# IMPLICATION OF IMPROVED IRRIGATION PUMPING EFFICIENCY FOR FARMER PROFIT AND ENERGY USE

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Irrigated crop production on the Texas High Plains accounts for more than 80 percent of the value of total crop production in the region. Total economic activity associated with crop production was estimated to be $2.18 billion in 1967 [11]. Because of the importance and contribution of irrigation to the regional economy, any significant adjustments in irrigation create repercussions throughout the region.

The price of natural gas within Texas is not subject to interstate regulations. Since 1973, dramatic increases in natural gas price (from $0.50 to more than $2.00/mcf) in the state have caused considerable concern about the economic feasibility of continued irrigation. Research was conducted to estimate the effect of continuing natural gas price increases on irrigation [8].

In addition, the recent price increases for natural gas in conjunction with relatively low crop prices have accelerated research directed to reducing costs of production. For example, emphasis has been placed on modified crop production systems which seek to improve the energy efficiency of irrigated production by reducing the usage of energy inputs. However, energy requirements can be reduced by many other methods, including reducing the amount of water pumped, improving irrigation and pumping plant efficiency, and lowering the pressure requirements. Many of these opportunities have been addressed previously [1, 4, 5, 9, 15].

One method which has received much research attention is the improvement of pump efficiency. Pump efficiency has an inverse relationship with the amount of fuel required to pump an acre-foot of water and will generally decline after a period of time. Periodic replacement and/or repair of the pump equipment can maintain a relatively high level of pump efficiency. Current average pump efficiency on the Texas High Plains can be vastly improved. However, the benefit to farmers and the effect on energy use of improved efficiency need to be quantified. The purpose of this article is to report estimation of the effect of improved well and pump efficiency on present value of returns to groundwater over a 20-year period.

## STUDY AREA

The Texas High Plains is a fairly level, semi-arid region on the Southern Great Plains encompassing about 35,000 square miles. More than 6 million acres in this region are irrigated from the Ogallala aquifer; 1.74 million acres are sprinkler irrigated and the remainder are under furrow systems. The exhaustible nature of the aquifer and the sensitivity of irrigation agriculture to increases in energy costs contribute to the need to determine the possible benefits of greater efficiency in the pumping and use of irrigation water.

Average pump efficiency on the Texas High Plains is about 52 percent [17]. Improving pump and engine efficiencies could result in a 41 percent reduction in energy used for irrigation in Texas [9]. The savings would be about 41.6 million mcf (thousand cubic feet) of natural gas on the Texas High Plains alone. Fischbach [3] indicates that improving pump efficiencies would result in an annual savings of $3.1 million in Nebraska. Such studies suggest that improved efficiency may result in benefits to farmers through increased profits and to society as a whole from the reduction in energy usage and production costs.

## METHOD

A linear programming model was applied to maximize yearly net returns for a 640-acre farm on the Texas High Plains. The model includes the major crops in the area (corn, grain, sorghum, soybeans, cotton, and wheat) under all applicable dryland and irrigation options. In addition, a stocker alternative for small grain grazing is included. A total of 59 production activities are represented.

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Crop enterprise budgets developed by area economists of the Texas Agricultural Extension Service for the 1978 [2] crop year are the basis for developing the model coefficients. Yield data for alternative irrigation levels are taken from statistical production functions estimated for the area [13, 14]. Target prices for 1978 are used for all crops.

Irrigation applications and water availability are divided into 10 critical periods. The upper limits of water availability are established with the maximum amount that could be pumped in each time period, based on well yield in gallons per minute and average number of days in each period not used for well repairs and maintenance.

The model includes a cash flow section separated into two-month periods. Borrowed money is automatically repaid at the end of a two-month period, then reborrowed if necessary. An opportunity to invest excess capital also is provided. Labor usage is separated into two-month periods for compatibility with the cash flow section and is charged on an hourly basis. Fixed costs for machinery and all irrigation equipment, including pumps and the distribution system, are also part of the analysis. Including all rows used for transfers and accounting, the model has 142 rows, 20 of which are limited by a right-side value.

For the temporal analysis used in this study, the LP model is established in a recursive framework. An extension of linear programming is utilized which consolidates a FORTRAN program with the LP model. The FORTRAN model functions as a subroutine which modifies the LP model to reflect the farm situation for the following year. This updating procedure performs the following steps.

1. Calculates the decrease in saturated thickness[1] of the aquifer and associated increase in pumping lift based on the amount of water withdrawn in the previous year.
2. Calculates the change in well yield, if any, based on the change in saturated thickness.
3. Calculates the amount of irrigation fuel required to pump an acre-foot of water based on the adjusted pumping lift.
4. Calculates the maximum acre-feet of water which can be pumped in each time period based on the adjusted well yield.
5. Calculates the present value of net returns to the farm plan.
6. Modifies the LP tableau with the new irrigation water upper limits and irrigation fuel requirements.

The following equations are used in the FORTRAN program (sources of equations or data used to develop equations are given in brackets where applicable). All coefficients relate to the current time period unless otherwise denoted by subscript. Decline in saturated thickness of the aquifer is represented by

$$D = W_{t-1}/(.15 * CA) \tag{1}$$

where

$D$ = decline in static water level of the aquifer
$W_{t-1}$ = acre-feet of water pumped in the previous year
$CA$ = acres contributing to the aquifer (including noncultivated acres and dryland).[2]

Well yield [6] is represented by

$$GPM = GPM_0 \qquad \text{if } ST/250 \geq .83667 \tag{2}$$

$$GPM = 1.14 * (ST/250)^{0.71} * GPM_0 \qquad \text{if } ST/250 < .83667 \tag{3}$$

where

$GPM$ = current period well yield in gallons per minute
$GPM_0$ = original or maximum well yield based on the size of the well
$ST$ = saturated thickness of the aquifer in the current time period.

The amount of natural gas required to pump water [7] is given by

$$NG = (.022L + .051\,PSI)/PE \tag{4}$$

where

$NG$ = natural gas required to pump one acre-foot of water
$PSI$ = water pressure required, in pounds per square inch
$L$ = pumping lift
$PE$ = pump efficiency.

Water availability by critical time period is established by

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[1] Saturated thickness refers to feet of water-bearing sand. The specific yield of the Ogallala is about 15 percent, or 100 inches of saturated thickness yields 15 inches of water.

[2] Acres contributing irrigation water are expected to exceed acres irrigated because all acres cannot be cropped; i.e., there is water available beneath land used for turn rows, roads, and homesteads.

(5) $$M = .0044 * GPM * T$$

where

M = maximum acre-feet of water that can be pumped in a specified period by one well
T = days available for pumping in a specified time period.

The focus of this analysis is irrigation pump efficiency. An irrigation pump that is appropriately designed for the aquifer will have a relatively high efficiency for many years except where excessive damage from sand or air bubbles occurs. Many irrigation pumps on the Texas High Plains have been operating 15 years or more and have not been tested for efficiency during that time. The inexpensive energy available during that time period provided very little economic incentive to design highly efficient pumps or to test old pumps for efficiency. Reductions in pumping costs could not have been expected to offset the cost of attaining improved efficiency. Consequently, average pump efficiency is 52 percent for the High Plains [7].

To achieve and maintain a high pump efficiency, the pump is designed on the basis of well and aquifer characteristics. In terms of an engineering efficiency curve, pump efficiency is specified to fall on the right side of the curve — that is, as water is pumped and the aquifer begins declining, well pump efficiency will actually increase for a period, reach a maximum, and then begin to decrease. Thus, if initial pump efficiency is 75 percent, the efficiency will increase into the 80 percent range and then begin to decline [10].

The value of improved pump efficiency was estimated for two distribution systems, center pivot sprinkler and furrow or gravity flow irrigation, and for each of two beginning water situations: good water, where the farm has four 500-foot irrigation wells each having a beginning saturated thickness equal to 250 feet, and poor water, where ten 150-foot wells are available with saturated thickness of 75 feet. In each case, two applications of the model were made; a base run using an average pump efficiency of 50 percent and another run using an improved efficiency of 75 percent. The 75 percent efficiency would be achieved by correctly designing the pump and making timely repairs. The expected cost to improve the efficiency for an average well in the region is $3,000 [10].

In each application the model was applied recursively over 20 years or until physical or economic exhaustion of the water supply was reached. Physical exhaustion is defined as the point at which the next year's planned irrigation would diminish saturated thickness to less than 10 feet; economic exhaustion occurs when returns to water are less than zero.

To estimate returns to the groundwater resource, it is first necessary to establish returns to land and management. Returns were maximized by considering only dryland crop alternatives. These annual dryland net returns ($17,870) were assumed to be a constant over 20 years. Thus, returns to land and management were defined as the discounted stream of dryland net returns over the 20-year planning horizon.[3]

## RESULTS

The purpose of the study was to evaluate the economic implications of improved pumping efficiency. The recursive linear programming model permitted an annual and a temporal analysis. Table 1 illustrates the detailed results from one specific analysis. Output provided with each analysis includes the first and last year of the analysis, aquifer characteristics, energy requirements, cropping patterns, and irrigation MVP's. In this case, two computer runs were combined to give a comparison between average and improved efficiency for a furrow system with poor water. Results of this type summarized for all analyses are presented in Table 2.

### Sprinkler Irrigation

Improved efficiency has very little physical effect on sprinkler irrigation, the only difference being with good water. One post-plant irrigation is eliminated in the last three years under average efficiency, resulting in slightly higher saturated thickness and well yield in comparison with improved efficiency. In each case, all acres are planted in grain sorghum, with a minimum of 106.67 acres dryland representing corners of the field which cannot be reached by a center pivot system. With poor water, an additional 105 acres have been diverted to dryland by the time exhaustion of the water supply occurs.

The economics effects of improved efficiency, however, are dramatic. The decrease in fuel costs due to the decreased natural gas requirements results in increased present value of returns of $162,793 for good water and $61,940 for poor water. Even after subtraction of the estimated per-well cost of achieving the improved efficiency, the increase in value, on a per-acre basis, would be $235 with good water and $50 with poor water.

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[3] A discount rate of 7.3 percent was assumed. It was adjusted for an annual inflation rate over all costs and prices of 5.7 percent [12].

## TABLE 1. A DETAILED COMPARISON OF TEMPORAL EFFECTS OF IMPROVED PUMP EFFICIENCY FOR A 640-ACRE FARM WITH 75 FEET OF SATURATED THICKNESS UNDER FURROW IRRIGATION

| Item | Unit | Pump Efficiency | | | |
|---|---|---|---|---|---|
| | | 50 percent | | 75 percent | |
| | | Year 1 | Year 12 | Year 1 | Year 12 |
| Saturated Thickness | Feet | 69.64 | 12.81 | 69.57 | 12.52 |
| Depth to Water | Feet | 80.36 | 137.19 | 80.43 | 137.48 |
| Pumping Energy | | | | | |
| Natural Gas-Sprinkler Irrig. | MCF/AF | 12.68 | 15.18 | 8.45 | 10.13 |
| Natural Gas-Furrow Irrig. | MCF/AF | 4.55 | 7.05 | 3.04 | 4.71 |
| Electricity-Sprinkler Irrig. | KWH/AF | 608.36 | 728.28 | 608.51 | 728.90 |
| Electricity-Furrow Irrig. | KWH/AF | 218.35 | 338.28 | 218.50 | 338.89 |
| Well Yield | GPM | 368.03 | 110.64 | 367.76 | 108.85 |
| Net Returns | $ | 42041.91 | 30974.22 | 44141.07 | 30693.24 |
| Returns to Water | $ | 24171.91 | 13104.22 | 26271.07 | 12823.24 |
| Total Acres Dryland | Acres | 171.65 | 268.92 | 155.74 | 274.36 |
| Cotton | Acres | 0.0 | 0.0 | 0.0 | 0.0 |
| Grain Sorghum | Acres | 0.0 | 7.80 | 0.0 | 27.07 |
| Wheat, Grain Only | Acres | 0.0 | 0.0 | 0.0 | 0.0 |
| Wheat, Grazing | Acres | 171.65 | 261.11 | 155.74 | 247.29 |
| Total Acres Furrow Irrigation | Acres | 468.35 | 371.08 | 475.25 | 365.64 |
| Corn | Acres | 0.0 | 0.0 | 0.0 | 0.0 |
| Cotton | Acres | 455.26 | 269.88 | 457.91 | 265.92 |
| Grain Sorghum | Acres | 3.44 | 0.0 | 0.0 | 0.0 |
| Soybeans | Acres | 0.0 | 101.20 | 0.0 | 99.72 |
| Wheat, Grain Only | Acres | 0.0 | 0.0 | 0.0 | 0.0 |
| Wheat, Grazing | Acres | 9.64 | 0.0 | 17.34 | 0.0 |
| Light Feeders | Head | 0.0 | 61.32 | 0.0 | 65.70 |
| Heavy Feeders | Head | 0.0 | 0.0 | 0.0 | 0.0 |
| Marginal Value Product | | | | | |
| Period 1 Water | $/AF | 0.0 | 0.0 | 0.0 | 0.0 |
| Period 2 Water | $/AF | 0.0 | 0.0 | 0.0 | 0.0 |
| Period 3 Water | $/AF | 0.0 | 63.26 | 0.0 | 63.24 |
| Period 4 Water | $/AF | 0.0 | 0.0 | 0.0 | 0.0 |
| Period 5 Water | $/AF | 0.0 | 0.0 | 0.0 | 0.0 |
| Period 6 Water | $/AF | 0.0 | 31.90 | 0.0 | 41.23 |
| Period 7 Water | $/AF | 0.0 | 11.83 | 0.0 | 2.42 |
| Period 8 Water | $/AF | 0.0 | 0.0 | 0.0 | 0.0 |
| Period 9 Water | $/AF | 0.0 | 0.0 | 0.0 | 0.0 |
| Period 10 Water | $/AF | 0.0 | 0.0 | 0.0 | 0.0 |

## TABLE 2. ECONOMIC AND PHYSICAL IMPLICATIONS OF IMPROVED PUMP EFFICIENCY FOR TWO WATER RESOURCE SITUATIONS AND FOR SPRINKLER AND FURROW DISTRIBUTION SYSTEMS ON A 640-ACRE TEXAS HIGH PLAINS FARM

| Item | | Good Water [a] | | | Poor Water[b] | | |
|---|---|---|---|---|---|---|---|
| | Unit | 75% efficiency | 50% efficiency | Difference | 75% efficiency | 50% efficiency | Difference |
| Sprinkler Irrigation: | | | | | | | |
| Ending Saturated Thickness | Feet | 153.4 | 156.3 | -2.9 | 11.9 | 11.9 | 0 |
| Ending Well Yield | GPM | 644.7 | 653.3 | -8.6 | 105.4 | 105.4 | 0 |
| Natural Gas Use: | | | | | | | |
| Beginning | MCF/AF | 13.4 | 20.1 | -6.7 | 8.3 | 12.4 | -4. |
| Ending | MCF/AF | 16.1 | 24.1 | -8.0 | 10.1 | 15.1 | -5. |
| Irrigated Acres: | | | | | | | |
| Beginning | Acres | 533.3 | 533.3 | 0 | 533.3 | 533.3 | 0 |
| Ending | Acres | 533.3 | 533.3 | 0 | 428.1 | 428.1 | 0 |
| Years of Analysis | No. | 20 | 20 | 0 | 14 | 14 | 0 |
| Present Value of: | | | | | | | |
| Net Returns | $ | 780017 | 617224 | 162793 | 647576 | 585636 | 61940 |
| Returns to Water | $ | 473209 | 310416 | | 409130 | 347190 | |
| Furrow Irrigation: | | | | | | | |
| Ending Saturated Thickness | Feet | 144.0 | 167.0 | -23.0 | 12.5 | 12.8 | -.3 |
| Ending Well Yield | GPM | 616.4 | 684.7 | -68.3 | 108.9 | 110.6 | -1.7 |
| Natural Gas Use: | | | | | | | |
| Beginning | MCF/AF | 8.0 | 12.0 | - 4.0 | 2.9 | 4.3 | -1.4 |
| Ending | MCF/AF | 11.0 | 16.5 | - 5.5 | 4.6 | 6.9 | -2.3 |
| Irrigated Acres: | | | | | | | |
| Beginning | Acres | 460.6 | 458.4 | 2.2 | 475.3 | 468.4 | 6.9 |
| Ending | Acres | 460.6 | 458.4 | 2.2 | 365.6 | 371.1 | -5.5 |
| Years of Analysis | No. | 20 | 20 | 0 | 12 | 12 | 0 |
| Present Value of: | | | | | | | |
| Net Returns | $ | 619690 | 525343 | 94347 | 479869 | 454874 | 24995 |
| Returns to Water | $ | 312882 | 218535 | | 270225 | 245230 | |

[a] Good water is represented by 250 feet of saturated thickness and 250 feet of lift.

[b] Poor water is represented by 75 feet of saturated thickness and 75 feet of lift.

### Furrow Irrigation

Furrow irrigation is associated with greater labor requirements; hence, improved efficiency results in several physical differences for the farm using a furrow system. With good water, cropping patterns are constant over time, but adjust slightly when efficiency is improved. With average efficiency, 14 acres of dryland grain sorghum, 168 acres of dryland wheat with grazing, and 458 acres of irrigated cotton are produced. When efficiency is improved, a change is made to 179 acres of dryland wheat with grazing, 453 acres of irrigated cotton, and 8 acres of irrigated grain sorghum. In addition, irrigation levels are increased, resulting in a larger (23 feet) decline of the aquifer.

The poor water situation results in great cropping pattern changes, both over time and with improved efficiency. Continual pumping of limited groundwater rapidly changes the water resource restriction, thus causing relatively rapid adjustments by the farmer. Appropriate adjustments in cropping patterns are important to maintaining economic viability of the firm.

Cropping pattern changes for the poor water situation under furrow irrigation are shown in detail in Table 1. In general, by the time exhaustion of the groundwater is reached (after 12 years), production of cotton and wheat with grazing under irrigation have decreased, dryland grain sorghum and wheat with grazing have increased, and irrigated soybeans and light feeder steers have entered the solution.

The present value of returns increases with improved efficiency ($97,347 and $24,995, respectively, with good and poor water), although not as dramatically as with the sprinkler system. The net per-acre value of the improvement in efficiency is $129 with good water. This increase is slightly offset by the comparatively large decrease in saturated thickness. However, after the $3,000 estimated per-well cost is subtracted, the increase in returns disappears in the poor water situation, indicating that, in this case, improved efficiency would not be economically feasible.

On a general basis, energy savings can be projected for the High Plains area. The survey by Ulich [17] indicated that 26 percent of the irrigation pumps on the High Plains were operating at less than 50 percent efficiency. Another report [16] indicated that, in 1976, the total amount of natural gas used for irrigation pumping on the High Plains was 101,362,000 mcf. If 26 percent of this total were used by the pumps operating at less than 50 percent efficiency, the annual fuel savings from improved efficiency would be nearly 8.7 million mcf. Even if as little as 10 percent of the fuel were used by inefficient pumps, the savings would amount to more than 3.3 million mcf. This range of energy savings of 3.3 to 8.7 million mcf is based on improved efficiency of only those pumps operating at less than 50 percent efficiency. Even greater energy savings would be possible if those pumps operating at greater than 50 percent efficiency were improved. With current natural gas prices approaching $2 per mcf, even conservative estimates of fuel savings from improved efficiency indicate substantial economic benefits.

## CONCLUSIONS

The average efficiency of an irrigation pump on the Texas High Plains is well below the technically achievable level. The results presented here indicate that, with the exception of a furrow irrigation system with low beginning saturated thickness, it is profitable to the individual producer to make the expenditure to improve pump efficiency. In addition, improved efficiency results in energy savings which could favorably affect society as a whole.

This study is based on an application of a linear programming model using 1978 target prices and 1978 input prices. Crop price effects of changing output are not addressed. The opportunity from improved pumping efficiency is demonstrated to be large. Thus, there is a need to define better the optimal timing of improvements in the pumping plant which increase efficiency, as well as the cost of these adjustments.

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