated for the alternate power source, the annual operating costs are estimated using the same procedure as in the beginning of the model.

In the evaluation of switching power units, the model first estimates the energy savings from switching to the alternative power source. The energy savings are estimated for a ten year period. The same procedure is used in this evaluation as was used in the evaluation of pump repair or replacement. Equations 47 and 48 are used to estimate the energy savings.

Next, the total savings are estimated for a ten year period. The procedure is the same as in the evaluation of pump repair or replacement. Equations 50 and 51 are used to estimate the total savings expected from switching power units.

If the total savings from switching power units is positive, the evaluation will continue. If it is negative, the evaluation is complete and the power unit switch is not economically feasible.

When continuing, the model evaluates the cost of purchasing and installing a new power unit. This is compared to the present value of the total savings from switching power units over a ten year period.

The model will ask the user for an estimate of the cost to install a new power unit and gear head(if needed). If the user doesn't have an estimate, the model will estimate the cost. When switching to natural gas or propane(L.P.), the user has the option of choosing a light-duty(automotive) engine or a heavy-duty(industrial) engine. The model assumes a gear head is needed when switching from an electric motor to an internal combustion engine. Otherwise the gear head cost is not estimated.

Regression equations were developed to estimate power unit and gear head costs using 1984 prices. The prices used to estimate diesel engine cost came from Caterpillar, Cummins and International Harvester. For natural gas and propane the prices were from Caterpillar, International Harvester and Ford.

The natural gas engine prices from Caterpillar were used to estimate the cost for the heavy-duty type of engine and the International Harvester and Ford prices were used to estimate the costs for the light-duty engines.

The electric motor cost was estimated using prices from U.S. Motors. The prices used to estimate the motor cost are for 3-phase super-standard hol-loshaft motors which are common motors used for irrigation. Prices for Newman vertical hollow shaft motors used for irrigation were also obtained. Because these prices were virtually the same as U.S. Motors, only the U.S. Motors prices were used.

The gear head costs are estimated using prices from Randolph gear heads. Prices were also obtained for Amarillo gear heads and they were about the same, so only the Randolph gear head prices were used to develop the equation to estimate gear head costs.

The regression equations, used in the model, will give an estimate of the actual cost to purchase a power unit or gear head. The prices collected are from various dealers in Kansas and the prices varied from dealer to dealer. To get a more accurate estimate of the actual cost to purchase a power unit or gear head, it is advisable to contact a dealer.

The equations used in the model are as follows:

$$\text{Diesel} = 3572.85 + (\text{RHP} \times 43.56) \qquad [53]$$

(R-squared = 0.82)

$$\text{Industrial Nat Gas or L.P.} = -7928.76 + (\text{RHP} \times 192.24) \qquad [54]$$

(R-squared = 0.83)

$$\text{Automotive Nat Gas or L.P.} = -945.129 + (\text{RHP} \times 56.318) \quad [55]$$

$$(\text{R-squared} = 0.93)$$

$$\text{Electric motor} = 1156.06 + (\text{BHP} \times 41.27) \quad [56]$$

$$(\text{R-squared} = 0.99)$$

$$\text{Gear head} = 331.631 + (\text{RHP} \times 16.957502) \quad [57]$$

$$(\text{R-squared} = 0.95)$$

where RHP = rated horsepower

BHP = brake horsepower

The model will not allow the user to get a price for the natural gas or L.P. engines below $11,000 for industrial or $2,200 for automotive. The data used to develop these equations, along with the regression analyses, are in Appendix A.

After the power unit and gear head cost are estimated, the model asks the user for the following information:

1. Interest rate to finance power unit switch.
2. Salvage value of old power unit.
3. Miscellaneous cost of switching power units.

With the interest rate, the model will calculate the present value of the total savings expected over a ten year period. To do this, the model uses Equation 52 from the section which evaluates pump repair or replacement.

Because of the variability of the costs associated with switching power units, the power unit and gear head costs are the only items estimated by the model. Any other costs associated with switching power units must be entered as miscellaneous costs by the user, if they are to be considered. If there are any components of the pumping plant discarded due to the power unit switch, the salvage value of these components must be entered by the user of the model for it to be considered in the evaluation.

The power unit, gear head(if needed) and miscellaneous costs are subtracted from the present value of the ten year total savings and any salvage value is added to get the net savings. If this results in a positive value, the switching of power units is economically feasible and the model will estimate the number of years required to pay back the costs associated with switching power units. If the net savings is negative, the procedure is complete and the switching of power units is not economically feasible.

Effect of Water Table and Pump Efficiency Decline on Operating Costs

This evaluation shows the user the effect of a falling water table and/or pump efficiency decline on operating costs. The user has to enter the expected annual drop in the water table and a percentage estimate of the annual pump efficiency decline.

This evaluation uses the same procedures that were used in the sections which estimated annual operating costs and pump repair or replacement costs. These procedures are used for a ten year period, so the annual operating cost changes due to the falling water table and pump efficiency decline may be observed.

The model assumes the original amount of water will be pumped, so pumping hours will increase as the water table falls and the pump efficiency declines. This will increase the total pumping costs. The model starts out with the current pump efficiency as estimated in the beginning of the model and assumes the power unit will be maintained at the standard power unit efficiency for the ten year period. To use this procedure the user needs the following information:

1. Average annual decline in water table in feet.
2. Average annual percentage point decline in pump efficiency.
3. Estimate of annual fuel inflation rate over the next ten years.
4. Input horsepower from a pump test.
5. Current static water level.
6. Current pumping water level.

The evaluation starts out with the first year costs being the same as in the beginning of the model. For the next nine years, the model uses a loop and recalculates the expected flow rate(GPM) and the pumping water level(PWL). Using this information, the model is able to use another loop to recalculate the annual operating costs using the same procedure as used originally.

To estimate the new flow rate, the model uses the same procedure used in the evaluation of pump repair or replacement. In Equation 18 the expected overall pumping plant efficiency changes annually as pump efficiency declines. When estimating the expected overall efficiency, the power unit efficiency is assumed to remain at the Nebraska standard. The expected overall efficiency used in the procedure is calculated as follows:

$$EOE = Ep \times PUE \qquad [58]$$

where EOE = expected overall pumping plant efficiency

Ep = pump efficiency

PUE = power unit efficiency

The current pump efficiency(Ep) is estimated using Equation 32. This value is lowered each time the model calculates the next years flow rate and pumping water level.

Water table decline is accounted for when using Equation 19 to estimate the new pumping water level. The static water level, entered by the user, is increased every time the model calculates the next years pumping water level. The amount of the increase is entered by the user of the model. The yield or GPM/ft of draw down is assumed to remain constant through the ten year period.

Having an estimate of the flow rate and the pumping water level, the model can calculate the pumping hours and water horsepower required to apply the same amount of water every year for ten years. Equations 1 and 2 are used to calculate pumping hours and water horsepower.

Knowing the pumping hours and water horsepower required, the new annual operating costs can be estimated using the same procedure used to estimate the annual operating costs in the beginning of the model. The only difference is, when the annual energy costs are estimated, they are inflated using the annual fuel inflation rate entered by the user. The procedure used to inflate the energy cost is the same as in Equation 46.

When the procedure is complete, the model will show the user the annual energy cost, annual total operating costs and the annual changes in each, that can be expected due to a drop in the water table and/or pump efficiency decline.

## DISCUSSION

The procedure used to estimate the annual operating costs for the irrigation pumping plant takes into account the costs associated with the operation of the pumping plant. Differences between the costs estimated by the model and an irrigators actual costs may be accounted for from any of the following:

1. Amount of oil consumed.
2. Differences in maintenance costs.
3. Labor required to maintain the power unit.
4. Labor required for set up, take down and operating the system.
5. Costs to run a reuse pump or drive a center pivot.

All of the cost estimates may vary from the actual costs incurred by the irrigator. The estimate by the model will only be as accurate as the input data entered. Any errors in the data entered should be changed to give a better estimate of the actual operating costs.

In all of the evaluation procedures a ten year period was selected to analyze savings. Ten years is well within the expected life of the pumping plant components, so the estimated savings could be realized. In some cases, the cost to improve the pumping plant may not take ten years to be paid back. If this is the case, the model will estimate the number of years required to pay back the cost of pumping plant improvements.

The fuel inflation rate asked for in each evaluation is optional to the user. It may be left at zero. It was put into the model to show the user how fuel inflation can affect operating costs over a ten year period.

Evaluating pump repair or replacement costs and the estimation of operating costs after pump repair or replacement is a difficult task. The model can give an estimate of both. To obtain the actual costs associated with pump repair or replacement, an irrigator should contact a pump dealer. This can be incorporated into the model to do the economic analysis.

Evaluating a pump in the model works best when the system has a power unit which is operating close to the standard power unit efficiency, because the model assumes the power unit is operating at the Nebraska Standard..

In order to realize savings from pump repair or replacement, the pump needs to be fairly inefficient. The amount of inefficiency necessary before repairs are economical, is influenced significantly by the price paid for fuel. Other operating costs are also affected, as the pump becomes more inefficient, but not as significantly as the total fuel cost.

In the evaluation of switching power units, all of the costs associated with operating the pumping plant, included in the initial estimation of the annual operating costs, are included.

All of the annual operating costs are reestimated for the alternative power unit. Some of the costs would be the same regardless of the type of power unit, but to assure accuracy they are reestimated.

To estimate power unit and gear head costs, the model needs an estimate of the rated horsepower requirement of the system. The model estimates the rated horsepower requirement, assuming the power unit is operating at the Nebraska standard efficiency. If the system being evaluated has a power unit efficiency above or below the Nebraska standard efficiency, the rated horsepower estimate will be low or high. The engine derating used in the model may also vary from actual conditions observed by the irrigator. This could effect the estimate of the rated horsepower required of the pumping plant.

If the estimate of the rated horsepower required to operate the pumping plant is inaccurate, the power unit and gear head cost estimate will also be inaccurate. The prices used to develop the regression equations for power unit and gear head costs were obtained from various dealers in Kansas. The actual cost to purchase a power unit or gear head may vary from area to area. The prices estimated by the model are only intended to give the user an estimate of the cost to purchase a power unit or gear head. To obtain the actual costs, the irrigator should consult with an irrigation dealer.

To account for any costs not estimated by the model, the user may enter any miscellaneous cost of switching power units and the salvage value of the old power unit. The miscellaneous costs include any cost of changing power units, not already accounted for in the model. This may include such things as the installation costs of the power unit and gear head. The salvage value may include the value of any components of the pumping plant discarded due to the power unit switch.

Estimating the annual operating costs as the water table falls and pump efficiency declines uses the same procedure used in evaluating pump repair or replacement. The major assumption in this procedure, like the other procedures, is the power unit is efficient. If this isn't true, the annual operating costs estimated as the water table falls and the pump efficiency declines may be different from the actual costs.

The yield of the well or GPM/ft of draw down is also assumed to be constant in this procedure. This is a reasonable assumption due to the fact that a well will yield about the same amount of water per foot of draw down, regardless of the static water level or pump efficiency.

This procedure is in the model to show the irrigator the effect of a falling water table and/or a declining pump efficiency on annual operating costs over time. The estimates made by the model may vary from observed annual costs due to different conditions at different locations.

# CONCLUSION

The main objective of the study was completed. Simple but applicable procedures to evaluate an irrigation system's costs under a variety of operating conditions have been developed.

Specifically the model is able to do the following:

1. Estimate annual operating costs for the current pumping plant conditions. All costs associated with the operation of the pumping plant are taken into account in this procedure. Variations between the estimate and the actual cost observed by the irrigator may be accounted for by differences, in the amount of money and time, spent in maintaining the pumping plant.

2. Determine the feasibility of pump repair or replacement. By estimating the flow rate that can be expected after pump repair or replacement, the model is able to recalculate the operating costs and compare them to the original operating costs to determine if pump repair or replacement is feasible. The model can make an estimate of the costs associated with the repairs, if the user doesn't have an estimate.

3. Determine the economic feasibility of switching power units from one power source to another. A procedure which can evaluate the economic feasibility of switching power units, has been developed. It may be a good way for some irrigators to cut operating costs. The model will analyze all of the costs associated with the pumping plant operation. The new power unit and gear head costs are also included in the analysis. Any additional costs associated with the power unit change needs to be entered by the user of the model for them to be considered in the analysis. Any salvage value of the old power

unit and components discarded because of the switch may be accounted for by the user entering there value.

4. Show the effect of a falling water table and/or pump efficiency decline on the annual operating costs. It is intended to show an irrigator what effect a falling water table and pump efficiency decline has on annual operating costs. Any interpretation of the output is intended to be done by the irrigator or user of the model.

## SUGGESTIONS FOR FUTURE RESEARCH

The main area that needs additional work and refinement is the procedure used to estimate maintenance costs of the power unit, and the repair and maintenance costs on the distribution system.

Obtaining good maintenance and repair information from irrigators is difficult. The primary reason being most irrigators don't have detailed records of the costs of operating the irrigation system.

To develop an accurate equation to estimate repair and maintenance costs, one should obtain data from hundreds of irrigators. This would be a difficult process since a pump test is desired for each pumping plant.

The most accurate way to get the necessary information from irrigators would be to contact irrigators a year before the data is required and have them keep records for that year. At the end of the year the data could be collected from the irrigators and the necessary pump test could be conducted. With this procedure, the amount of data required could be reduced and would allow the researcher more control over the quality of data collected.

This would take a number of people and a lot of time, but improving the procedure to estimate the repair and maintenance costs of the pumping plant will make the model better.

The equations used to estimate the pump repair or replacement cost, power unit costs, and gear head costs should also be updated periodically, to account for inflation and any changes in technology.

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# APPENDIX A.

## Data for Power Unit and Gear Head Cost Equations, Along With the Regression Analysis

Table 6. Power Unit Data

| Diesel | | Nat Gas & L.P. (Industrial) | | Nat Gas & L.P. (Automotive) | | Electric | | Electric | |
|---|---|---|---|---|---|---|---|---|---|
| HP | Price | HP | Price | HP | Price | HP | Price | HP | Price |
| 64 | 5622 | 83 | 11960 | 40 | 2287 | 3 | 1110 | 125 | 6492 |
| 72 | 6350 | 95 | 11960 | 65 | 2555 | 5 | 1110 | 125 | 6768 |
| 80 | 6342 | 125 | 15530 | 70 | 2350 | 7.5 | 1142 | 150 | 7256 |
| 90 | 9120 | 145 | 15530 | 73 | 3122 | 10 | 1286 | 150 | 7810 |
| 98 | 7120 | 195 | 22530 | 76 | 3578 | 15 | 1536 | 150 | 7596 |
| 115 | 12100 | 220 | 22530 | 90 | 3140 | 20 | 1750 | 200 | 10612 |
| 130 | 13000 | 200 | 38630 | 94 | 4492 | 25 | 1952 | 200 | 11072 |
| 150 | 9570 | 225 | 38630 | 100 | 4475 | 30 | 2194 | 200 | 9858 |
| 150 | 7910 | 265 | 49340 | 140 | 7550 | 40 | 2550 | 250 | 11128 |
| 160 | 8254 | 295 | 49340 | 170 | 8700 | 50 | 3026 | 300 | 13234 |
| 175 | 8940 | | | | | 60 | 3494 | 350 | 15214 |
| 225 | 10590 | | | | | 75 | 4254 | 400 | 17228 |
| 135 | 10820 | | | | | 100 | 4940 | 450 | 19130 |
| 175 | 11320 | | | | | 100 | 5374 | 500 | 21708 |
| 245 | 14130 | | | | | 100 | 5602 | | |
| 300 | 17170 | | | | | | | | |
| 325 | 18600 | | | | | | | | |
| 369 | 20570 | | | | | | | | |

Table 7. Regression Analysis for Diesel Engines

Dependent Variable: Price

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F VALUE | PROB>F |
|---|---|---|---|---|---|
| MODEL | 1 | 259044386 | 259044386 | 71.61 | 0.0001 |
| ERROR | 16 | 57875101 | 3617194 | | |
| C TOTAL | 17 | 316919487 | | | |

| | | | |
|---|---|---|---|
| ROOT MSE | 1901.89 | R-SQUARE | 0.8174 |
| DEP MEAN | 10973.78 | | |
| C.V. | 17.33 | | |

| VARIABLE | DF | PARAMETER ESTIMATE | STANDARD ERROR | T FOR H0: PARAMETER=0 | PROB > \|T\| |
|---|---|---|---|---|---|
| INTERCEP | 1 | 3572.85 | 982.75 | 3.64 | 0.0022 |
| HP | 1 | 43.56 | 5.148 | 8.46 | 0.0001 |

Table 8. Regression Analysis for Natural Gas and L.P. Engines, Industrial

Dependent Variable: Price

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F VALUE | PROB>F |
|---|---|---|---|---|---|
| MODEL | 1 | 1676174383 | 1676174383 | 38.94 | 0.0002 |
| ERROR | 8 | 344401377 | 43050172 | | |
| C TOTAL | 9 | 2020575760 | | | |
| ROOT MSE | | 6561.26 | R-SQUARE | 0.8296 | |
| DEP MEAN | | 27598.00 | | | |
| C.V. | | 23.77 | | | |

| VARIABLE | DF | PARAMETER ESTIMATE | STANDARD ERROR | T FOR HO: PARAMETER=0 | PROB > \|T\| |
|---|---|---|---|---|---|
| INTERCEP | 1 | -7928.77 | 6059.83 | -1.31 | 0.2271 |
| HP | 1 | 192.24 | 30.81 | 6.24 | 0.0002 |

Table 9. Regression Analysis for Natural Gas and L.P. Engines, Automotive

Dependent Variable: Price

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F VALUE | PROB>F |
|---|---|---|---|---|---|
| MODEL | 1 | 41212613 | 41212613 | 114.67 | 0.0001 |
| ERROR | 8 | 2875237 | 359405 | | |
| C TOTAL | 9 | 44087851 | | | |
| ROOT MSE | | 599.50 | R-SQUARE | 0.9348 | |
| DEP MEAN | | 4224.90 | | | |
| C.V. | | 14.19 | | | |

| VARIABLE | DF | PARAMETER ESTIMATE | STANDARD ERROR | T FOR HO: PARAMETER=0 | PROB > \|T\| |
|---|---|---|---|---|---|
| INTERCEP | 1 | -945.13 | 518.69 | -1.82 | 0.1059 |
| HP | 1 | 56.32 | 5.26 | 10.71 | 0.0001 |

Table 10. Regression Analysis for Electric Motors

Dependent Variable: Price

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F VALUE | PROB>F |
|---|---|---|---|---|---|
| MODEL | 1 | 930166559 | 930166559 | 3760.83 | 0.0001 |
| ERROR | 27 | 6677920 | 247330 | | |
| C TOTAL | 28 | 936844479 | | | |

| | | | |
|---|---|---|---|
| ROOT MSE | 497.32 | R-SQUARE | 0.9929 |
| DEP MEAN | 7118.14 | | |
| C.V. | 6.987 | | |

| VARIABLE | DF | PARAMETER ESTIMATE | STANDARD ERROR | T FOR H0: PARAMETER=0 | PROB > \|T\| |
|---|---|---|---|---|---|
| INTERCEP | 1 | 1156.06 | 134.09 | 8.62 | 0.0001 |
| HP | 1 | 41.26 | 0.67 | 61.33 | 0.0001 |

Table 11. Gear Head Data

| HP | Price | HP | Price |
|---|---|---|---|
| 20 | 925 | 125 | 2100 |
| 40 | 1275 | 150 | 2770 |
| 60 | 1445 | 200 | 3060 |
| 80 | 1695 | 250 | 5000 |
| 100 | 1815 | 300 | 5700 |

Table 12. Regression Analysis for Gear Heads

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F VALUE | PROB>F |
|---|---|---|---|---|---|
| MODEL | 1 | 22159852 | 22159852 | 172.69 | 0.0001 |
| ERROR | 8 | 1026551 | 128319 | | |
| C TOTAL | 9 | 23186403 | | | |

| | | | |
|---|---|---|---|
| ROOT MSE | 358.21 | R-SQUARE | 0.9557 |
| DEP MEAN | 2578.50 | ADJ R-SQ | 0.9502 |
| C.V. | 13.89 | | |

| VARIABLE | DF | PARAMETER ESTIMATE | STANDARD ERROR | T FOR H0: PARAMETER=0 | PROB > \|T\| |
|---|---|---|---|---|---|
| INTERCEP | 1 | 331.63 | 205.10 | 1.617 | 0.1446 |
| HP | 1 | 16.96 | 1.29 | 13.14 | 0.0001 |

# ECONOMIC ANALYSIS OF IRRIGATION PUMPING PLANTS

by

Gary John Dvorak

B.S., University of Wisconsin-Madison, 1983

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AN ABSTRACT OF A MASTER'S REPORT

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## ABSTRACT


A computer model to estimate annual operating costs for irrigation systems, along with the evaluation of possible improvements to the pumping plant, has been developed. The primary reason for developing the model was to improve the methods used to estimate the annual operating costs and allow irrigators to economically evaluate alternative ways to reduce irrigation costs. Falling water tables in the Ogallala aquifer and the rising cost of energy have contributed to increasing pumping plant operating costs.

The model, entitled "Irrigation Cost Estimator and System Evaluator" (ICEASE), has been developed, to estimate annual pumping plant operating costs for irrigators. The model can also evaluate pump repair or replacement, the feasibility of switching power units from one fuel source to another, and indicate the effect of a falling water table and/or declining pump efficiency on annual operating costs.

All of the operating costs associated with the operation of the pumping plant are taken into account when estimating the annual operating costs. The annual operating costs are used in all of the evaluation procedures.

The model estimates pump efficiency, assuming the power unit operates at the Nebraska Standard. This allows the model to make an estimate of the brake and rated horsepower requirements, to estimate some annual operating costs and to estimate a new power unit and gear head cost, when switching power units.

In all of the evaluations, the model will estimate costs for a ten year period. It takes into consideration fuel inflation over this period if the user enters an estimate of the expected annual fuel inflation rate.

When the model evaluates pump repair or replacement, it determines the flow rate of the well that can be expected after repairs. Annual operating costs are then recalculated with the new flow rate and compared to the old annual operating costs. The model is capable of estimating the cost to repair or replace the pump, if the user doesn't have an estimate.

Pump repair or replacement is economical if the cost to repair or replace the pump doesn't exceed the present value of the ten year total savings estimated by the model.

To evaluate the feasibility of switching power units, the fuel consumption of the current system is converted to an equivalent amount of fuel for the proposed system. Using the proposed system's fuel consumption and fuel cost per unit, the annual operating cost are calculated, assuming operating conditions remain the same.

The ten year total savings is the difference between the sum of the annual operating costs of the two systems. If the present value of the total savings and salvage value exceeds the investment cost of the power unit, gear head and miscellaneous costs, the power unit switch is economical.

When determining the effect of a falling water table and/or declining pump efficiency on annual operating costs, the model uses the procedure to estimate a new flow rate for the system. The new flow rate is estimated for ten consecutive years. The annual operating costs are also estimated for ten years, to show the user how operating costs will increase as the water table falls and/or the pump efficiency declines.