EVALUATION OF IRRIGATION PUMPING PLANT EFFICIENCIES AND COSTS IN THE HIGH PLAINS OF EASTERN COLORADO

by

D. L. Miles

and

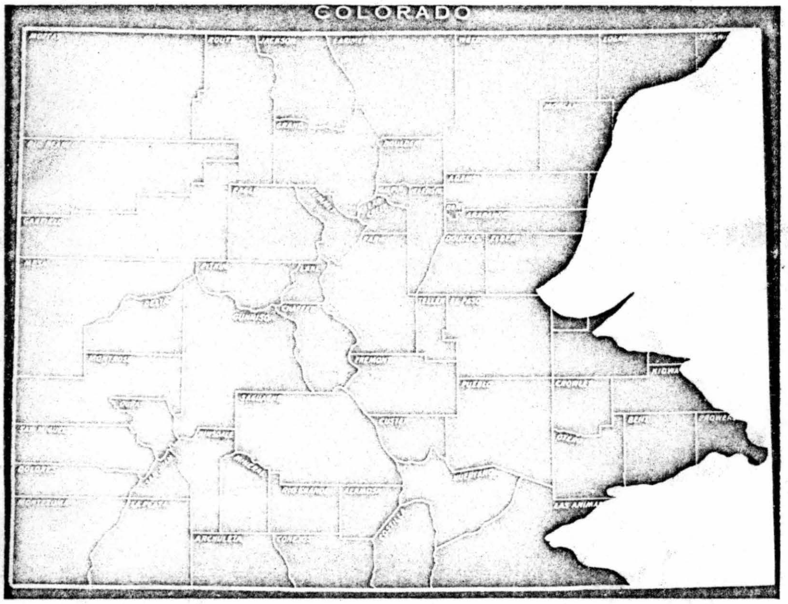
R. L. Longenbaugh

Colorado State University Experimentstation
Fort Collins, Colorado

December 1968

CER68-69RLL-DLM43

Evaluation of Irrigation Pumping Plant Efficiencies and Costs in the High Plains of



EASTERN COLORADO

COLORADO STATE UNIVERSITY EXPERIMENT STATION
FORT COLLINS, COLORADO

TABLE OF CONTENTS

ACKNOWLEDGMENTS

The authors wish to acknowledge the financial assistance provided by Plateau Natural Gas Company, Kansas-Nebraska Gas Company, Y-W Electric Association, Highline Electric Association, K-C Electric Association and the Colorado Farm Power Council. Suggestions and technical assistance provided by personnel of these power and fuel suppliers was greatly appreciated.

The success of the efficiency testing program was largely due to the excellent cooperation of individual farmers. The assistance of County Extension Agents in scheduling the tests is also acknowledged.

Colorado State University personnel serving on the project included R. A. Longenbaugh, who initiated the study and supervised efficiency tests; Richard Turner, field engineer; F. E. Brown, Extension Irrigation Specialist, since retired; and D. L. Miles, Extension Irrigation Engineer, who analyzed much of the data for the report.

2.5M 12-68

December 1968

EVALUATION OF IRRIGATION PUMPING PLANT EFFICIENCIES AND COSTS IN THE HIGH PLAINS OF EASTERN COLORADO

by

D. L. Miles and R. L. Longenbaugh*

INTRODUCTION

More than a century ago several of the early irrigation developers dreamed of diverting streams from the Rocky Mountains to irrigate vast acreages in the High Plains of Eastern Colorado. However, Those dreams faded when it was discovered that the surface water supplies were not adequate for even the easily accessible portions of the South Platte and Arkansas River Valleys Local ground water remains the primary water source for the nearly 12,000 square miles of land in the High Plains of Eastern Colorado.

This area is divided into two parts by the Arkansas River Basin. The Northern High Plains includes all of Phillips, Yuma and Kit Carson Counties and parts of Sedgwick, Logan, Washington, Lincoln, Cheyenne, Kiowa, and Powers Counties. Nearly all of the ground water used in this area comes from the Ogallala formation, consisting of beds of clay, silt, sand and gravel mixed and cemented together in varying degrees. The Southern High Plains includes most of Baca County and a portion of Southeastern Powers County. Most irrigation wells in the Southern High Plains obtain water from the Ogallala formation, but many also tap the lower lying Dakota and Cheyenne sandstones. (2)**

In the period of 1908-1910, interest developed in attempts to use large windmills to pump irrigation water from the Ogallala formation in Western Kansas. Several windmills were spaced around small reservoirs which provided temporary storage for the water. Wind was considered to be free power, but the giant windmills proved too costly to construct and maintain.

Soon crude turbine pumps were available, but they were quite inefficient and early internal combustion engines were too expensive to operate. Pumping equipment was improved greatly over the next thirty years, but very few wells were drilled. Few farmers were convinced that irrigation from deep wells was profitable.

Good prices and favorable weather encouraged a large increase in dryland crop acreage in the High Plains after WW II. A few irrigation wells were drilled but by 1950 there were only about 180 irrigation wells in the Northern High Plains and about 30 in the Southern High Plains. Dry weather in the mid-1950's encouraged more irrigation development. By the end of 1960, the number of wells had increased to about 500 in the Northern High Plains and over 200 in the Southern High Plains.

Most pumping plants were powered by gasoline, diesel or propane engines. The introduction of natural gas in Baca County by Plateau Natural Gas Company triggered acceleration in irrigation development. Plateau expanded into Kit Carson County in 1963 and 1964. During the same period, the rural electric associations were also building new lines and supplying low-cost power in much of Yuma, Phillips, Washington and Kit Carson Counties. Irrigation development boomed. As of January 1, 1968, there were approximately 2,000 irrigation wells in the Northern High Plains and over 700 in the Southern High Plains.

---

*Extension Irrigation Engineer, Agricultural Engineering Department, CSU; and Assistant Professor, Civil Engineering Department, CSU respectively.

**Numbers in ( ) are References Cited.

One of the major costs of irrigation farming in the study area is the cost of obtaining the water. Inefficient pumping plants can greatly increase this cost and be the difference between profit and loss on a marginal farming operation. Taken collectively, excessive pumping costs in an area can have a substantial effect on that area's economy.

As rapid irrigation development got under way, several power suppliers, well drillers, the CSU Extension Irrigation Specialist and others became concerned about the efficiencies of many of these deep well pumping plants. Irrigation clinics were held by the Colorado State University Extension Service during the Winter of 1962-63. At these meetings, information on obtaining a good irrigation well and conducting successful irrigation enterprises was presented to the farmers, land owners, bankers and power suppliers. These clinics brought out considerable interest in irrigation pumping plants.

The need for pumping plant efficiency data became generally recognized, and with the cooperation and financial support of local natural gas and electric power suppliers, a pumping plant efficiency study was initiated in August of 1964. The principle objectives were to measure pumping plant efficiencies and to gather pumping cost data on the plants tested.

PROCEDURE

Farmers desiring to have their pumping plants tested contacted their county agent who scheduled the tests in an order which resulted in a minimum of travel distance between tests. The applicants were given a set of record forms and asked to furnish all information which they had available on their pumping plant and to keep records on its operation during that pumping year. Included were well depth, driller's name, date drilled, well specifications, well costs, power unit costs, pump make and model, repairs, maintenance, labor, hours of operation, crop acreages irrigated and other relevant data. When the field test personnel arrived to test the pumping plant, they checked and recorded all available information on the pumping plant.

Pumping lifts or elevation head were measured by lowering an electrical sounder in the well until it contacted the water. Pressure head was measured by use of a pressure gauge in the discharge line. Friction head or friction losses in the pump column and discharge head were taken from manufacturer's tables. Elevation head, friction head and pressure head were then added to determine total operating head.

On most tests the discharge was measured with a twelve-inch Sparling propeller meter. The meter was calibrated to record the total number of gallons pumped. A stop watch was used to time the flow. These measurements were used to calculate the discharge in gallons per minute. Other measuring methods were used when necessary.

Rates of use of electrical power and natural gas were measured by timing meters with a stop watch. Equipment was not available for precise measurement of fuel use by propane and diesel engines, so it was estimated from the operator's records. As a result, the efficiency measurements for plants using these fuels were much less accurate than for electrical and natural gas plants.

Water horsepower was calculated using the total operating head and the discharge. Input horsepower was determined from the fuel or power consumption data. Efficiency was calculated as water horsepower divided by input horsepower multiplied by 100 to express it as a percentage.

MEANING OF EFFICIENCY DATA

Efficiency figures presented in this report are the percentages of the potential energy in power or fuel which is transformed into lifting water and putting it under pressure. An efficiency percentage for one type of power source may be compared with other efficiencies for the same power source or a standard for that power source, but they should never be compared with the efficiency figures for another type of power source.

DESIRABLE LEVELS OF EFFICIENCY

Each pump can operate at near peak efficiency only under a limited range of head-discharge conditions. This is also true of power units. Since it is not practical for each manufacturer to make a model for each set of conditions, most pumps and power unit applications will fall between the peak efficiency points of two models. Also, different models have different peak efficiencies. Therefore, it may be possible to fit one particular well with a pumping plant which operates at a higher efficiency than is possible for another well which has different characteristics.

However, nearly all wells can be fit with pumping plants which can operate at reasonably high efficiency. A theoretical analysis by combining performance data on pumping plant components indicates that if all equipment is properly selected and operated, new electric plants should have efficiencies of 64-71% with an average of 66.4%, and new natural gas plants should have efficiencies of 15.0-17.4% with an average of 15.8%. Wear would be expected to reduce these efficiencies, so slightly lower efficiencies and a wider range of efficiencies would be expected in the field. As discussed in more detail later in this report, the measured efficiencies of well-designed electrical plants ranged from 60.5% to 70.0% with an average of 65.6%. The measured efficiencies of well-designed natural gas plants ranged from 14.4% to 17.1% with an average of 15.6%. Therefore, the theoretical efficiencies appear to be reasonable goals for pumping plant design.

MEASURED EFFICIENCIES

A total of 302 plants were tested. Of these, 132 were powered by natural gas engines, 125 by electric motors, 42 by L.P. gas engines, and 3 by diesel engines.

Physical features of some wells and pumping plants prevented accurate measurement of pumping levels of other necessary information. Tests on such plants were omitted from the summaries. Also included are a few wells outside the study area, which were tested to obtain special data for comparison purposes, but they are not included in the summaries.

Table 1

Summary of Pumping Plant Efficiency Tests by Counties

	Electric Powered		Natural Gas Powered	
County	Plants Tested	Ave. Effic.	Plants Tested	Ave. Effic.
Sedgwick	6	52.8%	2	11.2%
Phillips	17	59.0%	4	13.6%
Washington	8	44.6%	3	15.6%
Yuma	22	60.0%	10	13.9%
Kit Carson	14	52.3%	57	11.6%
Northern High Plains	67	55.7%	76	12.2%
Baca	0	--	42	10.2%
Prowers	0	--	11	10.8%
Southern High Plains	0	--	53	10.5%

It is apparent from Table 1 that the average efficiencies were generally much lower than should be expected from good plants. The fact that measured efficiencies varied greatly from county to county suggests that differences in type of water bearing formations, in safe well yields or in pumping rates might be responsible. However, analysis of the data did not indicate that such relationships existed. Therefore, designs of individual pumping plants were examined to determine the causes of low efficiency.

Very few natural gas powered pumping plants were found to be operating within the efficiency range which should be expected from well-designed plants. Among electric powered installations, a larger percent were reasonably efficient, but even so, many electric plants were operating at very low efficiencies. The average efficiencies and the efficiency ranges for both natural gas and electricity were similar to those measured in previous studies in Nebraska and Kansas.(3,6)

DIAGNOSIS OF PERFORMANCE PROBLEMS

To determine the causes of low efficiency, it is necessary to have complete information on the pumping plant. If the number and model of pump bowls were not stamped on the discharge head or if pump performance did not agree with the nameplate, correct bowl model numbers were obtained from the driller or pump manufacturer when possible. Pump performance was compared with the manufacturer's performance curves. Pump characteristics were compared with well characteristics to see if the pump fitted the well. Specifications for power units and other components were compared with requirements to see how well they had been selected.

The causes of low efficiency were found to be among the following:

1. Inadequate well testing and knowledge of well characteristics.
2. Incorrect pump selection.
3. Changes in pumping requirements because of altered irrigation system.
4. Incorrect engine selection.
5. Improper well construction.
6. Inadequate maintenance pumping plant.
7. Improper operating procedures.

Discussion of Table 2:

In Table 2, more than one cause of low efficiency may be combined into one classification. For example, pumps may be poorly fitted for a well because of inadequate well testing, incorrect pump selection, changes in the irrigation system, water table declines or a combination of these factors. The cause of inefficiency of an individual plant was determined if the data were adequate, but because of interaction of causes, the data are presented in general classifications. Also, the data are classified by what is believed to be the principal cause of low efficiency for each pumping plant. For example, some of the plants listed as having pumps that are poorly fitted to the wells also have incorrectly selected power units.

Well Testing:

About 30% of both the electric and natural gas wells included in Table 2 are listed as having poorly fitted pumps. Inadequate well testing was found to be at least partially responsible for most of these. This was particularly true in Kit Carson County where the usual practice was to use very short well tests, even though the characteristics of the water bearing formation make such well tests very unreliable. In Kit Carson County, it was found that about 55% of all wells tested could not safely yield as much as 80% of the design capacity of the pumps which were installed, and 14% could not safely yield 50% of the design capacity of the pump.

Several of the pumping plants tested had been selected without the benefit of a well test to determine the yield and accompanying drawdown. In some instances, the farmer's new pump was used to develop the well, resulting in severe wear on the new pump due to removal of sand and drilling mud in the initial discharges. Wells should never be developed with the pump that is to be used for irrigation.

Table 2

Diagnosis of Pumping Plants in Kit Carson, Yuma, Washington, and Phillips Counties for which Adequate Information was Available

	Natural Gas		Electric	
	Number	Ave. Eff.	Number	Ave. Effi.
All pumping plants	68	12.0%	34	58.2%
Pumps poorly fitted to wells	21	11.2%	10	45.4%
Reasonably well fitted pumps	47	12.3%	24	63.5%
Tests indicated pump performance much below manufacturer's specifications (likely caused by severe impeller wear or excessive impeller clearance)	21	10.4%	3	54.6%
Pumps performing at near manufacturer's specifications	26	13.8%	21	64.8%
Pumps fitted but engines or motors incorrectly selected	16	12.7%	7	63.1%
Pumps and engines or motors properly applied	10	15.6%	14	65.6%

Test pumping should not be begun until the well has been fully developed. The pump and power unit used for testing should be capable of pumping the well at a yield of at least 25% more than the desired pumping rate. The well should be pumped at a rate greater than the desired discharge for sufficient lengths of time (often 24 hours or longer) to establish a fairly steady pumping level. Measurements of discharge and drawdown should be made at this pumping rate, at near the desired discharge and at lower pumping rates to obtain the data needed for the proper selection of the pump and power unit. Recommended procedures for well tests can be obtained from County Extension offices. Good well tests cost more, but the results of this study indicate that they are worth the cost.

Pump Selection:

Incorrect pump selection was also a major cause of low efficiency. In many instances, it appeared to be a result of lack of understanding of proper pump selection procedures by those making pump selections. Another problem is that although wells in the study area tend to decrease in capacity over time, some pump manufacturers have advised installers to use pump selection procedures which fit conditions in areas where well yields increase with time. Also, it was found that some well installers attempted to fit all wells with only a very limited number of pump models.

It appeared that poor pump selection was an even more serious problem in those pumping plants which are not included in Table 2. Adequate data was not available to make full analysis possible, but the test results indicated a tendency for suppliers who were careless in selecting pumps to also provide customers with inadequate records on pumping plant specifications.

Combined sprinkler and gravity irrigation:

Attempts to design pumping plants for alternate sprinkler and gravity irrigation resulted in very low efficiency. Pumps are designed to operate most efficiently at a single discharge-head point. Even very minor changes in operating conditions can cause serious reductions in efficiency of some pump models. However, most pumps that are used for irrigation will operate at acceptable efficiency if the selection is close enough to result in a discharge within ±20% of the best efficiency point. Dual purpose use requires great deviation from the head-discharge relationships at best efficiency point. Therefore, the use of a single pump for alternate sprinkler and gravity irrigation should not be considered. If it is necessary to use a single well for both purposes, the pumping plant should be designed for gravity irrigation and a booster pump should be used to provide pressure for sprinkler operation.

Irrigation system changes:

Changes in irrigation systems involving increased pumping head cause lower efficiency and result in reduced discharges. Some of the pumping plants in the study had been designed for open discharge operation, but are now used with pipe distribution systems. Others were pumping water through added pipe and/or to a higher elevation than was allowed for in their design. If it is expected that the acreage to be irrigated will increase, that pipe is to be added to the system or that other changes will be made, these changes should be considered in the initial pump selection.

Power unit selection:

Incorrect power unit selection is another major cause of low efficiency. Table 2 indicates that this consideration is much more important for engines than for electric motors. While the efficiency of electric motors does not vary greatly with loading, it should be noted that overloaded motors have shorter lives, are less dependable and are more expensive to maintain. On the other hand, because of graduated energy costs, underloaded motors increase the average cost per kilowatt of power used. Overloaded motors were considered to be those having a power input of more than 0.87 kw per nameplate horsepower (105% full load). Underloaded motors were considered to be those with a power input of less than 0.65 kw per nameplate horsepower (75% full load).

Incorrect engine selection was a major cause of low efficiencies among the natural gas pumping plants. A few engines were found to be too large, but it was found that the majority of all natural gas engines tested were overloaded (exceeded the loading recommended in the following paragraph). Many of the internal combustion plants in this study were so overloaded that they could not drive the pump at its rated speed, and as a result, the discharge was low and efficiency reduced. Farmers with inadequate water to supply their crops during critical periods found that incorrect engine selection cost them crop yield reductions in addition to higher water costs as a result of pumping plant inefficiency. Recent observation indicates that more of the power units currently being installed are adequate in size in spite of the higher initial cost.

In selecting natural gas engines for pumping in the Colorado High Plains, adequate consideration should always be given to type of fuel, Btu rating of natural gas, altitude and temperature. A power allowance should be made for continuous duty reserve and friction losses in the gearhead and drive shaft. Neither overloaded nor underloaded engines are efficient. Also, excessive engine size increases fixed costs. Considering all costs, it is suggested that engines be selected so that the horsepower required on the pump shaft is 46-59% of the maximum natural gas horsepower rating of the engine for the speed at which it is to be operated. If no natural gas rating is available, the horsepower required at the pump shaft should be 36-47% of the gasoline rating for the engine selected. Since these ranges allow for gearhead losses, the figures for horsepower required at the pump shaft can be directly compared to electric motor size requirements unless a belt or gear drive is used.

Engine rpm:

High engine speeds were often used to obtain adequate horsepower from undersized engines. The results were a reduction in efficiency and a great reduction in engine life.. Maintenance costs were greatly increased, and ignition system malfunctions reduced efficiency still more. Such engines were also more likely to fail during critical periods in the irrigation season.

Long stroke engines should be operated at lower speeds than short stroke engines. It is recommended that the maximum speed for long stroke engines be limited to 1400 rpm for those with six inch strokes (i.e. Minneapolis-Moline HD800-6A and Waukesha F-817-G) and 1600 rpm for those with five inch strokes, with other long stroke engines having their maximum speeds adjusted accordingly.

The so-called short stroke-high speed engines (i.e. Crysler HT-413, Ford 534 and GMC 478) can be operated at higher speeds, but most of those in the study area have been applied at excessive speeds. Generally, they should be limited to maximum speeds of 1900-2000 rpm, depending on the length of stroke and the engine construction. It should always be remembered that altitude and the Btu rating of the natural gas in the Colorado High Plains make it desirable to operate engines at lower speeds and with lighter loads than in some pump irrigation areas.

In selecting engines, it is often found that one engine model is too small while the next larger model can produce more power than is needed. Too often, the smaller model is used at excessive speed. However, a few plants were found which had the larger engine models operating with a light load at excessive speed. The efficiency of these plants can be improved by using gearhead ratios which will allow the engines to operate at lower speeds and more nearly full load conditions.

Compression ratios:

Engines should have higher compression ratios for natural gas than for propane. Test results indicated that efficiencies and horsepower output were generally lower for engines having compression ratios of less than 8.5:1. Some engine manufacturers recommend compression ratios of at least 10:1 for natural gas operation in the study area.

Well construction:

Improper well construction often results in sand pumping which wore out pumps rapidly. Poor screen selection and gravel packing with gravel which is too large are the most common causes. One of these wells was producing only 35% of the water that the pump was designed for, but it was using more power than should have been required to pump at the pump's design capacity.

Another problem resulting from poor well construction was air pumping as a result of cascading water. Both sand pumping and cascading water are responsible for much of the low efficiency in the Southern High Plains, where cost rather than quality of well construction appears to have been given primary consideration.

It should also be noted that incomplete well development and inadequate open area in well screens and perforated casing reduce pumping rates and increase water costs. Some of the effects of improper well construction are not reflected in efficiency data, but they may considerably increase pumping costs.

Maintenance:

Inadequate maintenance and improper operating procedures reduce both efficiency and the life of pumping equipment. Engines out of time, spark plugs misfiring, bad ignition points, improper engine cooling, inadequate lubrication, dirty air cleaners and similar conditions can result in loss of power and poor performance of a properly selected engine. Manufacturers' recommendations on adjustment and maintenance should be carefully followed for all pumping plant components.

Water table decline:

The last cause of low efficiency which was noticed is water table decline. There are two types which are important in most of the High Plains area. The most obvious is long-term decline, but of equal or greater importance are cyclical fluctuations in pumping level which occur yearly. In some areas of concentrated irrigation development, the pumping lifts will increase by 20 to 40 feet during the irrigation season, but the net water table decline from year to year may be quite small. At the time of the pumping plant tests, long term decline had been insignificant. However, it will be much more important in the future because of the great increase in irrigation development which has occured. The effects of these declines and fluctuations should be anticipated and pumps selected accordingly. Pumps should generally be selected for pumping somewhat less water at a greater total head than indicated by the well test. The correct amount for this adjustment depends on local conditions.

Brand names:

Questions are often asked about which brand of pump or engine is most efficient. The results of this study indicate that these are relatively unimportant questions. On the average, plants having pumps made by small manufacturers had significantly lower efficiencies, but no significant difference was noticed between the average efficiency of various brands produced by major manufacturers. Efficiencies varied greatly within each major brand of pump according to how well it was applied. Also, it should be noted that performance data furnished by major pump manufacturers indicates much more difference between the efficiencies of pumps within a brand than between brands.

The same is also true of engines. It is much more important to the efficiency of the pumping plant to have a properly applied engine than to have one of a particular brand. Efficiencies seemed to vary relatively little among engines if the compression ratios were adequate, if the engines were operated at speeds which were reasonable for their design and operating conditions, and if the engines were properly loaded.

RESULTS OF LOW EFFICIENCY

Low or high efficiencies are not ends in themselves. They are important because they are closely related to the economic well being of irrigation farmers and their communities. The principal results of low pumping plant efficiencies are:

1. Additional pumping costs to water users.
2. Usually less water is available when needed.
3. Economic failure of an area may result if irrigation farming is marginal.
4. Greater power supplies and larger investments in distribution equipment are required.

EVALUATION OF PUMPING COSTS

A procedure frequently used to determine irrigation pumping costs is to conduct a survey or study to find the actual costs for a large number of pumping plants. The records thus obtained are summarized to determine pumping costs.(1,4,5) Many problems are involved, making it important to recognize the limitations of this procedure and to make interpretations accordingly.

In this study, an attempt was made to obtain cost records on the pumping plants tested. It was found that very few farmers had records which were adequate to make reasonably accurate evaluation of their annual pumping costs. Also, it was believed that most of those farmers participating in this study were above average managers. This was especially likely to be true of those having good records, so it is probable that they had better pumping plants for the money spent than the average in the High Plains.

In addition, costs were found to vary greatly throughout the area as a result of great differences in the amount of water pumped, pumping lift, pumping plant efficiency, maintenance and care, annual hours of use and other factors. Comparisons between competing power sources based on averages of such variable data could result in conflicting and unfair interpretations by readers who were not familiar with the differences in conditions under which the plants were operating. Therefore, instead of summarizing the cost data, it has been used in developing cost relationships and procedures for predicting pumping costs. The following sections will be devoted to a discussion of the various costs involved in pumping irrigation water and the methods which can be used to estimate these costs.

Annual Investment Costs

Costs can be classified as either investment or fixed costs and operating or variable costs. Investment costs occur whether or not equipment is used. Operating costs are related, but not always in direct proportion, to the amount of use. Also, investment or fixed costs are not always independent of the amount of annual use.

When a well is drilled and a pumping plant installed, the owner has committed himself to substantial investment costs regardless of whether or not the facility is used. These costs are depreciation, interest on the investment, taxes and insurance. Too often when statements are made about pumping costs, fixed costs are ignored and operating costs emphasized.

Depreciation is considered to be a fixed cost, but it is only fixed if deterioration or obsolescence, rather than wear, determine the useful life of the equipment. This is essentially true for properly constructed wells. However, depreciation of pumps and power units is a fixed cost only for a limited amount of annual operation. Greater amounts of annual operation shorten the lives of pumps and power units so the depreciation is greater.

Interest is another major investment cost which should always be considered. It is a cost whether or not the money is borrowed, because the money is capable of producing a return if invested elsewhere. If the money is borrowed, the interest rate used in cost analysis should always be at least as high as the rate paid. In any event, the minimum rate used in determining the cost of pumping should be at least as high as that currently being earned by savings accounts or high grade bonds. Alternative investment opportunities should be considered when selecting an appropriate interest rate.

A convenient way to compute interest and depreciation on equipment is by using capital recovery factors. This procedure accounts for the cost of interest on the investment plus the money which could be set aside on interest each year to replace the equipment at the end of its estimated useful life. Capital recovery factors are listed in Table 3.

Table 3

Capital Recovery Factors

Expected Useful Life (years)	Compounded Interest Rates 5%	6%	7%	8%
5	.2310	.2374	.2439	.2504
6	.1970	.2034	.2098	.2163
7	.1728	.1791	.1856	.1921
8	.1547	.1610	.1675	.1740
10	.1295	.1359	.1424	.1490
12	.1128	.1193	.1259	.1327
15	.0963	.1030	.1097	.1168
20	.0802	.0872	.0944	.1019
24	.0710	.0782	.0858	.0937
40	.0583	.0665	.0750	.0839

Capital recovery factors are multiplied times the difference between the initial cost of the equipment and its salvage value to obtain an annual depreciation and interest cost on that portion of the investment. This result does not include interest on the part of the investment represented by the salvage value, so the interest on this portion of the investment should be added to obtain the total annual cost of depreciation and interest. As an example, consider an internal combustion engine which costs $3000, has an expected useful life of 8 years and has a trade-in or salvage value of $500. The capital recovery factor for 6% interest would be 0.1610. The annual depreciation and interest costs would be computed as follows:

Total Depreciation = $3000 - $500 = $2500
Annual dep. & int. = ($2500)(0.1610) + ($599)(0.06) = $402.50+$30.00 = $432.50

Depreciation and interest are the major investment costs, but taxes and insurance should not be ignored. Taxes vary considerably over the area. They may be based on the pumping rate of the well, irrigated acreage, valuation of the well and equipment, or a combination of these. Also, pump taxes levied by ground water management districts should be included in the annual pumping costs.

Some well owners do not carry insurance on their pumping plants. However, even though an insurance premium is not paid, an allowance for the risk taken by the owner should be considered part of the cost of pumping water.

Operating Costs

The most obvious operating cost is the cost of the fuel or electric power. Also included is pump maintenance and repair, pump oil, power unit maintenance and repair, supplies and maintenance and operating labor. Cutting corners on investment costs usually results in higher operating costs which may, over the life of the pumping plant, add up to several times as much as the initial savings. The landowner should try to purchase a well and equipment which are adequate but not excessive.

Cost Classification for Decision Making

When a landowner decides to put down an irrigation well, he has committed himself to making an almost endless number of management decisions for the duration of his ownership. The initial decisions made during the development phase are particularly important because to change them later will usually result in a rather substantial financial loss.

Among the initial decisions are those related to pumping, conveying and applying the irrigation water. The whole system must work together as a unit, so the decisions need to be made in a logical order and based on valid reasons. It is beyond the scope of this publication to discuss selection of cropping programs, irrigation methods and equipment for conveying and distributing irrigation water. However, all of these decisions should be considered when selecting pumping equipment.

The decisions on well construction, development and testing can be made independently of those involved with the pump and power unit. In fact, pumps and power units should never be contracted for until well construction, development and testing are completed. The well test is the basis for selection of a pump and a power unit that will operate efficiently. Similarly, the selection of a pump is usually quite independent of the type of power used and the choice of power unit. Therefore, in this publication, costs of pumping will be classified according to whether they are associated with the well, with the pump, or with supplying the power to operate the pump.

Well Costs

Well costs were found to be highly variable throughout the High Plains area. Variations between the charges made by different drillers were found to generally reflect differences in well construction and the effort that went into well development and testing. However, some of the more expensive wells were not superior in quality indicating that price alone does not assure a good well.

The greatest ranges in both well cost and well quality were found in Baca County. Those records which were available showed a range in initial well costs of $6.80 to $15.50 per foot of depth. Many of the wells tested in Baca County were found to be cased only through the Ogallala formation and were open holes through the shale and sandstone formations. Most of the wells were not gravel packed, and torch-cut perforating casing was often used. Sand pumping was common, resulting in severely worn pump impellers. Poor well construction was one of the major reasons for the low average efficiency in Baca County. It is also significant to note that the well with the highest average cost per foot of depth also had the highest efficiency, and that both the well cost and the efficiency for this plant were comparable to those for the most efficient plants in the Northern High Plains.

Records obtained in the Northern High Plains of Colorado showed an average well cost $13.40 per foot of depth with a range of $11.00 to $16.60 per foot. Some of the records were believed to be incomplete, so the actual average cost was probably about $14.00 per foot. Included was the cost of drilling, casing, gravel packing, drilling water, well permit, test holes, well development, well testing and sales taxes. Some of these charges were usually combined on the well driller's statement.

The results of the efficiency tests provide very strong evidence that inadequate well testing and poor well construction generally result in excessive operating costs. Also, while very few wells in the High Plains area have completely failed, several others have been replaced because of sand pumping or plugging of the perforated casing or gravel pack. Therefore, good well construction appears to be necessary if assuming an expected 25 year life for the wells is to be justified.

On the basis of the costs reported, it appears that wells which are properly constructed, developed and tested will probably cost $13.50 to $17.00 per foot of depth depending on local conditions. An average of $15.00 per foot appears reasonable for a well with an expected life of 25 years. Unlike most other pumping plant components, the well would have no trade-in or salvage value. Therefore, the capital recovery factor would be applied to the entire initial cost to determine the annual depreciation and interest cost. Referring to Table 3, we find that for a 25-year life at 6% interest, the capital recovery factor if 0.0782. The annual depreciation and interest cost for the well would be $15.00 times 0.0782 or $1.17 per foot.

Well taxes assessed by ground water management districts are based on pumping rate, so they will be considered to be a pump cost rather than a well cost. Some counties base property taxes for pumping plants on pumping rates, irrigated acreage or other criteria on the theory that this method makes possible the taxing of the water supply in addition to the investment in equipment. However, for the examples in this publication, the property taxes will be assumed to be levied on only the pumping plant components at the average annual rate of 1% of the original investment. Taxes for the $15.00 per foot well would then be $0.15 per year per foot of depth.

Insurance and maintenance costs would be negligible, so the total annual cost would be $1.17 depreciation and interest, plus $0.15 property taxes, for a total of $1.32 per foot of depth. Appropriate adjustments in this annual cost should be made if the interest rates are higher than 6% or if the useful life of the well is expected to be less than 25 years because of declining water level or other problems.

Pump Costs

The cost of pumps varies with the length and diameter of the pump column, the number of bowls, the diameter and type of bowls and, to a considerable extent, with the quality or brand of the pump. No simple formula is available for estimating pump costs.

The expected useful life of a pump depends on hours of use, pump quality, maintenance, amount of sand pumped, operating speed, impeller adjustment and many other factors. The average life of the better quality pumps operating 2000 hours per year or less is estimated at fifteen years. Corrosion and obsolescence are more likely to determine the life of these pumps than is wear. Also, it should be recognized that individual pumps may vary in life because of differences in corrosive properties of water, but these variations cannot be accurately predicted in advance. Wear is likely to determine the life of pumps used more than 2000 hours per year, so an expected life of 30,000 hours of total operation is suggested for these pumps.

Maintenance costs were found to vary greatly. However, sand and air pumping appeared to be the principal causes of excessive pump maintenance, greatly increasing the average maintenance costs of the existing pumping plants. Therefore, these average maintenance costs are considerably higher than those which would be expected for pumps which are correctly selected and are installed in properly constructed wells.

Power Units and Related Equipment

Questions are frequently asked about the type of power which is most economical for irrigation pumping. This study did not provide the answer. In fact, it indicated that there was no general answer. Each pumping plant presents a separate problem. Therefore, the purpose of this section is not to provide the answers, but to give general information and to illustrate a method which can be used to estimate the costs for a particular set of conditions.

Initial costs of equipment for pumping with electricity are generally lower than when internal combustion engines are used. No gearhead or driveshaft is required since the motor is mounted directly on the discharge head. Annual investment costs are further reduced by the longer life and lower maintenance costs of the equipment. However, the investment costs of the power supplier are quite high and are passed on to the customer in the form of much higher rates for the first few hundred hours of annual use.

Electric motors, controls and wiring are assumed to have an expected life equal to that of the well if they are not overloaded. Maintenance costs on properly applied equipment were also found to be low. However, casualty losses, primarily due to lightning, were found to be considerably more frequent than for other pumping plant components. Therefore, insurance allowances should be higher.

Annual costs of providing power with internal combustion engines were found to average much higher than had been expected by engine manufacturers. The major reason appeared to be that very few engines were properly applied. Most were found to be overloaded and/or operated at excessive speeds. It also appeared that some of the engine manufacturers were basing their expectations on experience with engines operating continuously in oil fields and industry, where engines are operated at lower speeds, with more conservative loading and with high quality maintenance performed by well-trained maintenance specialists. Irrigation experience at lower elevations has also resulted in too little consideration being given to compression ratio and the BTU rating of the fuel. Full consideration should be given to the special conditions in the Colorado High Plains which result in different or more severe problems than are generally found elsewhere.

Overloading engines and/or operating them at excessive speeds results in shorter useful lives, larger repair and maintenance costs, excessive fuel consumption and greater risk of a breakdown during a critical part of the irrigation season. The agrument is frequently advanced that high engine speeds and overloading can be justified by the lower initial cost of the smaller engine. However, records obtained on forty natural gas powered plants in the High Plains area indicate that this is not a valid agrument. The engines which were installed at the time that the records were obtained ranged in age from 6 months to 5 years, with an average age of less than 2 years. Seven of these had required major repair work during their first year of operation as a result of improper application.

Ten of the original engines had been replaced. Four of these had been considerably overloaded. Their average life was 1.5 years, resulting in an average annual depreciation of nearly $700. The other six engines were applied fairly well, but some of them may have been slightly overloaded. They ranged in life from 5 to 9 years for an average of 6.5 years, resulting in an average annual depreciation of about $360. Since very few older pumping plants were included and because lifetime records of loading, hours of operation, maintenance and other data were not available, it is not possible to accurately estimate the useful life of irrigation engines. However, the limited information which was available provides general indications which will be used in estimating engine investment and operating costs.

The useful life of engines may vary greatly with hours of annual use, loading, operating speed, maintenance, lubrication and engine quality. Good quality engines which are properly selected and maintained should have useful lives of 20,000 hours if used 2000 hours per year or more. Engines used 1000 hours per year or less are estimated to have useful lives of about 15 years. However, it should be emphasized that fewer than 20% of the engines in use in the High Plains, and not more than 50% of those installed in 1967 can be expected to meet these goals.

PUMPING COST EXAMPLE

No attempt will be made to provide charts giving pumping costs for the infinite number of pumping conditions. The following tables will show estimated pumping costs for one set of conditions. Estimates could be made for other conditions.

The example will be for a pumping plant having a 300-foot deep well, a pumping rate of 1000 gpm and a total operating head of 260 feet. Pumping costs are estimated for 500, 1000, 2000, and 3000 hours of annual use. It is assumed that natural gas and electrical efficiencies of 15.0% and 65.0% are achieved as a result of good well construction, pump selection and power unit selection. Also, it is assumed that good quality equipment and maintenance practices will be used. These assumptions result in higher initial costs but lower annual costs than the average plants now in use in the High Plains.

It should be recognized that these are estimates of average useful life. Individual units will have a useful life which varies considerably from the average.

Table 5 and Table 7 are based on the useful lives shown on Table 4, on 6% interest rates and on repair and maintenance records for better than average plants. Power and fuel costs vary in the study area, due to individual suppliers' policies and areas served. Table 6 explains the rates which were used for Table 5 and Table 7.

Table 4

Estimated Useful life (years) of Components of Well Designed Pumping Plants

	Annual Hours of Use			
	500	1000	2000	3000
Well	25	25	25	25
Pump	15	15	15	10
Gearhead	15	15	15	10
Drive Shaft	15	15	15	10
Engine	15	15	10	7
Gas Line	25	25	25	25
Engine Foundation	25	25	25	25
Electric Motors	25	25	25	25
Electric Controls & wiring	25	25	25	25

Table 5. Estimated Annual Pumping Costs for a Typical Well Pumping 1000 gpm at 260 Feet of Head for 2000 Hours per Year

	Natural Gas		Electric	
Well (300' Deep)				
Depreciation & Interest(a)	$326		$326	
Property Tax	45		45	
Well Investment Costs		$ 371		$ 371
Pump				
Depreciation & Interest(a)	397		397	
Property Tax & Insurance	64		64	
Pump Tax (GWM District)	50		50	
Pump Investment Costs		511		511
Pump Oil	20		20	
Pump Repairs(b)	50		50	
Pump Operation & Maintenance		70		70
Total Annual Well & Pump Costs		$ 952		$ 952
Power Unit				
Engine or Electric Motor, Control & Wiring				
Depreciation & Interest(a)	380		164	
Property Tax	32		23	
Insurance	16		40	
Gearhead & Drive Shaft Inv. Costs(a)	110			
Gas Line & Foundation Inv. Costs(a)	35			
Power Unit Investment Costs		573		227
Engine Oil & Oil Filters	86			
Spark Plugs & Ignition Points	56			
Tune-ups	20			
Overhaul(b)	81			
Battery(b)	10			
Other(b)	20		20	
Oper. & Maint. Labor	115		30	
Power Unit Oper. & Maint.		388		50
Power Unit Costs Other Than Fuel or Power		961		277
Total Annual Well & Pump Costs		952		952
Annual Costs Other Than Fuel or Power		1913		1229
Fuel or Power (rates NG-1 & E-1)(c)		901		2040
Total Annual Costs		$2814		$3269

(a) Based on useful lives shown in Table 4, 6% interest and overall efficiencies on 15% for natural gas and 65% for electricity.

(b) Repairs may not be needed for all plants and will not occur yearly. Estimated average annual costs are charged to each plant.

(c) Rate schedules are given in Table 6.

Table 6

Fuel and Power Rates for Pumping in High Plains[a]

NG-1	Natural gas at 39¢ per 1000 cubic feet. Lines along section lines provided by supplier. (Plateau - Burlington)
NG-2	Natural gas at 28¢ per 1000 cubic feet. Customer pays for pipeline to reach farm. Average cost estimated at $3000 and assigned at 25-year useful life. (Kansas-Nebraska - Yuma)
NG-3	Natural gas at 30¢ per 1000 cubic feet. Lines along section lines provided by supplier. (Plateau - Springfield)
E-1	5.0¢ each for first 1500 KWH of annual use 3.0¢ each for next 250 KWH per nameplate horsepower 1.5¢ each for next 350 KWH per nameplate horsepower 1.0¢ for each additional KWH Present value of capital credit estimated at 9% of power bill[b] (K-C Electric - Stratton)
E-2	5.0¢ each for first 1000 KWH of annual use 4.0¢ each for next 100 KWH per nameplate horsepower 2.5¢ each for next 200 KWH per nameplate horsepower 0.9¢ for each additional KWH Present value of capital credit estimated at 9% of power bill[b] (Y-W Electric - Akron)
E-3	5.0¢ each for first 150 KWH per nameplate horsepower 3,0¢ each for next 150 KWH per nameplate horsepower 1.5¢ each for next 300 KWH per nameplate horsepower 1.0¢ for each additional KWH Also, 1.0¢ per KWH rate replaces 1.5¢ rate for each KWH over 30,000 KWH of annual use. Present value of capital credit estimated at 10% of power bill.[b] (Highline Electric - Holyoke)
D-1	Diesel fuel at 14¢ per gallon
P-1	Propane at 11¢ per gallon

(a) Rate schedules are constantly being revised. Investment decisions should be made on the basis of current rates rather than those shown.

(b) Present policy of the Rural Electric Associations is to place a portion of each customer's power payments in an emergency fund which is returned to the customer at a later date without interest. Present value of capital credit is estimated by discounting capital credits at 6%.

Table 7. Effect of Annual Hours of Operation on Total Annual Costs for Pumping 1000 GPM Against 260 Feet of Head

		Annual Hours of Operation			
Rate	Type of Cost	500	1000	2000	3000
NG-1	Well & Pump	$ 910	$ 927	$ 952	$1099
	Power Unit Investment	492	492	573	724
	Power Unit O & M	151	233	388	543
	Fuel	225	450	901	1351
	Total	$1778	$2102	$2814	$3717
NG-2	Well & Pump	910	927	952	1099
	Power Unit Investment	492	492	573	724
	Gas Line Inv. Costs	246	246	246	246
	Power Unit O & M	151	233	388	543
	Fuel	149	298	595	893
	Total	$1948	$2196	$2754	$3505
NG-3	Well & Pump	910	927	952	1099
	Power Unit Investment	492	492	573	724
	Power Unit O & M	151	233	388	543
	Fuel	174	347	693	1040
	Total	$1727	$1999	$2606	$3406
E-1	Well & Pump	910	927	952	1099
	Power Unit Investment	227	227	227	227
	Power Unit O & M	34	39	50	61
	Power	903	1355	2040	2726
	Total	$2074	$2548	$3269	$4113
E-2	Well & Pump	910	927	952	1099
	Power Unit Investment	227	227	227	227
	Power Unit O & M	34	39	50	61
	Power	919	1228	1845	2462
	Total	$2090	$2421	$3074	$3849
E-3	Well & Pump	910	927	952	1099
	Power Unit Investment	227	227	227	227
	Power Unit O & M	34	39	50	61
	Power	1184	1623	2301	2979
	Total	$2355	$2816	$3530	$4366
D-1	Well & Pump	910	927	952	1099
	Power Unit Investment	593	593	646	732
	Power Unit O & M	138	204	312	467
	Fuel	454	908	1816	2724
	Total	$2095	$2632	$3726	$5022
P-1	Well & Pump	910	927	952	1099
	Power Unit Investment	507	507	550	681
	Power Unit O & M	144	220	358	509
	Fuel	671	1342	2684	4026
	Total	$2232	$2996	$4544	$6315

Table 8. Effect of Annual Hours of Operation on the Cost per Acre-Foot for Pumping 1000 GPM Against 260 Feet of Head

	Annual Hours of Operation			
Rate[a]	500	1000	2000	3000
NG-1	$19.33	$11.42	$ 7.65	$ 6.73
NG-2	21.17	11.93	7.48	6.35
NG-3	18.77	10.86	7.08	6.17
E-1	22.54	13.85	8.88	7.45
E-2	22.72	13.16	8.35	6.97
E-3	25.60	15.30	9.59	7.91
D-1	22.77	14.30	10.13	9.10
P-1	24.26	16.28	12.35	11.44
Quantity Pumped (ac.-ft.)	92	184	368	552

[a] See Table 5 for fuel and power price schedules.

Electricity vs Natural Gas

It should be clearly understood that the relationships shown in the previous cost example apply only to a particular set of conditions. Other relationships can be expected for other horsepower requirements and different prices for power and fuel.

Generally, the cost data indicates that for the natural gas and electrical rates listed in Table 5, the total annual cost of pumping with natural gas will be consistantly lower when 100 horsepower or more is required at the pump shaft. On the other hand, it appears that electric pumping is less expensive when 40 horsepower or less is required at the pump shaft. When the pump shaft requirement is less than 100 horsepower but more than 40 horsepower, the cost relationship will depend on which power and fuel rate schedules are being compared and on the annual hours of operation.

However, both efficiency and annual hours of operation have much more effect on the cost of pumping than does the type of power used. Other factors remaining constant, a highly efficient natural gas or electric power plant will pump water at a considerably lower cost per acre-foot than will either an electric or natural gas plant of average efficiency. Table 8 shows the average pumping cost for 2000 hours of annual operation at rate NG-2 is $7.48 per acre-foot. However, this cost is based on 15.0% efficiency. Combining the classifications of "Pumps poorly fitted to wells" and "Tests indicated pump performance much below manufacturer's specifications" from Table 2, the average efficiency is 10.8%. In the example, reducing the efficiency from 15.0% to 10.8% would increase pumping costs to $9.88 per acre-foot. Similarly, for rate E-2, a decrease in efficiency from 65.0% to 45.4% would increase costs from $8.35 to $11.43 per acre foot.

Table 8 illustrates the relationship between annual hours of operation and cost per acre-foot. For all power sources, the average pumping cost per acre-foot pumped decreases considerably with increased annual use. However, in this example, the unit cost decreased at a much slower rate for diesel and propane than for natural gas and electricity. This would also be true where electricity or natural gas rates are higher than those in the study area.

For this example, Table 8 indicates that the average cost per acre-foot pumped would range from $10.86 to $15.30 for 1000 hours of annual pumping based on the various electricity and natural gas rates in the study area. However, the total costs only increase at a rate of $3.30 to $4.90 per acre-foot of additional water pumped. Therefore, the latter are the costs which would be considered by individuals making decisions on off-season irrigation of non-irrigated crop land if pumping limitations are not in effect.

It should also be noted that pumping cost alone is not always the only factor to be considered in selecting the type of power to be used. Some of the newer types of semi-automatic irrigation equipment have characteristics which are better adapted for use with internal combustion engines than electric motors, but the opposite is true for some other equipment. Before any purchases are made, the well, the pump, the power unit and the irrigation system should be selected so that they fit together as a well-coordinated unit.

REFERENCES CITED

1. Cole, J. F., "Cost of Pumping Water in the Estancia Valley of New Mexico," Agricultural Experiment Station Bulletin 444, New Mexico State University, University Park, New Mexico, February, 1960.
2. Duke, H. R., "Groundwater in the High Plains of Eastern Colorado," Colorado Agricultural Experiment Station General Series 852, Colorado State University, Fort Collins, Colorado, July, 1967.
3. Hanson, R. E., "Irrigation Pumping Plants," Project Report No. 203, Engineering Experiment Station, Kansas State College, Manhattan, Kansas, 1951.
4. Long, R. B., "Cost of Pumping Irrigation Water in Ten New Mexico Counties," Agricultural Experiment Station Bulletin 490, New Mexico State University, University Park, New Mexico, March, 1965.
5. Nelson, A. G. and Busch, D. C., "Cost of Pumping Irrigation Water in Central Arizona," Arizona Agricultural Experiment Station Technical Bulletin 182, The University of Arizona, Tucson, Arizona, April, 1967.
6. Schleusener, P. E. and Sulek, J. J., "Criteria for Appraising the Performance of Irrigation Pumping Plants," Agricultural Engineering, Vol. 40, No. 9, pp. 550-551, September, 1959.

SUMMARY

During 1964 and 1965, a study of pumping plant efficiencies and costs was conducted in the High Plains of Eastern Colorado. A very wide range of efficiencies was found with some pumping plants operating at very low efficiencies and, as a result, costing their owners several hundred dollars per year more than was necessary.

The principal causes of low efficiency and high pumping costs were inadequate well testing, incorrect pump selection, changes in irrigation systems after pump installation, and incorrect engine selection. Additional causes were improper well construction, inadequate maintenance, improper operating procedures, and water table declines and fluctuations.

Pumping costs were found to be highly variable. Records obtained from well owners indicated that attempts to reduce initial costs of pumping plants generally resulted in much higher total annual cost because of shorter equipment life and excessive operating costs. However, some of the plants with higher initial costs also had excessive total costs. All components of pumping plants must be properly selected if performance is to be satisfactory and the cost per acre-foot of water pumped is to be minimized.

Analysis of the cost of pumping with electricity and natural gas indicates that for most rates currently in effect in the Northern High Plains, the efficiency of the pumping plant and the number of hours of annual use have much greater effects on total pumping costs than does the type of power used.

Information obtained from this study was used by the Extension Service as a base for an intensive educational program on well construction, well testing, pump selection and power unit selection. It is also being used in economic studies of irrigation development and in ground water management for the Northern High Plains.