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Factors Affecting Irrigation Pumping Costs

By Robert Dean Von Bernuth

Department of Agricultural Engineering

UNIVERSITY OF IDAHO

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BIOGRAPHICAL SKETCH OF THE AUTHOR

Robert D. von Bernuth was born in Del Norte, Colorado in 1946 and grew up on his parents irrigated farm near Del Norte. In May of 1964 he graduated from Del Norte High School, and he enrolled at Colorado State University in the fall of that year. He received his Bachelor of Science degree in Agricultural Engineering from Colorado State University in June of 1968 and was honored by the Colorado Engineering Council as the honor engineer of his class. In August of 1968 he came to the University of Idaho and in June 1969 he completed requirements for a Master of Science degree in Agricultural Engineering of which this thesis is a part.

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DEFINITIONS

Total Pumping Lift - The total pressure expressed in feet of water against which the pump must operate.

Observation - The collection of data points at a given well. In this case an observation corresponds to a well or average of similar wells (See Chapter II, Separation of Data, and Appendix).

Data Point - The recorded numerical value of a given variable at a given well.

Variable - A specific physical quantity which in this case is measurable and is believed to be a factor of cost.

$\underline{\text{Variable}}$ - A variable or mathematical combination of variables believed to relate linearly to cost. (It is denoted in this paper by the underscore.)

Coefficient of Determination - Commonly known as R^2, this is the fraction of the variation in the dependent variable attritable to regression of the dependent variable on the independent variables.

Coefficient of Variation - The standard deviation divided by the mean.

Partial Regression Coefficient - The regression of the dependent variable on the independent variable holding other variables constant.

Standard Error of Estimate - The variance of the dependent variable given the independent variable.

Electric Wells - Those wells observed which were pumped by an electric motor.

Natural Gas Wells - Those wells observed which were pumped by a natural gas engine.

ABSTRACT

A thorough understanding of the factors affecting the cost of pumping water for irrigation does not presently exist. The purpose of this study was to try to gain better understanding of these factors and attempt to determine the specific effect which total pumping lift may have on the cost of pumping water.

Data were gathered from various sources over five states and separated according to the source of power used to pump water. A multiple regression analysis was run on the data, which included a total of 193 observations, and the relative effect of each selected variable was determined from this analysis.

After a preliminary analysis was run, 14 different equations were selected for the analysis.

The most important factor affecting total costs in all cases was total investment divided by yield of water, and the most important factor affecting variable costs was lift.

The results showed that the variation in costs was well accounted for, and in most cases 80 per cent of the variation in total costs was accounted for. Lift alone accounted for approximately 40 per cent of the variation in variable costs with various other variables improving the correlation for different types of power units.

The best correlation found was with total costs for natural gas wells where 98 per cent of the variation was accounted for.

The results of this study indicate that with the variables used total costs can be well accounted for, but additional variables must be used to account for variable costs.

CHAPTER I

INTRODUCTION

Purpose

Although most of the western states have developed a rather intricate system of water laws for that portion of the water which flows on the surface of the ground, few have developed a workable system of laws for that portion of the water which is beneath the surface of the ground (known as ground water).

The need to develop a system of laws for ground water has become painfully apparent to agriculturalists and conservationists alike. It is becoming more and more apparent that we are truly mining our ground water in many areas of the world, and there should be some regulation as to whom may be allowed to participate in this mining and to what extent.

Homer was probably the first to try to explain the phenomena of ground water, and he did so with his theory known as the oceanus concept. He theorized that the ocean was the source of all water and that it arrived at the inland underground through a system of underground caverns and in the process was desalinized. These ideas were further expounded upon, especially with respect to the purification aspect, by Plato and Aristotle.

It was not until da Vinci proposed his theory of the hydrologic cycle that man began to really understand ground water. Unfortunately, however, the science of ground water is still not well understood, for if it were there would be no need for studies of such a nature as this one.

An area of deficiency in the knowledge of ground water in the state of Idaho, which is of much concern in the regulation of ground water, is in the true meaning of the phrase "a reasonable ground water pumping level". This wording comes from the Code of the State of Idaho (37) and reads as follows:

> And while the doctrine of "first in time is first in right" is recognized, a reasonable exercise of this right shall not block full economic development of underground water resources. Early appropriators of underground water shall be protected in the maintenance of reasonable ground water pumping levels as may be established by the state reclamation engineer as herein provided.

In an effort to approach this problem of definition some attempts have been made to determine the maximum depth from which one can pump water and still have enough money left to reimburse himself for his efforts. These studies have proven to be localized due to the very nature of the approach, and are therefore inadequate as a tool to define a general level. It would be much more feasible then, if a study could be made where the results were not localized, and could apply generally to all areas. With this study in hand a person wishing to define the economic pumping level for a given area could merely modify the general study with localized constants to arrive at the appropriate answer. This is the specific purpose of this research.

Objectives

The main objective of this study was to arrive at a relationship which could be used to define the "reasonable ground water pumping level". However, in order to do so, it was necessary to first determine what all is involved in determining this level, and to what extent each factor affects the end result.

Four sub-objectives are implied in the main objective of this study, and they are: 1. to determine what factors are important to the cost of pumping water, 2. to determine what the relative magnitude of each of these factors is, 3. to quantitatively relate these important factors to the total cost, and 4. to develop a relationship for lift.

CHAPTER II

LITERATURE REVIEW

Water Law

Although water is the world's most abundant natural resource, it is also the most essential to life. It is then no surprise that modern man should devote much effort to attempt to utilize, regulate, economize, and synthesize that vital compound of oxygen and hydrogen known to us as water. With one eye on the arid regions of the world and the other on the exploding megalopolis we realize immediately that there must be something done to insure that we will always have enough water for everyone.

In the western United States, where irrigation is often a necessity for agriculture, the demand for water has pushed us to exploit many different means to satisfy our thirst. Unfortunately our technological advancements have far outstripped our ability to guarantee each man's fair share of water. While water law is no fledgling in the flock of statutes, it is quite similar to the ostrich in that it has never learned to fly. Of the two basic theories of water law, that of riparian rights[1] and that of most beneficial use[2], the theory of most beneficial use has been most widely accepted in the western United

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[1] A riparian right to the use of water is by virtue of ownership of land adjacent to a water source and has no bearing on the type of use to which it is put.

[2] The concept of most beneficial use implies that the owner must put his water to a use described as beneficial under the statutes of the state and implies no restriction on the geographic location of the land. This is a doctrine of appropriative rights with a modification for correlative rights.

States (36, 12). These theories apply mostly to the surface water within the respective states, and laws concerning the use of ground water are not clearly defined. However, due to the innovation of the vertical turbine pump and new well techniques stimulated by land reclamation, the development and withdrawal of water from underground has become commonplace, and the regulation of the same is inadequate.

Land reclamation in Idaho has been largely under the Desert Land Act of 1877 (subsequently revised) which allowed for 3.3 million acres to be developed. By 1965 nearly 1.5 million acres had been developed (35).

Perhaps the greatest fallacy perpetuated by lawmakers in ground water legislation is in the attempt to regulate it as an entity separate from surface water. Such is not the thesis of this study however, and the argument will not be undertaken here. It should be noted that no study of the ground water picture can be complete without at least a look at the implications that the development of this resource may have on its future use.

The Code of the State of Idaho defines the following terms for use in ground water regulation (Sec. 42-230) (37).

> Ground water - all water under the surface of the ground whatever may be the geological structure in which it is standing or moving.
>
> Well - an artificial excavation or opening in the ground by which ground water is sought or obtained.
>
> Well driller - any person or group of persons who excavate or open a well or wells for compensation or otherwise upon the land of the well driller or upon other land.
>
> Domestic purposes - water for household use and livestock, and water used for all other purposes not in excess of 13,000 gallons per day.

> Water rights - the legal right, however acquired, to the use of water for beneficial purposes.

When it became obvious that something had to be done in order to preserve and properly regulate ground water usage in the state, the state of Idaho adopted the following rules (as of 1967).

> All ground waters in this state are declared to be the property of the state, whose duty it shall be to supervise their appropriations and allotment to those diverting the same for beneficial use. All rights to the use of ground water in this state however acquired before the effective date of this act are hereby in all respects validated and confirmed.

It is further defined that water may be used only by appropriation after a license has been issued by the State.

Logically we now ask who is to regulate the ground water and to issue the aforementioned licenses for the appropriation of ground water. The Code of the State of Idaho further delineates authority under "Duties of the State Reclamation Engineer".

> It shall likewise be the duty of the state reclamation engineer to control the appropriation of the use of the ground water of this state as in this act provided and to do all things reasonably necessary or appropriate to protect the people of the state from depletion of ground water sources contrary to the public policy expressed in this act (Sec. 42-231).
>
> And while the doctrine of "first in time is first in right" is recognized, a reasonable exercise of this right shall not block full economic development of underground water resources. Early appropriators of underground water shall be protected in the maintenance of reasonable ground water pumping levels as may be established by the state reclamation engineer as herein provided.

The priority of time is established in the Code as shown in Section 42-226, and priority of use is established elsewhere in the Code. In the order of decreasing priority are the following four uses: domestic, agriculture, mining, and manufacturing. As we will be concerned in this study primarily with domestic and agricultural uses of water, no special attention is commanded by the priority of use.

Terms which are not well defined arise in the wording of the Code and give birth to an entirely new study. While "beneficial use" is not well defined, it is well understood and widely used. It is in this first term of water law that we are subjected to accepting someone's decision of exactly what is "beneficial use". We might suggest that beneficial use should be that use which derives some profit, no matter how small, to someone and no harm to anyone. But how are we to define "full economic development" or "reasonable ground water pumping levels"?

Further examination of the Code reveals more duties of the state reclamation engineer.

> After an application has been duly filed with the state reclamation engineer, as in this act provided, it shall be the duty of the state reclamation engineer to make such further investigation as he may deem necessary to determine whether ground water subject to appropriation exists in the location or locations described in the application; and the state reclamation engineer may also require from the applicant such additional information as he, the state reclamation engineer, deems reasonably necessary to enable him to act upon the application (Sec. 42-233).

We should immediately ask what is important to help the engineer determine whether or not an application should be allowed and water appropriated. What information is pertinent to that decision? Answering this question is the purpose of this project.

One final section of the Code pertains to the regulation of ground water in the state of Idaho.

> To supervise and control the exercise and administration of all rights hereafter acquired to the use of ground

> waters and in the exercise of this power he may by summary order, prohibit or limit the withdrawal of water from any well during any period that he determines that water to fill any water right in said well is not there available. To assist the state reclamation engineer in the administration and enforcement of this act, and in making determinations upon which said orders shall be based, he may establish a ground water pumping level or levels in an area or areas having common ground water supply as determined by him as hereafter provided. Water in a well shall not be deemed available to fill a water right therein if withdrawal therefrom of the amount called for by such right would affect, contrary to the declared policy of the act, the present or future use of any prior surface or ground water right or result in the withdrawing of ground water supply at a rate beyond the reasonably anticipated average rate of future natural recharge.

How will the state engineer arrive at a "ground water pumping level"? The most logical approach seems to be from the cost vantage.

Cost of Pumping Water

The determination of the cost of pumping water would not appear to be too difficult if one were to look at it from merely a theoretical standpoint. The equation defining brake water horsepower for pumping water against gravity is given as:

$$bhp = \frac{Qh}{3960\ E} \qquad (18)$$

where Q = pump discharge in gallons per minute
h = pressure head against which the pump works in feet of water
E = pump plant efficiency

From the required brake water horsepower we could estimate the cost of fuel to pump the water. This method of estimating fuel costs necessitates the assumption of a pump efficiency, a fuel consumption rate and an engine efficiency. Empirical data are available for estimating these figures, but the variation is wide and is therefore just an estimate. Estimates can be made from Nebraska Tests (Nebraska

Agricultural Experiment Station), Hicks (17), Johnson Drillers Journal (19), or numerous other documents. Perhaps the best document on pump selection and application is by Hicks.

This estimation of fuel costs is just a part of the total costs involved in pumping water. Smith and Oliver (32) suggest the following procedure for estimating machinery operation costs.

Overhead Costs - referred to as fixed costs, including:

1. Depreciation - the amount of money lost due to loss of resale value of initial investment.
2. Interest - the amount of money lost due to having invested in machinery and therefore not drawing interest.
3. Taxes
4. Insurance

Operating Costs - referred to as variable costs, including:

1. Fuel
2. Lubrication and maintenance - the cost of oil, grease, and repairs not exclusive of preventative maintenance.
3. Labor - the cost due to time spent fueling, maintaining, lubricating or repairing the machine.

There are several sources available for estimating machine life, but Hicks (17) has the best discussion pertaining to pumps.

Although the relative magnitudes of variable costs and fixed costs vary considerably with many factors including annual operating time; for an average annual operation time, the two will be of the same order of magnitude (23).

The above procedure allows one to account for all costs expended in the operation of a pump, but we would like to be able to predict costs of pumping water from known facts concerning the well and pumping unit.

Dickerson, Larson, and Funk (9) have suggested that the following factors are important to pumping costs.

1. Total pumping lift
2. Size of pump and power unit
3. Initial cost of pump and power unit
4. Rate of pumping
5. Fuel consumption
6. Cost of fuel
7. Annual hours of operation

Wantrup and Snyder (33) suggest that lift, power source, volume pumped, and size of the installation are important to pump costs.

Following a procedure as described previously for accounting for pumping costs, Dickerson, Larson, and Funk further outline the procedure for determining costs and present a graphical correlation between costs of pumping water and pumping lift. This is shown in Figure 2.

Numerous other men have attempted accounting budgets for water pumped (5, 23, 24, 25, 30), but few attempt to predict costs.

Kansas State University studies show a graphical correlation of data correlating power consumption to plant efficiency, fuel consumption to plant efficiency, and costs to hours of pump operation as shown in Figure 1.

A non-linear chart of costs against lift, power rate, and

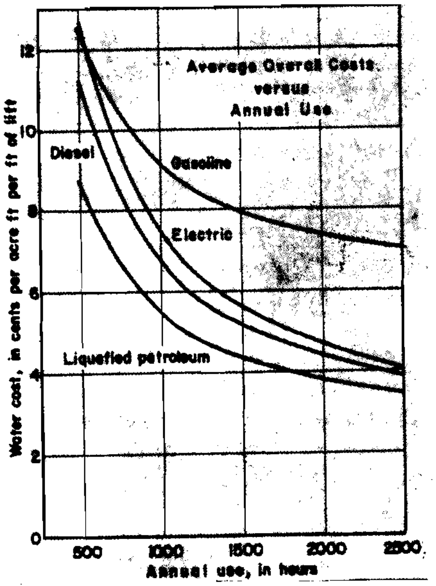
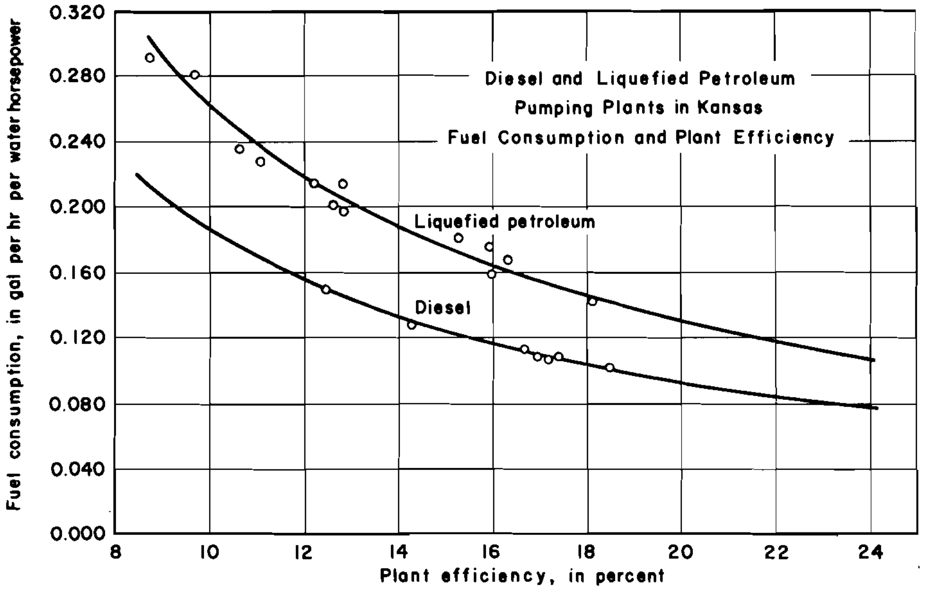


Figure 1

From Johnson Driller's Journal (19)



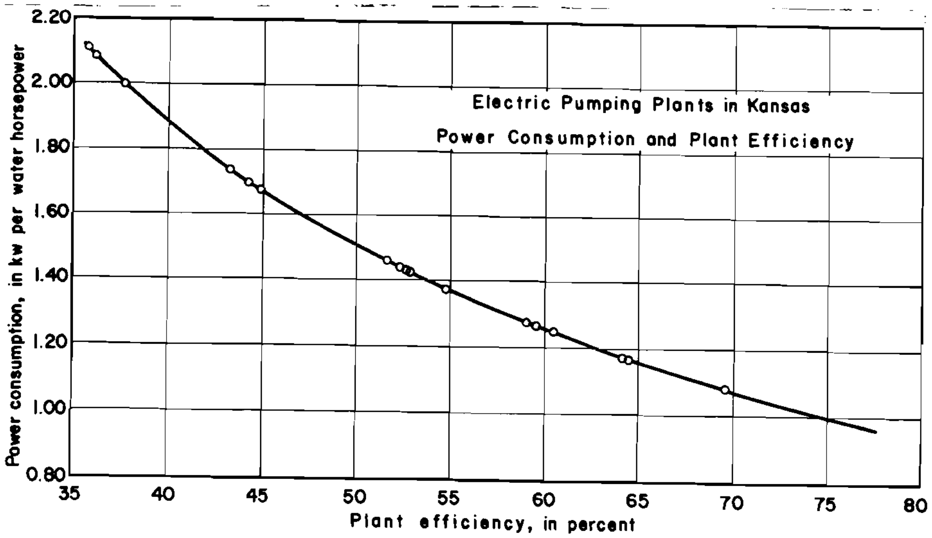
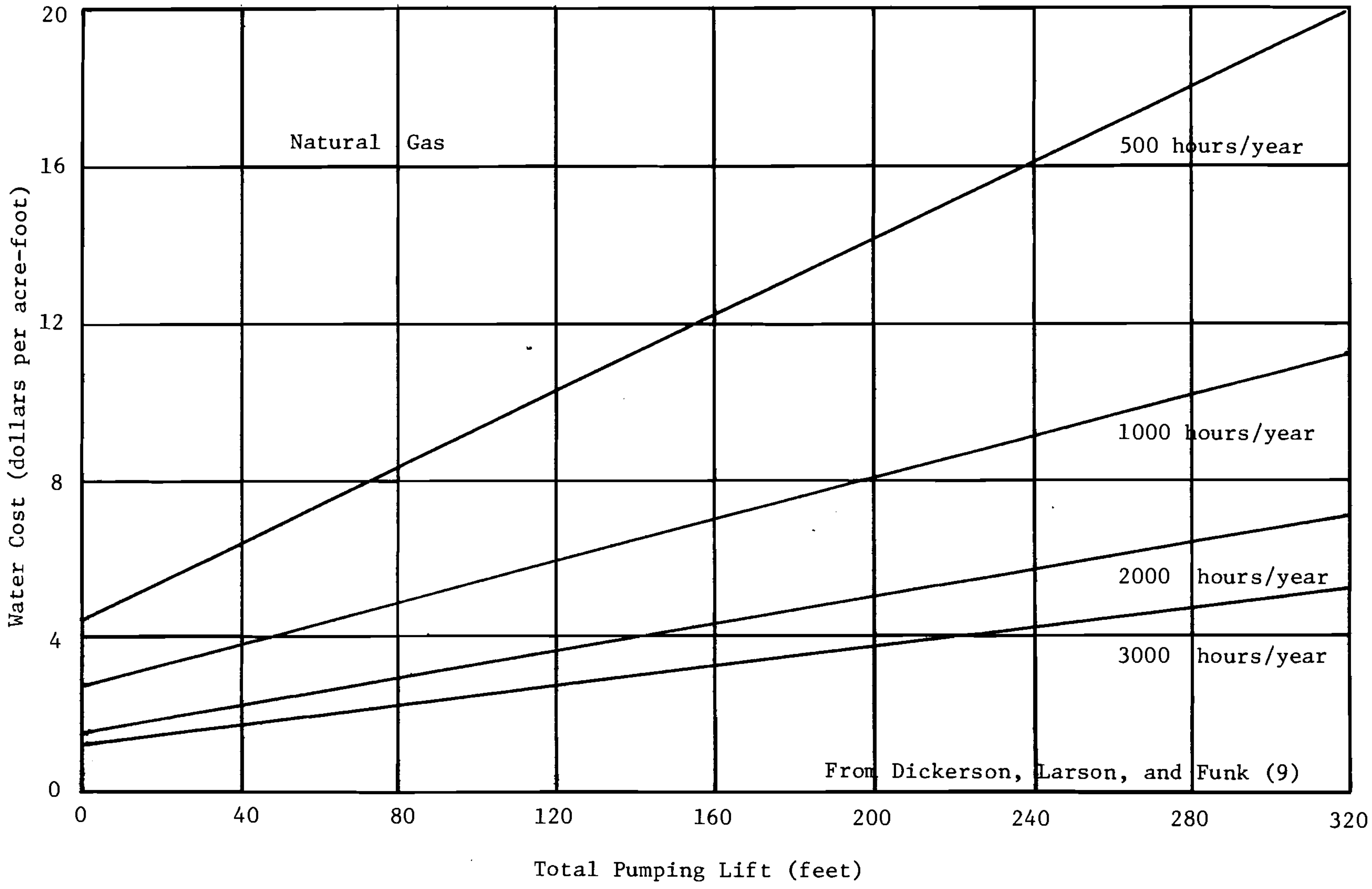


Figure 2 Water Cost



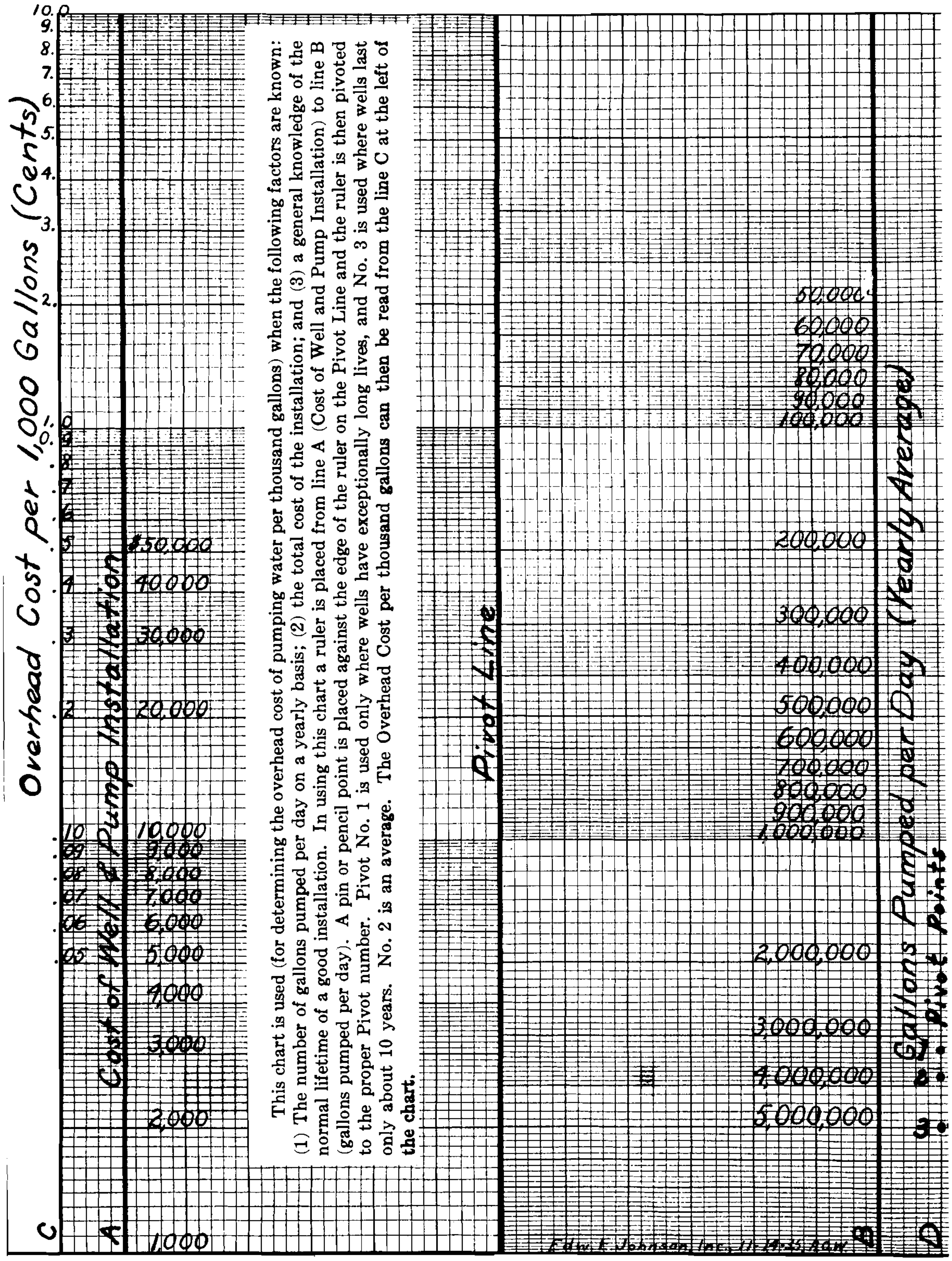
From Dickerson, Larson, and Funk (9)

efficiency is presented by the Johnson Division of Universal Oil Products in Figure 3 (8).

Ackerman presents an analysis of pump costs and correlates costs against pump efficiency and lift. He also presents a method whereby the cost of drilling and developing a well can be estimated (1, 2). These are reproduced in Figures 4 and 5. Long (23) correlated variable costs with acre-feet of water pumped for ten counties in New Mexico and found a significant relationship, but his correlations did not account very well for the deviations in the variable costs. His best correlation was in Luna county where the average lift was 200 feet and the average discharge was 400 gallons per minute. The correlation coefficient was .767 which accounts for approximately 59% of the variation in variable costs. All of his correlations were simple correlations, and he did not try any independent variables other than acre-feet of yield. His poorest correlation was in Chaves and Eddy counties for artesian wells where his coefficient was .415 which accounts for approximately 17% of the variation in variable costs. Long also correlated total investment per well with well depth where the correlation coefficient was .764 and total cost per acre-foot with discharge where the correlation coefficient was .806.

In a study for the Nebraska Agricultural Experiment Station Epp (10) plotted total costs per acre-foot against acre-feet of yield and found the relationship to be hyperbolic. In this study he found that the total cost for pumping with natural gas power and electricity averaged $6.31 and $6.35 respectively, and the total cost per acre-foot per foot of lift was 3.8¢ and 9¢ respectively. This study was concluded in 1954.

Figure 3

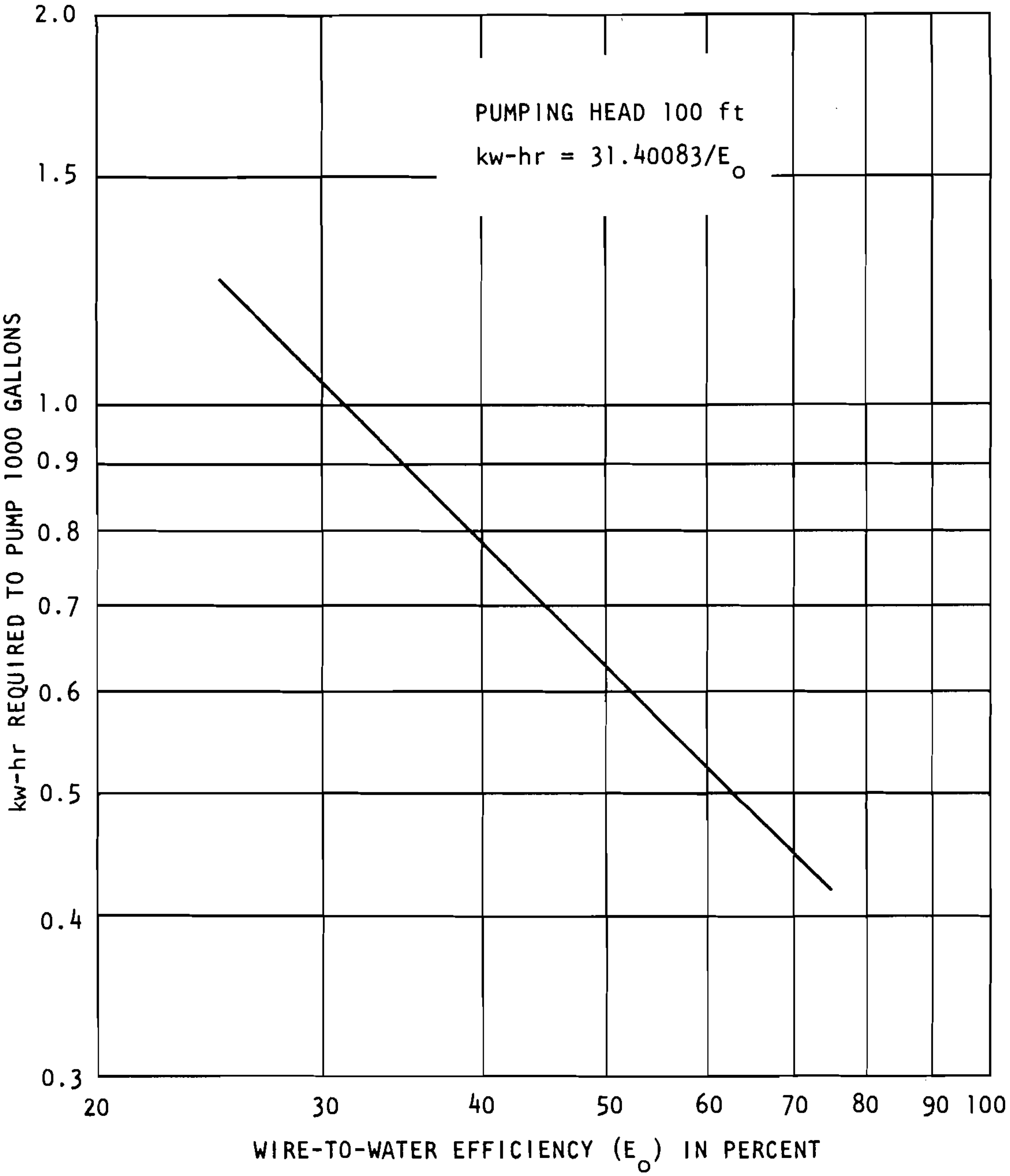


This chart is used (for determining the overhead cost of pumping water per thousand gallons) when the following factors are known: (1) The number of gallons pumped per day on a yearly basis; (2) the total cost of the installation; and (3) a general knowledge of the normal lifetime of a good installation. In using this chart a ruler is placed from line A (Cost of Well and Pump Installation) to line B (gallons pumped per day). A pin or pencil point is placed against the edge of the ruler on the Pivot Line and the ruler is then pivoted to the proper Pivot number. Pivot No. 1 is used only where wells have exceptionally long lives, and No. 3 is used where wells last only about 10 years. No. 2 is an average. The Overhead Cost per thousand gallons can then be read from the line C at the left of the chart.

From Johnson Division of Universal Oil Products (8)

Figure 4

Wire-to-Water Efficiency Versus kw-hr Required to Pump 1000 Gallons of Water

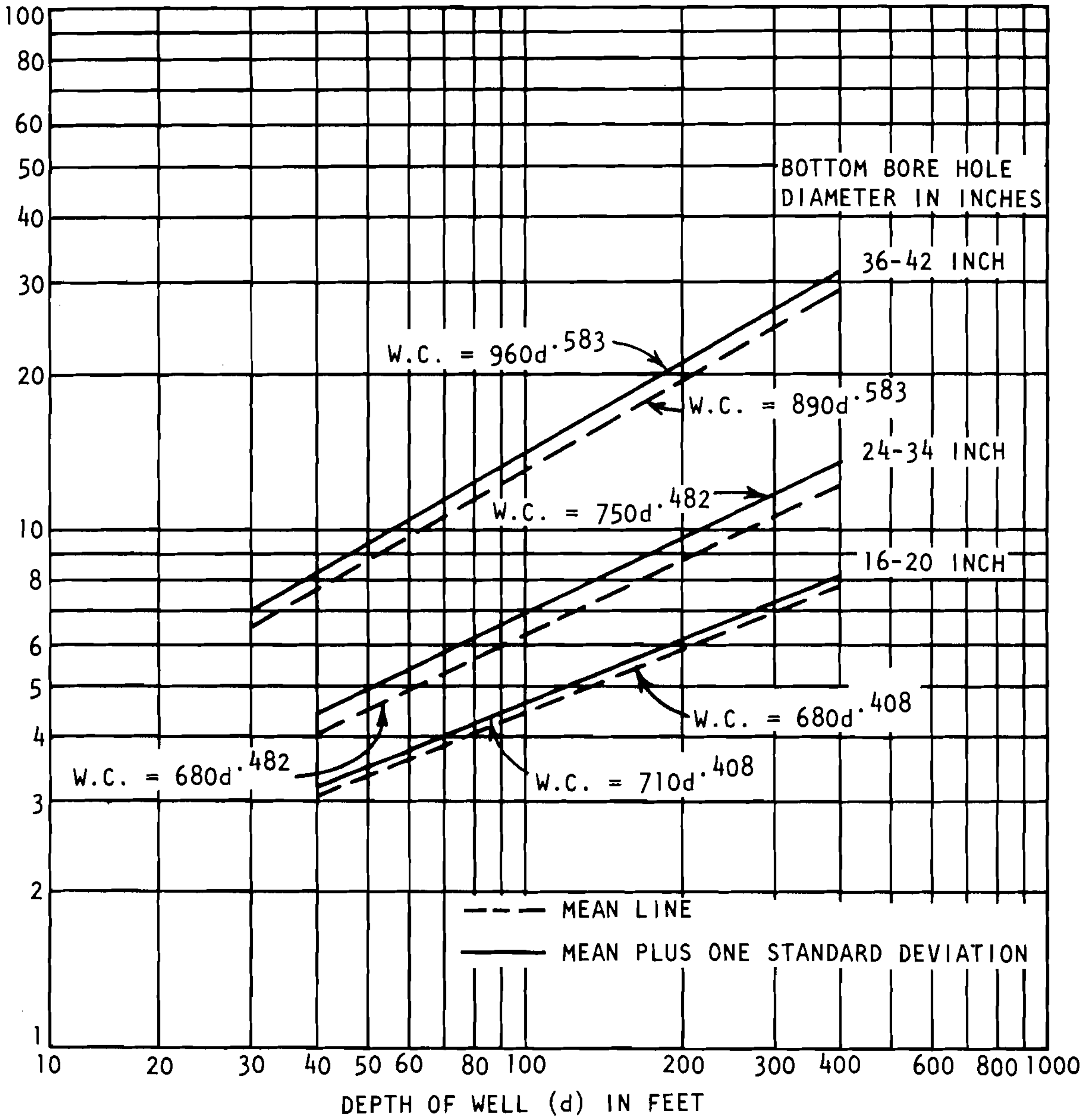


From Ackerman (2)

Figure 5

Cost of Gravel-Packed Wells

Finished in Sand and Gravel



From Ackerman (1)

(ordinate is 1966 well costs in thousands of dollars.)

A very good study of pumping costs, by Miles and Longenbaugh (25), explains how actual data can be used to estimate future pumping costs. It should be noted that their estimates are based on actual data, but do not use actual data for the prediction. Their estimate is at best an optimum level. They do give considerable discussion to the factors summarized hereafter and to the limitations of predicting costs.

A definitive effort toward determining what is an economical pumping lift is presented by Fogel and Myles (13). In their analysis they attempt to determine exactly what lift a farmer can afford with the following procedure:

1. Estimate the cost of operating a pump from:
    a. Estimate pumping plant costs due to given lift and discharge.
    b. Estimate water needed from consumptive use data.
    c. Estimate annual fixed costs from 1.
    d. Estimate annual variable costs from b.
    e. Determine estimated cost per acre-foot of water pumped.
2. Estimate returns from projected increase in production.
3. Estimate non-pumping production costs.
4. Multiply 2 by the appropriate factor to determine profit.
5. Subtract 3 from 4 for the amount that could be spent on pumping water.
6. Determine acre-feet of water needed (1b).

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6. Determine acre-feet of water needed (1b).

7. Determine acre-feet times cost of lifting one foot by:
    a. electricity: (6) x .026
    b. diesel: (6) x .032
8. Determine feet water can be lifted by:
    a. electricity 5/7a
    b. diesel 5/7b

Although the above analysis is empirical, it is an attempt to determine what lift is economically feasible.

Fogel and Myles further suggest that the farmer should determine for himself the answers to the following questions.

1. Will additional income from the well justify the extra investment in the well?
2. Is the water quality adequate to insure future productivity of the farm?
3. What credence should be given to the risk of a falling water table, well damage in construction and several other factors?

It should be pointed out here that the aforementioned literature would lead us to believe that the relationship of cost to lift is not clear and is a function of many variables. Dickerson, Larson, and Funk have shown that cost is clearly a function of lift, plant efficiency, and operation time, and is not linear with all of them.

Of all the literature reviewed, only Gibb and Sanderson (14) and Long (23) tell what the correlation coefficients were between their variables. The others merely present graphical correlations. Gibb and Sanderson found that a highly significant correlation between cost of the pump and the required brake water horsepower existed. The same was true between the cost of wells and the depth of the wells. Intuitively we would expect this, but intuition is far from scientific proof.

From all of the literature reviewed the following variables were presented as being important to the cost of pumping water:

1. lift
2. discharge rate
3. depth of well
4. size of the installation (combination of 1, 2, and 3 above)
5. power source
6. initial cost of pump and power unit
7. efficiency and fuel consumption
8. annual hours of operation
9. repair and maintenance
10. taxes and insurance
11. depreciation
12. yield (product of 2 and 8 above).

Water as a Natural Resource

No discussion of any aspect of water would be complete without some discussion of water as a natural resource and its effect on the arid lands of the world. In the state of Idaho alone there are 11 million acre-feet of water diverted each year for irrigation. The life-giving attribute of water is clearly shown by the annual increase of irrigated acreage in Idaho of 50,000 acres per year over the last 13 years (21). Of the 3.5 million acres of irrigated farmland in

Idaho, one third is irrigated by pumped water. As an example the Sailor Creek project with six pumps of 1250 gallon per minute capacity provides water to 3500 acres. In 1964 the potato yield on this land was 400 hundred weight per acre representing a gross return of $700 per acre (35). With these facts alone, no one will argue that our greatest natural resource should not be protected.

A thorough analysis of all literature on the subject of water as a natural resource would be impossible, but those pertaining to ground water are not so numerous.

Ciriacy-Wantrup suggests that if we are to preserve our ground water we must submit to some authority (6). In order to reduce wasteful depletion of natural resources there are two ways suggested. The first, that of governmental control, is the most commonly used method (for example the Idaho Code) but perhaps inadequate. The second method, that of stabilizing the occupants' tenure on the land, seems more efficient. If an owner or tenant feels insecure on his land, if he feels he may not be able to insure his future occupancy due to mortgages, low prices, or whatever the cause may be, he will be economically insecure and will therefore attempt to maximize short term profit. The most common method used to maximize short term profit is to mine natural resources, and the most commonly mined resource on farm land is water. This tendency to mine resources gives rise to a discussion on the "imbalance of property rights" defined by Ciriacy-Wantrup as:

> Property rights are imbalanced if they lead to such a distribution of revenues and costs from resource utilization among members of a social group that the agent responsible for conservation decisions is not interested

> in taking all of the revenues of all of these revenues and costs into account.

Three remedies for the imbalance of property rights are possible: First, compensation can be offered. This can be accomplished by means of a civil law concerning property rights, or a government subsidy can be offered. Second, prohibitions such as zoning can be imposed thus forcing the semblance of balance. Third, requirements can be made. An example of such a requisite is the requirement of pollution control devices.

In reference to ground water specifically we should be especially careful to avoid the point at which ground water depletion becomes irreversible. When the aquifer becomes compacted and the area actually experiences a decline of ground elevation due to the dewatering of the aquifer, the process is irreversible. This occurs when the safe yield is far exceeded. Such has been the case in areas of the San Joaquin Valley. When salinity protection is inadequate the process is irreversible. The aquifer can become saline if recharge is impure or if drilling allows impure aquifers to pollute the fresh aquifers.

The disadvantages of a safe minimum standard (for example Idaho's ground water level) must be overcome if the policy is to be workable. The exact policy to be followed must not be nebulous, this policy must be proven effective, and it must be shown that no other practice is better (6). Apparently the legislators of the state of Idaho have assumed that the establishment of a ground water pumping level satisfies the criteria.

Considerable discussion has been given to the topic of water as a stock or flow resource. Kelso (20) maintains that ground water is indeed a stock resource, and that theory in itself should cause concern.

Tying together Kelso's theory of water as a stock resource and Ciriacy-Wantrup's theory of insecurity of tenure causing a tenant to mine water, Renshaw (31) discusses how to manage aquifers. As he too feels that no property rights are valid for the future, therefore causing user to tend to maximize the present value of total extractions over time, what is to be done? Where recharge is not significant with respect to withdrawal, the question is not whether to mine, but at what rate. Renshaw states that the value of recharge is determined by first estimating the increase in future costs due to increased lift and hence the discounted savings that would result if water were left. The annual saving has three variables:

1. C - the cost of lifting one acre-foot of water one foot.
2. The amount of lift saved in the future. This is proportional to the inverse of specific yield (S). For a discussion of specific yield see Todd (34).
3. The amount of water to be lifted.

If we call the natural expected recharge (in acre-feet per acre) y and the money saved by recharge M and assume a capitalization factor, a, equal to annual savings divided by a given interest rate the following is true.

$$M = a\ C\ \left(\frac{1}{S} \right) y \qquad (31)$$

Nuzman (29) further discusses the administration of ground water.

The USDA (28) has developed a summary of methods used to recharge ground water. Since the topic often arises, it is presented here.

In the basin method of recharge water is impounded in a series of small basins or by dikes which follow the contour. This method is especially applicable if gullies cut across the land. In the furrow method a series of furrows or flat bottomed ditches are constructed close together to utilize maximum area. This method is most applicable where recharge water is abundant. A method of releasing the water to run wildly on the surface of the ground is known as the flooding method, but this method works only for nearly level land. Old wells, mine shafts, or gravel pits are used for recharge, and water is allowed to flow freely into these areas. Although water low in suspended matter is needed and recharge is slow due to small recharge area, this method is especially helpful if high percolation rates are needed. When a well is used to inject water under pressure where the aquifer is located underneath a confining layer the method is called the injection well method.

Several items of caution must be noted before attempting recharge. An area of local recharge must be found where water has access to the aquifer or the efforts to recharge it will be futile. The operator should be careful not to compact the soil in the recharge area. The quality of the recharge water should be good and one should be careful to check for high sodium contents as sodium can be most harmful to soil. The grass and vegetation in the recharge area will aid infiltration, so effort should be made not to destroy it.

It is significant to note that in many states the use of water for ground water recharge is not a beneficial use.

Choosing Farming Patterns to Fit Pumping Conditions

Several studies have been conducted which attempt to optimize farm profits with respect to pumping conditions including lift. One such study by Cheline (3) relates the profits of optimum farms of three different sizes to pumping lifts. Another by Grandin (15) discusses the feasibility of farming under irrigation when water must be pumped from a considerable depth.

Lindeborg (7) has shown how much a farmer can pay for irrigation water costs by accounting for all expenses using different farming patterns.

Many detailed studies have been undertaken with the result being an analysis of pumping costs for a specific area or specific size farm but with no correlation of factors. Two such studies, Lamoreaux (22) and Haynes (16) are representative of this type effort.

Summary of Literature

Ground water is a natural resource that must be protected. The authority for the protection and use of ground water in Idaho is clearly defined, but the criteria is not. Several factors have been presented which suggest criteria for judgment and the decision then must be a singular one.

It has been pointed out that ground water should be dealt with in the total picture of water, not just as a single entity, and that the basis for administration should be economic, not merely financially economic but socially economic too.

Determination of the actual cost of water can be done accurately in an accounting procedure, but although there are several proposals of ways to predict the cost of pumping water, none are refined to the point that an administrative decision could be made based on them. The relationship between the cost of pumping water and lift is very important but not fully understood.

It should be remembered that although most efforts deal with the tangible and immediately accountable costs of pumping water, the socio-economic costs should not be forgotten.

CHAPTER III

METHODOLOGY

Variables

In order to evaluate what parameters are important to the cost of pumping water, one must first determine the total cost and then attempt to determine the source of that cost. This implies the collection of data. However, before collecting data, one must know what data to collect. The problem became one then of where to begin.

The following variables were chosen to be used in the analysis:

1. Total pumping lift in feet
2. Discharge rate in gallons per minute
3. Nameplate horsepower of power unit
4. Hours of operation per season
5. Total yield of water per season in acre-feet
6. Investment cost of well, pump, and power unit (excludes distribution equipment) in dollars
7. Total costs in dollars per acre-foot
   a. Variable costs
   b. Fixed costs
      i. Depreciation
      ii. Interest
      iii. Taxes
8. Variable costs in dollars per acre-foot
   a. Fuel costs
   b. Operation and maintenance costs
   c. Associated labor

Data

Collection of data which contained all of the variables for each observation became very difficult because few studies undertaken thus far have used all of the above variables, and few farmers are really certain of the exact values of each variable. Some data were gathered from literature on previous studies. These data were assumed to be reliable. The observations in these cases were averages of several wells under similar conditions, and in some cases the separation of total costs into fixed and variable costs was not known. Observations gathered from literature totaled 40.

The remainder of the data were obtained from operating records of Idaho Power Company and individual farms. These observations totaled 153.

Due to the drawdown of wells during long and continuous pumping, the total pumping lift increases with time in most cases. As many of the wells studied were pumped into mobile sprinkling systems, some variation due to elevation of the sprinkler heads was also encountered. In most cases the depth to water in the well was measured by the appropriate state agency and approximate corrections were allowed for friction loss and sprinkler pressure. It is assumed that the input data are reasonably accurate. Input data are presented in the Appendix.

Discharge measurements are assumed to be quite accurate as they were measured either by state agencies or by the person investigating.

Operation time is reliable in most cases, especially on the electric units, as a meter had been installed which read the cumulative time directly. On some of the natural gas engines there may have been malfunctions with the hour meter and some error may be introduced here. There really is no way of checking the accuracy of this measurement, but inspection of fuel consumption compared to hours of operation did give the investigators some indication of malfunctions in hour meters.

The only other variable which may be in error is that of operation and maintenance cost. Few farmers keep separate accounts of lubrication costs or repair costs for their wells, and this factor involves approximation. In many cases this factor had to be estimated, and this was accomplished by comparison with those observations where operation and maintenance costs were known.

Incomplete Data

Some cases were encountered where the exact investment cost could not be determined. In these cases the costs were estimated from other known relationships. This estimation will cause some error and intercorrelation for the input data, but it is not expected that the estimated costs are far in error. Care was taken to make any error an overestimate if there was to be any error. In the final analysis 193 observations were used.

Data Collection

No attempt was made to restrict the collection of data to Idaho, and data were collected over a five state area including Colorado, Idaho, California, New Mexico, and Arizona.

All data were second hand; no data were obtained directly. Several data points were obtained from technical publications, but the bulk of the data was collected through the courtesy of Idaho Power Company and a large farm in Colorado.

In all cases all data points for a given observation point were obtained from the same source to eliminate the variation in reporting procedures. It should be noted that any consistent difference in reporting procedures will not significantly affect the correlation if all data points for an observation are from the same source.

Method of Analysis

The method of analysis chosen for this study was a step-wise multiple regression analysis programmed on the IBM 360 computer at the University of Idaho computer center.

The program ran simple correlations between all combinations of the input data and the multiple regression analysis correlating the dependent variable (cost) to the selected independent variables. In the step-wise analysis the effect of each independent variable on the correlation is easily seen and is printed out in order of decreasing effect. In other words the program employed does a step-up multiple regression.

Independent Variables

The choice of independent variables was necessarily limited to mathematical combinations of the independent variables. The following variables were chosen:

1. F - the product of lift, discharge, and operating time. This variable should be a measure of fuel consumption and therefore a measure of fuel costs.
2. E - the product of lift and discharge divided by nameplate horsepower. This is a crude measure of efficiency and design.
3. Y - total water yield in acre feet per season.
4. P - product of lift and discharge, a measure of required water horsepower.
5. L - lift in feet.
6. Q - discharge rate in gallons per minute.

7. T - operating time in hours.
8. H - nameplate engine horsepower.
9. I - Investment cost divided by yield, in dollars per acre-foot, a measure of annual fixed cost.

Dependent Variables

1. Y_1 - total cost divided by yield in dollars per acre-feet.
2. Y_2 - variable cost divided by yield in dollars per acre-feet.

Choosing Equations

In choosing the equations with which to estimate the costs, the regression analysis was run using all nine variables with Y_1. From the respective correlations to cost, the following equations were chosen for analysis on the computer:

1. $Y_1 = b_1 L + b_2 I + b_3 E + b_4 F + C$
2. $Y_1 = b_1 L + b_2 I + b_3 P + b_4 E + C$
3. $Y_1 = b_1 L + b_2 Q + b_3 H + b_4 T + b_5 Y + b_6 I + b_7 E + b_8 P + b_9 F + C$
4. $Y_1 = b_1 L + b_2 I + C$
5. $Y_1 = b_1 L + b_2 I + b_3 E + C$
6. $Y_2 = b_1 Y_1 + C$
7. $Y_2 = b_1 L + b_2 Q + b_3 H + b_4 T + b_5 Y + b_6 P + b_7 E + b_8 F + C$

8. $Y_2 = b_1 L + b_2 F + C$

9. $Y_2 = b_1 L + C$

10. $\log_e (IY) = b_1 \log_e (P) + C$

11. $Y_2 = b_1 L + b_2 P + C$

12. $Y_2 = b_1 L + b_2 E + C$

13. $Y_2 = b_1 L + b_2 P + b_3 E + C$

14. $I Y = b_1 P + C$

where a-k are partial regression coefficients and C is a constant. The basis for choosing equations 10 and 14 was not to correlate the costs of pumping water, but rather to attempt to correlate initial investment costs with water horsepower, and to determine what effect, if any, the estimation of initial investment cost had on intercorrelation. This correlation was suggested by Ackerman (2).

Separation of Data

The data used in this study could be categorized in four groups. The first group of 25 observations were observations for wells where each observation was an average of several wells under similar conditions. For these 25 observations the separation of total costs into variable and fixed costs was not known, so only correlations with total costs could be attempted.

The second group which included 116 observations were for individual electric wells. Many of these observations did not include the investment cost, so this variable was estimated from known relationships and driller's catalogs.

A group of 44 observations was used for individual natural gas wells. Data for this group were complete and probably the most reliable of all data used in this study.

The final group of 8 wells were observations for averages of wells under similar conditions where the separation of total costs into variable and fixed costs was known.

The data were separated into four runs for correlations. The first run was made with all 193 observations and was run only for Y_1 correlations. The second run of 168 observations included only those for which the separation of total costs into variable and fixed costs was known. The two remaining runs were made with just electric wells and just natural gas wells respectively.

CHAPTER IV

RESULTS

Simple correlation coefficients and partial regression coefficients are presented in chart form in Tables (1-4, 7-11). The coefficients of correlation varied from .27 to .99 with coefficients of determination of .08 to .98 respectively. This means that 8 per cent and 98 per cent of the variation in the dependent variable was accounted for. For example, as shown in Tables 9 and 11, the best prediction equation for total costs divided by yield, Y_1, using equation 3* is: $Y_1 = .753\ L - .057\ T + 11.09\ I + 263$. This equation has a coefficient of determination of .88.

The best fit equation for all 193 observations was with equation 3 which yielded a coefficient of determination value of .86. However, using equation 4 with only 3 variables the coefficient of determination was .84, and with equation 5 with 2 variables the coefficient of determination was .80. Tables (1-4) show the intercorrelation of variables with their respective levels of significance.

For 168 observations the best fit equation with Y_1 was equation 3 with the coefficient of determination equal to .93. Again equation 4 was nearly as good with the coefficient of determination equal to .92. With correlations of Y_2 the best fit was with equation 7 where the coefficient of determination was .52. Equation 12 using just 2 variables had a coefficient of determination of .45. With the simple correlation of lift against variable cost, the correlation coefficient was .39. This is significant at the .5 per cent level. It is suggested

Table 1

Intercorrelations

Simple Correlation Coefficients

All Wells (193 observations)

	Y_1	Y_2	L	Q	H	T	Y	I	P	E	F
Y_1	1.000										
Y_2	-----	1.000									
L	.596	-----	1.000								
Q	- .315	-----	.053	1.000							
H	.133	-----	.573	.741	1.000						
T	- .606	-----	- .319	.255	.078	1.000					
Y	- .518	-----	- .114	.847	.589	.676	1.000				
I	.879	-----	.502	- .308	.032	- .708	-----	1.000			
P	.060	-----	.583	.798	.946	.052	.598	.023	1.000		
E	- .032	-----	.444	.435	.306	- .061	.250	.061	.551	1.000	
F	- .315	-----	.253	.788	.780	.551	.879	- .416	.812	.402	1.000

.138 is significant at the 5 percent level.

.181 is significant at the 1 percent level.

Table 2

Intercorrelations

Simple Correlation Coefficients

Wells with Y_2 Known (168 observations)

	Y_1	Y_2	L	Q	H	T	Y	I	P	E	F
Y_1	1.000										
Y_2	.758	1.000									
L	.597	.630	1.000								
Q	- .353	- .242	- .023	1.000							
H	.040	.191	.499	.762	1.000						
T	- .735	- .453	- .317	.338	.120	1.000					
Y	- .592	- .400	- .163	.865	.611	.711	1.000				
I	.955	-----	.522	- .344	.006	- .713	.597	1.000			
P	.004	.158	.511	.803	.956	.138	.629	.022	1.000		
E	- .013	.052	.412	.422	.313	.108	.306	.011	.532	1.000	
F	- .431	- .174	.153	.802	.766	.631	.903	- .458	.808	.421	1.000

.149 is significant at the 5 percent level.

.196 is significant at the 1 percent level.

Table 3

Intercorrelations

Simple Correlation Coefficients

Electric Wells (116 observations)

	Y_1	Y_2	L	Q	H	T	Y	I	P	E	F
Y_1	1.000										
Y_2	.886	1.000									
L	.458	.648	1.000								
Q	- .252	- .160	.097	1.000							
H	.055	.218	.536	.803	1.000						
T	- .495	- .387	.036	.188	.165	1.000					
Y	- .452	- .310	.069	.869	.716	.576	1.000				
I	.918	-----	.322	.244	- .011	- .494	- .462	1.000			
P	.037	.199	.557	.838	.961	.155	.719	- .024	1.000		
E	- .005	.072	.389	.399	.243	.085	.283	- .021	.456	1.000	
F	- .253	- .048	.422	.776	.841	.537	.882	- .320	.875	.392	1.000

.174 is significant at the 5 percent level.

.228 is significant at the 1 percent level.

Table 4

Intercorrelations

Simple Correlation Coefficients

Natural Gas Wells (44 observations)

	Y_1	Y_2	L	Q	H	T	Y	I	P	E	F
Y_1	1.000										
Y_2	.787	1.000									
L	.333	.290	1.000								
Q	- .028	- .007	.502	1.000							
H	.146	.163	.822	.848	1.000						
T	- .525	- .186	- .416	.077	- .198	1.000					
Y	- .493	- .153	- .301	.261	- .026	.980	1.000				
I	.979	-----	.295	- .037	.113	- .612	- .582	1.000			
P	.137	.107	.824	.892	.951	- .225	- .046	.128	1.000		
E	.231	.116	.762	.550	.564	- .312	- .205	.243	.762	1.000	
F	- .515	- .199	.114	.593	.405	.795	.876	- .599	.387	.124	1.000

.288 is significant at the 5 percent level.

.372 is significant at the 1 percent level.

Table 5

Coefficients of Variation of Input Data

	all observations (all wells)	168 observations (Y_2 known)	116 observations (electric wells)	44 observations (natural gas wells)
L	.41	.37	.39	.17
Q	.55	.54	.53	.13
H	.58	.55	.61	.20
T	.46	.48	.31	.54
Y	.78	.98	.64	.62
I	.83	.82	.92	.36
P	.65	.61	.64	.28
E	.22	.20	.19	.89
F	.93	.92	.77	.47
Y_1	.64	.66	.56	.30
Y_2	---	.37	.41	.20

Table 6

Order of Entry of Independent Variables

in Stepwise Multiple Regression

	all wells 193 observations	wells with Y_2 known 168 observations	electric wells 116 observations	natural gas wells 44 observations
1	I	I	I	I
2	L	L	L	Y
3	E	T	T	L
4	P	E	E	P
5	H	P	Q	T
6	F	Y	F	Q
7	T	F	P	H
8	Y	Q	H	E
9	Q	H	Y	F

Table 7

Partial Regression Coefficients (all wells)

Independent Variable	L	Q	H	T	Y	I	P	E	F	Y*	#
Y_1	1.720					13.34		- .205	-.001	539	1
Y_1	1.849					13.22	- .129	- .193		510	2
Y_1	1.736	.010	3.960	- .067	.096	13.89	-1.748	- .053	.013	205	3
Y_1	1.056					14.41				63.5	4
Y_1	1.680					13.51		- .208		541	5
ln YI		ln P:	.428							1.66	10
YI							1.550			661	14

Y* - Y intercept

- Equation number

Table 8

Partial Regression Coefficients (wells with Y_2 known)

Independent Variable	L	Q	H	T	Y	I	P	E	F	Y*	#
Y_1	1.131					14.47		- .063	-.005	216	1
Y_1	1.151					14.91	.123	- .063		201	2
Y_1	1.418	- .060	- .674	- .168	.362	13.98	- .273	- .072	.006	516	3
Y_1	.804			- .087		13.92				272	3*
Y_1	.751					15.61				47.3	4
Y_1	.997					15.18		- .078		232	5
Y_2			Y_1: .188							252	6
Y_2	.521	- .011	.945	- .005	- .206		- .083	- .005	.002	305	7
Y_2	.792				- .120					245	7*
Y_2	.860								-.006	194	8
Y_2	.860									165	9
ln (IY)			log (P): .478							.986	10
Y_2	1.015						- .133			173	11
Y_2	1.001							- .062		314	12

Independent Variable	L	Q	H	T	Y	I	P	E	F	Y*	#
Y_2	1.067						- .082	- .049		288	13
IY							1.595			597	14

Y* - Y intercept

- Equation number

* indicates regression was stopped when R^2 did not significantly increase with more independent variables.

Table 9

Partial Regression Coefficients (electric wells)

Independent Variable	L	Q	H	T	Y	I	P	E	F	Y*	#
Y_1	.923					11.26	- .035		-.004	227	1
Y_1	.872					11.65	- .063	- .036		225	2
Y_1	.793	- .036	.429	- .083	.0071	11.01	- .216	- .016	.006	394	3
Y_1	.753			- .057		11.09				263	3*
Y_1	.666					12.74				129	4
Y_1	.779					11.78		- .044		244	5
Y_2			Y_1: .381							144	6
Y_2	1.002	- .043	.363	- .065	.000		.082	- .021	-.005	354	7
Y_2	1.149			- .075	- .053			- .039		407	7*
Y_2	1.287								-.008	115	8
Y_2	1.027									107	9
ln YI			ln P: .511							.612	10
Y_2	1.233						- .130			107	11
Y_2	1.157							- .058		256	12

Independent Variable	L	Q	H	T	Y	I	P	E	F	Y*	#
Y_2	1.283						.099	- .044		221	13
YI							1.616			638	14
Y_1	2.005		1.652	- .112					-.031	457	**

Y* - Y intercept

- Equation number

**Special equation run without variable I.

* indicates regression was stopped when R^2 did not significantly increase with more independent variables.

Table 10

Partial Regression Coefficients (natural gas wells)

Independent Variable	L	Q	H	T	Y	I	P	E	F	Y*	#
Y_1	.733					18.58	- .213		.037	460	1
Y_1	.368					17.06	- .213	- .157		455	2
Y_1	22.31	9.368	-71.50	-2.021	6.783	17.15	-1.695	-2.946	.187	1135	3
Y_1					.627	18.60				131	3*
Y_1	.368					17.14				200	4
Y_1	.932					17.17		- .187		541	5
Y_2		Y_1:	.156							247	6
Y_2	3.155	1.198		- .232	3.463		-1.658	- .081	-.165	- 827	7
Y_2	3.230	1.480			2.320		-1.915		-.168	-1281	7*
Y_2	.497								-.015	400	8
Y_2	.456									334	9
ln (YI)		ln P:	.271							3.52	10
Y_2	1.003						- .387			271	11
Y_2	.767							- .102		521	12

Independent Variable	L	Q	H	T	Y	I	P	E	F	Y*	#
Y_2	1.098						- .332	.057		384	13
(YI)							.647			869	14

Y* - Y intercept

\# - Equation number

* indicates regression was stopped when R^2 did not significantly increase with more independent variables.

Table 11

Accuracy of Prediction Equations

Equation	Number of Observations	Coefficient of Determination	Standard Error of Estimate
1	193	.84	254
2	193	.84	253
3	193	.86	246
4	193	.80	281
5	193	.84	252
10	193	.70	.233
14	193	.68	283
1	168	.93	168
2	168	.93	168
3	168	.94	157
3*	168	.93	166
4	168	.92	175
5	168	.93	170
6	168	.58	103
7	168	.52	112
7*	168	.48	113
8	168	.47	115
9	168	.39	123
10	168	.77	.207
11	168	.43	119
12	168	.45	118
13	168	.46	117

Equation	Number of Observations	Coefficient of Determination	Standard Error of Estimate
14	168	.73	255
1	116	.88	135
2	116	.88	136
3	116	.89	134
3*	116	.88	134
4	116	.87	138
5	116	.88	136
6	116	.79	76.2
7	116	.63	103
7*	116	.63	102
8	116	.54	112
9	116	.42	125
10	116	.83	.193
11	116	.46	122
12	116	.46	122
13	116	.48	120
14	116	.82	227
#	116	.57	260
1	44	.97	94.6
2	44	.96	104.6
3	44	.98	78.1
3*	44	.97	98.5
4	44	.96	104.4
5	44	.96	104.1
6	44	.62	65.6

Equation	Number of Observations	Coefficient of Determination	Standard Error of Estimate
7	44	.60	73.0
7*	44	.57	73.2
8	44	.15	99.6
9	44	.09	101.5
10	44	.24	.163
11	44	.15	99.2
12	44	.12	101.0
13	44	.16	100.0
14	44	.08	272

\# Special equation without variable I.

* Indicates regression was stopped when R^2 did not significantly increase with more independent variables.

Equation	Number of Observations	Coefficient of Determination	Standard Error of Estimate
7	44	.60	73.0
7*	44	.57	73.2
8	44	.15	99.6
9	44	.09	101.5
10	44	.24	.163
11	44	.15	99.2
12	44	.12	101.0
13	44	.16	100.0
14	44	.08	272

Special equation without variable I.

* Indicates regression was stopped when R^2 did not significantly increase with more independent variables.

that the calculated F level for a good predictor be four times that of the F level of the variable, and in this case it is (at 1% level).

The electric well observations did not yield as good coefficient of determination values for Y_1 as the other runs but better values for Y_2. The best coefficient of determination with Y_1 was .89 with equation 3 and .63 for Y_2 with equation 7. Using equation 13 a coefficient of determination of .48 was found using only 3 variables.

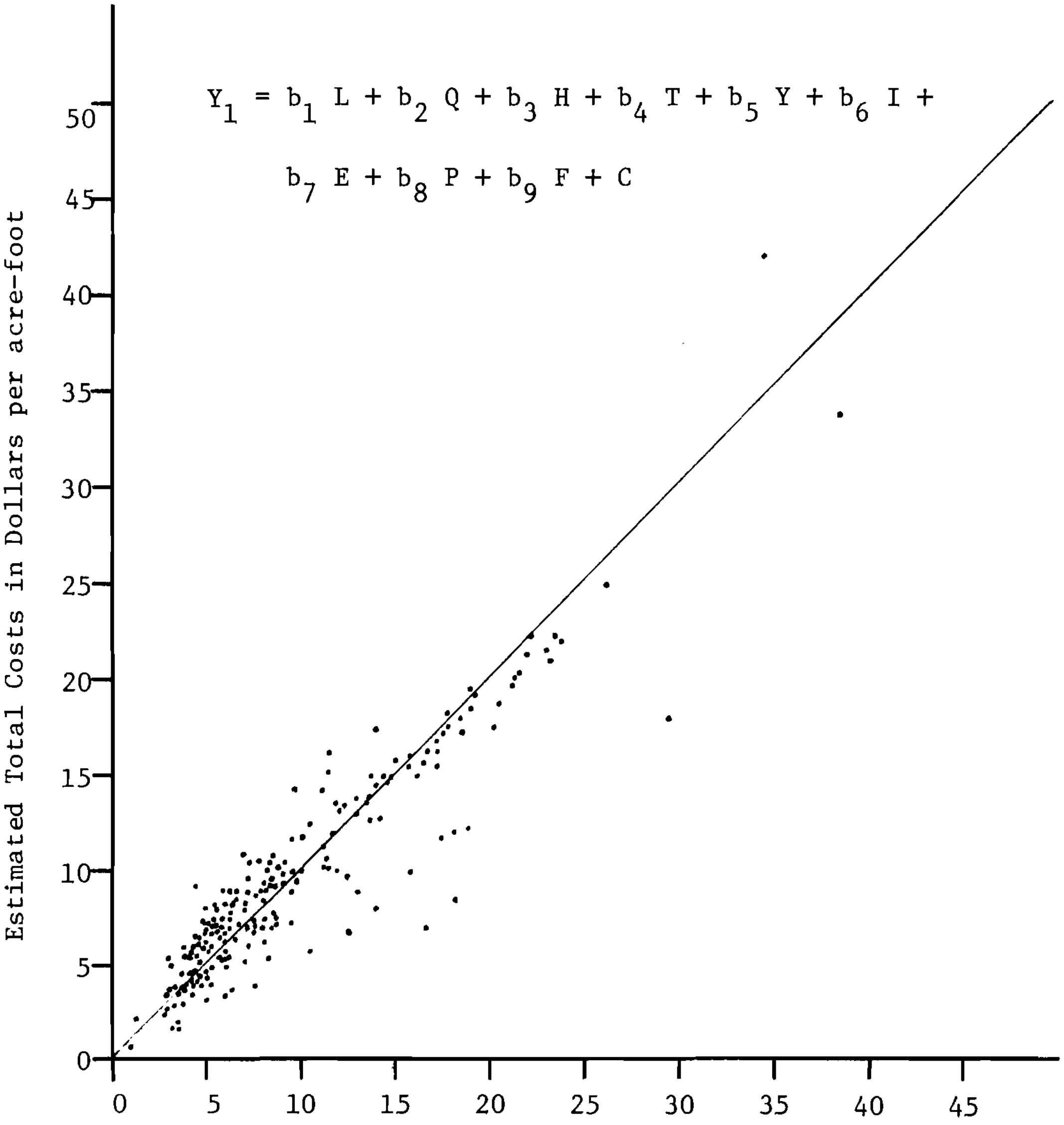
Natural gas well observations yielded very good correlations for Y_1 but rather poor correlations for Y_2. The best coefficients of determination were .98 and .60 with equations 3 and 7 respectively.

The values of the estimated costs per unit yield for several prediction equations shown in Tables (7-11) are plotted against the actual cost per unit yield in Figures (6-16).

Figure 6

Estimated Costs Versus Actual Costs, Equation 3

All Wells (193 observations)



Actual Total Costs in Dollars per acre-foot

Figure 7

Estimated Costs Versus Actual Costs, Equation 3

Wells with Variable Costs Known (168 observations)

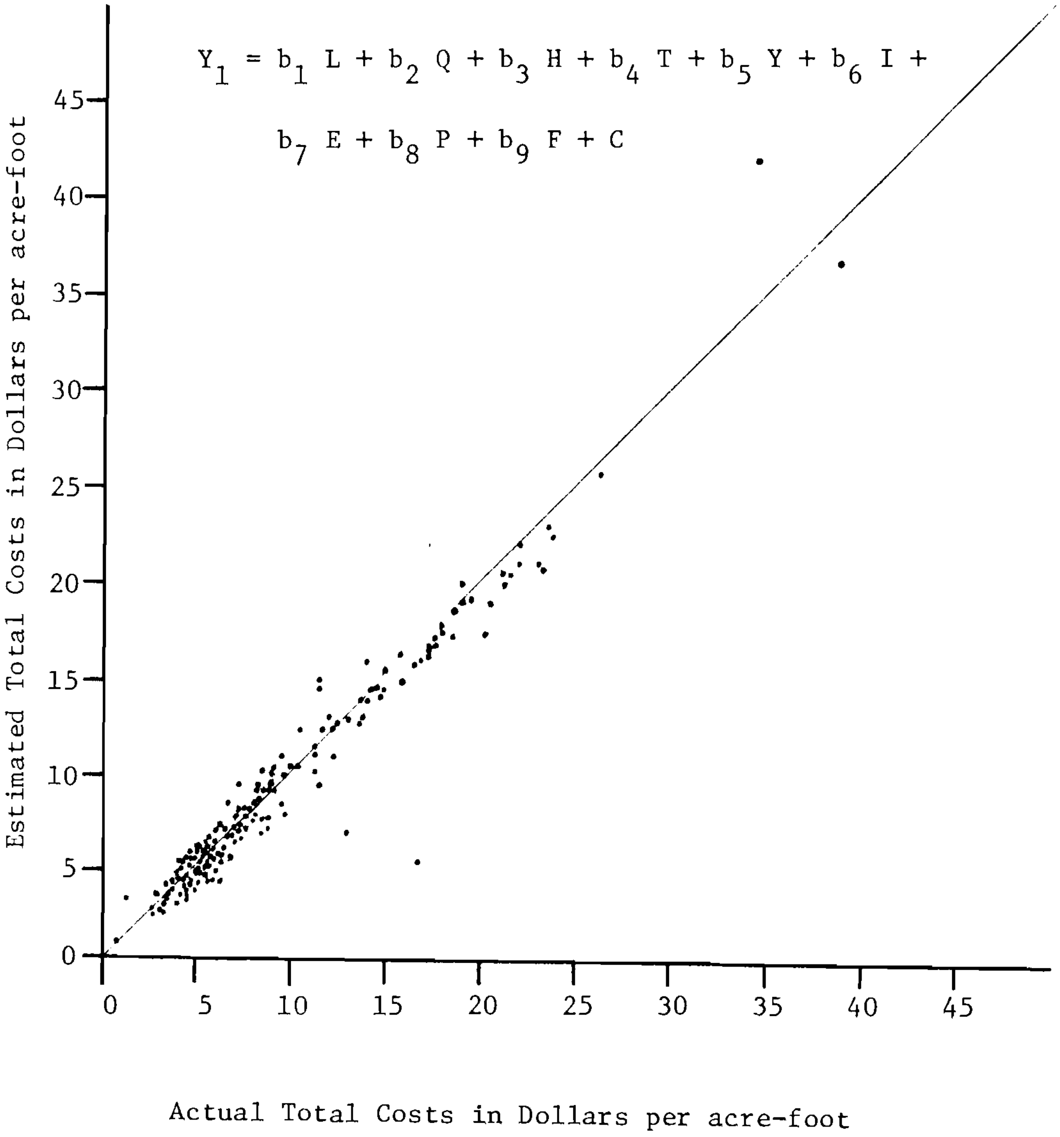
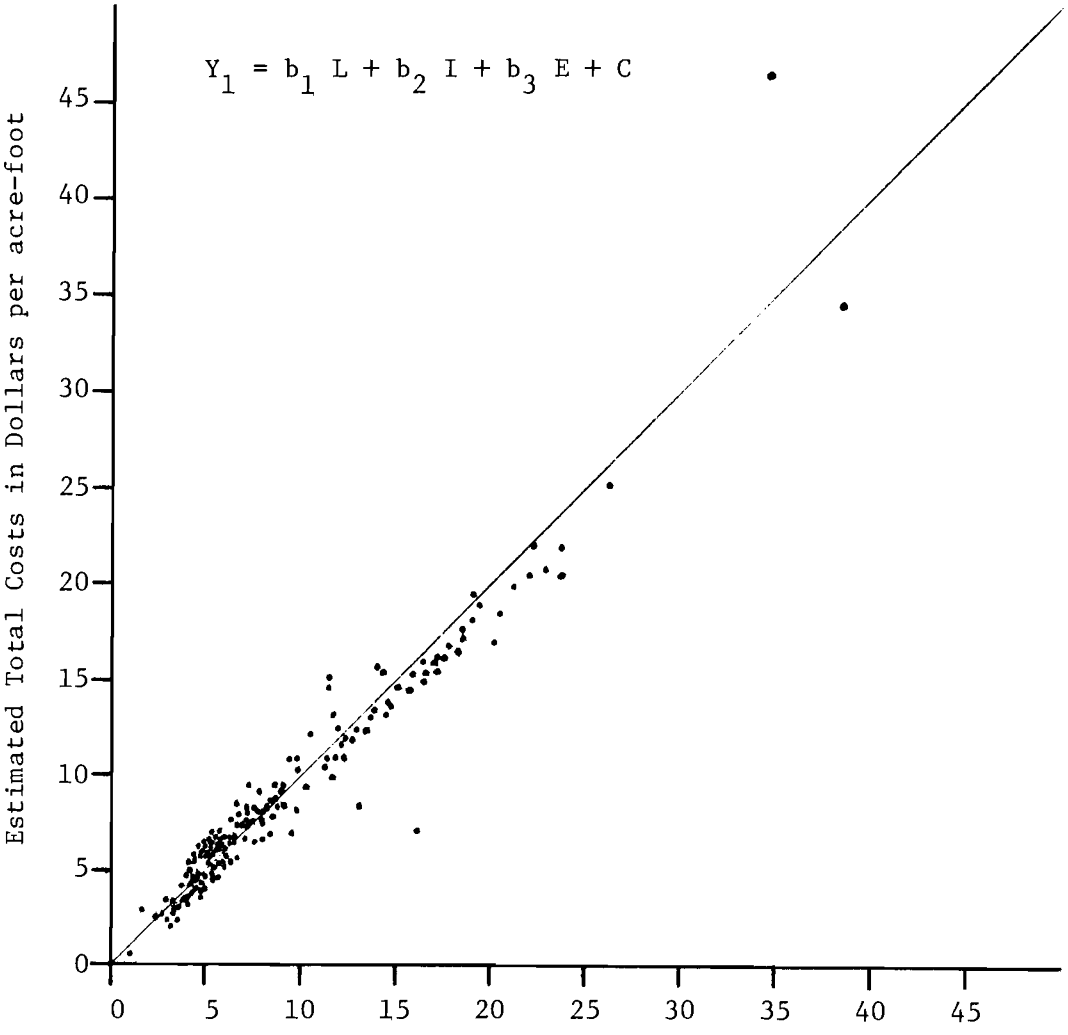


Figure 8

Estimated Costs Versus Actual Costs, Equation 5

Wells with Variable Costs Known (168 observations)



Actual Total Costs in Dollars per acre-foot

Figure 9

Estimated Costs Versus Actual Costs, Equation 7

Wells with Variable Costs Known (168 observations)

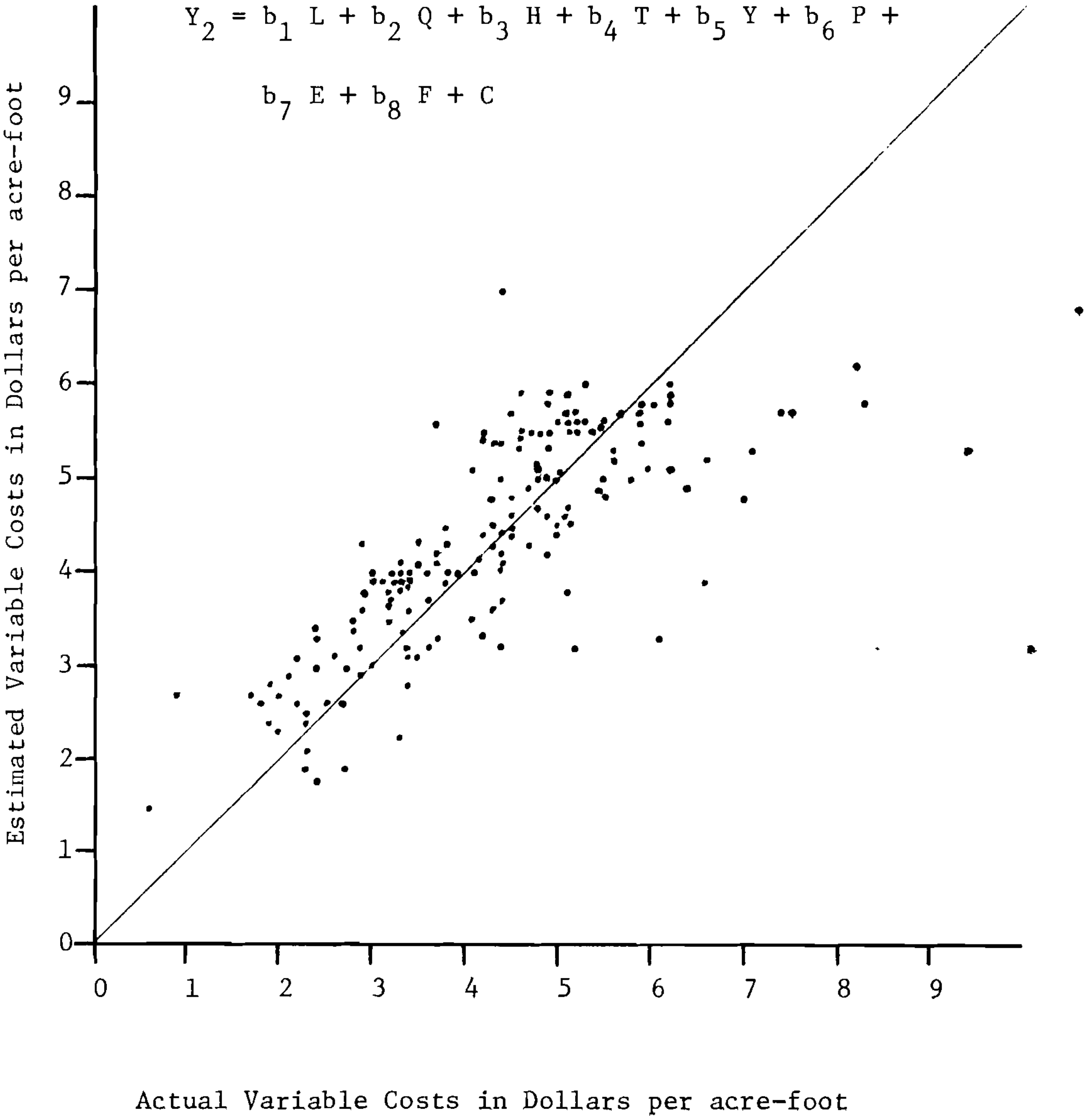
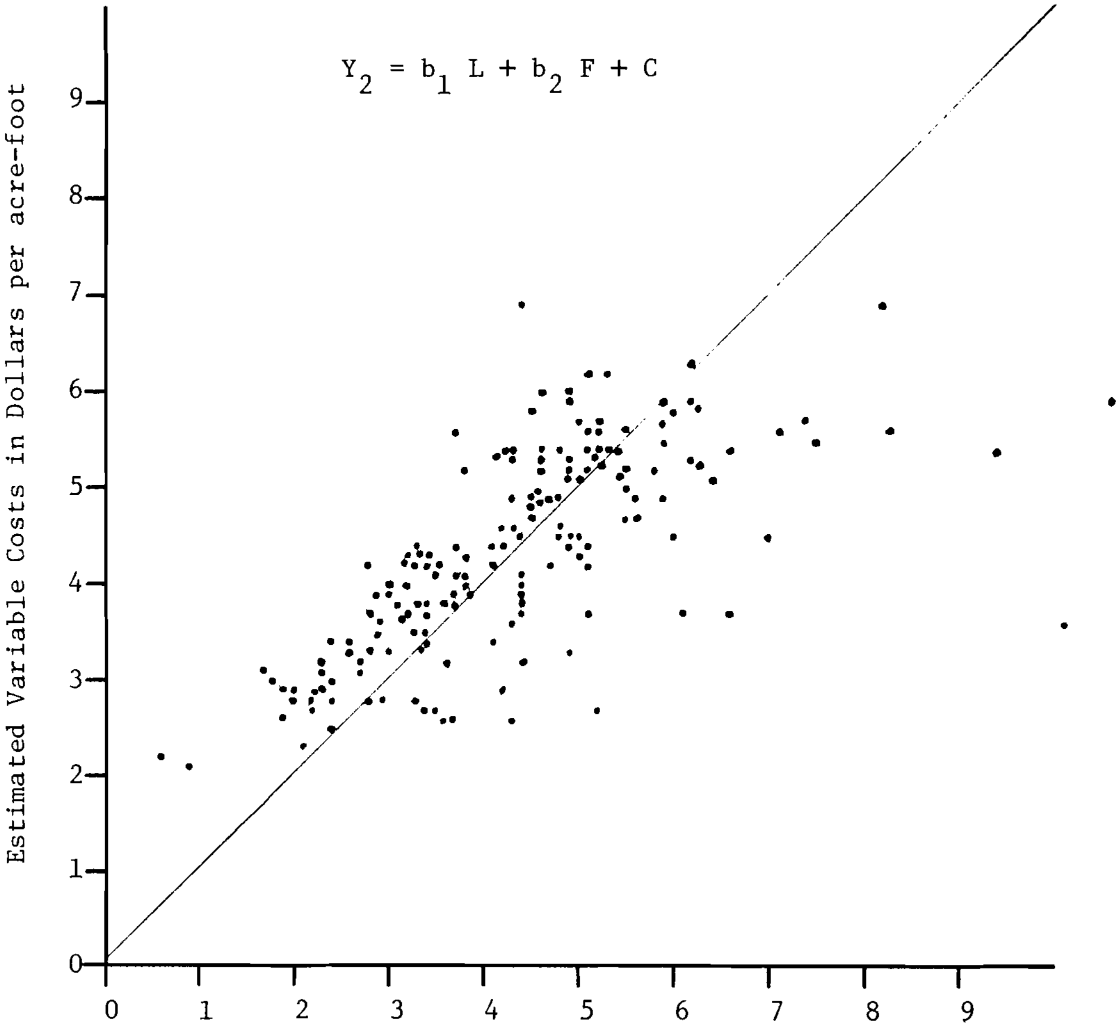


Figure 10

Estimated Costs Versus Actual Costs, Equation 8

Wells with Variable Costs Known (168 observations)



Actual Variable Costs in Dollars per acre-foot

Figure 11

Estimated Costs Versus Actual Costs, Equation 5

Electric Wells (116 observations)

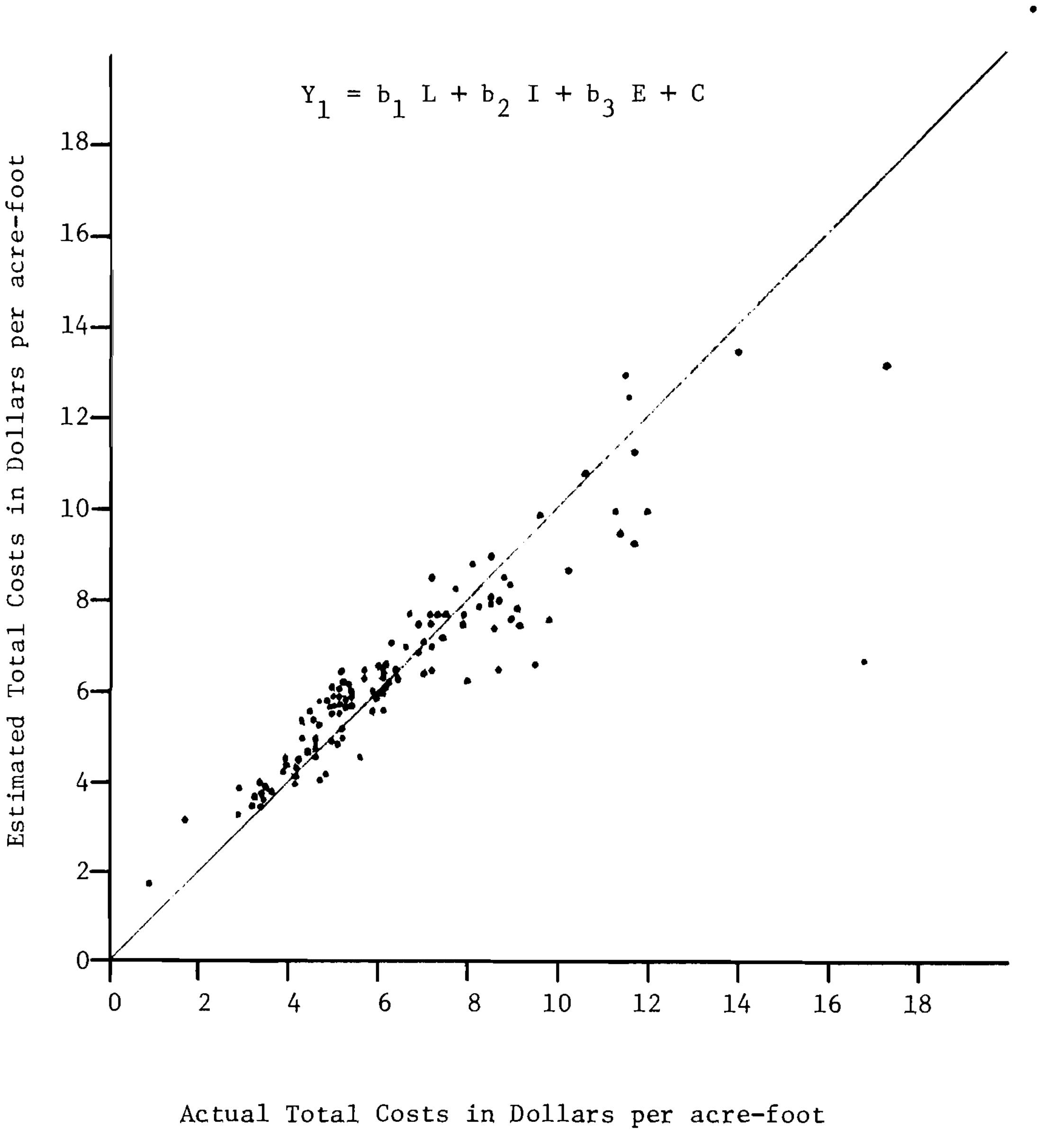


Figure 12

Estimated Costs Versus Actual Costs, Equation 7

Electric Wells (116 observations)

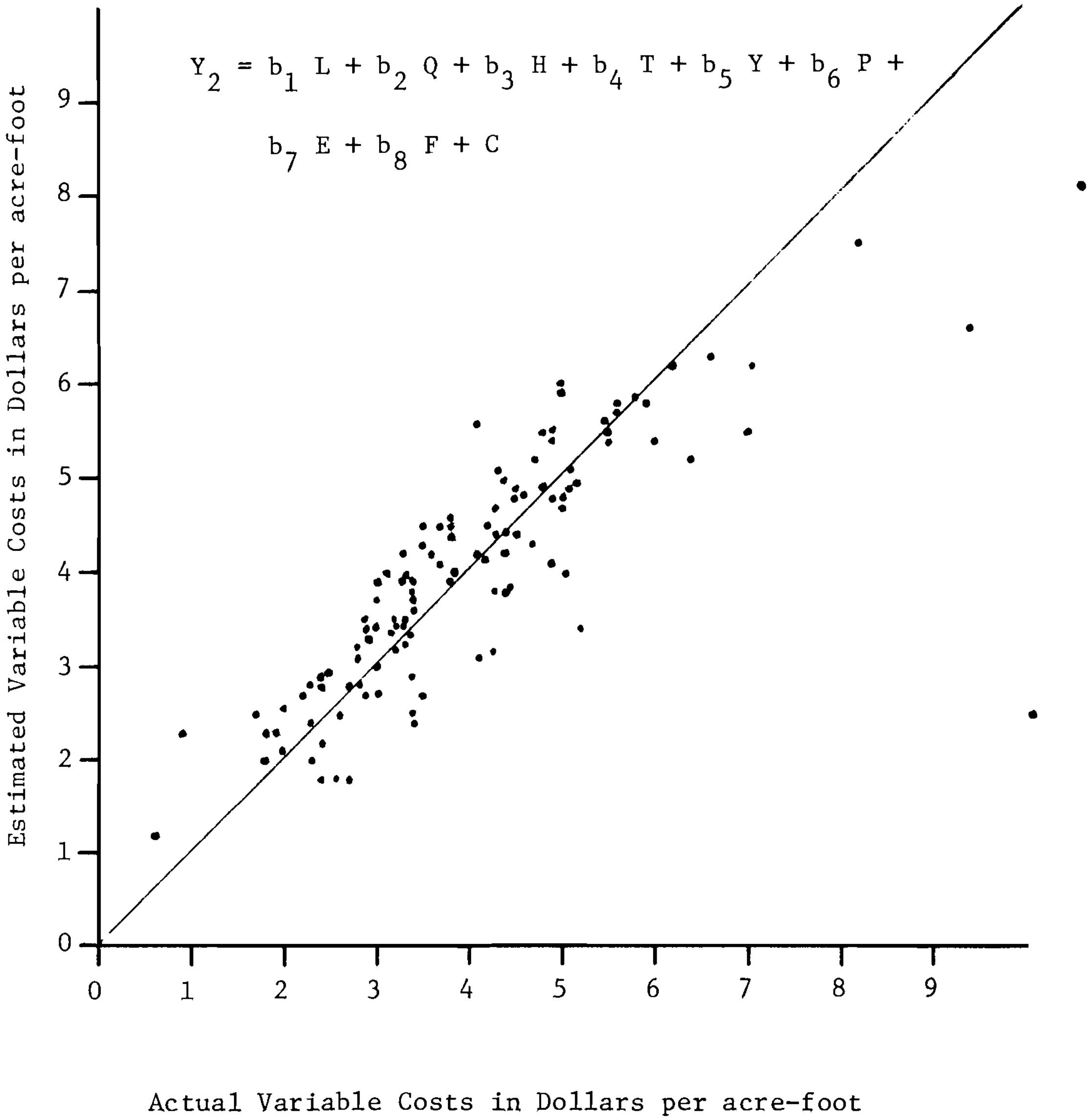


Figure 13

Estimated Costs Versus Actual Costs, Equation 8

Electric Wells (116 observations)

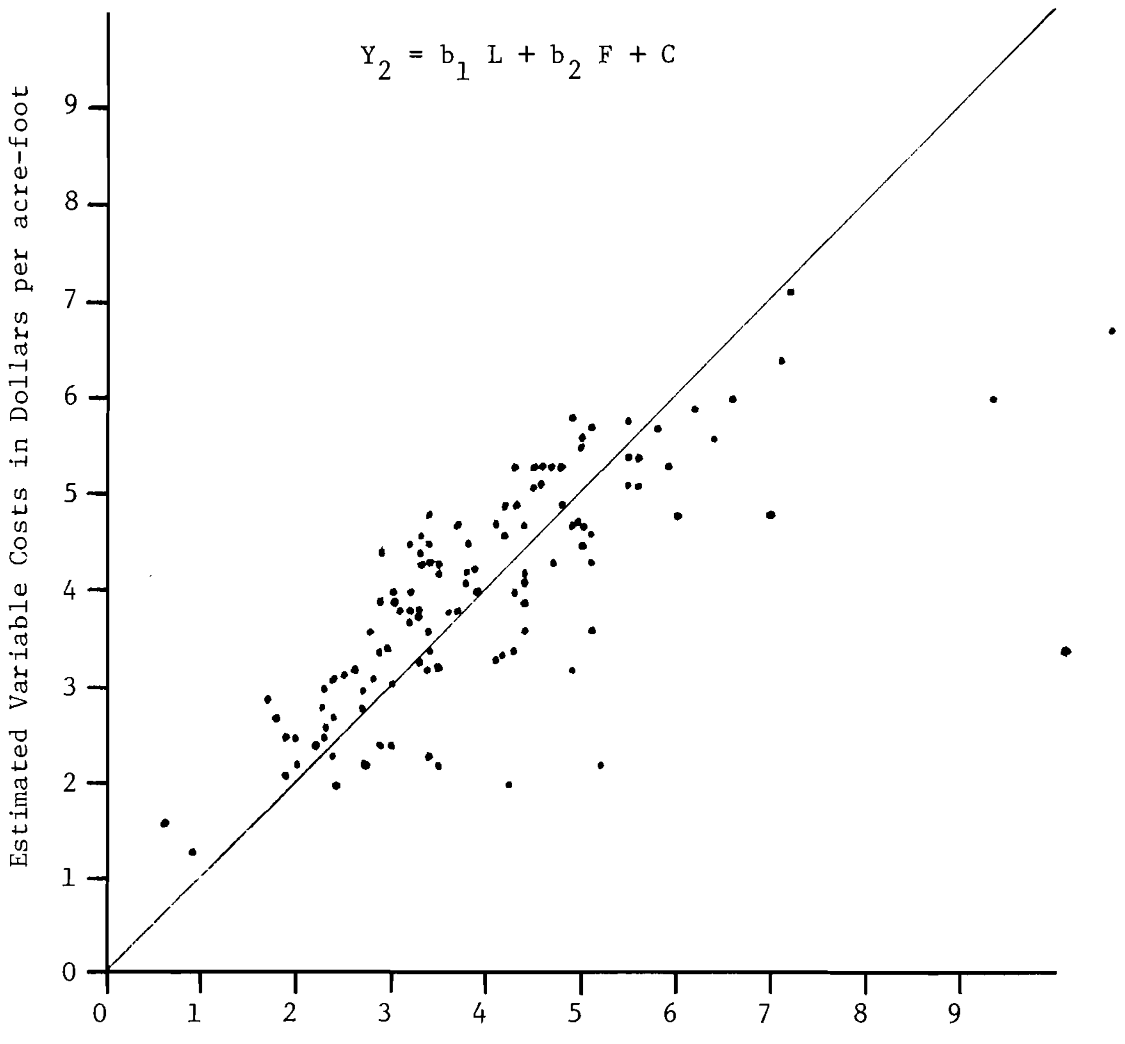


Figure 14

Estimated Costs Versus Actual Costs, Equation 12

Electric Wells (116 observations)

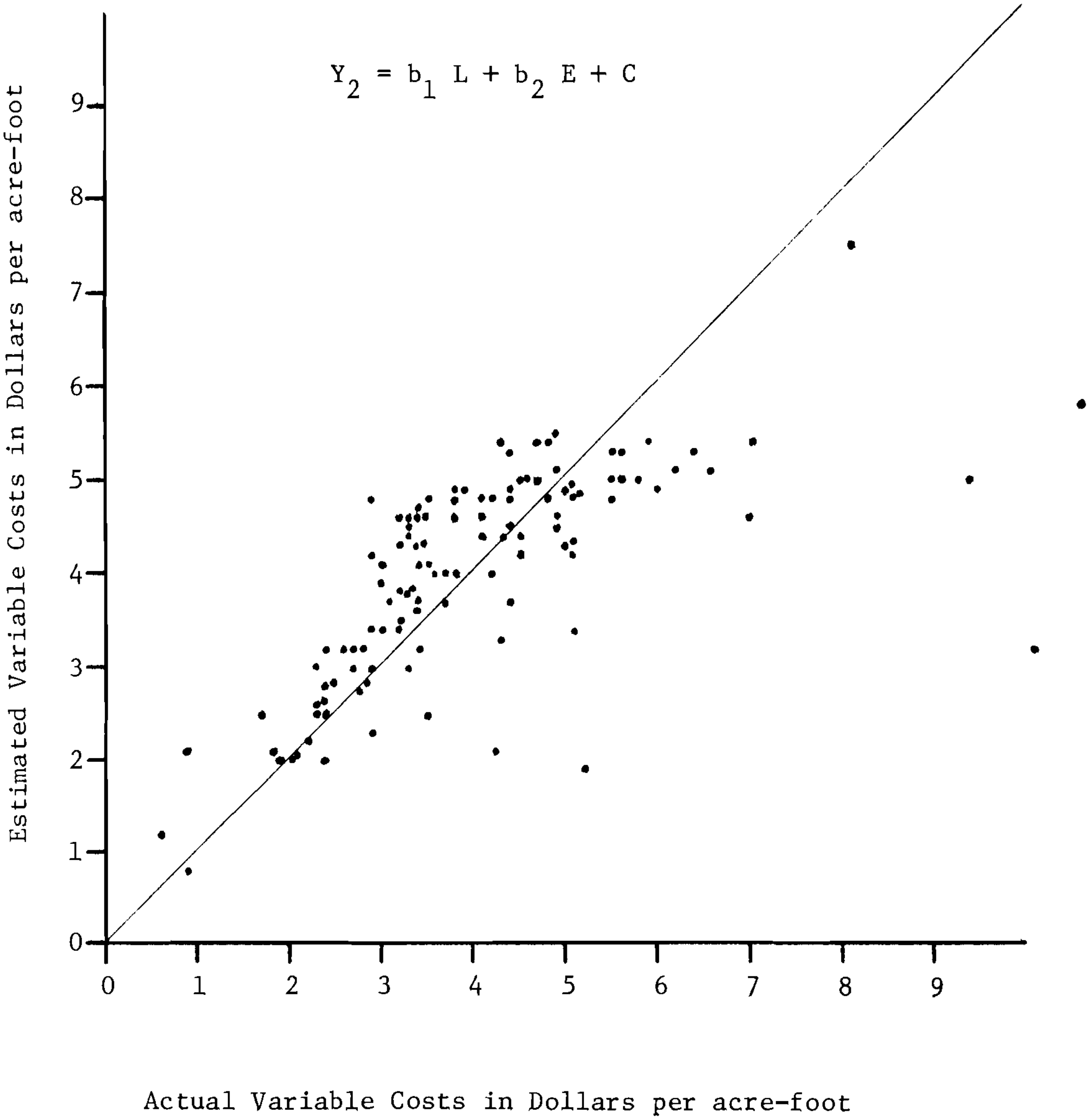
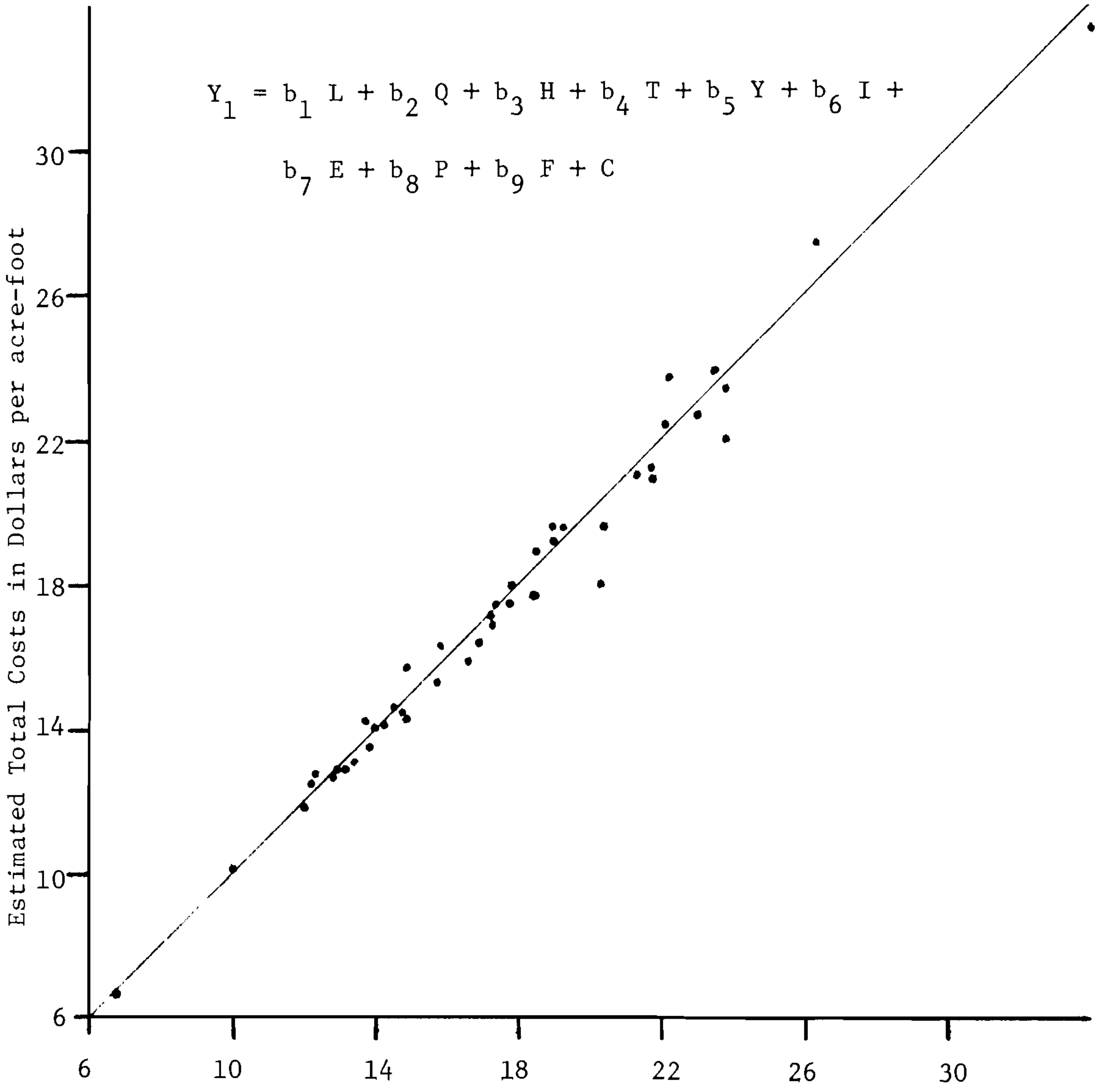


Figure 15

Estimated Costs Versus Actual Costs, Equation 3

Natural Gas Wells (44 observations)

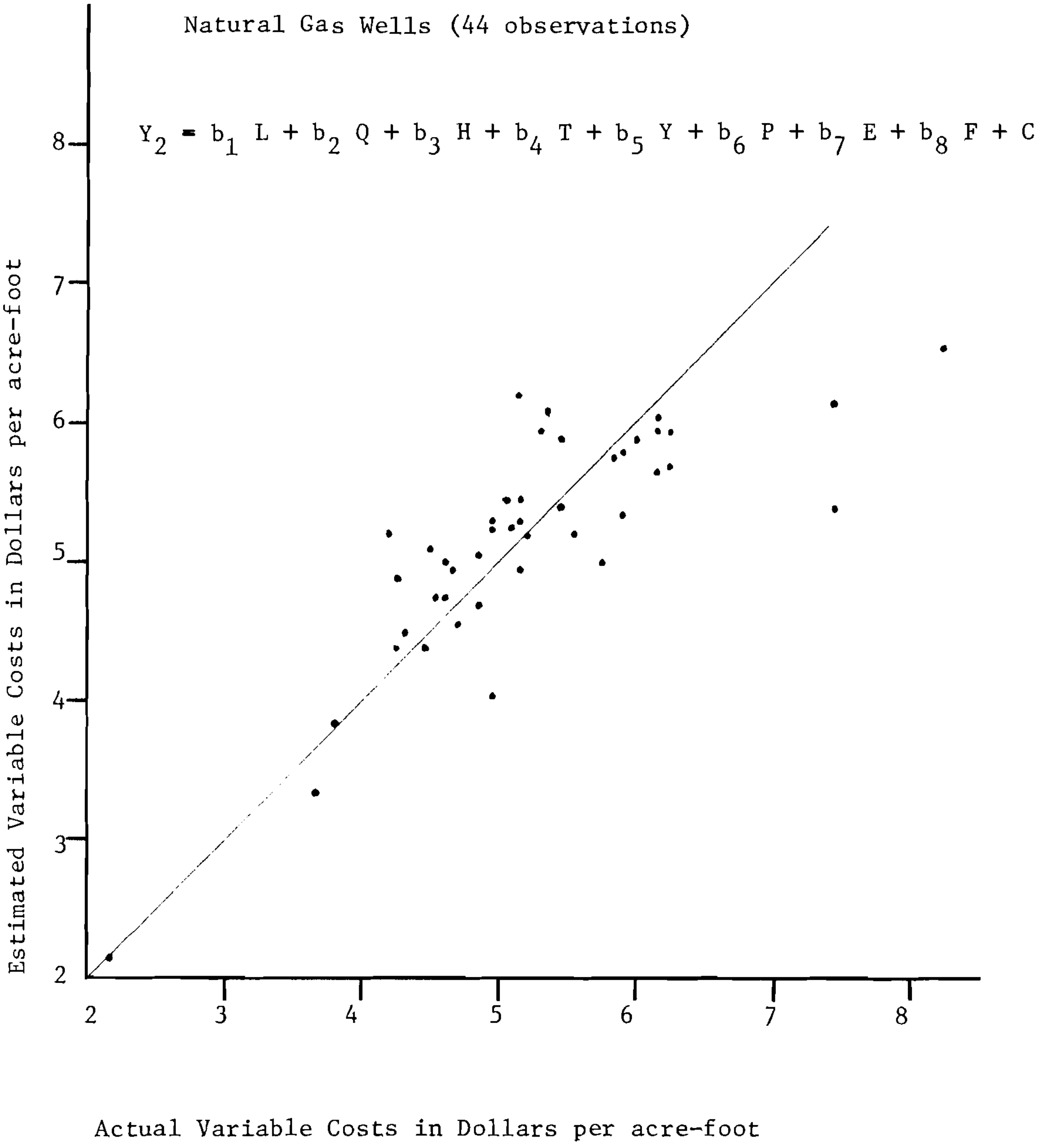


Actual Total Costs in Dollars per acre-foot

Figure 16

Estimated Costs Versus Actual Costs, Equation 7

Natural Gas Wells (44 observations)



$$Y_2 = b_1\ L + b_2\ Q + b_3\ H + b_4\ T + b_5\ Y + b_6\ P + b_7\ E + b_8\ F + C$$

CHAPTER V

DISCUSSION

It was anticipated that water horsepower and operating time would have a significant effect on the variable costs, and that investment would have a significant effect on total costs. In the final analysis it was found that although the total costs were very much a function of investment, the time of operation did not appear to have a strong effect on the variable costs. However, when an equation was run for the 116 electric well observations which correlated total costs with the independent variables but omitted the variable I, the time of operation was the first variable to enter the correlation. The partial correlation coefficient for time of operation was negative, indicating that costs per unit yield decrease with increase in time. This is because cost is divided by yield. We are led to believe that the reduction of costs with time is not large or that the intercorrelation of input variables somehow masked the effect of time. Since it can be easily shown that variable costs are a function of operating time, it can only be that the covariance of the input variables masked out the effect of time. Dividing the total costs by yield caused some intercorrelation since yield is a product of discharge and time.

Multiple Regression Assumptions

In using the multiple regression analysis two assumptions are made: common variances are equal, and the independent variables are uncorrelated among themselves. It can be seen from Table 5 that the variances for natural gas and electric wells are not equal. As an example the coefficient of variation in discharge rate is .55, .54, .53, and .13 for the respective four data separations. Tables (1-4) show that the independent variables are not independent but are highly intercorrelated. Thus we have violated the assumptions of the regression analysis. The effect of violating these assumptions cannot be readily determined, but this must be kept in mind.

Use of the Prediction Equations

Although the coefficient of determination for the multiple regression equation 3 for natural gas wells is .98 it is probably not a good predictor for wells other than those used in the analysis. Since investment divided by yield and multiplied by an appropriate depreciation rate is essentially fixed cost per unit yield, we have a case of correlating a part (fixed costs) with a whole (total costs). We have an automatic "built-in" relationship. This is why the variable I correlates the strongest of all variables. With the high correlation of investment cost (I Y) with water horsepower (P) one might suspect that total costs could be predicted without using the variable I, but such was not the case (See Table 9). This was clearly shown by the special equation run on the electric well observations omitting I. The fact of correlating a part against the whole is borne out by this. The correlation of the special equation might be improved by introducing a variable P divided by Y, but this was not tested.

The similarity of the natural gas wells had a significant effect on the correlation of total costs with the independent variables. For these observations the discharge rate, initial investment (based on a contract for 42 of the 44 wells), and nameplate horsepower were a constant. Lift also had a very narrow range. Because these variables were essentially constant, the phenomena of correlating a part against the whole was accentuated. The coefficient of determination with just variable I against total cost per unit yield was .96 and increased only to .98 with 8 additional variables. The narrow range of lift with other previously mentioned variables being nearly constant probably explains the relatively low coefficient of determination found for the correlation of lift with variable cost per unit yield. Here the opposite effect was operating.

The prediction equation for the electric well observations also may not prove to be as good as the .82 coefficient of determination would indicate for future estimates. This may be due to the high correlation between water horsepower and initial cost. Not too much credence should be detracted by this correlation since the correlation in this case is not a significant amount greater than for the 168 observations or the 193 observations and may therefore be a correlation that is found in all observations. The obvious relationship involved is that as horsepower increases, initial investment increases accordingly. It is believed that the estimation of initial investment cost did not affect the correlations significantly, but it was difficult to analyze.

In contrast the natural gas well observations showed coefficients of determination for water horsepower correlated against initial investment of .24 and .08 compared to the .83 and .82 for electric well observations. The low correlation of initial cost with P is no doubt due to the similarity of the wells as previously discussed. Because investment and discharge are essentially constant while lift varies, the correlation really is with a variable times a constant against a constant and is necessarily low.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

In spite of all the reservations taken here to the validity of the prediction equations, the equations did nevertheless account quite well for the cost of pumping water. Since the observations encompassed five states and included a variety of conditions with wide ranges in each variable, it would appear that the study was general enough to justify its use for estimating costs.

The factors which are important to cost as determined by this study are in order of entry in the regression equations for each separation detailed in Table 6.

Solving the relationship for lift was an objective of this study, but since it has been shown that lift alone is not the most important factor of cost, it seems unnecessary to do so.

Points which must be noted which affected the results are generally summarized by the analysis of the input data. The input data were highly correlated and the independent variables did not have equal common variances or slopes for all separations. A case of correlating a part against a whole was discovered. These facts taken together with the fact that an independent variable was entered in many combinations made it impossible to say exactly what the individual effect of a single variable was. It was shown that the effect of an independent variable was not important when it had a narrow range, since a wide range will generally increase the correlation between variables. Such was the case for the variables of discharge and investment for natural gas wells (See Tables 7-10).

From the results of this study it is easy to see how a more exact study might be conducted. Although the study showed that costs could be accounted for in total in this manner, it was not shown how to account for variable costs. The high relative importance shown for the variable E indicates the importance of evaluating both the design of the system and the efficiency of the system as was suggested and done by Miles and Longenbaugh (25). Such evaluations were not possible in this study.

It is recommended that further studies of this nature be taken from an economist's approach. With this approach the relationship of output (yield) would be related to input (independent variables) utilizing such factors as quality of design, efficiencies, and operator effectiveness. This would allow variables to be taken into account which affect yield directly but costs only indirectly. Perhaps some method could be devised to use dimensionless parameters.

Once the relationship of input to output were known, then the relationship of output to costs could be determined. This time proven method is quite similar to the practice of determining partial derivatives which are unknown (such as the change of a variable with time, $\frac{\partial V}{\partial t}$), by using a relationship which can be evaluated. For example if $\frac{\partial V}{\partial X}$ is known and $\frac{\partial X}{\partial t}$ is known then $\frac{\partial V}{\partial t}$ can be evaluated by the relationship $\frac{\partial V}{\partial t} = \frac{\partial V}{\partial X}\frac{\partial X}{\partial t}$.

Data were very difficult to obtain for this study, and the researchers experienced difficulty in finding data which contained all points for a given observation. Power companies were helpful, but they do not keep data as complete as was needed and are not legally allowed to release information in detail without individual owner consent. This problem was also encountered in attempting to use data gathered for other studies.

This project was intended only as a pilot project to determine what data are needed for such a study and what might be omitted, and it should be viewed in that light.

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APPENDIX

Data

Mixed Averages - Variable Cost Unknown

#	lift (ft)	discharge (gpm)	nameplate hp.	operating time (hrs)	yield (A-ft)	investment ($)	total cost (¢/A-ft)	variable cost (¢/A-ft)
001	067	1554	045	3000	0886	08700	0312	----
002	092	0755	033	3000	0430	08300	0432	----
003	170	0780	062	3000	0445	13000	0746	----
004	398	1178	187	3000	0672	21000	1750	----
005	654	1248	332	3000	0712	26000	2940	----
006	402	1240	203	3000	0686	21000	1810	----
007	147	1309	082	3000	0724	12700	0691	----
008	059	0562	016	3000	0318	06800	0301	----
009	084	0415	018	3000	0230	07500	0428	----
010	073	0458	015	3000	0254	07500	0424	----
011	207	1109	098	3000	0614	13300	1240	----
012	264	0785	101	3000	0435	15500	1190	----
013	260	1099	120	3000	0609	16000	1820	----

#	lift (ft)	discharge (gpm)	nameplate hp.	operating time (hrs)	yield (A-ft)	investment ($)	total cost (¢/A-ft)	variable cost (¢/A-ft)
014	409	1162	192	3000	0645	20600	1880	----
015	165	1258	084	3000	0696	13700	1055	----
016	115	1456	069	3000	0806	10600	0736	----
017	174	0776	059	3000	0430	13000	0801	----
018	304	1262	123	3000	0700	19700	1399	----
019	168	1281	168	3000	0710	13500	0975	----
020	139	0813	139	3000	0450	11500	1580	----
021	305	0721	075	2451	0326	11500	0858	----
022	295	0635	065	2418	0283	11000	1286	----
023	308	0545	060	1872	0188	11000	1368	----
024	073	0575	012	0915	0093	04600	0811	----
025	065	0800	020	1123	0166	05000	0816	----

Data

Electric Well Observations

#	lift (ft)	discharge (gpm)	nameplate hp.	operating time (hrs)	yield (A-ft)	investment ($)	total cost (¢/A-ft)	variable cost (¢/A-ft)
001	072	0600	020	0940	0100	03600	0804	0425
002	108	1200	042	2250	0470	12000	0511	0244
003	094	1168	055	1772	0303	06000	0563	0354
004	360	1890	200	3600	0882	17580	0498	0286
005	134	1620	060	2400	0710	08237	0289	0197
006	081	0668	020	0560	0076	03050	0948	0520
007	087	1071	035	1675	0355	09071	0520	0198
008	209	0786	062	1675	0244	13856	1220	0505
009	086	1669	052	1675	0521	09496	0407	0186
010	203	1329	094	1675	0427	13667	0865	0430
011	115	1523	059	1675	0536	09242	0468	0222
012	209	0725	050	3600	0480	16140	1680	1010
013	302	0900	110	1150	0191	09000	1173	0702

#	lift (ft)	discharge (gpm)	nameplate hp.	operating time (hrs)	yield (A-ft)	investment ($)	total cost (¢/A-ft)	variable cost (¢/A-ft)
014	386	1000	110	1463	0270	09000	0911	0578
015	375	1000	110	1218	0224	09000	0902	0500
016	373	1000	110	1218	0224	09000	0902	0500
017	400	1000	110	1209	0223	09000	1022	0619
018	390	1000	110	0615	0114	09000	1725	0935
019	398	1000	110	1031	0190	09000	1136	0662
020	200	1090	075	3331	0600	09000	0388	0258
021	160	1510	060	2785	0640	10000	0317	0181
022	230	1040	075	2374	0375	09000	0527	0319
023	250	0810	075	2400	0358	09000	0521	0303
024	320	0275	025	2508	0105	08600	1153	0451
025	380	0484	050	2310	0170	08800	0955	0511
026	305	0965	100	3489	0619	12500	0505	0332
027	220	2475	150	2446	1122	13700	0339	0234
028	300	1080	100	1572	0315	12600	0851	0508
029	260	0713	075	1908	0207	09000	0722	0350

#	lift (ft)	discharge (gpm)	nameplate hp.	operating time (hrs)	yield (A-ft)	investment ($)	total cost (¢/A-ft)	variable cost (¢/A-ft)
030	330	1260	125	2944	0686	15000	0509	0321
031	170	1530	075	2447	0700	10000	0291	0168
032	340	0360	060	1860	0156	11000	1155	0550
033	125	1220	040	2154	0400	06800	0333	0187
034	310	1000	075	2200	0405	12400	0595	0332
035	220	3010	150	2446	1122	16000	0352	0232
036	215	3280	200	3200	1596	17000	0359	0268
037	150	4050	200	2304	1420	15000	0334	0243
038	200	2310	125	2182	0764	12500	0415	0273
039	240	2100	150	2323	0897	13000	0415	0291
040	260	3600	300	2931	1945	17000	0405	0330
041	270	2120	200	1965	0768	16000	0543	0364
042	213	2030	150	2514	0939	15000	0440	0303
043	200	2210	150	2654	1080	15000	0386	0267
044	240	1170	100	2020	0436	10000	0509	0312
045	377	2000	300	2359	0879	20000	0690	0494

#	lift (ft)	discharge (gpm)	nameplate hp.	operating time (hrs)	yield (A-ft)	investment ($)	total cost (¢/A-ft)	variable cost (¢/A-ft)
046	390	1620	200	1700	0510	19000	0881	0561
047	400	1530	200	2210	0632	18500	0729	0478
048	340	0830	100	2774	0425	11500	0656	0424
049	330	1265	125	3105	0725	13200	0486	0330
050	310	0400	040	2477	0184	08300	0814	0428
051	160	0520	030	2060	0198	07800	0629	0281
052	130	0487	030	2380	0210	05800	0473	0236
053	335	1440	150	2079	0460	16000	0792	0494
054	240	0823	075	2904	0440	09600	0503	0316
055	255	0670	050	3174	0323	09200	0567	0323
056	305	0890	075	2443	0330	11000	0702	0416
057	325	0513	050	2024	0194	09000	0848	0450
058	230	1160	075	2647	0468	10600	0471	0276
059	400	0930	100	1842	0260	15300	1057	0552
060	016	0540	008	1665	0167	01600	0170	0088
061	320	1850	150	2493	0702	17000	0588	0380

#	lift (ft)	discharge (gpm)	nameplate hp.	operating time (hrs)	yield (A-ft)	investment ($)	total cost (¢/A-ft)	variable cost (¢/A-ft)
062	324	2420	250	2875	1060	18000	0590	0444
063	390	1130	150	2635	0549	16000	0976	0426
064	355	2480	250	2439	1121	19500	0528	0379
065	384	2740	250	3548	1478	20000	0523	0407
066	375	0548	075	2516	0210	12800	1168	0644
067	284	1690	125	3776	0970	14000	0465	0341
068	220	2940	150	3043	1359	15000	0321	0226
069	320	1170	150	2613	0568	13000	0574	0377
070	212	1350	125	3217	0805	11000	0462	0344
071	290	1460	110	1987	0440	15600	0743	0439
072	340	1530	200	3046	0863	17000	0635	0466
073	292	1220	125	1655	0380	13000	0794	0500
074	360	1860	200	3397	0960	20000	0615	0436
075	430	2200	250	1919	0640	21000	0868	0587
076	397	1620	200	3162	0945	19000	0614	0441
077	400	2070	200	2287	0720	20000	0716	0478

#	lift (ft)	discharge (gpm)	nameplate hp.	operating time (hrs)	yield (A-ft)	investment ($)	total cost (¢/A-ft)	variable cost (¢/A-ft)
078	385	3820	400	2010	1165	25000	0624	0440
079	370	3240	400	3022	1714	24000	0606	0486
080	390	2400	200	2606	0954	21000	0601	0412
081	310	1050	100	1818	0290	11000	0826	0500
082	360	2250	250	2530	1055	19000	0536	0382
083	170	0540	040	2890	0289	06400	0432	0242
084	300	0810	075	3484	0521	10000	0453	0288
085	300	0975	100	3321	0596	11000	0501	0342
086	450	1860	200	2580	0725	21000	0716	0467
087	330	2250	250	3200	1330	23000	0492	0344
088	338	3400	300	3680	1903	26000	0460	0343
089	359	2780	300	1460	0756	24000	0686	0414
090	435	1270	150	2340	0507	15000	0746	0492
091	385	1120	125	2570	0505	16000	0724	0452
092	310	2050	200	3085	1156	15000	0434	0323
093	338	2880	300	2034	1040	23000	0624	0434

#	lift (ft)	discharge (gpm)	nameplate hp.	operating time (hrs)	yield (A-ft)	investment ($)	total cost (¢/A-ft)	variable cost (¢/A-ft)
094	040	1540	020	2490	0708	02500	0093	0063
095	350	1340	150	1650	0408	16000	0890	0554
096	335	2160	250	2130	0849	19000	0703	0511
097	360	0840	100	1970	0306	11500	0770	0447
098	595	0720	125	2220	0295	20000	1397	0815
099	440	2170	300	0224	0090	25000	3459	1059
100	329	1170	125	3170	0690	13000	0504	0342
101	332	2390	200	2650	0922	18000	0510	0342
102	242	3070	200	1950	0910	17500	0501	0336
103	242	1670	100	1495	0379	11500	0600	0329
104	360	1890	200	2790	0970	20000	0526	0349
105	360	1620	125	2565	0630	18000	0611	0366
106	386	2270	250	1595	0550	19000	0859	0563
107	382	2360	250	1840	0660	20000	0856	0596
108	288	1960	250	3630	1080	16000	0460	0333
109	213	3060	150	2710	1260	16000	0342	0233

#	lift (ft)	discharge (gpm)	nameplate hp.	operating time (hrs)	yield (A-ft)	investment ($)	total cost (¢/A-ft)	variable cost (¢/A-ft)
110	255	2440	200	1340	0605	17000	0608	0367
111	458	1180	125	1680	0302	15000	1131	0705
112	220	2310	125	2170	0765	13000	0387	0241
113	185	0324	020	2203	0132	05800	0666	0289
114	243	0665	075	2814	0345	09000	0522	0298
115	362	2160	250	3117	1240	23000	0544	0385
116	110	1224	050	1800	0400	06975	0476	0289

Data

Natural Gas Well Observations

#	lift (ft)	discharge (gpm)	nameplate hp.	operating time (hrs)	yield (A-ft)	investment ($)	total cost (¢/A-ft)	variable cost (¢/A-ft)
001	083	0785	025	0927	0137	05864	0668	0215
002	250	1090	100	3674	0725	27410	1305	0614
003	449	1000	135	0666	0123	11000	1845	0493
004	485	1000	135	0651	0120	11000	1900	0510
005	466	1000	135	0636	0117	11000	1918	0493
006	460	1000	135	0595	0110	11000	1895	0455
007	495	1000	135	0588	0107	11000	2178	0623
008	445	1000	135	0582	0106	11000	2167	0586
009	446	1000	135	0516	0094	11000	2378	0616
010	400	1000	135	0585	0108	11000	2133	0591
011	441	1000	135	0803	0148	11000	1577	0451
012	407	1000	135	0550	0102	11000	2377	0745
013	381	1000	135	0544	0100	11000	2212	0545

#	lift (ft)	discharge (gpm)	nameplate hp.	operating time (hrs)	yield (A-ft)	investment ($)	total cost (¢/A-ft)	variable cost (¢/A-ft)
014	387	1000	135	0859	0159	11000	1567	0519
015	382	1000	135	1066	0197	11000	1304	0458
016	393	1000	135	0511	0093	11000	2217	0527
017	404	1000	135	1137	0210	11000	1219	0425
018	384	1000	135	1454	0268	11000	1001	0379
019	381	1000	135	0533	0099	11000	2306	0624
020	476	1000	135	0497	0092	11000	2346	0534
021	387	1000	135	0960	0177	11000	1405	0463
022	447	1000	135	0631	0117	11000	2041	0615
023	400	1000	135	0837	0155	11000	1494	0418
024	431	1000	135	0705	0130	11000	2026	0744
025	397	1000	135	0735	0136	11000	1740	0513
026	388	1000	135	0916	0169	11000	1471	0485
027	404	1000	135	1010	0186	11000	1379	0484
028	438	1000	135	0833	0154	11000	1655	0574
029	400	1000	135	0951	0176	11000	1369	0423

#	lift (ft)	discharge (gpm)	nameplate hp.	operating time (hrs)	yield (A-ft)	investment ($)	total cost (¢/A-ft)	variable cost (¢/A-ft)
030	412	1000	135	0429	0079	11000	2625	0515
031	407	1000	135	0299	0055	11000	3855	0825
032	442	0800	135	0775	0143	11000	1767	0602
033	427	1000	135	1188	0200	11000	1200	0366
034	425	1000	135	0754	0139	11000	1716	0516
035	398	1000	135	1122	0208	11000	1229	0429
036	395	1000	135	0934	0172	11000	1486	0516
037	406	1000	135	1057	0195	11000	1337	0472
038	429	1000	135	0722	0133	11000	1844	0592
039	394	1000	135	0760	0140	11000	1733	0543
040	419	1000	135	0708	0131	11000	1778	0506
041	440	1000	135	1136	0210	11000	1289	0495
042	420	1000	135	0796	0147	11000	1685	0553
043	592	1800	270	0799	0266	18000	1418	0444
044	402	1000	135	0913	0169	11000	1447	0461

Data

Mixed Averages - Variable Cost Known

#	lift (ft)	discharge (gpm)	nameplate hp.	operating time (hrs)	yield (A-ft)	investment ($)	total cost (¢/A-ft)	variable cost (¢/A-ft)
001	305	0700	150	2382	0301	13320	0986	0480
002	083	0900	060	1400	0232	04800	0593	0373
003	111	0900	065	1852	0293	07000	0675	0420
004	150	0400	062	2670	0222	07600	0719	0357
005	043	1600	065	1151	0345	06500	0412	0211
006	200	0400	040	2120	0151	07200	1163	0655
007	150	0700	060	1612	0191	06600	0804	0437
008	080	0805	025	0734	0124	04405	0739	0360