The cost of pumping water in central Arizona

Item Type	Thesis-Reproduction (electronic); text
Authors	Kleinman, Alan P.
Publisher	The University of Arizona.
Rights	Copyright © is held by the author. Digital access to this material is made possible by the University Libraries, University of Arizona. Further transmission, reproduction or presentation (such as public display or performance) of protected items is prohibited except with permission of the author.
Download date	13/08/2020 20:49:33
Link to Item	http://hdl.handle.net/10150/191449

THE COST OF PUMPING IRRIGATION WATER IN CENTRAL ARIZONA

by

Alan P. Kleinman

A Thesis Submitted to the Faculty of the

DEPARTMENT OF AGRICULTURAL ECONOMICS

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

1 9 6 4

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: Alan P. Kleinman

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

Aaron G. Nelson
Aaron G. Nelson
Professor of Agricultural Economics

July 21, 1964
Date

ACKNOWLEDGMENTS

The author wishes to acknowledge the guidance, patience and helpful suggestions of Dr. Aaron G. Nelson throughout this study.

To Dr. M. M. Kelso, the author expresses appreciation for counsel and direction.

The author feels indebted to Dr. C. D. Busch for his interest and guidance with the technical aspects of this study.

Gratitude is expressed to Dr. R. O. Kuehl for his patience in answering the many questions concerning the statistical analysis.

Thanks is extended to the Bureau of Reclamation at Phoenix, Arizona, which furnished pertinent data and cooperated fully to make this study possible. A special thânks is due Marvin Nystrom who accomplished the necessary field work in Maricopa County.

As the study was in cooperation with the Department of Agricultural Engineering, the author feels indebted to those of the Department participating, especially Gene Franzoy who collected the well performance data and answered the author's many questions concerning the engineering aspects of pumping water.

Without the cooperation of the farmers this study would not have been possible. Electricity and natural gas suppliers, pump companies, well drillers, and engine and motor suppliers were most helpful in providing access to records and pertinent cost data.

A special thanks goes to the secretaries of the Department of Agricultural Economics whose patience with the typing of the drafts is most appreciated.

To my wife, Mary, who put in many long hours of preparing the text, the author owes a deep debt of gratitude for the patience and consideration of the many inconveniences and loss of attention due to this study.

To all of the above persons I extend my sincere thanks.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF ILLUSTRATIONS

ABSTRACT

Irrigation water is a major component of the cost of crop production for farmers in central Arizona. For many, water is the main factor limiting the size of operation. In order to attain maximum profits, the farmer must have advance knowledge of costs.

The cost of pumping water needs to be known to organize farms efficiently. This study attempts to add to the body of knowledge about the farmer's environment to assist in achieving this efficiency.

A description of groundwater conditions and pumping installations gives a cross-sectional look at pumping in central Arizona. Rates and service availability of utilities were examined.

Cost and physical inventory data were collected from various farmers and complete costs were computed for all components contributing to the cost of pumping water. The importance of these components was indicated and statistical analysis demonstrated the degree of reliability that should be placed in the estimates. Variations of costs between geographical areas were determined. The cost of reusing waste water was examined briefly.

Use of the results of such a study was illustrated so that it might be useful for individual farmers. Unless a farmer is applying

the correct amount of water to his land, he is not obtaining the maximum possible profit. It appears that the cost of pumping water in central Arizona is placing restrictions upon land use.

INTRODUCTION

Area of Study

This study relates to the irrigated areas outside of irrigation districts in Maricopa and Pinal Counties of central Arizona. The area under study in Pinal County is the lower Santa Cruz basin, which is drained principally by the Santa Cruz River. The area in Maricopa County is the Salt River Valley and tributary valleys. All the areas are characterized by private, individual ownership of pumping installations. Throughout this study the term central Arizona will refer to the general areas outlined.

The Problem

Irrigation water is a major cost factor in agricultural production in central Arizona. Information on current costs of pumping water is needed in the decision-making process to facilitate maximum income by individual farmers. Current cost information is needed by irrigation districts, by related industries, and for use in other economic analyses.

Reliable, up-to-date, water cost data are not generally available to the farmers of central Arizona. This is because of the lack of facilities for farmers to individually ascertain all cost components associated with lifting water from underground reservoirs. Evidence indicates most farmers in central Arizona that rely solely upon their private pumps for water are unable to estimate the amount of water pumped or applied to a specific crop.

When planning cropping patterns and input combinations, costs are needed to facilitate profitable decisions. As the ground water level declines, costs will change. This in turn may change the optimum input mix. In order to maximize returns factors should be combined in such a way that the marginal rate of substitution of factor x_1 for factor x_2 is equal to the inverse of the respective price ratio. The amount of factor to use per fixed unit is found by equating the cost of the last unit applied with the value of the additional product gained from that last unit. To facilitate this optimum organization a farmer needs accurate cost data.

When a farmer already has a well on his place he may not consider fixed costs of pumping since these are not influenced by the amount of water he pumps. In other words, he must stand these costs whether or not he pumps any water. In the long run, however, the equipment on the well, and the well itself, will have to be replaced. Thus, in the long run, replacement cost must be considered and as this is a major investment, the cost estimate should reflect all costs and should be as precise as possible. Long run decisions are pertinent to farmers who must drill "replacement" wells, and to a farmer buying a farm in determining how much he can afford to pay for a well. In the long run all costs become variable and are treated as such.

The majority of depth to water measurements occur in the winter and early spring months which is the slack pumping period. During these months few pumps are operated which gives the water table a chance to stabilize at a level generally somewhat above the level which prevails during the heavy pumping season. This, plus the fact that each individual well creates its own cone of depression, makes the winter measurements of limited value to the farmer in calculating his water pumping costs. In order to obtain accurate costs the pumping lift must be measured during periods of greatest withdrawal. As the lift increases the output of the well may decline and this will have a definite effect upon unit costs.

In order to run an efficient enterprise, a farmer must also be aware of the relative costs and profitabilities of reusing waste water versus additional pumping.

Review of Earlier Studies

Three earlier studies on the cost of pumping water have been made in central Arizona in 1951, 1939, and 1891. Two other studies were made earlier, in the Tucson area in 1904 and in the Yuma area in 1893.

The study made in 1951 (Rehnburg 1953) was limited to the Pinal County area. Twenty natural gas and 20 electric wells were randomly chosen and costs per acre foot were calculated for various lifts. The average lifts of the wells measured were 209 feet for electric wells and 250 feet for natural gas wells. The total cost per acre foot was $13.50 and $10.50, respectively. A comparison of natural gas with electricity was made between various cost components.

The 1939 study (Thompson and Steenberger 1939) which also centered in Pinal County, included 73 irrigation wells with an average lift of 122 feet. The average total cost was $4.64 per acre foot of water pumped.

The 1891 study, based upon records made available by the Phoenix Water Works, compared the cost of pumping to gravity flow water in that area. This study indicated it was cheaper to pump than to purchase gravity flow water (Stolbrand 1891).

The 1904 study (Woodward 1904) centered around farms in the vicinity of Tucson. Most of the wells used were hand dug and used steam power. The average lift was 47.8 feet and the cost of lifting the water averaged $8.56 per acre foot.

In 1893 a bulletin was published (Gulley and Collingswood 1893) which reported the cost of pumping water by the Yuma Water and Light Company. The power used was a steam engine with mesquite wood for fuel. As a result of this and other studies it was concluded that 50 feet was the maximum economical pumping lift for irrigation purposes (Forbes 1911).

Objectives and Scope of Study

The objective of the present study is to ascertain the costs of pumping water for irrigation in various private pumping areas of central Arizona. All major costs are to be determined--fixed, added capital, and variable.

Fixed costs are to include taxes, interest on investment, and depreciation. As a by-product of arriving at fixed cost figures actual capital costs of pumping installations will be computed. Fixed cost will be considered on the basis of acre foot, acre foot per foot of lift, and total fixed cost per well per year.

Due to the continual lowering of the groundwater table, additional capital is applied to existing installations. This may be a substantial portion of the cost of pumping water and, therefore, will be considered as a separate cost component. Added capital expense will be examined as a total cost per year and on the basis of acre feet and lift.

Variable costs will be computed on the basis of lift and acre feet to facilitate comparisons between areas. Variable costs are important in the short run to determine optimum relationships of inputs and the application of water per acre that yields maximum profits. The variable costs include energy, pump and well repair, power unit repair, attendance and lubrication costs. The study is designed to include both electricity and natural gas to provide easy comparison.

In addition to deriving the cost of pumping water the study will consider the reuse of tailwater, water pumped per well, acres irrigated per well, and acre feet of water applied to particular crops.

Source of Data

The principal sources of data were farmers, pump companies, well drillers, and electric and natural gas suppliers. Performance data on individual wells was obtained from the Department of Agricultural Engineering, University of Arizona, a cooperator in the study.

The primary data source was the farmers themselves. The farm survey included 34 electric wells and 20 gas wells in Pinal County and 16 electric and 4 gas wells in Maricopa County. The survey of farmers in Maricopa County was made by Marvin Nystrom, an employee of the Bureau of Reclamation. Cost, inventory data, and other information were obtained in the survey.

Pump, motor and engine distributors were contacted to obtain accurate, up-to-date equipment replacement cost. As near as possible, current cost of individual items now in use on each well was obtained. Similarly, well drillers were interviewed and current costs of drilling and of the various types of casings reported by farmers in the farm survey were obtained for various sizes of wells. The replacement cost figures were used to ascertain the fixed costs involved in the operation of pumping units.

Amounts used and charges made for gas and electricity for individual wells, by months, were supplied by the respective districts and other suppliers. Tax data were obtained from county assessors' offices. Information was also obtained from federal agencies, county agents, and other institutions directly interested in agriculture.

Sampled Areas and Techniques

In consultation with the Bureau of Reclamation it was decided to obtain a separate sample for each area considered somewhat independent geologically. This gave rise to five geographically different areas and seven separate samples. The areas were (1) east Pinal electric, (2) south Pinal electric, (3) south Pinal gas, (4) west Pinal electric, (5) west Pinal gas, (6) Queen Creek, and (7) Harquahala. It was decided to take a sample of eleven wells from each area, giving a total sample of 77 wells. The original plan was to include in the sample the same 40 wells used in the 1951 study and to determine changes which had taken place in costs and related factors over the period. It was found, however, that some of the wells used in 1951 were no longer operating and have been abandoned. Others could not be located because of changes in ownership that had taken place. Thus, this plan was abandoned.

After some surveying in the field it was found, due to the difficulty of obtaining usable wells, that some of the electric well samples had to be reduced in size. Moreover, in two areas (Queen Creek and Harquahala) it was necessary to combine electric with gas wells in the area sample. Because of the small number of usable gas wells in the south Pinal area, the south Pinal gas and the west Pinal gas were combined into one area in which a sample of 20 was taken. The revised sample areas are shown in Figure 1. The final results were: (1) east Pinal electric--13 wells, (2) south Pinal electric--10 wells, (3) west Pinal electric--11 wells, (4) Pinal gas--20 wells, (5) Queen Creek--10 wells, and (6) Harquahala--10 wells. This made the total number of wells 74.

The basis used to determine whether or not a well was suitable to be used in the study was twofold: (1) owners' willingness to cooperate, and (2) testability. For the most part, farmers were very willing to cooperate in the study. This meant they would allow their well to be tested and in addition supply cost and other necessary data to the interviewer. The testing entailed measuring water output, pumping lift, and power input. Many wells were not acceptable because the engineer was unable to obtain measurements of lift or output or both.

The samples were drawn on a random basis with a view to obtaining a true representation of each area. Maps were obtained from electricity

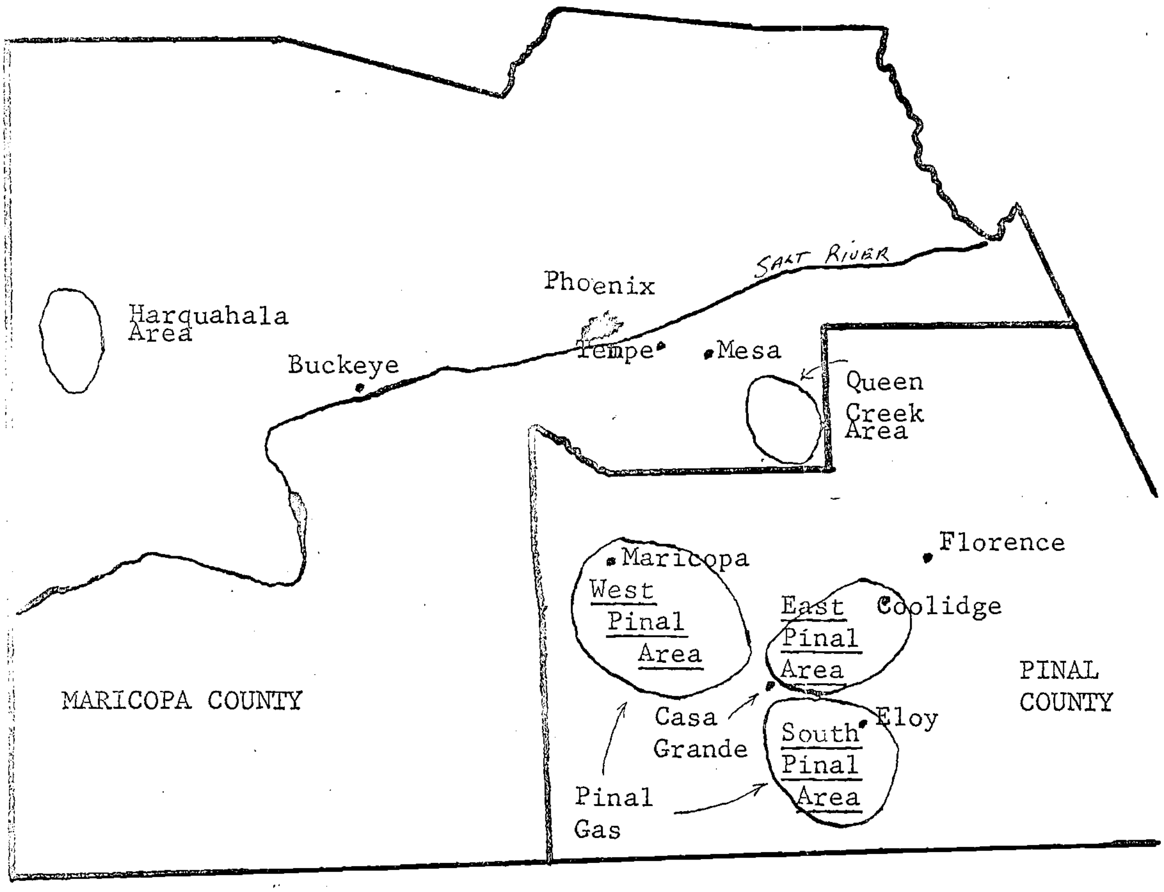

Figure 1. Map Showing Sampled Areas in Central Arizona

and gas suppliers which showed each of their present service connections. Each section (as defined by the rectangular survey system) in an area that had at least one operating well in it was assigned a number. A table of random numbers was employed and the required sample size was drawn. A number of alternates were drawn and when the original draw was exhausted the alternates were used in order of draw. As a section may have anywhere from one to sometimes eight wells in it, some method was needed for priorities within each section. The method employed is the use of quadrants lettered from A to D, counterclockwise with A in the northeast. Quadrant A was used first. Wells within that quadrant had priority in a counterclockwise movement from a to d. Only after quadrant A was completely exhausted was the next quadrant used. This pattern was followed until a usable well was found. If a testable well was not found within a section, an alternate section was used.

Procedure of Data Collection

The name and address of the owner of each well drawn was furnished by the utility company serving him. The farmer was then contacted and his cooperation solicited. If he agreed and the well was testable, a preliminary schedule was taken which gave a physical inventory of the pumping installation, location, and other pertinent facts. The preliminary schedule is shown in Appendix A. Complete cost data were not obtained on the first interview because of the pressing need to have a number of wells ready for testing by the engineer.

The Agricultural Engineering Department conducted the well tests during the summer of 1963 in Pinal County. The sampled wells in Maricopa County were tested by the Bureau of Reclamation. Each well was tested once each month during June, July, and August. Data on the lift, water output, and efficiency were averaged for the three observations. These three months are during the heaviest pumping period of the year for most farmers. A copy of the schedule filled out by the engineer each time the well was tested is shown in Appendix B.

As soon as all wells for each sample were lined up a second visit was made to the owner of each well. During this interview a schedule was taken concerning expected life and salvage value of individual components of each installation. This form is shown in Appendix C. Cost of operation (excluding energy) was secured for a one-year period from July 1, 1962 to June 30, 1963. This form is reproduced in Appendix D.

The physical inventory of equipment now in use obtained from each farmer served as a guide as to which equipment suppliers should be contacted. New cost data were obtained from them and applied to each individual well. The same method was followed for the drilling and deepening of wells.

At the end of the year (1963) the amount of power or gas used, by months, and its cost was secured for each installation from the power or gas suppliers.

Analysis Procedure

Data assembled were tabulated and costs compiled for each well and for each area. Weighted averages were used to construct representative well data for individual areas. The data were analyzed statistically to determine if significant differences of costs existed between areas. This analysis will be presented in the discussion. Simple regression analysis was used to analyze hypothesized functional relationships.

SURFACE AND GROUNDWATER SUPPLIES

Supplies of surface water are considered in this section to give a complete picture of the water supply situation in central Arizona.

Irrigation Districts

The agricultural area of central Arizona is characterized by approximately eighteen organized irrigation and drainage districts. While the districts were not all organized for the same purpose, the majority were organized, as their names imply, for purposes of control and distribution of irrigation water and implementation of drainage systems. The conservation of water is important to many if not all. The prime purpose of others is cooperative flood control. A number of the districts are quite small when measured in total acres and were created primarily for the utilization of excess and waste water from larger adjacent districts. Some of the smaller districts that were organized for purposes other than the distribution of irrigation water, are currently inactive. The more important districts at present are outlined on the map of Figure 2.

The largest district is the Salt River Project consisting of 238, 150 acres of land (Bureau of Reclamation 1963, p. 20).[1] To the east of the

---

[1] The total project acreage originally was 238, 150. Of this total only 146, 286 acres were under irrigation in 1962 due to urban development. Much of the urban land still has water rights.

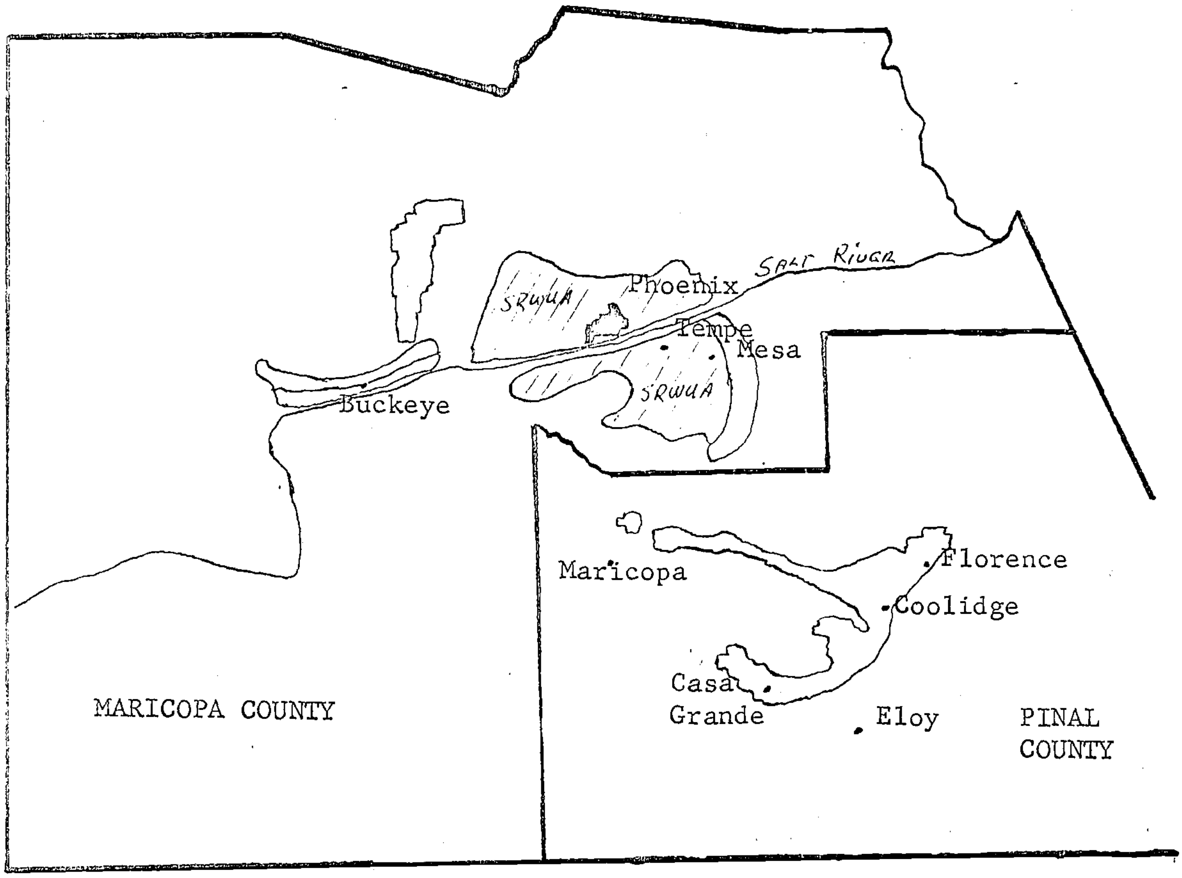

Figure 2. Map Showing Major Irrigation Districts in Central Arizona

Salt River Project in Maricopa County is the Roosevelt Water Conservation District containing 39,417 acres (Bureau of Reclamation 1963, p. 20).[2] On the west end of the Salt River Project 38,014 acres (Bureau of Reclamation 1963, p. 20)[3] make up the Roosevelt Irrigation District and along side it lies the Buckeye Water Conservation and Drainage District consisting of approximately 17,600 acres (Barr 1956, p. 13). Situated north of the Gila River and west of the Aguq Fria lies 26,000 acres (Nelson 1962) organized as the Maricopa County Municipal Water Conservation District No. 1. In Pinal County the San Carlos Irrigation and Drainage District coupled with the San Carlos Project Indian lands make up 105,083 acres (Cox 1963, p. 11) of irrigated land. The other organized districts will not be considered either because they are very small or because their prime objective is not irrigation.

The surface water used in central Arizona comes from two principal sources--the Salt and Verde River flows which are stored in a series of reservoirs controlled by the Salt River Valley Water Users Association, and the flow of the Gila River which is stored in the San Carlos Reservoir controlled by the San Carlos Irrigation and Drainage District.

---

[2] This is the total project size but in 1962 only 31,345 acres were actually irrigated. The difference is in non-agricultural use.

[3] Only 28,258 acres were irrigated in 1962 with the balance shifted to other uses.

The total combined storage capacity of the Salt and Verde system is about 2.1 million acre feet (White _et al._ 1962, p. 31). The average withdrawal from the system per year is around 700,000 acre feet (White _et al._ 1962, p. 31). The usable stored water in the system at the end of 1963 was 796,800 acre feet (Enz 1964, 1. 4). This is above the 53 year average of 616,100 acre feet (Enz 1964, p. 4). This water is applied mainly to Salt River Project lands with portions going to the Roosevelt Water Conservation District, Buckeye Water Conservation and Drainage District, and other projects that utilize excess and waste water of the Salt River Project. All of these districts supplement their surface flows with withdrawals from the groundwater basins.

The San Carlos Reservoir has a capacity of 1.2 million acre feet (White _et al._ 1962, p. 31). The usable stored water at the end of 1963 stood at 59,790 acre feet (Enz 1964, p. 4). This is considerably lower than the 34-year average of 102,900 acre feet (Enz 1964, p. 4). The surface flow represents about 60 percent of the water applied to San Carlos District lands (Cox 1963, p. 25). The balance of the water used is drawn from the underground supplies. The water used yearly by the District over the last few years is approximately 240,000 acre feet (White _et al._ 1962, p. 31); this includes pumped water as well as surface.

Groundwater Supplies

In Arizona, groundwater reservoirs are the main source of water supply (White _et al._ 1963, p. 2). The Salt River Valley of Maricopa County and the lower Santa Cruz basin have wide areas of alluvial fill that can store large amounts of groundwater. This structure yields water readily to the vast number of irrigation, domestic and industrial wells. Because the current annual rate of recharge to the groundwater reservoirs is negligible (White et al. 1963, p. 1) in comparison to the large amounts of groundwater withdrawn each year, the water level in nearly all areas is declining. The greatest declines in the state are in the Salt River Valley and the lower Santa Cruz basin. Withdrawals from the underground basins of these areas accounted for more than 3.05 million acre feet in 1962 (White et al. 1963, p. 2). More than 90 percent of this water is used for agricultural purposes (White et al. 1963, p. 2).

The groundwater basins pertinent to this study are outlined in Figure 3.[4] Number 1 is the lower Santa Cruz basin, which is divided into the three sub areas: the Casa Grande-Coolidge area, the Eloy area, and the Maricopa-Stanfield area. Number 2 is the Salt River Valley which will be considered only generally except for the Queen Creek-Magma area, which will be looked at separately. Number 3 is the Harquahala Plains area.

The regional movement of groundwater in the lower Santa Cruz basin is northward toward the Gila River. Before irrigation development

---

[4] The information in the following discussion of basins, changes in static water levels and depth to static water is taken from White et al., 1963. The data on depth and output during the summer of 1963 was part of the present study.

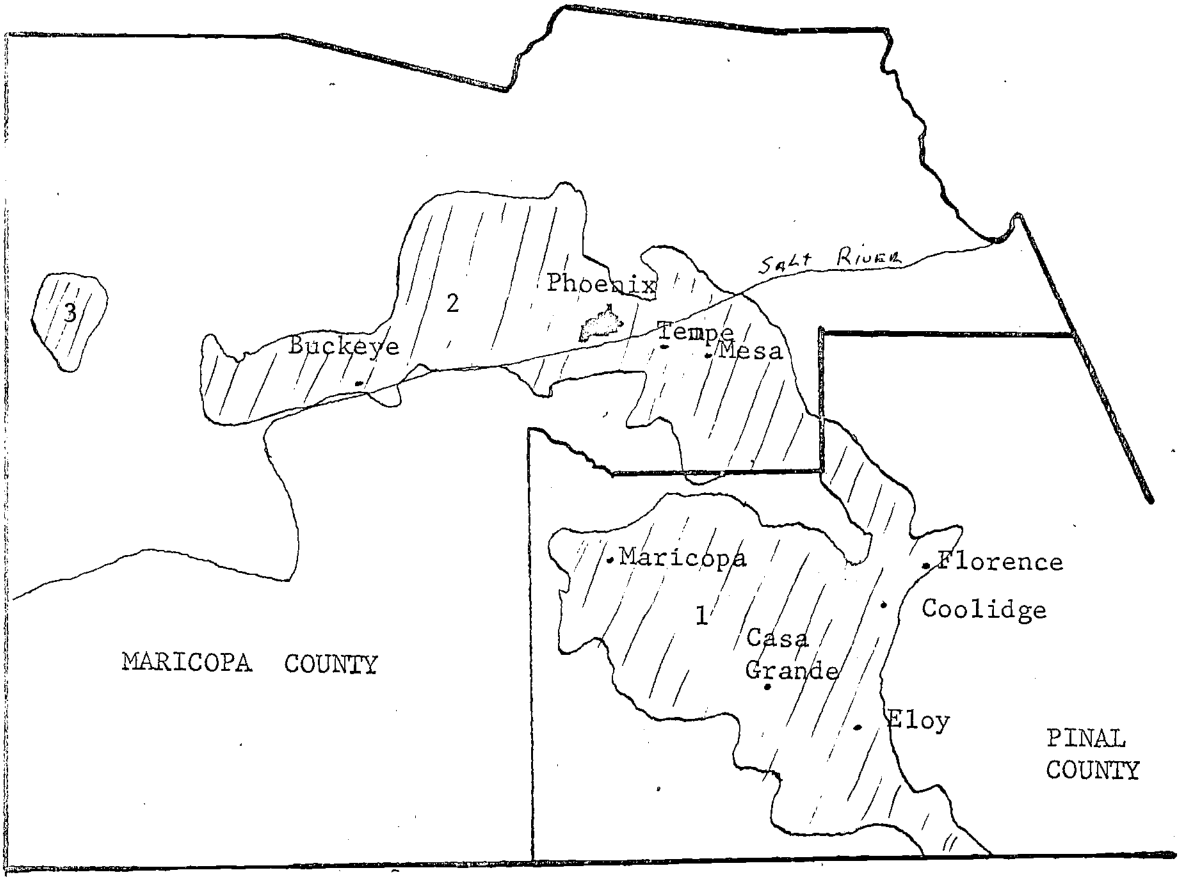

Figure 3. Map Showing Developed Groundwater Basins in Central Arizona

and pumping, the groundwater moved down the Santa Cruz River Valley through Red Rock and Eloy toward the Sacaton Mountains. The flow then divided; part went towards Coolidge and part towards Stanfield and Maricopa.

Since 1940 the rapid agricultural growth has caused heavy groundwater withdrawals, resulting in two large depressions of the groundwater table centering principally in the Eloy-Coolidge area and the Maricopa-Stanfield area. This caused a groundwater divide to form between the cones of depression near Casa Grande. The groundwater along this divide is generally of poor quality, and low water yields are common.

The depth to static water in the east Pinal area generally has been less than 200 feet. The mean pumping lift in the thirteen wells sampled was the 339.9 feet. The range was from 254 feet to 504 feet in the summer of 1963. From the spring of 1962 to the spring of 1963 the changes in the static water level ranged from rises of a foot to 6 feet to declines of 17 feet. Many of the declines were less than 5 feet. Most of the rises were along the Gila River. Generally the declines in this area were less than for the rest of the lower Santa Cruz basin because of the availability and use of surface water of the San Carlos Project. Wells which were tested in the area produce from 136 to 1835 gallons per minute with a mean of 715 gallons per minute.

The depth to static water in the south Pinal area ranged from 100 feet to nearly 350 feet in the spring of 1963. The range of pumping lifts in this sample was from 365 feet to 583 in the summer of 1963. The mean pumping lift was 460 feet. Yearly water level changes ranged from increases of 10 feet to declines of 24 feet. Most declines were less than 10 feet. Output of wells in the Eloy area ranged from 539 to 2,915 gallons per minutes with an average of around 1,800 gallons per minute.

Depth to static water in spring of 1963 in the west Pinal area ranged from 50 feet near Casa Grande to as much as 400 to 500 feet west of Stanfield. The groundwater gradient is very steep in this area, more than 75 feet per mile. The pumping lifts of the sampled wells during the summer of 1963 ranged from 192 to 521 feet. The yearly change in the water level ranged from no change to declines of 35 feet. The output of the wells in the sample ranged from 425 to 2,553 gallons per minute. The average was about 1,400 gallons per minute.

The Salt River Valley consists of the valley lands near Phoenix. It is drained by the Salt, Agua Fria, and Hassayampa Rivers. In the valley, the groundwater moves with the slope of the ground towards the southwest. Groundwater movement is also influenced by three major cones of depression--one near Gilbert, one in Deer Valley, and one northwest of Litchfield Park.

In the Queen Creek-Magma area, static water levels generally declined from six to 16 feet per year. The pumping lifts from the sample wells ranged from 454 to 585 feet with the average about 490 feet. The well outputs ranged from 1,100 to 2,200 gallons per minute with most being around 1,500 to 1,600 gallons per minute.

The Harquahala Plains area is a northwest-trending basin drained principally by the Centennial Wash. In 1963 measurements indicated yearly declines of more than 20 feet. Depths to static water ranged from 31 feet in the extreme southeast to about 380 feet in the center of the cultivated area. The pumping lifts for the wells sampled ranged from 175 to 403 feet. Outputs of 695 gallons per minute to 3, 626 gallons per minute were measured during the summer of 1963.

The amount of land cultivated has generally decreased due to the increasing pumping lifts except in the Harquahala area where expansion has taken place in recent years. As pumping lifts increase faster than pumping technology, the cost of water rises. As water costs increase, farmers are forced to raise only those crops that are most profitable. Cotton is generally the most profitable crop in central Arizona. The advent of cotton acreage restrictions with increasing water costs has effectively decreased the size of many farms. As it becomes unprofitable to continue to cultivate a particular crop that land cannot shift to cotton. Consequently, many farms have a high proportion of fallow land. As long as the withdrawal of groundwater exceeds the recharge, the water table will fall. How long the farmers can continue to farm and make a profit depends upon the changes in costs and returns relative to the change in the pumping lifts.

ELECTRIC POWER AND NATURAL GAS

Energy Sources

Pumping units are powered principally by two forms of energy, electricity and natural gas.

Electrical energy is transformed into mechanical energy through induction motors. The majority of pumping installations in central Arizona use electricity as the prime mover. Electrical districts are franchised to service given geographical areas. This avoids the waste that could occur due to duplication of lines and facilities in competing for customers. The electrical districts pertinent to this study are outlined in Figure 4. Electrical District No. 2 serves the east Pinal area. Districts No. 4 and 5 serve the south Pinal area. The west Pinal area is serviced by District No. 3. The area not covered by these districts in Pinal County is serviced directly by Arizona Public Service Company. In Maricopa County the Salt River Power District serves the Queen Creek area and the Harquahala Plains area is covered by Arizona Public Service Company.

Combustible natural gas is converted to mechanical energy through the internal combustion engine. This has proved to be an efficient prime mover for farmers situated relatively close to the main line of the El Paso Natural Gas Company. El Paso's main line runs from the

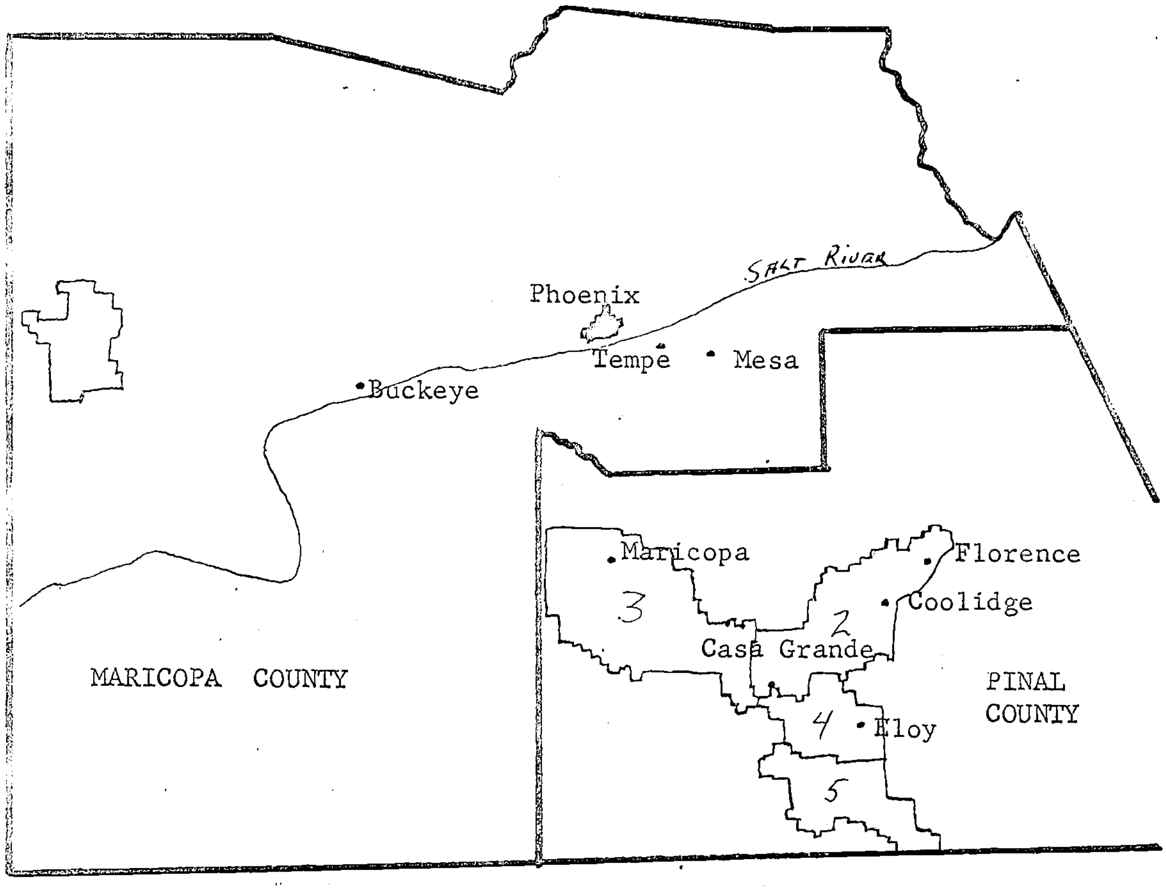

Figure 4. Map Showing Electrical Districts in Central Arizona Pertinent to This Study

southeast towards the northwest through the lower Santa Cruz basin. This gas is distributed exclusively in this area by the Southwest Gas Corporation which purchases direct from El Paso. Only a few natural gas installations are in use in the Queen Creek area. In the Harquahala Plains area the Arizona Public Service Company distributes natural gas, which it purchases from El Paso Natural Gas Company whose main line runs through the southern part of the area. Because of the higher cost of installing service lines for natural gas, the present gas users are generally clustered around the existing mains. Therefore, the distant wells are almost 100 percent electrically operated.

Electrical Rates

Each electrical district pays the same rate for its power, but its average cost per kilowatt hour is determined by the efficiency and consistency with which it can utilize its kilowatt demand for power in terms of kilowatt hours of energy.[5] Some suppliers of electrical power to the farmer charge a flat rate in mills per kilowatt hour for energy used, and no demand charge is used. Others include a demand charge in their rates to farmers. When a demand charge is used, the farmer's bill is computed by the retailer in the same manner in which the retailer is

---

[5] This information was obtained from the files of Dr. Aaron G. Nelson, Professor at the University of Arizona. A more complete discussion which gives details of operation and rate structuring of electrical districts can be found in Appendix E.

billed by the wholesaler. Each irrigation pump has its own meter and is billed individually. The billing demand is measured by a demand hour meter. The peak demand is determined by the average kilowatts supplied during the 15-minute period of maximum use during the month.

Electrical District No. 2 has a monthly minimum of five dollars per meter.[6] During the months of January and February, which are normally slack pumping periods, the rate is a flat 7.5 mills per kilowatt hour used. During the other ten months of the year, 8.5 mills per kilowatt hour is charged for the first 2,000 kilowatt hours used, figured on an annual basis. The rate then falls to 7.5 mills per kilowatt hour for all additional power used.

A five-dollar monthly minimum per meter is charged by Electrical District No. 4. A flat rate of 7.5 mills per kilowatt hour is charged for all power used during the year.

Electrical District No. 5 is similar to No. 4 in that a five-dollar minimum is charged with a flat year-around rate of 8.0 mills per kilowatt hour.

A monthly minimum based upon kilowatt demand is used by Electrical District No. 3. Eighty-one cents is charged for the first kilowatt, plus 65 cents for each additional kilowatt of the highest kilowatt

---

[6] The information contained in the subsequent discussions of the electrical district and gas suppliers' rates was obtained by personal interview with individual managers during 1963.

established during the 12 months ending with the current month--or the minimum kilowatt specified in the agreement for service, whichever is greater, but not more than an amount sufficient to make the total charges for such 12 months equal to $9.72 for the first kilowatt plus $7.80 for each additional kilowatt of the highest kilowatt demand, but in no event less than $101.92 per month. The monthly bill rate is 16 cents plus 11.6 mills per kilowatt hour, for the first 275 kilowatt hours, times the kilowatt demand. Eight and six-tenths mills per kilowatt hour is charged for all additional power used. When the total monthly charges are computed upon the foregoing basis, a flat 5 percent is then deducted from each customer's bill.

The Arizona Public Service Company rate structure is similar to that outlined for Electrical District No. 3. The monthly minimum is the same as District No. 3. The monthly bill rate for Arizona Public Service Company is 16 cents, plus 10.0 mills per kilowatt hour for the first 275 kilowatt hours for each kilowatt demand, plus 7.0 mills per kilowatt hour for all additional power used. Due to a change in the cost of gas purchased from the El Paso Natural Gas Company, effective January 14, 1963, the electrical fuel rate is adjusted downward by .037 mills per kilowatt hour. The customer's bill is figured as in the past, and the total kilowatt hours used is multiplied by the adjustment figure and subtracted from the total bill.

The Salt River Power District charges a monthly minimum of five dollars per meter. The monthly bill rate per meter during the months of April through September is 11.3 mills per kilowatt hour for the first 275 kilowatt hours for each kilowatt of billing demand, plus 8.6 mills per kilowatt hour for all additional power used. During October through March, the rate is 8.6 mills per kilowatt hour for all kilowatt hours used. Effective March 1, 1963, these rates were adjusted downward by the amount .113 mills per kilowatt hour in the same manner outlined for Arizona Public Service Company.

All monthly power billings are subject to a state sales tax of 1.5 percent and a state regulatory assessment of .199 percent. City sales taxes are charged where applicable. A district may or may not add these taxes to the customer's bill.

Natural Gas Rates

The Southwest Gas Corporation has a graduated rate schedule wherein the price of gas decreases as the quantity used increases. Gas is sold on the basis of cubic feet and the price is per thousand cubic feet. Rates are shown in Table 1. As shown, the minimum is $2.52 per meter per month. The practice of Southwest is to allow single billing of multiple meters so that most farmers are eligible for the most favorable rate per thousand cubic feet. In addition, the customer must pay 1.5 percent sales tax and 2 percent franchise tax on the amount of his bill.

TABLE 1.--Gas rates of Southwest Gas Corporation for service to irrigation installations 1963 in dollars.

			October to February	March to September
		Small irrigation		
First	1,200	cubic feet or less	$2.52 minimum charge	
next	1,800	cubic feet per mcf.	.988	.952
next	97,000	cubic feet per mcf.	.638	.602
next	100,000	cubic feet per mcf.	.458	.422
over	200,000	cubic feet per mcf.	.438	.402
		Large irrigation		
First	500,000	cubic feet per mcf.	.488	.452
next	1,000,000	cubic feet per mcf.	.438	.402
over	1,500,000	cubic feet per mcf.	.418	.382

The natural gas rates have been revised for 1964 and are 1.5 cents lower per thousand cubic feet.

Arizona Public Service Company meters natural gas to their customers in cubic feet but sells on the basis of therms. A therm is that amount of gas having a heating value of 100,000 British Thermal Units. This amount of gas varies with location due to air pressure, gas pressure, temperatures and other factors. The minimum monthly charge is 56 cents for the first horsepower plus 50 cents per additional horsepower of manufacturer's rated continuous capacity of internal combustion engines installed, but not more than an amount sufficient to make the total charges for the twelve months ended with the current month equal to $6.00 per horsepower plus 72 cents. The monthly rate per therm is shown in Table 2. The billed amount is subject to 1.5 percent state sales tax, .199 percent state regulatory assessment, and other local taxes where applicable. The rates were adjusted downward January 14, 1963, by .4 cents per therm for October through February and .0881 cents per therm for March through September.

TABLE 2.--Gas rates of Arizona Public Service Company for service to irrigation installation 1963.

$1.26 which includes the use of 5 therms

13.9 cents per therm next 20 therms

8.0 cents per therm next 25 therms

6.3 cents per therm next 300 therms

5.6 cents per therm next 350 therms

5.0 cents per therm next 500 therms

4.1 cents per therm next 33,800 therms

3.9 cents per therm next 215,000 therms

3.7 cents per therm for all additional therms

Service Availability

For electrical service, the distributor will provide service to any customer showing a need for power for an useful purpose. The three districts and Arizona Public Service Company will pay the first $500 cost of constructing lines to the pumping installation. The customer pays the estimated costs of providing his own service, minus the $500. The amount paid is refundable over a five-year period in amounts equal to 25 percent of the yearly electric bill over the minimum but not to exceed 20 percent of the total amount deposited in any one year. The Salt River Project will provide 1,000 feet of free line and the customer will pay the rest at the rate of 40 cents per foot.

The Arizona Public Service Company will provide free gas lines up to 15 feet of line per installed horsepower but not to exceed total cost of $5,000. Any additional line will be paid for by the customer at the estimated cost of installation which is about $1.00 per foot for main and $.85 per foot for service line. The Southwest Gas Corporation will provide service to any installation situated along existing lines having excess capacity under present use.

WELL AND PUMP INSTALLATIONS

Well Drilling and Casing

Two methods of drilling wells for irrigation purposes are presently employed in central Arizona, "cabled tool" and "rotary" drilling.

The most common is the "cable tool" method which operates with a vertical motion by repeatedly dropping a bit in the hole. This action loosens the aggregate while at the same time mixing it with water which suspends the material so it can be bucketed out of the hole. The well may or may not be cased as the drilling progresses depending upon the nature of the materials encountered. Because of the loose nature of much of the alluvial fill in central Arizona it is generally necessary to install casing while deepening the hole.

A less common method but one that has been quite successful in some areas is "rotary" drilling. As the name implies the action is circular and the hole is usually drilled larger than by the cable method and larger than the casing. The hole is not cased as it is drilled but casing is put in after it is finished. For example, the hole may be 24 inches in diameter and the casing 18 inches. When the casing is in place the area on the outside of the casing is filled with an aggregate such as gravel. The main advantage of this method seems to be the greater surface area in the well for water to flow in while avoiding the higher cost of a larger size casing. The casing may be perforated before installation or after. A variety of methods are employed to perforate the well.

The diameter of casing of wells drilled range from 16 to 22 inches with the great majority being 20 inches. The actual distribution of the well sizes included in this study are shown in Table 3.

TABLE 3.--A frequency distribution of initial casing diameters of 73 wells in central Arizona.

Diameter of casing in inches	No. of wells
16 inches	9
18 inches	1
20 inches	62
22 inches	1
TOTAL	73

The depth wells were drilled ranged from 300 feet to 2,500 feet. A frequency distribution of well depths is shown in Table 4. Of the 74 wells in the survey 20 have been deepened. When deeping is required a smaller hole is drilled inside the existing well. The diameter may be from two to four inches less. This portion is cased and perforated in the same manner as the original.

The mean age of the wells sampled was 8.7 years with a range from less than 1 to 37 years. The distribution is shown in Table 5, Analysis of variance (Steel and Torrie, 1960, p. 99) showed no

TABLE 4.--A frequency distribution of the drilled depth of 74 wells in central Arizona.

Depth drilled in feet	No. of wells
0-100	0
100-200	0
200-300	1
300-400	1
400-500	6
500-600	2
600-700	5
700-800	9
800-900	6
900-1000	8
1000-1100	16
1100-1200	2
1200-1300	7
1300-1400	1
1400-1500	3
1500-1600	3
1600-1700	1
1700-1800	0
1800-1900	1
1900-2000	0
2000 and over	2
TOTAL	74

TABLE 5.--A frequency distribution of the age of 64 wells in central Arizona.

Age in years	No. of wells
0-1	4
1-2	6
2-3	3
3-4	2
4-5	5
5-6	4
6-7	3
7-8	4
8-9	5
9-10	2
10-11	2
11-12	6
12-13	5
13-14	2
14-15	0
15-16	3
16-17	0
17-18	3
18-19	3
19-20	0
20 and over	2
TOTAL	64

significant difference in the age of wells between areas at the five percent level. A nonsignificant difference means that even though the data appears different on the basis of the data obtained we have no justification for saying means are actually different one from the other. Estimated expected life of the wells ranged from 10 to 50 years with the average being 18.64 years. In the population one would expect the mean age to be exactly half of the expected life. The mean age is almost half of the expected life indicating a representative sample by age of wells. Expected life of wells did not differ significantly at the five percent level between areas.

The reasons for abandonment of a well are five-fold: (1) inability to deepen because of a crooked hole or the lower portion of the casing not being large enough; (2) rusting out of the casing allowing the well to fill with sand or aggregate; (3) settling of the alluvium due to the water withdrawals affecting shifts underground which cause rupturing and twisting of the well casing; (4) being unable to recover bowls and column pipe accidentally dropped in the well, and (5) striking bedrock and exhausting the water supply which usually would result in farm abandonment.

The cost of well drilling and casing varies tremendously. Figures range from $16 per foot to $35 per foot which includes costs and installation of casing. The variation in costs is due to the size of the hole drilled, the quality of the casing used and what seems the most important influence, the amount of competition for an individual job. The costs of the "rotary" method is comparable to that for "cabled tool." Most drillers will guarantee a straight hole and the cost of actual drilling will run around ten dollars per foot. Casing cost will average around nine dollars per foot but may run anywhere from five dollars to ten dollars. Most of the casing used is oil field rejects and is considerably cheaper than first grade material. A shoe must be used on the bottom of the casing to protect the pipe while it is being driven. A shoe costs anywhere from $100 to $400 depending upon the size and quality. The perforation of the casing will cost one dollar per foot. The average cost of a typical 20-inch well is about $20.50 per foot, so a farmer may have a considerable investment in a well before he knows whether or not he has any water. Whenever a well is damaged and appears repairable a farmer can have work done at a cost of around $15 per hour for a well rig and a crew to operate it.

Pump and Column Assembly

A typical oil lubricated column assembly is comprised of the column pipe, the shaft, the oil tube, spacers, and bearings. A cutaway view of such an assembly and motor is shown in Figure 5. Oil is the most common lubricant in central Arizona; however, some installations use water in which case the oil tube is absent, the water being pumped lubricating the shaft.

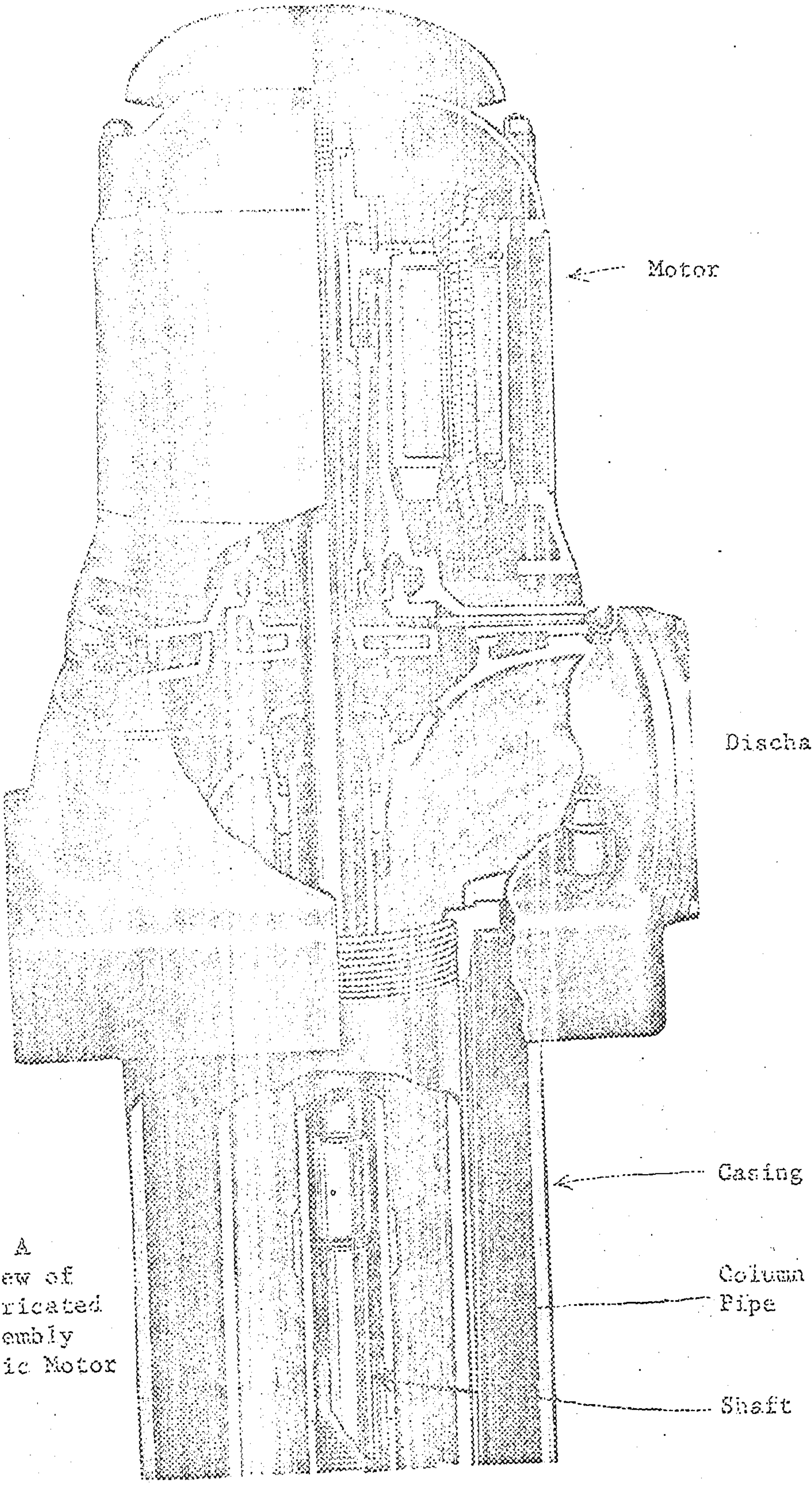

Figure 5. A Cutaway View of an Oil Lubricated Column Assembly and Electric Motor

The number of feet of column assembly in a well is dependent primarily upon the pumping lift. The size of the column is determined by the yield of the well. The water yield is a function of the surface area in the well below the static water table and the inflow rate. The water yield may be referred to as the developed capacity of the well.

Of the pumps in the survey, the column sizes ranged from 6 to 14 inches. A distribution is shown in Table 6. No correlation exists between column size and casing size.

TABLE 6.--A frequency distribution of size of column in 72 wells in central Arizona.

Column size in inches	No. of wells
6	1
8	12
10	25
12	33
14	1
TOTAL	72

The cost of column varies considerably by size and quality. It appears price per foot varies more between makes than from size to size within a given make. Cost figures reported by pump companies varied from $4.30 per foot for a six-inch column assembly to $26 per foot for a 12-inch assembly. The average installation will run $15.60 per foot.

The amount of column in a well varied from less than 200 to over 600 feet. Generally farmers do not have much excess column extending below the water level while in operation. Table 7 shows the distribution of the amount of column pipe in the wells surveyed.

TABLE 7.--A frequency distribution of the number of freet of column in 72 wells in central Arizona.

Feet of column	No. of wells
0-100	0
100-200	1
200-300	8
300-400	14
400-500	26
500-600	19
600 and over	4
TOTAL	72

Analysis of variance indicated a significant difference between lifts of different areas. The Student-Newman-Keul test (Steel and Torrie, 1960, p. 110) showed the following divisions at the five percent level: Harquahala area, significantly different from all areas; the east Pinal area, not different from the west Pinal area but both different from the other four; the south Pinal, Pinal gas, and Queen Creek areas, not different from each other but different from the other three areas. This is shown in Table 8. A solid line connecting the means indicates no significant difference.

TABLE 8.--Results of analysis of variance of feet of lift between sampled areas.

Harquahala	East Pinal Electric	West Pinal Electric	Pinal Gas	South Pinal Electric	Queen Creek
269	340	347	440	460	491
	———	———			
			———	———	———

The mean age of column installations was 3.9 years with a range of less than 1 to 23 years (see Table 9). Farmers' estimates of expected column life averaged 14 years. At the five percent level there was no significant difference shown between areas of either age or expected life.

The capacity of the pump is determined by the number of bowl stages and may be limited by the column size. Most installations are designed so that the column size is not an effective limitation upon the engineered capacity of the bowls. The number of bowl stages in the pump is determined by the necessary lift. The actual distance one

TABLE 9.--A frequency distribution of ages of column assembly in 61 wells in central Arizona.

Age in years	No. of wells
0-1	14
1-2	9
2-3	6
3-4	4
4-5	4
5-6	6
6-7	3
7-8	4
8-9	4
9-10	1
10-11	2
11-12	1
12-13	1
13-14	0
14-15	0
15-16	1
16-17	0
17-18	0
18-19	0
19-20	0
20 and over	1
TOTAL	61

stage will lift is dependent upon the engineering design of the bowls and the amount of wear that has occurred. In actuality the installed capacity should exceed the required so that a considerable amount of wear can occur and still obtain the desired flow of water before attention is required. The number of stages plotted against lift is shown in Figure 6. Simple regression indicated the average lift per bowl to be 83.3 feet. The b value (slope of the regression line) was significantly different from zero. Feet of lift explained only 41 percent of the variation in number of bowls (Steel and Torrie 1960, p. 161). The low r^2 (coefficient of determination) was expected because of different designs and planned excess capacity.

The expected life of a set of bowls varied from three months to ten years. The life is determined primarily by the amount of sand that is pumped with the water. In acute sand conditions it is not uncommon to shut off the pump every few days to facilitate cleaning out the ditch that has filled with sand. The life of bowls is affected by the amount of calcium carbonate in the water which forms deposits on the moving parts. Cases have occurred where the deposits completely immobilized the set of bowls. The set has to be pulled and either replaced or cleaned, either of which is very costly. The corrosive effect of salt deposits are of concern in some areas.

The cost of bowls varies greatly because of quality differences and design. Figures quoted ranged from $900 to $3,000 for an average set depending upon the specifications. Wide differences appeared between the various makes. In quoting prices, a price is usually

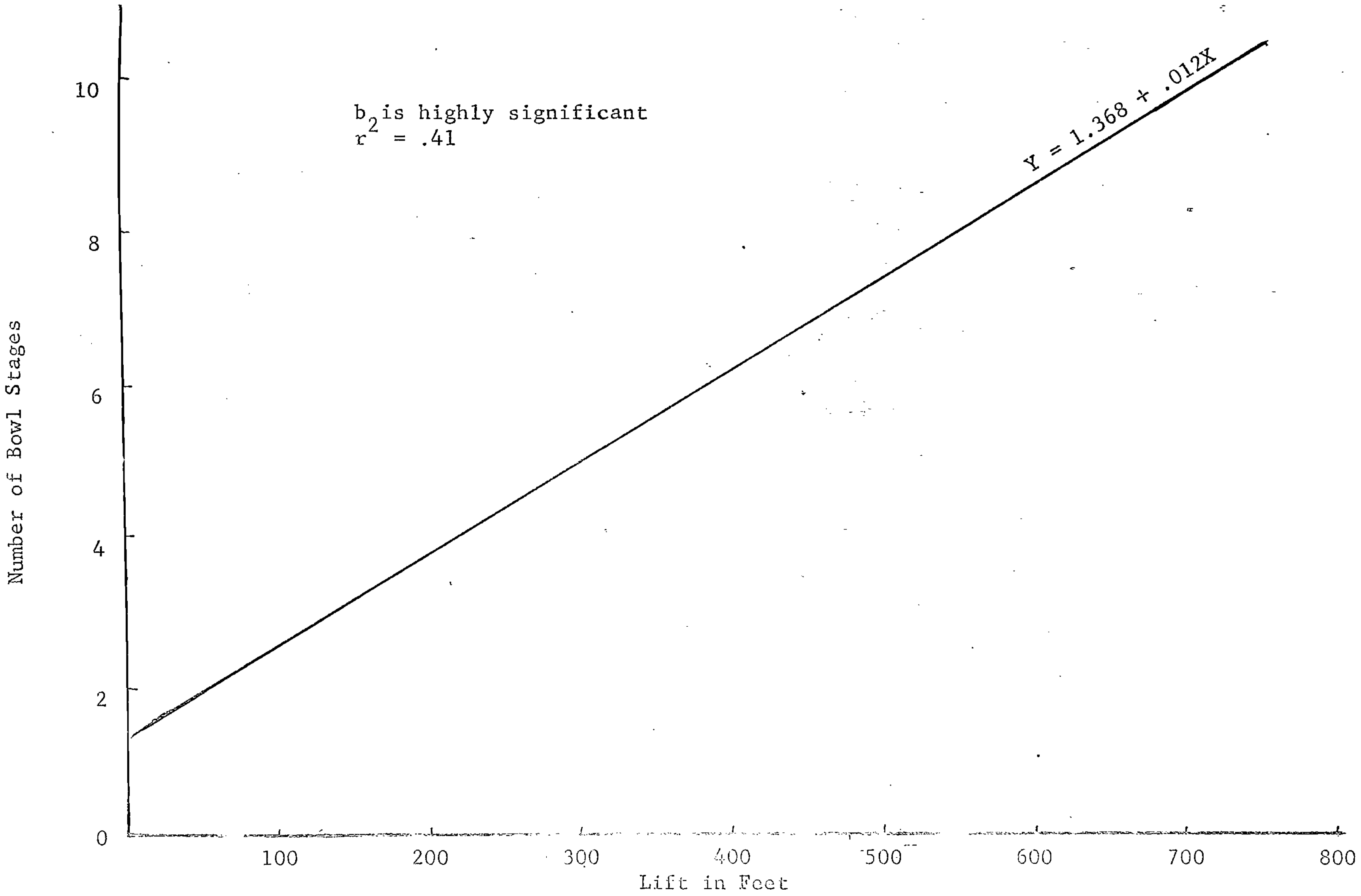

Figure 6. Number of Bowls Plotted as a Function of Lift

given for the initial stage and a flat rate for each additional. For example, a 14-inch,[7] 10-stage set of bowls of a particular make will cost $504 (initial stage) plus $1,476 ($164 x 9) or a total of $1,980. A cutaway view of a three-stage bowl set is shown in Figure 7.

Electric Motors

The size of electric motors in the samples ranged from 50 horsepower to 700 horsepower. The distribution is shown in Table 10.

TABLE 10.--A frequency distribution of the horsepower of electric motors on 50 wells in central Arizona.

Motor size in horsepower	No. of wells
50	3
100	5
150	10
200	16
250	6
300	6
350	2
500	1
700	1
TOTAL	50

---

[7] The size of bowls does not have to match the column size. A 14-inch bowl will adapt to most column sizes.

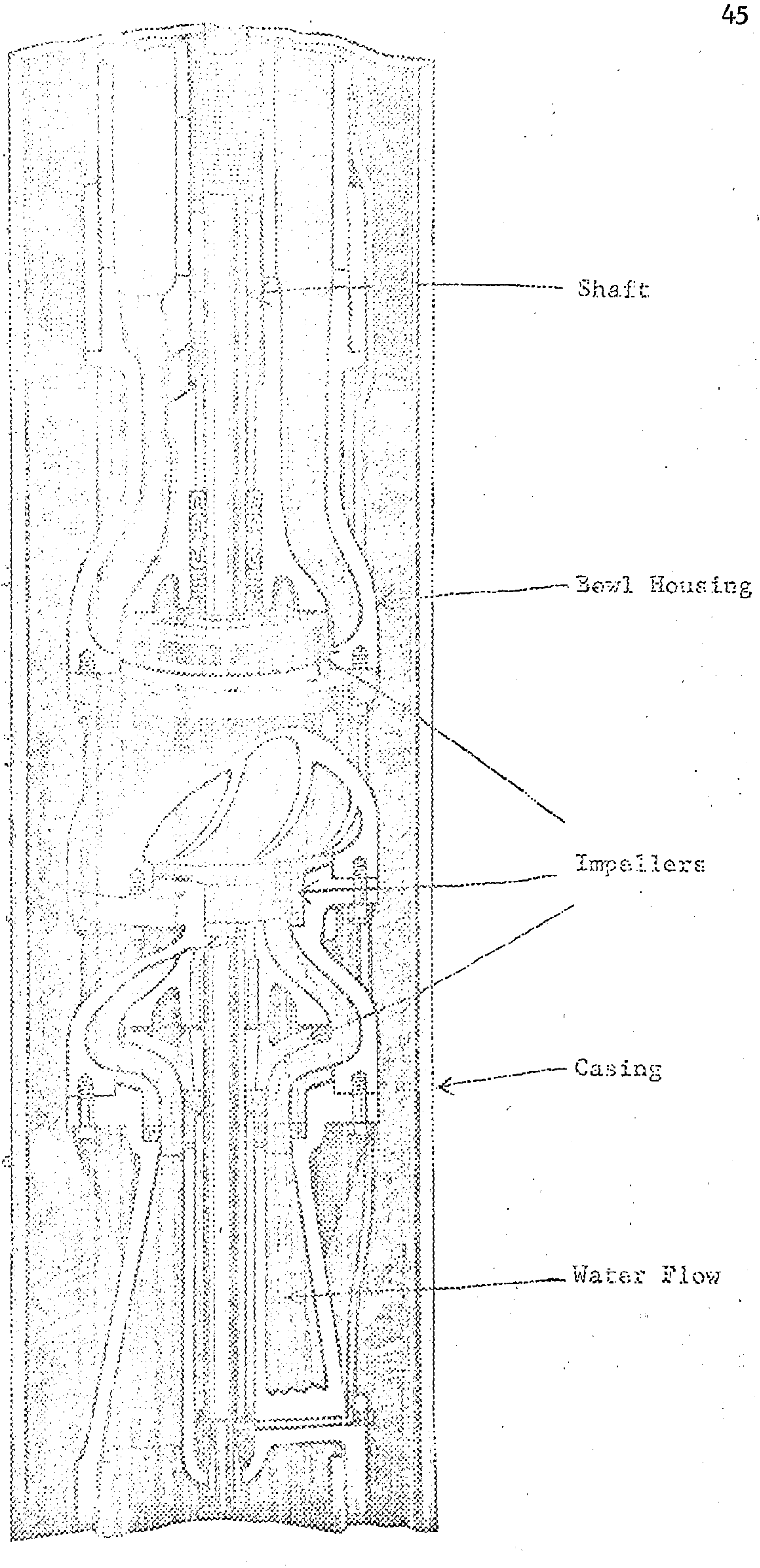

Figure 7. A Cut-away View of a Three Stage Set of Bowls

The horsepower necessary is a function of the feet of lift and the designed capacity of the pump. As the number of stages required is directly related to depth, we can plot motor size against lift as the determining relationship for horsepower requirements (see Figure 8). This figure shows a per foot of lift requirement of .57 horsepower on the basis of the sampled wells.

The range of motor ages was from less than 1 to 17 years with a mean of 5.4 years. The distribution of total motor age (not since rewind) is shown in Table 11. The average expected life was 17 years

TABLE 11.--A frequency distribution of the age of 45 electric motors on wells in central Arizona.

Year	No.	Year	No.
0-1	7	9-10	1
1-2	4	10-11	1
2-3	4	11-12	1
3-4	2	12-13	2
4-5	3	13-14	2
5-6	3	14-15	0
6-7	5	15-16	2
7-8	3	16-17	1
8-9	6	TOTAL	45

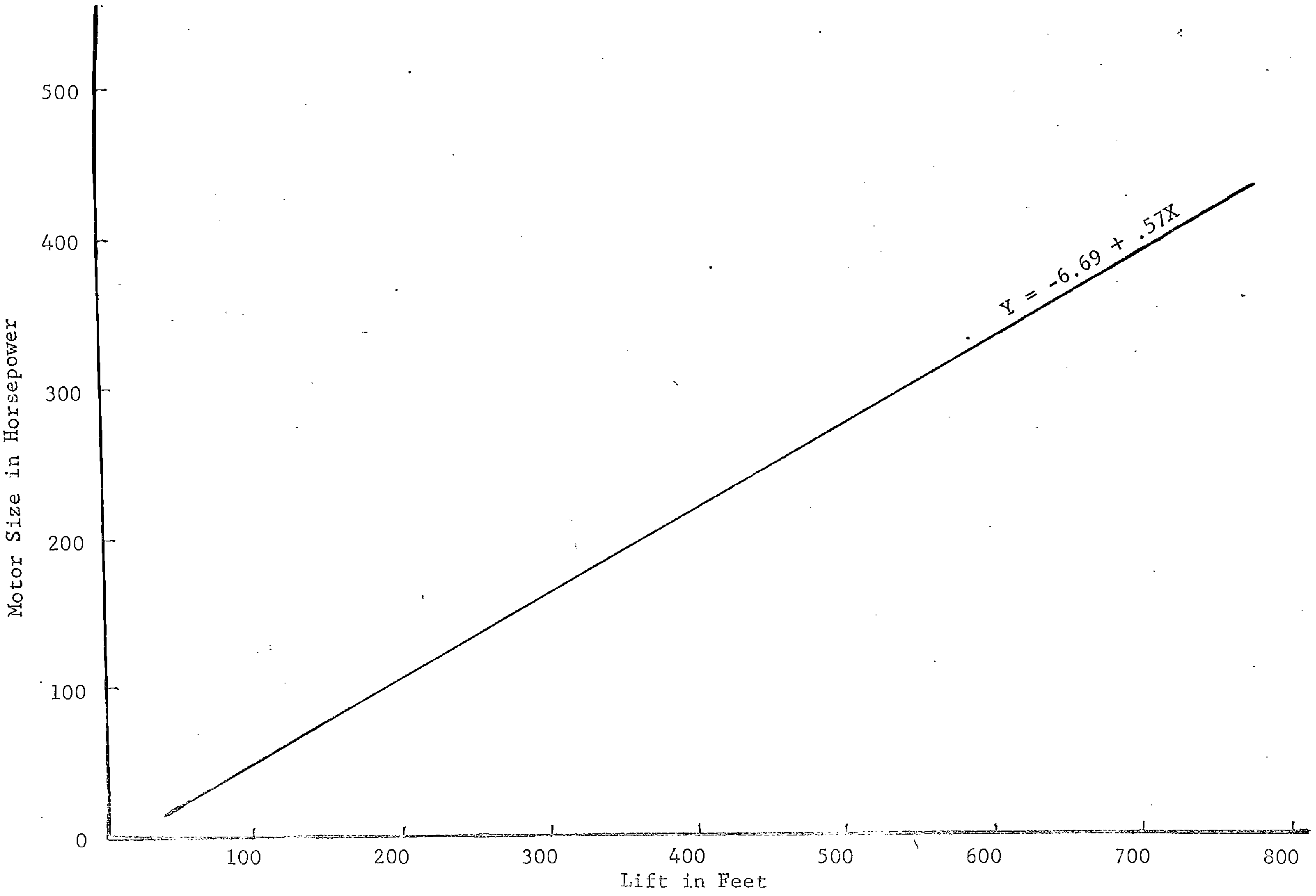

Figure 8. Electric Motor Size Plotted as a Function of Lift

to rewind. Most farmers felt that a motor would give almost indefinite service providing it is rewound on the average of every 17 years. Rewind cost was about one-third of new cost.

Analysis of variance showed no significant difference between areas of either age or expected life of motors.

The cost of electric motors varies with the horsepower but is quite constant on a per horsepower basis. Difference between makes were insignificant. The cost per horsepower for all sizes of motors were generally between 19 and 20 dollars, with most figures closer to $20.

Complements include starting equipment, transformer, and wiring. In the west Pinal electric area the district owns the transformers. The cost of complements is roughly equal to the electric motor cost. The most usual total cost for electric motor and complements was around $9,000 per well.

Natural Gas Engines

Manufacturers continuous duty horsepower rating of engines in the sample ranged from 275 horsepower to 500 horsepower with a mode of 325 horsepower. The distribution is shown in Table 12. The determinant of horsepower requirements is similar to that of electric motors with the most important, hypothetically, being lift. However, no correlation could be obtained on the basis of the sample data to support this hypothesis which indicates other factors not investigated are more important in determining the size of engine used.

TABLE 12.--A frequency distribution of engine size in horsepower for 23 gas wells in central Arizona.

Size in horsepower	No. of wells
275	2
300	4
325	5
350	5
375	1
400	0
425	0
450	1
475	2
500	3
TOTAL	23

Two and eight-tenths years was the mean age of engines of the range of less than 1 to 18 years. The distribution is in Table 13. The average expected life was 15 years with two major overhauls costing about one-third of new cost each time. Even though the average age is not half of the expected life, the cost analysis will not be affected because depreciation as computed is uniform for each year.

The cost of engines varies, of course, with the horsepower rating. Quite large variations occur between makes and models of

TABLE 13.--A frequency distribution of the age of 20 engines on wells in central Arizona.

Years	No.
0-1	5
1-2	7
2-3	3
3-4	1
7-8	1
8-9	1
9-10	1
17-18	1
TOTAL	20

engines. Of those in the survey, cost ranged from $11,000 to $15,000 with one engine costing $24,000. This cost is for the engine only. When adding shipping, installation, water cooler, driveline, and gearhead, the cost range was up to $17,000 and $21,000. The most usual cost was around $18,000 for the engine, complements and installation. The very expensive engine was primarily of longer life and lower maintenance design and ran in excess of $33,000.

Efficiency

Over-all efficiency of the pumping installation was calculated for each well by dividing the water horsepower by the input horsepower.

No attempt was made to determine the efficiency of each individual component such as motor, pump, etc. The average efficiency for electric wells was 51.5 percent and 13.13 percent for gas wells. Electric well efficiency ranged from 22.5 to 75.5 percent. Four and nine-tenths to 19.7 percent was the range for all gas wells.

Testing for significant differences of electric well efficiencies between areas yielded two subgroups. The areas and mean values are shown in Table 14. A solid line connecting two means indicates no significant difference at the five percent level on the basis of the sample data.

TABLE 14.--Results of analysis of variance of efficiencies of electric wells sampled.

East Pinal Electric	South Pinal Electric	West Pinal Electric	Harquahala	Queen Creek
42.4	45.5	51.2	61.6	63.9
———	———	———		
			———	———

Efficiency is a function of the condition of the power unit, the bowls, and the mechanical and water friction losses. The condition of the power unit and friction losses were not ascertained.

The condition of the bowls determines the amount of water that can be lifted. It seems reasonable, then, that efficiency is related to water output. As the output of the well increases, the efficiency increases also. Fitting a line by the method of least-squares shows that an increase in output of 100 gallons per minute gave an efficiency increase of 1.18 percent on electric wells. The same method showed an increase in efficiency of .29 percent per 100 gallons per minute increase in output for gas wells. The amount of variance in efficiency explained by output was 43 and 22 percent, respectively. The low r^2 values were expected for these relationships as many other factors affect efficiency but does give an indication of some of the causes of the wide variation found in the efficiencies of wells.

It was hypothesized that water output is a function of the amount of area in the well below the static water table. Consequently, one could expect the potential output of a well to increase as the depth of the well is drilled below the water table increases, assuming the water table constant between wells. This gives the rationale of drilling a well in excess of 2,000 feet which is considerably deeper than the foreseeable economic lift for agricultural purposes. With the greatly increased amount of inflow area, even a very tight underground structure with low transmisibility may yield an acceptable flow. Analysis of data failed to substantiate this hypothesis. The most probable explanation is that the underground stratas found in drilling are not homogeneous between wells or even within the same well.

Hours Operated Annually

The amount of hours a pump is operated annually depends upon the number of acres it must serve, the output of the well and the cropping pattern throughout the year.

Wells in the sample were operated an average of 3,753 hours per year. The range was 1,188 to 7,843 hours. There was no significant difference between areas as to the amount of hours operated yearly. The 1,188 hours was only 13.6 percent of the possible (8,760 hours) operating time per year while 7,843 is 89.5 percent. The mean of 3,753 was 42.8 percent of possible.

In Pinal County, the acres each well served was from 20 to 300 acres with the average being 166 acres per well. Maricopa County generally had higher yielding wells with a mean of 335 and a range of 120 to 800 acres per well.

Those wells that serve land that raised only cotton were used intermittently for about six months each year whereas some of the other served crops the year around. Whether crops other than cotton are grown depends upon the profitability of each alternative which is determined principally by the cost per acre foot of water, which in turn is dependent mainly upon the water lift. In some areas the electric power rate structure encourages consumption during the winter months which is the slack season for cotton. On the other hand, the natural gas rates increase during the slack period thereby discouraging water pumping. In addition to rate effects, the static water table generally rises during the winter giving a decreased lift which changes physical power requirements per acre foot. Figure 9 shows the distribution of hours run by months during the year for all wells. This graph represents the normal pumping pattern for all areas considered in this study.

Acre Feet of Water Pumped

The mean acre feet of water pumped per well per year in each area for 1963 is shown in Table 15.

TABLE 15.--Results of analysis of variance of acre feet of water pumped per well per year.

East Pinal Electric	West Pinal Electric	Pinal Gas	South Pinal Electric	Queen Creek	Harquahala
422.1	715.3	1,063.4	1,241.9	1,245.4	1,383.6

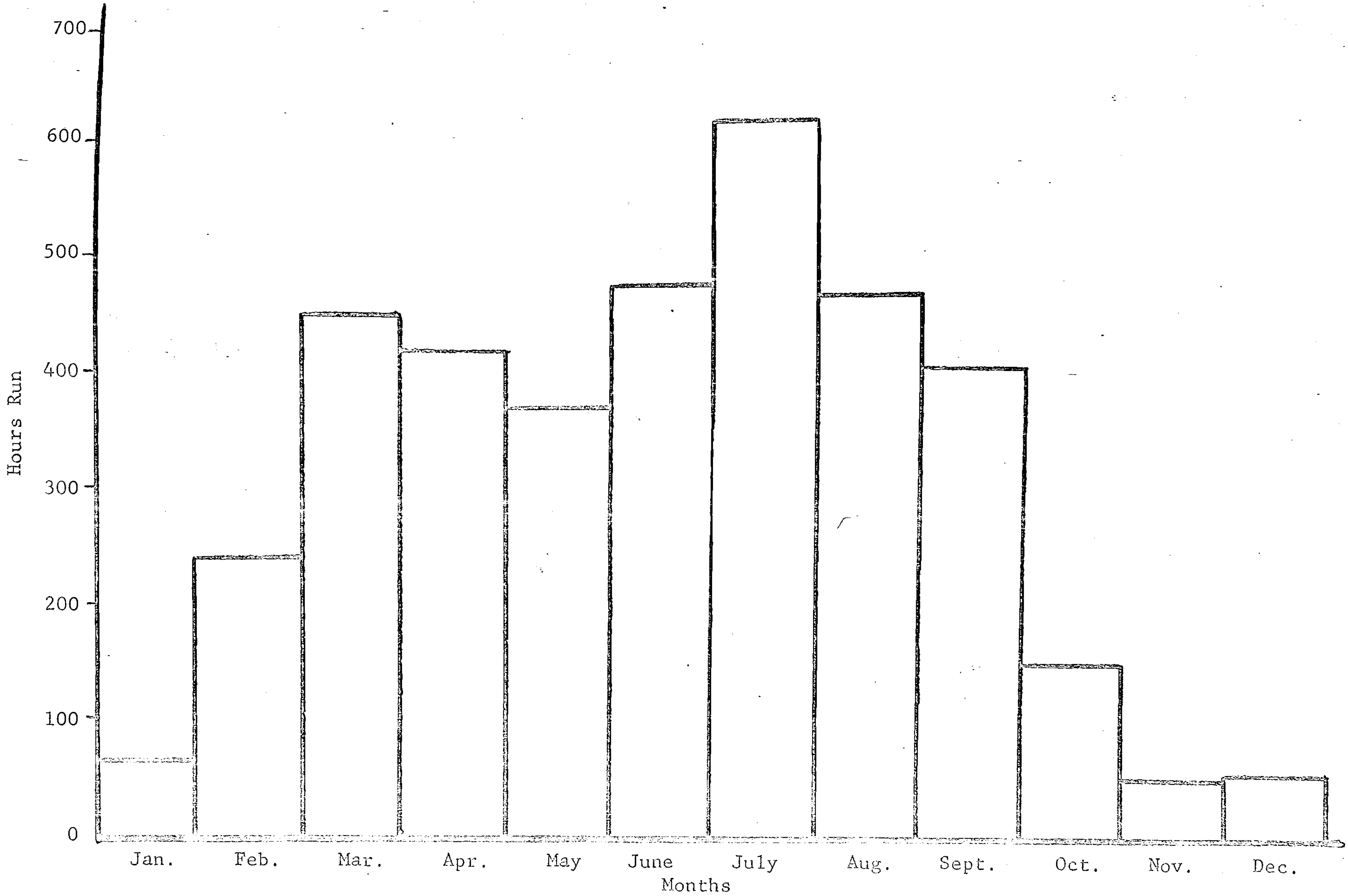

Figure 9. Hours Run by Months--Average of all Wells

Any two means connected by a solid line indicates no significant difference at the five percent level. This indiciates no difference in amount of water pumped per year because of the type of power used. Acre feet of water pumped over the entire sample ranged from 83 to 2, 752 acre feet per year. The mean was 991 acre feet.

Some of the difference in the amount of water pumped is because of the output of wells in gallons per minute. Results of analysis of variance of the output of wells in gallons per minute is shown in Table 16. Connecting lines indicate no difference at the five percent level.

TABLE 16.--Results of analysis of variance of output of wells in gallons per minute.

East Pinal Electric	West Pinal Electric	Pinal Gas	Queen Creek	South Pinal Electric	Harquahala
716	1, 223	1, 521	1, 567	1, 795	1, 925

Output ranged from 136 gallons per minute to 3, 626 gallons per minute with an over-all mean of 1, 433 gallons per minute.

Other factors that affect the amount of water pumped were not shown by the sample data. Number of acre feet pumped per year was thought to be a function of one or more of the following variables: size of the well, depth of well, type of power and efficiency. Regression analysis failed to show a significant relationship with any of these variables.

The distribution of water pumped throughout the year follows the hours operated distribution shown in the preceding section.

PUMPING COSTS

The Nature of Pumping Costs

Total cost of pumping water is made up of variable costs, added capital costs, and fixed costs. As in the case of other functional relationships, the total cost curve or cost function represents the functional relationship between output and total cost.

Variable costs refer to those outlays which are a function of output in the production period. Variable costs considered in this study are classified in the following categories: (1) energy, (2) pump and well repair, (3) power unit repair, (4) attendance, and (5) lubrication.

Added capital costs refer to the cost of enlarging the pumping plant because of the decline in the water table. While these costs represent an increase in the fixed investment, they are quasi-variable costs because they are essential to continued operation of the pumping plant. While not related to output, added capital costs are of a variable cost character in that they are not needed unless the well is operated. They are not under control of the individual farmer since decline of the water table is the result of pumping by all farmers in an area, the decision by one farmer regarding operation of an individual well having little effect on the level of the water table. Unless all farmers follow the same course of action an individual farmer's efforts will be to no avail and his savings will be appropriated by his neighbors.

Costs that do not vary with output are referred to as fixed costs. They include taxes, interest on investment, and depreciation. Services which are represented by fixed costs differ from those represented by variable costs in the sense that the former are given off in a constant flow irrespective of quantity of water produced. The latter arise from the services which are used up in the actual production process.

The exact nature of the total cost function depends on the nature of the production function which underlies it. A technical relationship fixes the output of a well with the variable inputs. For example, the gallons per minute output cannot be changed by adding more power.[8] This relationship cannot be changed without changing the fixed base. As successive units of input are added over time, the increase in total

---

[8] This is true of electrically operated wells; however, it is not necessarily true of those powered by natural gas. Natural gas engine speed can be regulated by a throttle which increases or decreases the gas input and this can change the gallons per minute output. In most cases, though, the engine is run at the optimum discharge speed which is the maximum gallons per minute that can be continuously maintained. The only situation that would cause a farmer to change the input and in turn affect the output is when the water level becomes so low that the pump begins to "surge" (discharging water intermittently). In order to maintain a steady flow the speed of the engine is decreased. The output is decreased accordingly. Slowing the engine is only a temporary measure to facilitate finishing a field or until such time that the pump can be stopped and the bowls lowered in the well. Consequently, it is expected, except in the situation just described, that the output of gas wells will not vary without a change in the fixed base.

product is constant. Because of these factors the production function is assumed to be linear. This in turn makes the total cost function linear if we assume no change in the purchase price of inputs. For a linear total cost curve, the marginal and average variable cost is constant while the average fixed and average total costs will decline throughout all ranges of output. A constant total fixed cost and linear total cost is shown in Figure 10. Average variable cost, marginal cost, average fixed cost, and average total cost corresponding to the Figure 10 curves are diagrammed in Figure 11. In pumping water total output is dependent upon total time operated. An absolute limit on total production is imposed by the maximum number of time units available within the period considered. The period in this study is a year. To put wells on a comparable basis the time units are hours. The maximum possible production in a year differs between wells because of varying output per hour but the maximum hours per year is the same for all wells.

Method of Computing Representative Costs for Each Area

In order to derive costs representative and typical of specific areas, individual well costs need to be weighted. Each well was weighted by the amount of water it pumped in the year 1963 in arriving at an acre foot cost. When calculating cost per acre foot per foot of lift, the individual costs were weighted by water pumped and also the distance the water was lifted.

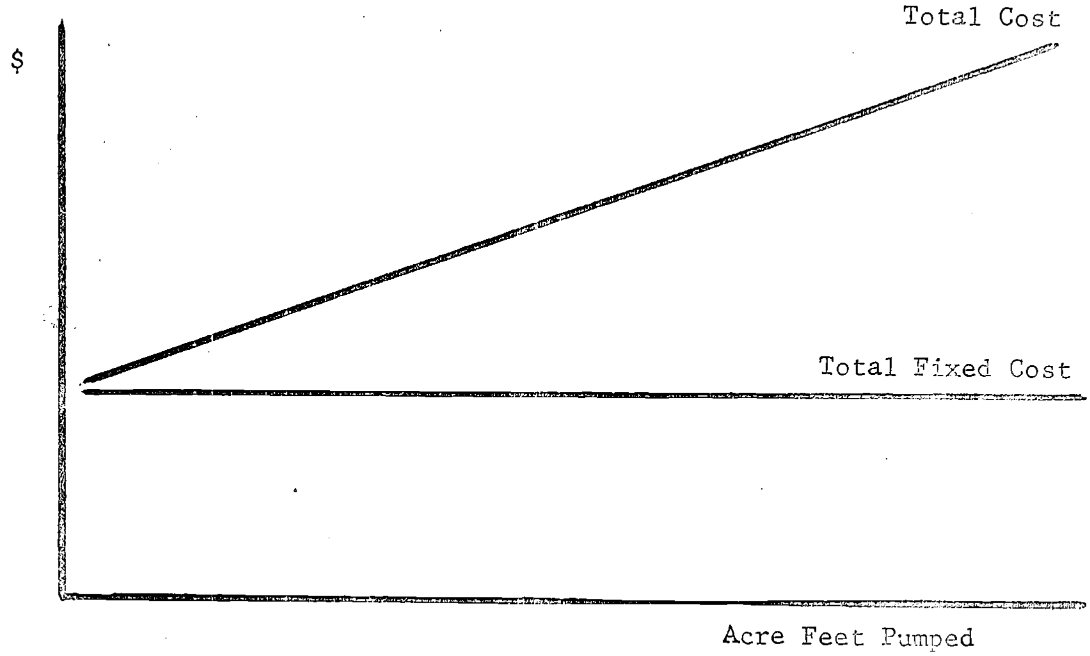

Figure 10. Nature of Total Fixed Cost and Total Cost in Pumping Water

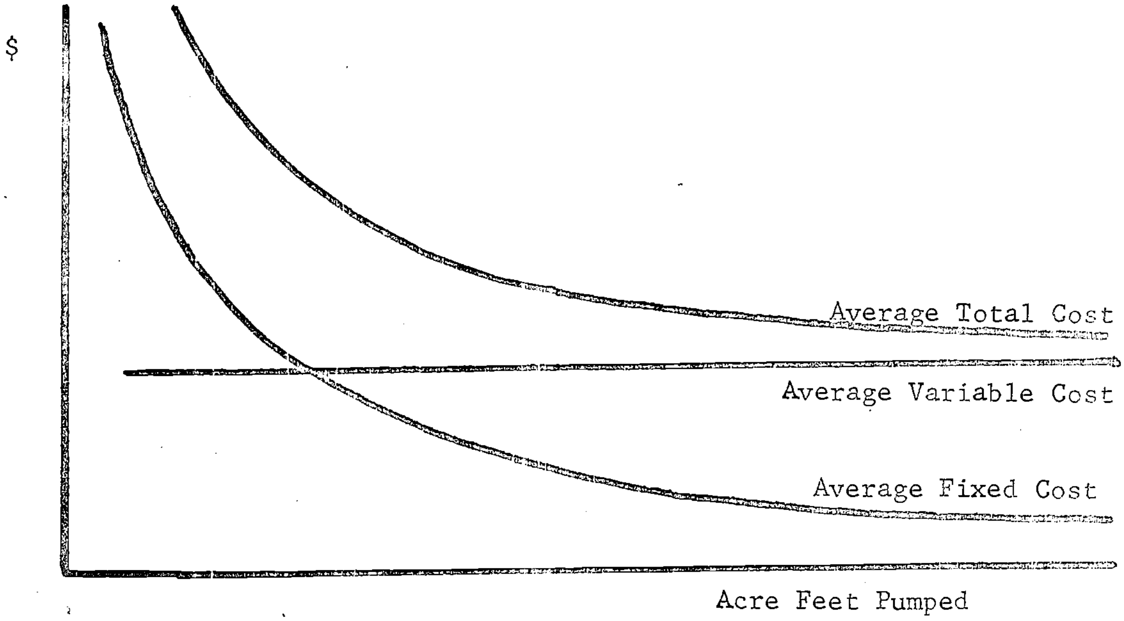

Figure 11. Nature of Average Costs of Pumping Water

The reason for deriving weighted average costs is best illustrated by fixed costs. Fixed costs per unit vary considerably by the amount of use. A well that pumps a few acre feet per year will have very high fixed costs per acre foot. If it has equal weight with others that run 80 percent of the year, it will make the representative per acre foot cost much higher. As an example, in the east Pinal area using simple averages instead of weighted averages raises the total cost per acre foot by three dollars. The simple average is not representative because the high cost wells receive more weight than they deserve relative to the total amount of water pumped and bias the cost estimate upward.

This weighted averaged method of estimating a cost from a simple random sample is referred to as ratio estimation.[9] The sample estimate is:

$$\hat{R} = \frac{\sum_{1}^{n} yi}{\sum_{1}^{n} xi}$$

where $\hat{R}$ is the estimated mean, $\sum_{1}^{n} yi$ is the sum of the particular cost by all wells in an area sample, and $\sum_{1}^{n} xi$ is the number of acre feet all wells in an area sample pumped during 1963 or number of acre feet multiplied by lift of all wells in an area sample.

---

[9] The subsequent statistical discussion is based upon William G. Cochran, Sampling Techniques, New York, John Wiley and Sons, Inc., 1963, pp. 29-33, 164-165.

In order to determine the reliability of the estimates it is necessary to place a confidence interval upon each estimate. The degree of significance used in the study was the five percent level. What an interval means is that if two intervals overlap even though the actual $\hat{R}$'s appear quite different, on the basis of the sample data we have no grounds for saying that the $\hat{R}$'s are different from one another.

To facilitate construction of an interval the variance of the data must be computed. Because we are working with weighted averages, obtaining a variance is considerably more complicated than for a simple average. In small samples the distribution of $\hat{R}$ is skew and $\hat{R}$ is a slightly biased estimate of the true mean, R. This bias leads to underestimating R. The distribution of $\hat{R}$ is positively skewed and the order of the bias of the ratio estimate is $\frac{1}{n}$, where n represents the size of the sample.

The number in the population (N) must be known in order to compute a variance, $V(\hat{R})$. The formula is:

$$V(\hat{R}) = \frac{1 - f}{n\bar{x}^2} \cdot \frac{\Sigma yi^2 - 2\hat{R}\Sigma yixi + \hat{R}^2\Sigma xi^2}{n - 1}$$

where $f = \frac{n}{N}$, $V(\hat{R})$ is the variance of the estimate, $\Sigma yixi$ is the sum of the cross products, and $\bar{x}^2$ is the mean of the x's squared. For the estimated standard error of $\hat{R}$ we simply take the square root of the variance.

A confidence interval for R may be obtained:

$$\hat{R} \pm t\sqrt{V(\hat{R})}$$

where t is the normal deviate corresponding to the chosen confidence probability, which is five percent in this study. We can then say that this interval contains R unless this is the one-in-twenty chance because of sampling error.

Fixed Cost

The new cost of a pumping installation and the intensity of use are the principal determinants of fixed cost per unit of product.

In order to arrive at fixed costs per well per year, replacement cost of all components necessary to duplicate the present installation were needed. The actual figures applied to each individual well are contained in Appendix F. The cost component classifications used are (1) drilling, (2) casing, (3) perforating, (4) bowls, (5) column assembly, (6) pump head, (7) discharge pipe, and (8) (for electric wells): (a) starting equipment, (b) transformers, (c) wiring, and (d) motor; (for gas wells: (a) engine, (b) shipping, (c) installation, (d) gearhead, (e) driveline, and (f) water cooler. These items are then combined into three major groups: well cost, pump cost, and power unit cost. The well cost is drilling, casing and perforating. Pump cost includes bowls, column, head, and discharge pipe. The power unit includes those items given for electric wells and for natural gas wells.

Depreciation was computed individually for each of the three major cost components because of differences in length of life. The straight line method is used throughout.

Well cost is depreciated over 18.64 years with no salvage value. This makes the yearly depreciation 5.3648 percent of new cost.

Depreciation on the pump is 7.1429 percent per year. This represents an expected life of 14 years. The only component having any salvage value was the pump head which is considered negligible.

The depreciation for power unit cost for electric wells was computed upon an indefinite life with a one-third of new cost every 17 years for rewind and overhaul of the motor. This makes the yearly percent of new cost charged 1.961. The salvage value was two-thirds of new cost at the end of 17 years.

For gas wells, depreciation of the power unit is based upon a total expected life of 15 years. The salvage value after 15 years was negligible. Two major overhauls are anticipated during the 15 years. The overhaul cost is about one-third of new cost each time. This gives a yearly depreciation figure of 11.114 percent.

The interest on investment was computed upon one-half the initial capital cost of each well at the rate of six percent per annum, the assumption being that the well and equipment was half worn out.

Each pumping installation is subject to county taxes. County assessors value the pumping units on the basis of installed horsepower.

The rate is uniform for all at $40 per horsepower. The maximum horsepower assessable is 250 which in turn limits the maximum assessment to $10,000 per well. A tax rate per hundred dollar valuation is applied to this figure to arrive at the taxes per year. The tax rate varies depending upon the particular school district in which the installation is located. The tax rates during 1962 ranged from $4.02 per hundred to $11.92 per hundred. The rates applied to the sample wells averaged around $8.00 per hundred.

The figures of the three components of fixed cost (depreciation, interest, and taxes) for each area were weighted by acre feet of water pumped in arriving at an average cost per acre foot. In order to obtain a cost per acre foot of lift the figures were weighted by water pumped and feet of lift. A variance and standard error was computed for each weighted average. A confidence interval was then placed upon the estimated average.

Components of fixed cost and total fixed costs per acre foot and per acre foot per foot lift by area are shown in Table 17. The figure in parentheses under each mean value is the standard error of that value. Figures 12, 13, 14 and 15 show relative magnitudes and positions of confidence intervals for acre foot and acre foot per foot of lift costs in various areas for taxes, interest on investment, depreciation and total fixed cost, respectively.

There is a significant difference in taxes between areas on the basis of acre foot and acre foot per foot of lift. Interest on investment

TABLE 17.--Taxes, interest, depreciation, and total fixed costs of pumping water for sampled areas in central Arizona in dollars.[a]

Area	Cost per acre foot				Cost per acre foot per foot of lift			
	Taxes	Interest	Depreciation	Total fixed[b]	Taxes	Interest	Depreciation	Total fixed[b]
East Pinal Electric	1.121	1.767	3.002	5.890	.00325	.00512	.00869	.01705
	(.117)	(.184)	(.307)	(.532)	(.00036)	(.00049)	(.00139)	(.00219)
South Pinal Electric	.531	1.003	1.760	3.237	.00133	.00252	.00442	.00827
	(.098)	(.205)	(.301)	(.722)	(.00028)	(.00050)	(.00080)	(.00481)
West Pinal Electric	.867	1.176	2.016	4.072	.00255	.00346	.00594	.01199
	(.112)	(.196)	(.341)	(.682)	(.00036)	(.00056)	(.00096)	(.00197)
Pinal Gas	.763	1.516	3.482	5.507	.00168	.00334	.00767	.01210
	(.078)	(.152)	(.483)	(.544)	(.00021)	(.00034)	(.00113)	(.00133)
Queen Creek	.492	.970	1.633	3.114	.00102	.00205	.00345	.00659
	(.350)	(.126)	(.217)	(1.400)	(.00024)	(.00026)	(.00044)	(.00092)
Harquahala	.138	.662	1.092	1.910	.00052	.00300	.00494	.00865
	(.021)	(.139)	(.236)	(.445)	(.00019)	(.00103)	(.00082)	(.00474)

[a] Figures in parentheses are standard errors of figure above, respectively.

[b] Parts may not add to total because of shifts in weighting when combining for totals because of missing data.

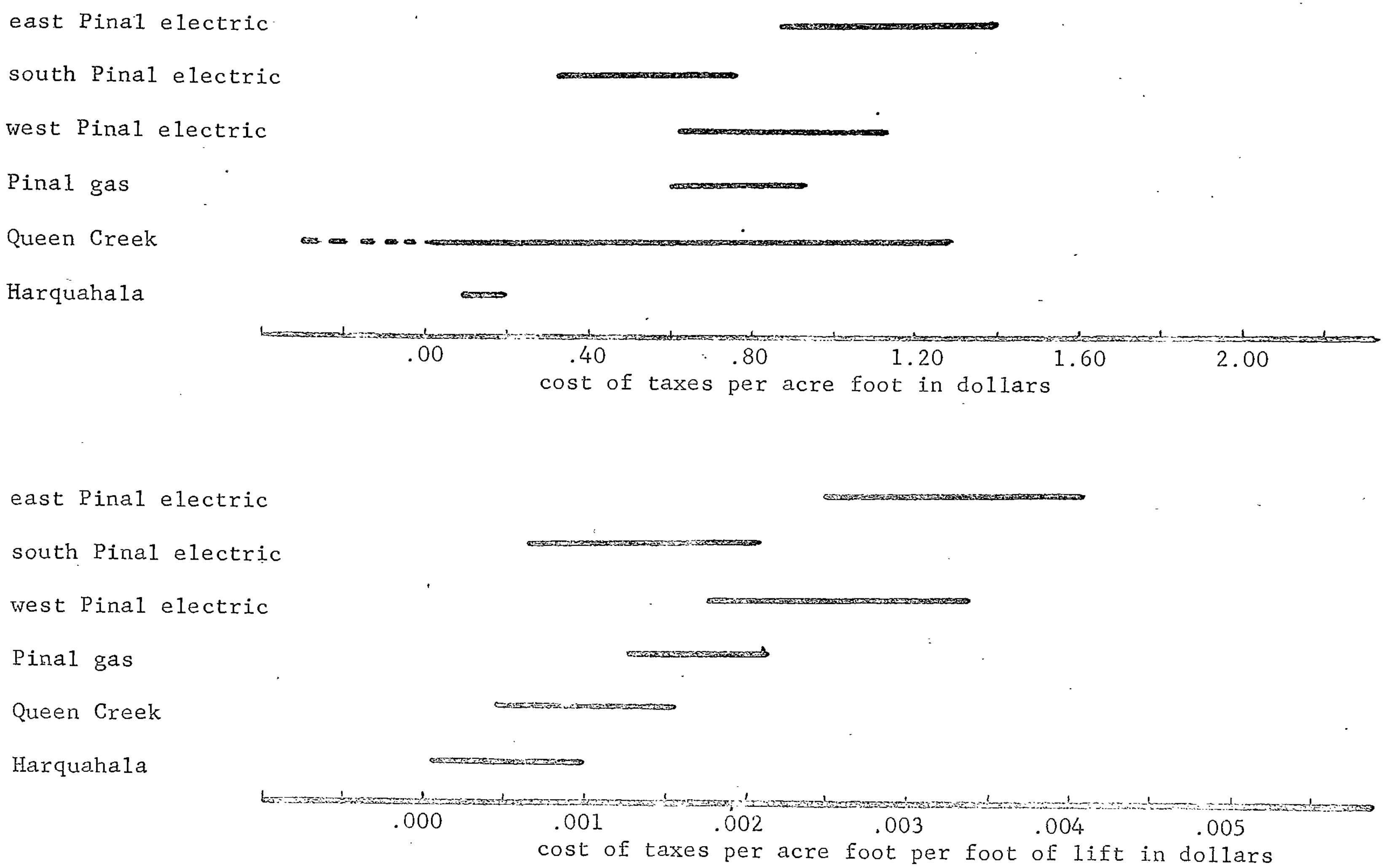

Figure 12. Confidence intervals of tax cost for sampled areas

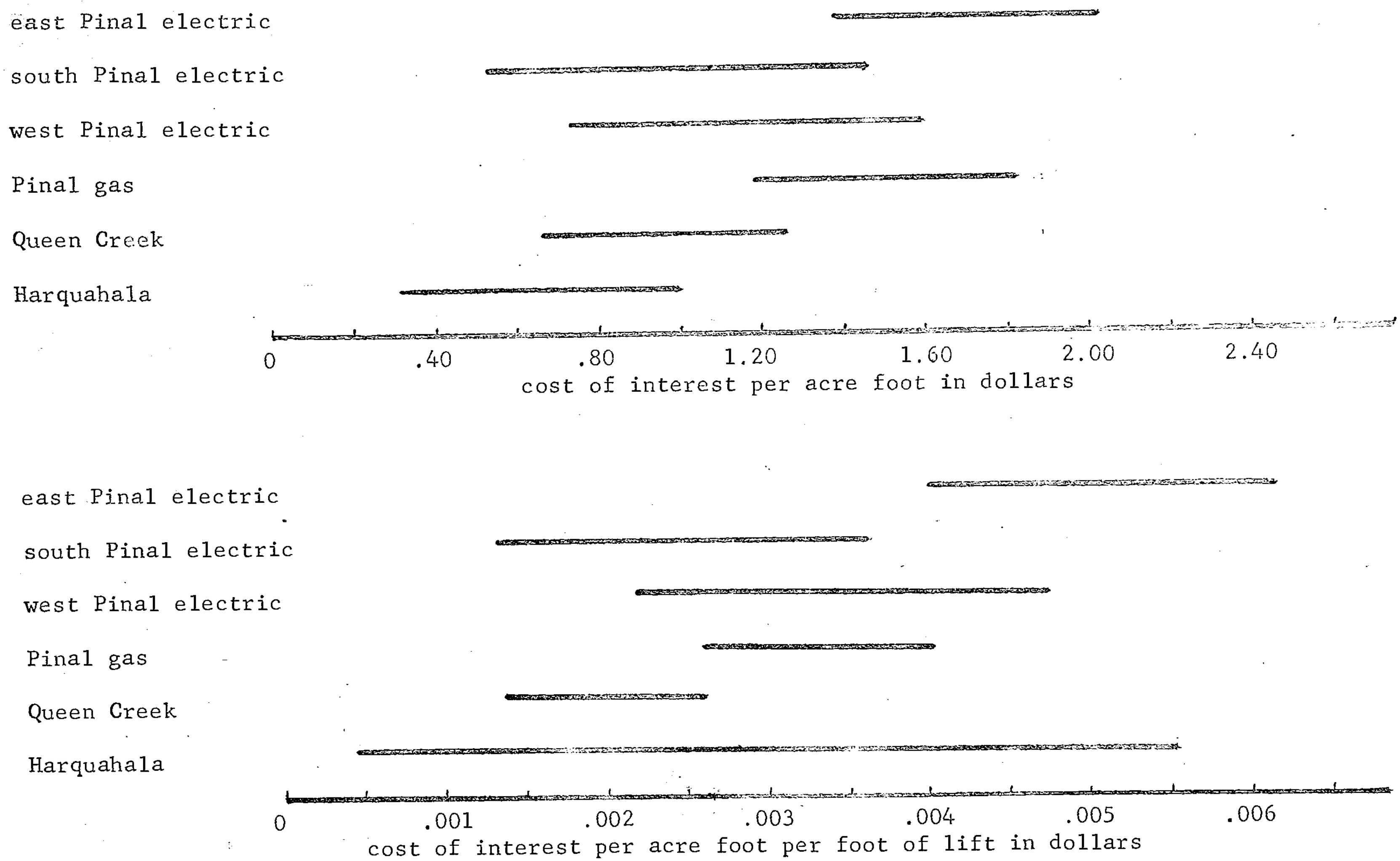

Figure 13. Confidence Intervals of Interest Cost For Sampled Areas

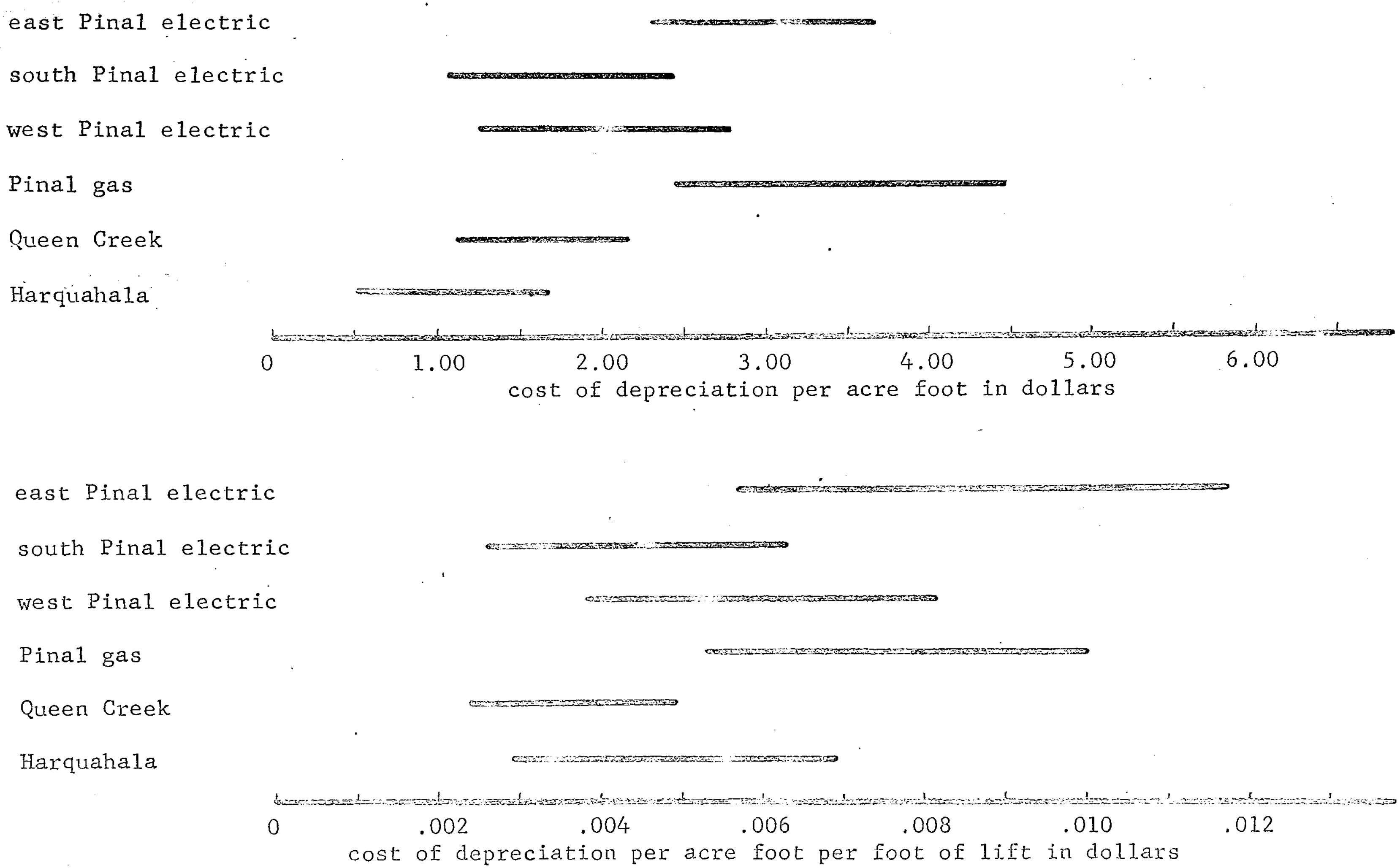

Figure 14. Confidence Intervals of Depreciation Cost for Sampled Areas

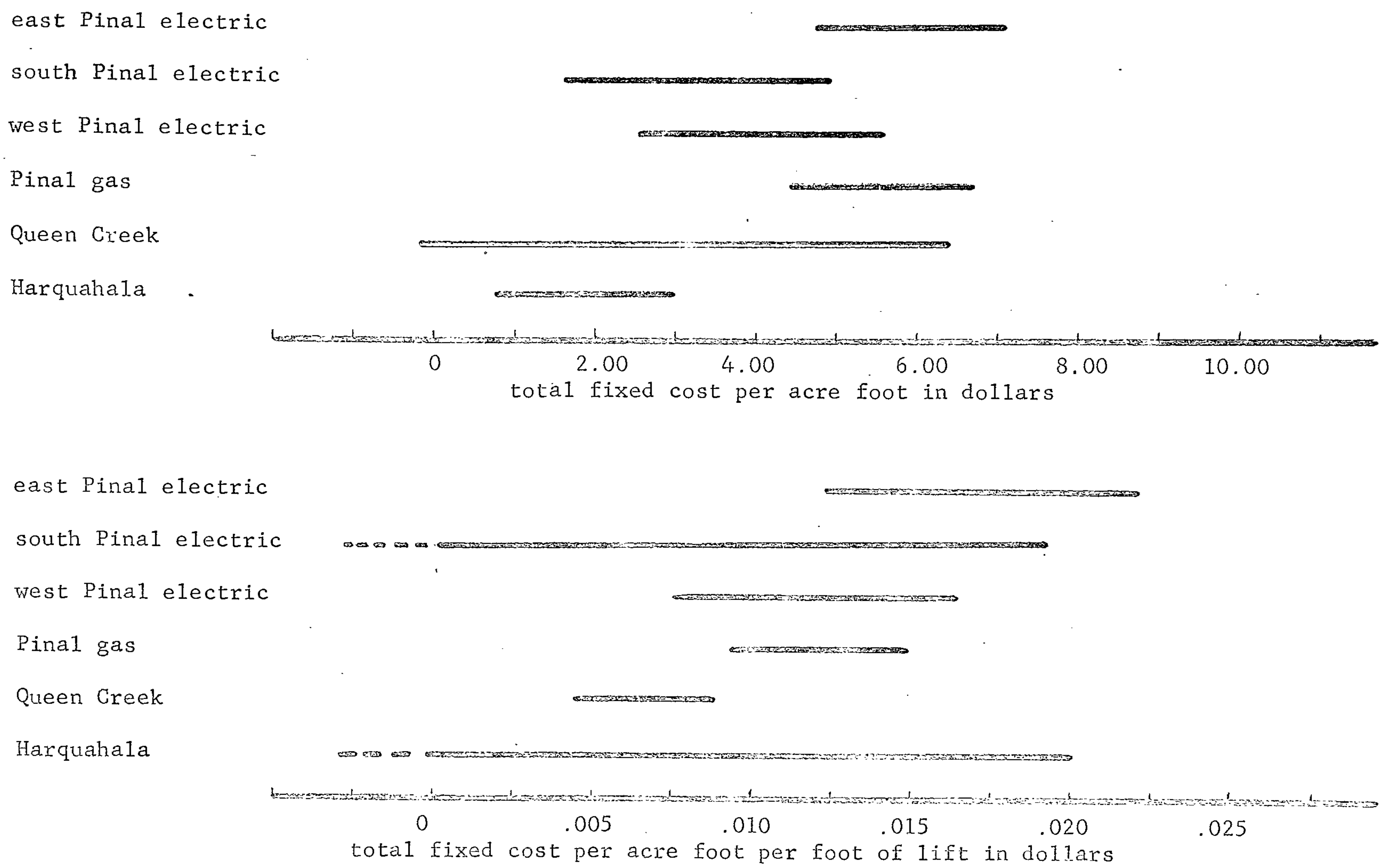

Figure 15. Confidence Intervals of Total Fixed Cost for Sampled Areas

differed also between areas. On the acre foot basis and acre foot per foot of lift considerable significant differences occurred between areas in depreciation costs.

Total fixed cost per acre foot in the east Pinal area is significantly different from the Harquahala area but it is not significantly different from the other areas. The Harquahala area is significantly different from the Pinal gas area as well as east Pinal but not significantly different from any other areas.

The east Pinal area has a significantly higher cost per acre foot per foot of lift than the Queen Creek area only. The Queen Creek area is significantly different from the Pinal gas area as well as the east Pinal area on the basis of fixed cost per acre foot per foot of lift.

In some instances, such as taxes in the Queen Creek area, the confidence interval includes zero. This is due to the wide variation in the data relative to the mean value. As a negative cost is illogical, the portion of the interval on the negative side of zero is represented by a broken line and is considered meaningless. This practice is followed through the balance of the analysis. In some cases, however, the raw data showed that some wells incurred no cost in a year for a particular component. In this case the inclusion of zero in the interval means that one can expect to have no cost in some years. This is particularly true of repairs. In the case of taxes in the Queen Creek area, however, every well is subject to this cost every year and the variability of data and smallness of sample gives rise to the peculiar circumstance.

As depth of the well increases, the capital investment increases. Likewise as lift increases the amount of column in the well must increase. The higher the capital investment the higher will be the fixed costs per acre foot assuming no change in output. As indicated earlier, as output increases average fixed costs decline.

The amount of water produced is fixed per unit of time with no change in physical installation; therefore, the product of a well can also be considered in terms of hours of service. As the number of hours of service increases per year the fixed cost per hour and in turn per acre foot will decline. If we assume again no change in investment and the lift increases, the cost per acre foot per foot of lift will fall. Increasing the lift has a similar effect to increasing hours run or water pumped because with the same fixed cost more work is being accomplished.

Added Capital Costs Resulting from the Decline in the Groundwater Level

Added capital costs are similar to fixed costs in that the cost is due to the fall in water table, and the decline takes place whether a farmer operates his pump or not. However, they are different from fixed costs because fixed costs are always present whereas added capital can be avoided if the well is never operated.

It appears logical that as the water table continually declines, the farmers find their pumps no longer in water and must add column pipe to get a flow, added capital costs will be directly related to the decline in the water table. This hypothesis was tested by the use of linear regression, but analysis failed to substantiate it. This indicates that for the wells in the sample at least one other factor had a more dominant influence upon added capital costs than the rate of groundwater decline.

Added capital costs spread over the number of acre feet of water pumped per year were computed as well as cost per acre foot per foot of lift. The figures were weighted by amount of water pumped and lift. A variance for each figure was computed and an interval placed upon the mean amount.

Added capital cost per acre foot and per acre foot per foot of lift is shown in Table 18 for eachof the six areas. Figure 16 shows relative magnitude and position of each of the confidence intervals. It should be pointed out that three of the intervals include zero indicating this cost may not occur every year. On the basis of the sample data we cannot say that any of the means were different at the five percent level. This is shown by all intervals having some value in common.

Added capital cost is made up of one or more three components: deepening the well, adding column and bowls, and enlarging the power unit.

As indicated earlier, 20 of the 74 wells in the survey have been deepened. Most of these were older wells, and some had been deepened twice. Most new wells are drilled such that they probably won't need

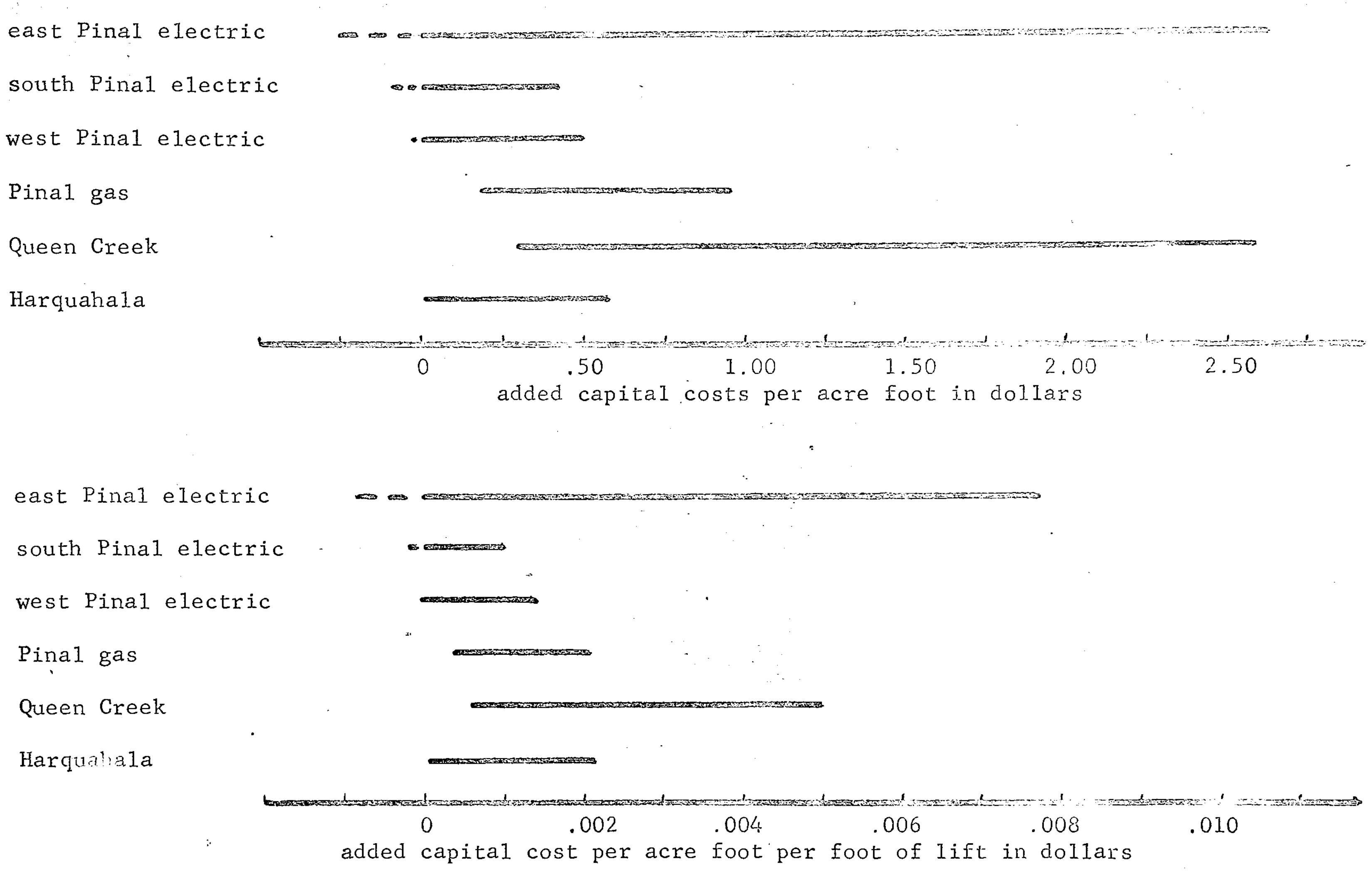

Figure 16. Confidence Intervals of Added Capital Cost for Sampled Areas

TABLE 18.--Added capital cost of pumping water for sampled areas in central Arizona in dollars.[a]

Area	Cost per acre foot	Cost per acre foot per foot of lift
East Pinal Electric	1.185 (.662)	.00343 (.00194)
South Pinal Electric	.174 (.114)	.00044 (.00025)
West Pinal Electric	.237 (.117)	.00070 (.00032)
Pinal Gas	.574 (.186)	.00126 (.00042)
Queen Creek	1.387 (.488)	.00288 (.00096)
Harquahala	.303 (.124)	.00115 (.00045)

[a] Figures in parentheses are standard errors of above figures, respectively.

deepening. Under the foregoing condition, what has been considered added capital cost becomes a part of total capital cost and enters into the fixed charges. This is one reason why the added capital costs varied so much between wells.

Most farmers, because of the substantial investment required, add column assembly only as it is needed. There were a few wells, however, that had installed substantial excess capacity. This caused wide variation in cost in the same manner as the wells that were drilled deep initially.

As the water lift increases the horsepower required increases. Correlating feet of lift with horsepower was done earlier and the analysis indicated .57 additional horsepower required per foot of lift for electric wells. As will be recalled, the analysis of the data failed to substantiate this hypothesis for gas wells.

While analysis failed to show a correlation between added capital costs and the rate of decline in the water table, we know that it has cost farmers additional investment to follow the falling water table. From cost data obtained in the survey we can estimate what it will cost on a particular well to maintain the water flow. Let's assume a 20-inch well that needs to be deepened. A well driller will deepen and case this well at a constant cost per foot. The farmer can probably have this done for $17 per foot. Assuming a 10-inch column assembly and a particular make of column which is about average, the cost per foot will increase by $15.60. Assuming one bowl will lift water 83.3 feet means that for each additional foot of lift we need .012 additional bowls. Using a bowl cost of $164 each gives $1.97 per foot of additional lift. Assuming motor cost of $20 per horsepower and multiplying it by .57 we have $11.40. Totaling these four we get $45.97 per foot. This is a rough approximation and it will vary with each individual well, but each farmer could calculate his cost. If we further assumed a 6-foot drop per year in the water table this would make the total added capital cost $275.82 per year. To arrive at the added capital cost per acre foot yearly costs are divided by the number of acre feet pumped per year.

Variable Costs

Average variable costs of pumping water is nearly constant throughout ranges of output. The only factor that may change this is the cost of energy as different quantities are purchased. However, the effect upon cost of a minimum charge is negligible. If power cost is a flat rate, the average variable cost will appear as a horizontal line when plotted against output (see Figure 11). If the rate charged decreases as the quantity used increases, the average cost curve will have sharp breaks in it. As the rate falls to the flat amount the average cost will approach the flat rate but never reach it. The quantity discount rate is primarily found in the natural gas area. A little is found in electrical districts but in gas and electricity both most farmers qualify for the most favorable rate so the price structuring of small quantities of energy has little effect upon the average cost.

As the water lift increases total variable costs increase directly with the lift. One might expect the cost per acre foot per foot of lift to remain constant or increase slightly as the lift increases. However, analysis of physical power requirements showed that it decreases slightly. Analysis by the Department of Agricultural

Engineering, University of Arizona, indicated that as the feet of lift increased one hundred feet, from 300 to 400, the kilowatt requirement per acre foot per foot of lift decreased by .05 kilowatt hours. As the lift increased from 400 to 500 feet on electric wells, the kilowatt hour requirement per acre foot per foot of lift decreased by .26. A similar occurrence took place with the gas wells in the survey. As the lift increased from 400 to 500 feet the cubic feet of gas required per acre foot of lift fell by 8.6. As the lift increases it is impossible for the energy requirement to fall, everything else remaining constant. In the case of the wells in this study, other factors are controlling and causing this unusual effect. The most likely cause is that the efficiencies of the greater lifts are higher than those with shallower lifts.

The efficiency of a well is inversely related to variable costs, As efficiency goes up more energy is converted into water horsepower so average cost goes down.

Hours operated annually has no appreciable effect upon the average variable cost of pumping water.

The breakdown of variable costs in order of their importance is: energy, pump and well repair, power unit repair, lubrication, and attendance. Table 19 shows these various costs for each area sampled. Costs were computed on a weighted average basis. The standard error of each mean is shown below it. Figures 17, 18, 19, 20, 21, and 22 show the magnitudes and relative positions of confidence intervals placed on the

TABLE 19.--Variable costs of pumping water for sampled areas in central Arizona in dollars.[a]

Area	Cost per acre foot						Cost per acre foot per foot of lift					
	Energy	Pump & well repair	Power unit repair	Lubri-cation	Attend-ance	Total[b]	Energy	Pump & well repair	Power unit repair	Lubri-cation	Attend-ance	Tot
East Pinal Electric	6.663 (.564)	.806 (.433)	.483 (.243)	.248 (.056)	.107 (.031)	8.343 (.857)	.01930 (.00121)	.00233 (.00124)	.00140 (.00063)	.00082 (.00018)	.00031 (.00009)	.024 (.00208)
South Pinal Electric	5.230 (1.175)	.573 (.391)	.029 (.018)	.082 (.103)	.096 (.168)	5.538 (1.360)	.01310 (.00233)	.00144 (.00097)	.00007 (.00004)	.00017 (.00007)	.00020 (.00095)	.01390 (.00714)
West Pinal Electric	6.686 (.686)	.525 (.314)	.259 (.209)	.132 (.034)	.050 (.015)	7.599 (.719)	.01970 (.00582)	.00155 (.00090)	.00076 (.00062)	.00039 (.00009)	.00015 (.00004)	.02246 (.00179)
Pinal Gas Electric	4.326 (.167)	.431 (.185)	.322 (.071)	.490 (.058)	.232 (.049)	5.618 (.390)	.00952 (.00048)	.00095 (.00040)	.00071 (.00016)	.00110 (.00014)	.00052 (.00012)	.01237 (.00058)
Queen Creek	6.974 (.305)	.770 (.289)	.422 (.161)	.072 (.017)	.059 (.009)	8.189 (2.044)	.01475 (.00059)	.00160 (.00060)	.00089 (.00032)	.00015 (.00002)	.00012 (.00002)	.01730 (.00121)
Harquahala	3.824 (.329)	.212 (.122)	.194 (.036)	.139 (.037)	.085 (.029)	4.610 (.498)	.01756 (.00073)	.00080 (.00039)	.00088 (.00036)	.00063 (.00015)	.00038 (.00012)	.02090 (.01178)

---

[a] Figures in parentheses are standard errors of the figures above, respectively.

[b] Parts may not add to totals because of shifts in weighting due to missing data.

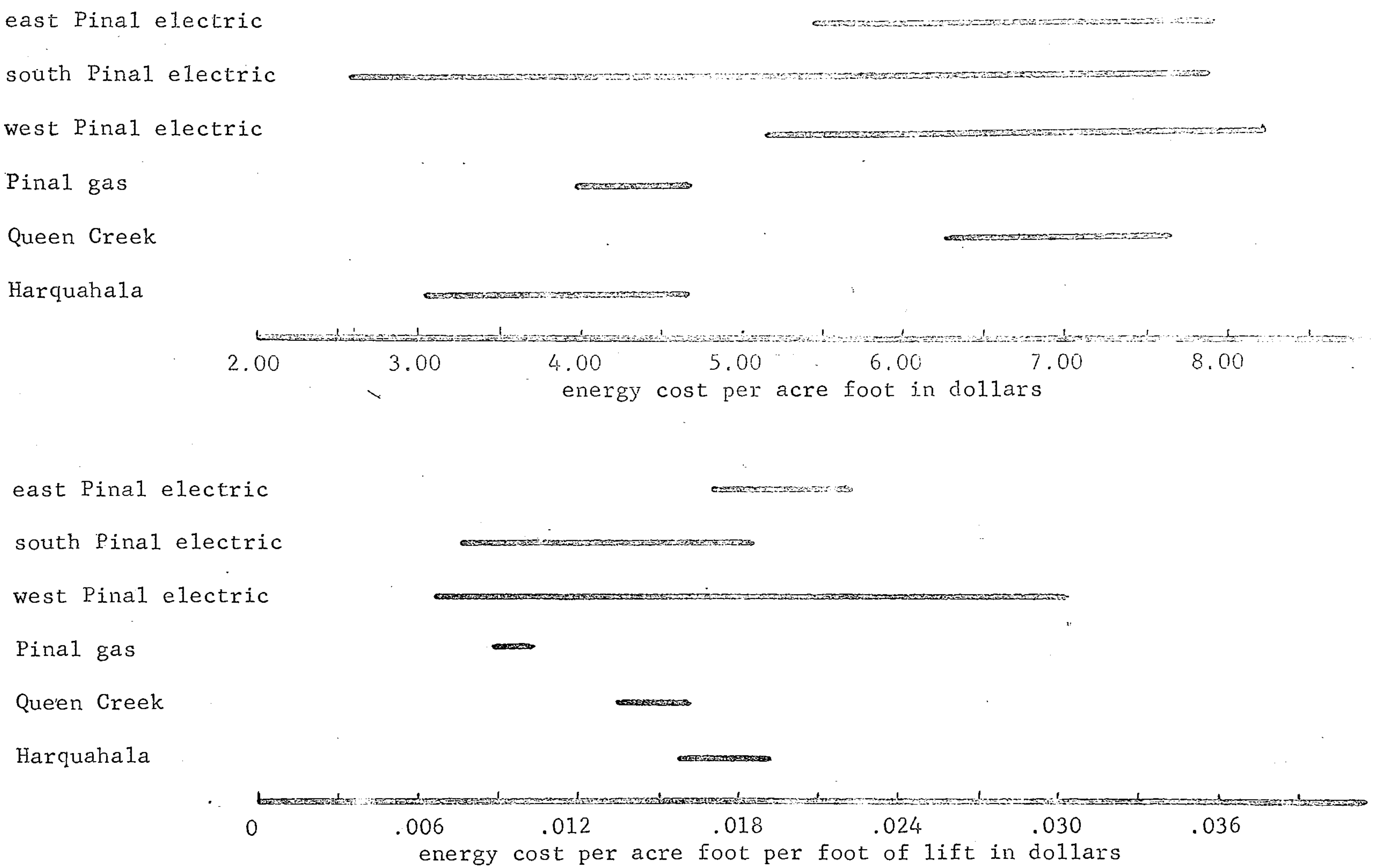

Figure 17. Confidence Intervals of Energy Cost for Sampled Areas

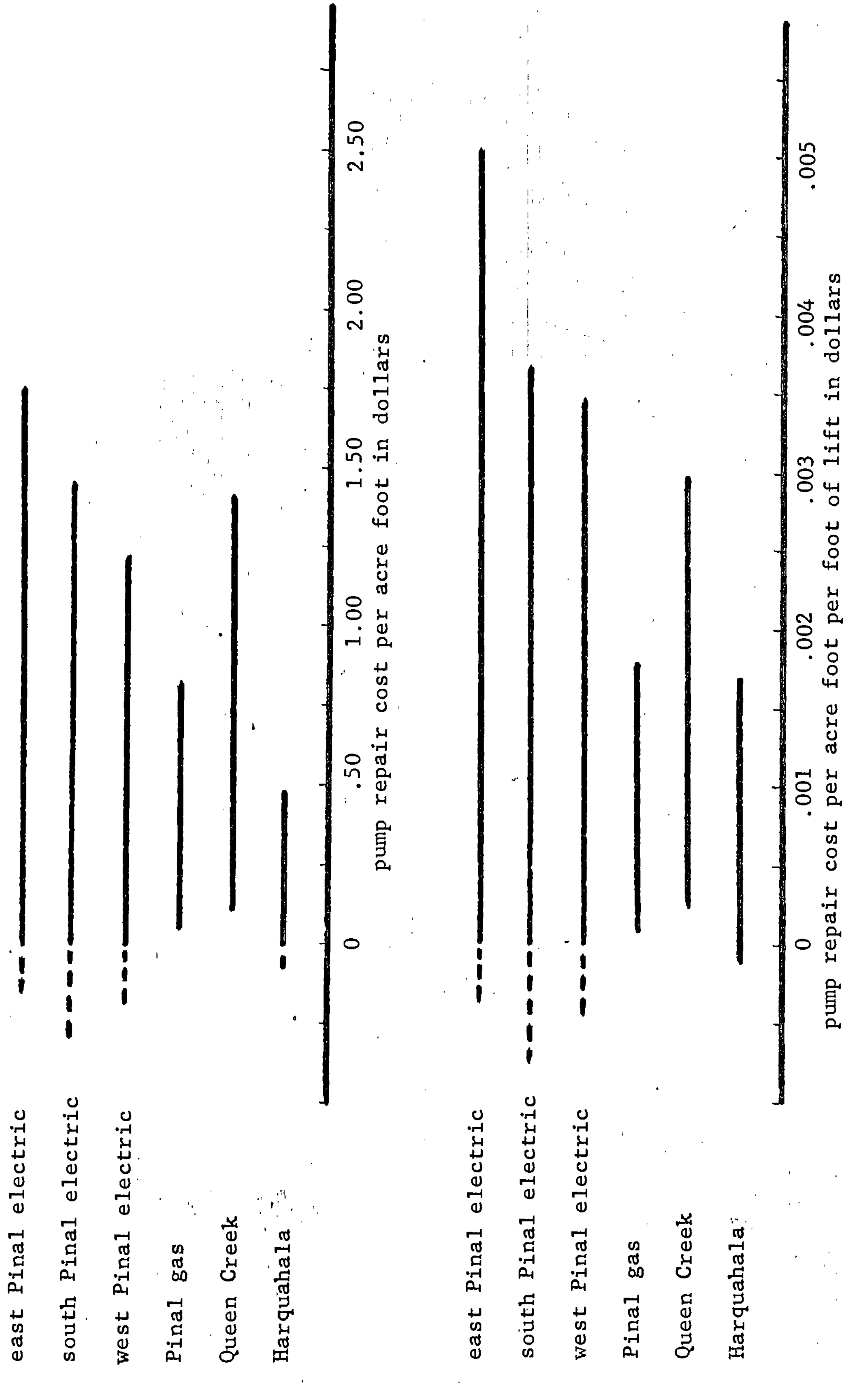

Figure 18. Confidence Intervals of Pump and Well Repair Cost for Sampled Areas

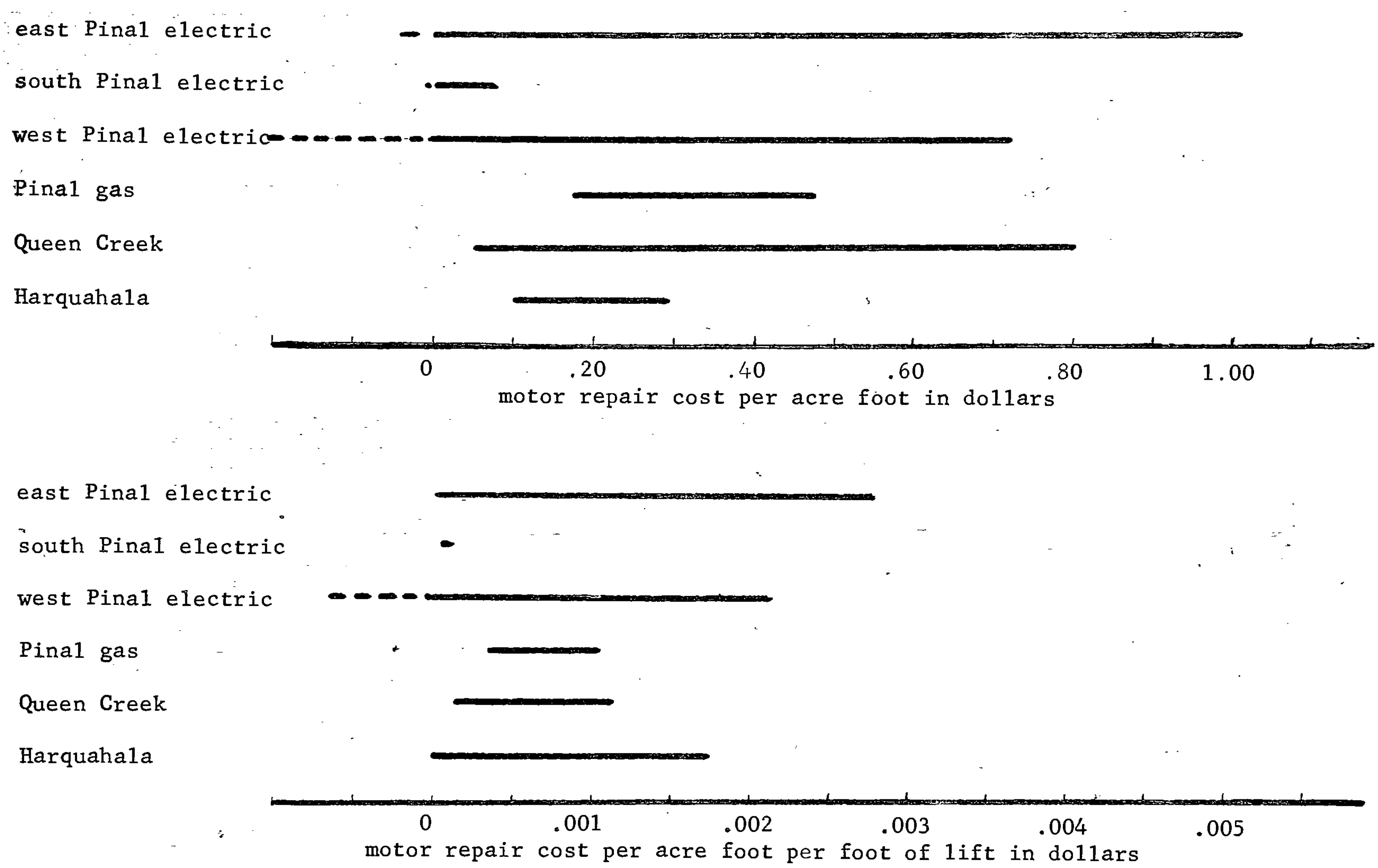

Figure 19. Confidence Intervals of Power Unit Repair Cost for Sampled Areas

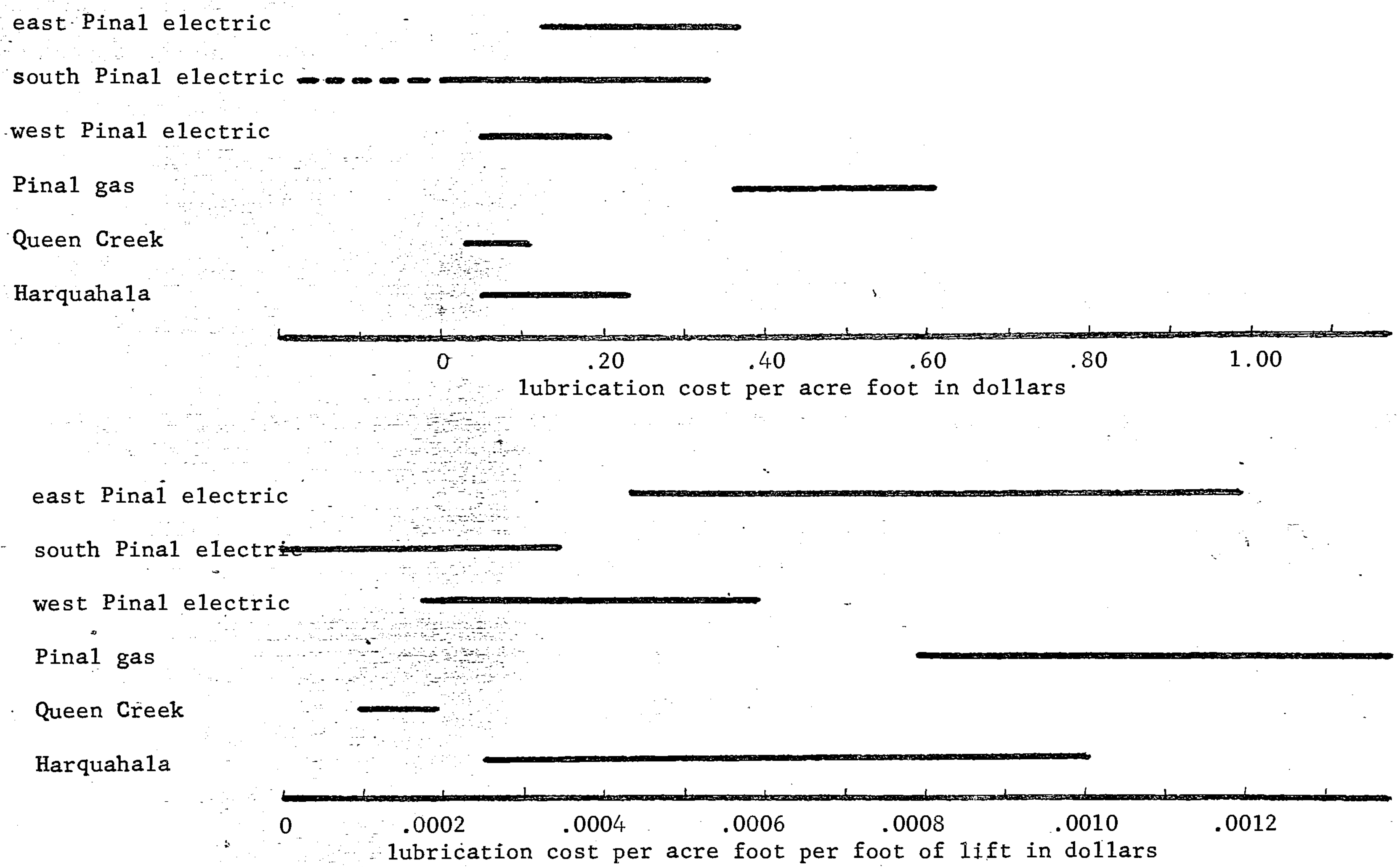

Figure 20. Confidence Intervals of Lubrication Cost for Sampled Areas

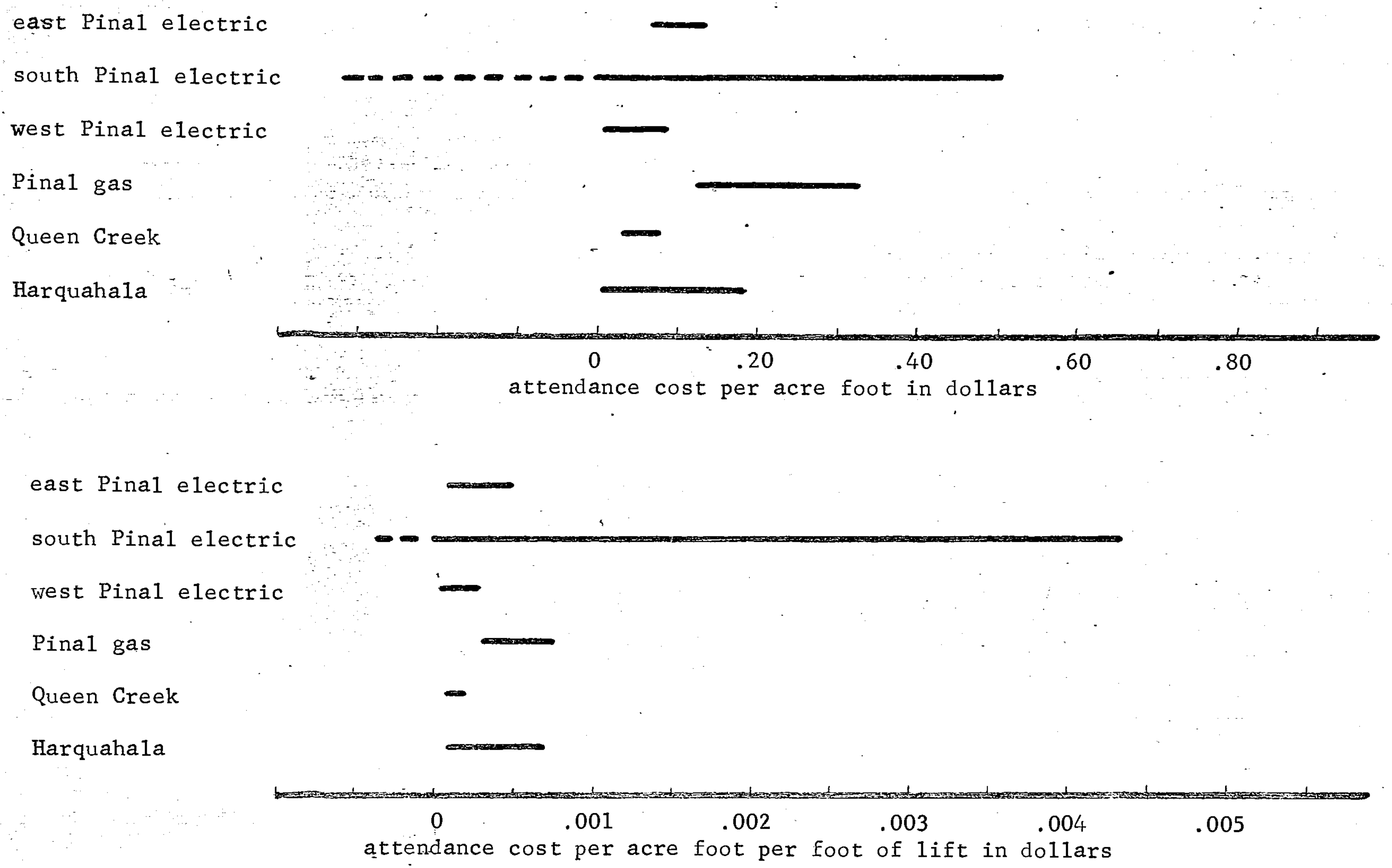

Figure 21. Confidence Intervals of Attendance Cost for Sampled Areas

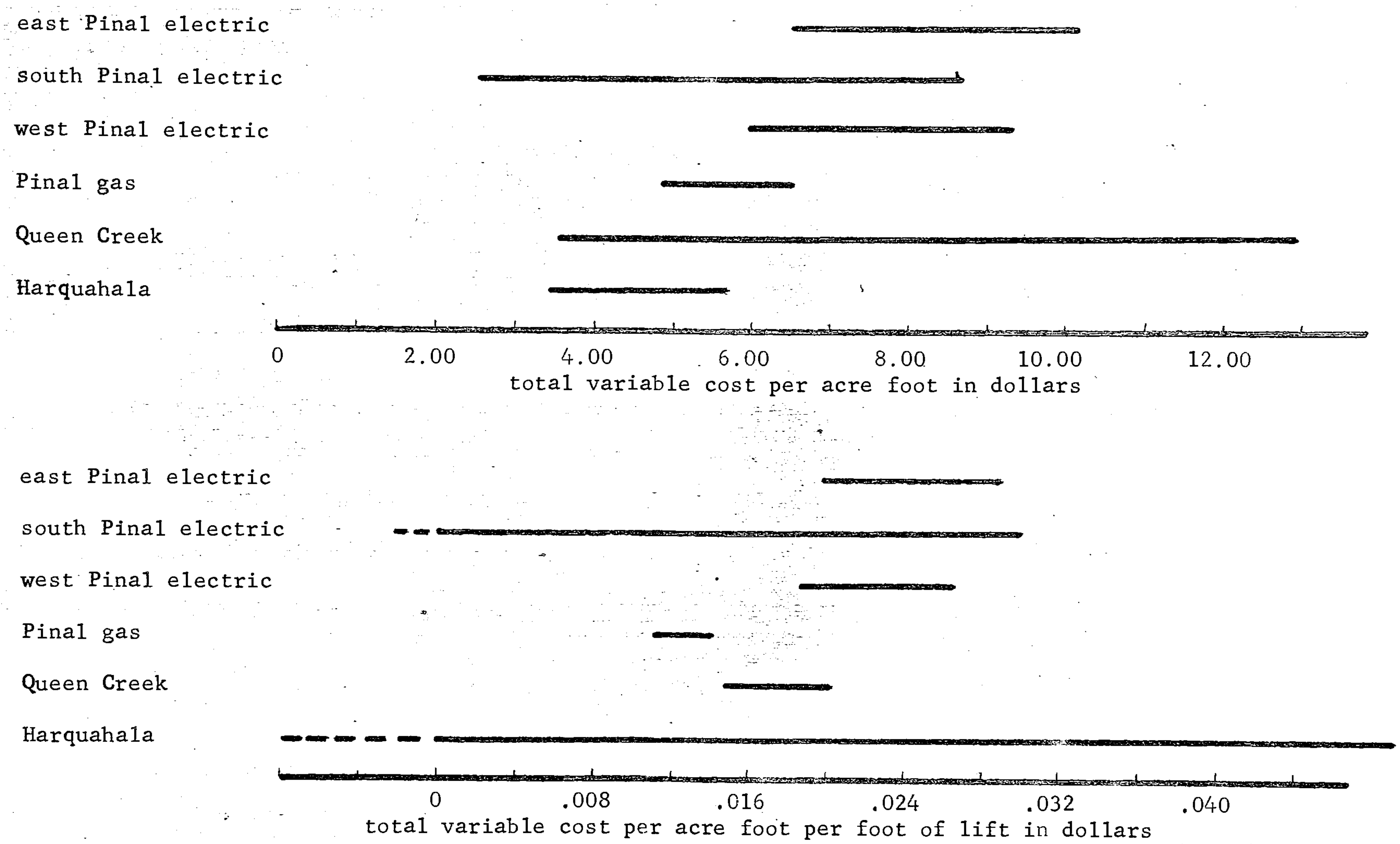

Figure 22. Confidence Intervals of Total Variable Cost for Sampled Areas

means for energy, pump and well repair, power unit repair, lubrication, attendance, and total variable cost per acre foot and acre foot per foot of lift.

Power cost per acre foot and per acre foot per foot of lift varied considerably as indicated by the intervals in Figure 17. Pump and well repair on either basis showed no significant difference between areas. Motor repairs were not significantly different except for the South Pinal area which differed from some on both acre foot and acre foot per foot of lift. A number of significant differences are evident in Figure 20 for lubrication cost. A wide dispersion and many differences are shown for attendance cost upon the basis of acre foot as well as acre foot per foot of lift.

Table 20 indicates power cost with a uniform power rate of 8 mills. Intervals placed on these means are shown in Figure 23. Comparing Figure 23 with Figure 17 we find with the uniform power rate the size of some of the intervals have changed but there is still a great deal of variation present, indicating a large influence of other factors. Probably the most important factor affecting power cost is efficiency.

Figure 22 shows total variable cost per acre foot in the East Pinal area significantly different from the Harquahala area but none others. The Harquahala area is significantly different from the West Pinal area as well as the east Pinal. On the basis of cost per acre foot per foot of lift the east Pinal area is significantly different only from the Pinal gas area.

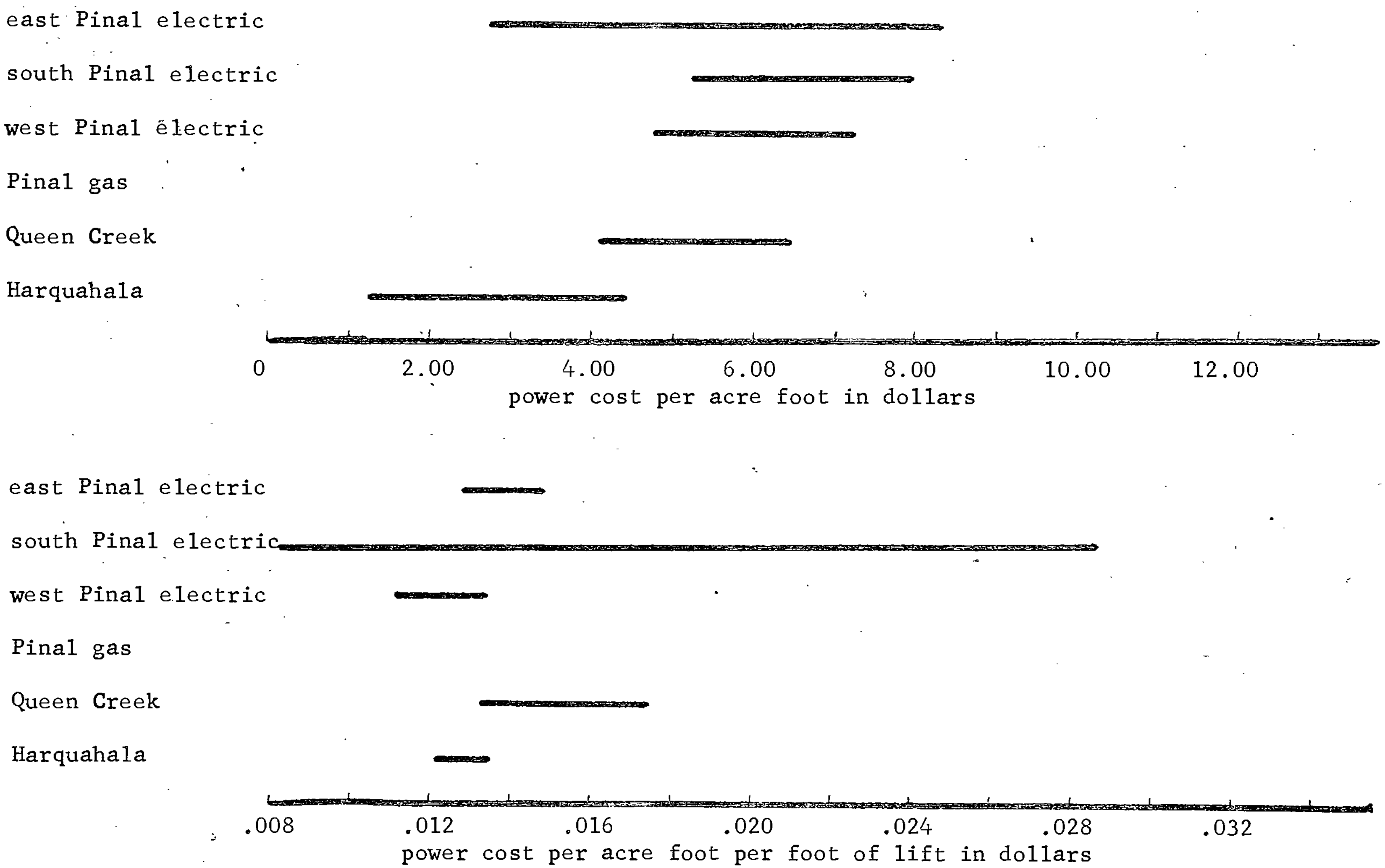

Figure 23. Confidence Intervals of Power Cost With a Uniform Rate of 8.0 Mills Per KWH for Electrical Areas

TABLE 20.--Power cost for sampled areas with uniform rate of 8.0 mills per kwh.[a]

Area	Cost per acre foot	Cost per acre foot per foot of lift
East Pinal Electric	6.597 (.643)	.01910 (.00430)
South Pinal Electric	5.509 (1.216)	.01382 (.00046)
West Pinal Electric	5.261 (.526)	.01550 (.00093)
Queen Creek	5.968 (.534)	.01263 (.00037)
Harquahala	2.849 (.637)	.01290 (.00026)

[a] Figures in parentheses are standard errors of each estimate, respectively.

The Pinal gas area is different from the west Pinal, Queen Creek and the east Pinal areas.

Pump and well repair varies directly with hours of use and one can expect the average to be constant at all levels of output.

Lubrication varies directly with use as does attendance. Wide variations appear between wells due to differences in personal preference in the amount of lubricants used and the frequency of visits to the well. Lack of homogeneity of rates charged for attendance also contributed considerably to variations in these costs.

Total Cost

The total cost of pumping water per acre foot and per acre foot per foot of lift by areas in central Arizona during 1963 is shown in Table 21. Table 22 contains all computed cost components for each area and out of pocket costs.

TABLE 21.--Total cost of pumping water for sampled areas in central Arizona in dollars.[a]

Area	Total cost AF	Total cost AFF
East Pinal Electric	15.418 (1.827)	.04464 (.00537)
South Pinal Electric	9.007 (1.954)	.02260 (.01072)
West Pinal Electric	11.931 (1.568)	.03515 (.00420)
Pinal Gas	11.696 (.799)	.02576 (.00206)
Queen Creek	12.668 (1.281)	.02680 (.00690)
Harquahala	6.925 (1.034)	.03140 (.01737)

[a] Numbers in parentheses are standard errors of the above values, respectively.

The total cost figures may not agree with the sum of individual cost components due to missing data on some components which was

TABLE 22.--Complete cost of pumping water summary of all costs for sampled areas in central Arizona.[a]

Area	Taxes	Interest	Depreciation	Added capital	Energy	Pump & well repair
East Pinal Electric						
Cost per acre foot	1.121	1.767	3.002	1.185	6.663	.806
	(.117)	(.184)	(.307)	(.662)	(.564)	(.433)
Cost per AFF	.00325	.00512	.00869	.00343	.01930	.00140
	(.00036)	(.00049)	(.00139)	(.00194)	(.00121)	(.00063)
South Pinal Electric						
Cost per acre foot	.531	1.003	1.760	.174	5.230	.573
	(.098)	(.205)	(.301)	(.114)	(1.175)	(.391)
Cost per AFF	.00133	.00252	.00442	.00044	.01310	.00144
	(.00028)	(.00050)	(.00080)	(.00025)	(.00233)	(.00097)
West Pinal Electric						
Cost per acre foot	.867	1.176	2.016	.237	6.686	.525
	(.112)	(.196)	(.341)	(.117)	(.686)	(.314)
Cost per AFF	.00255	.00346	.00594	.000698	.01970	.00155
	(.00036)	(.00056)	(.00096)	(.00032)	(.00582)	(.00090)
Pinal Gas						
Cost per acre foot	.763	1.516	3.482	.574	4.326	.431
	(.078)	(.152)	(.483)	(1.86)	(1.67)	(.185)
Cost per AFF	.00168	.00334	.00767	.00126	.00952	.00095
	(.00021)	(.00034)	(.00113)	(.00042)	(.00048)	(.00040)
Queen Creek						
Cost per acre foot	.492	.970	1.633	1.387	6.974	.770
	(.350)	(.126)	(.217)	(.488)	(.305)	(.289)
Cost per AFF	.00102	.00205	.00345	.00288	.01475	.00160
	(.00024)	(.00026)	(.00044)	(.00096)	(.00059)	(.00060)
Harquahala						
Cost per acre foot	.138	.662	1.092	.303	3.842	.212
	(.021)	(.139)	(.236)	(.124)	(.329)	(.122)
Cost per AFF	.00052	.00300	.00494	.00115	.01756	.00080
	(.00019)	(.00103)	(.00082)	(.00045)	(.00073)	(.00039)

TABLE 22--Continued

Power unit repair	Lubrication	Attendance	Total fixed[b]	Total variable[b]	Total costs[b]	Total cash
.483	.284	.107	5.890	8.343	15.418	10.649
(.243)	(.056)	(.031)	(.532)	(.857)	(1.827)	
.00140	.00082	.00031	.01705	.02416	.04464	.03084
(.00063)	(.00018)	(.00009)	(.00219)	(.00208)	(.00537)	
.029	.082	.096	3.237	5.538	9.007	6.715
(.018)	(.103)	(.168)	(.722)	(1.360)	(1.954)	
.00007	.000174	.00020	.00827	.01390	.02260	.02014
(.00004)	(.00007)	(.00095)	(.00481)	(.00714)	(.01072)	
.259	.132	.050	4.072	7.599	11.931	8.756
(.209)	(.034)	(.015)	(.682)	(.719)	(1.568)	
.00076	.00039	.00014	.01199	.02246	.03515	.02579
(.00062)	(.00009)	(.00004)	(.00197)	(.00179)	(.00420)	
.322	.490	.232	5.507	5.618	11.696	7.138
(.071)	(.058)	(.049)	(.544)	(.390)	(.799)	
.00071	.00110	.00052	.01210	.01237	.02576	.01574
(.00016)	(.00014)	(.00012)	(.00133)	(.00058)	(.00206)	
.422	.072	.059	3.114	8.189	12.668	10.176
(.161)	(.017)	(.009)	(1.400)	(2.044)	(1.281)	
.00089	.00015	.00012	.00659	.01730	.02680	.02141
(.00016)	(.00002)	(.00002)	(.00092)	(.00121)	(.00690)	
.194	.139	.085	1.910	4.610	6.925	4.913
(.036)	(.037)	(.029)	(.445)	(.498)	(1.034)	
.00088	.00063	.00038	.00865	.02090	.03140	.02192
(.00036)	(.00015)	(.00012)	(.00474)	(.01178)	(.01737)	

---

[a] Numbers in parentheses are standard errors of above numbers, respectively.

filled with mean values so as to not affect the variance but did affect the total average cost figure because of slight shifts in weighting.

Figure 24 indicates the magnitude and relative positions of confidence intervals placed upon the mean total cost figures. As indicated at the five percent level the cost per acre foot in the east Pinal area is significantly different from the Harquahala area but not different from the others. The Harquahala area is not significantly different from any except the east Pinal area. There is no significant difference in total cost per acre foot per foot of lift between areas except the east Pinal area is significantly different from the Pinal gas.

Water Applied

In Pinal County farmers applied an average of 5.14 acre feet of water per acre of cotton per year. Maricopa County farmers applied .89 acre feet less or 4.25 acre feet of water per acre of cotton per year. The average of all wells was 4.78 acre feet per acre. No significant difference exists at the five percent level so the over-all mean of 4.78 acre feet with a standard error of .26 acre feet may be considered representative. To arrive at the rate of water application, the total number of acre feet pumped by each well per year was applied to the farmers estimate of the number of acres served by the well. If other crops besides cotton were raised the water was allocated in a ratio conforming to farmer estimates. Using this amount of water per acre

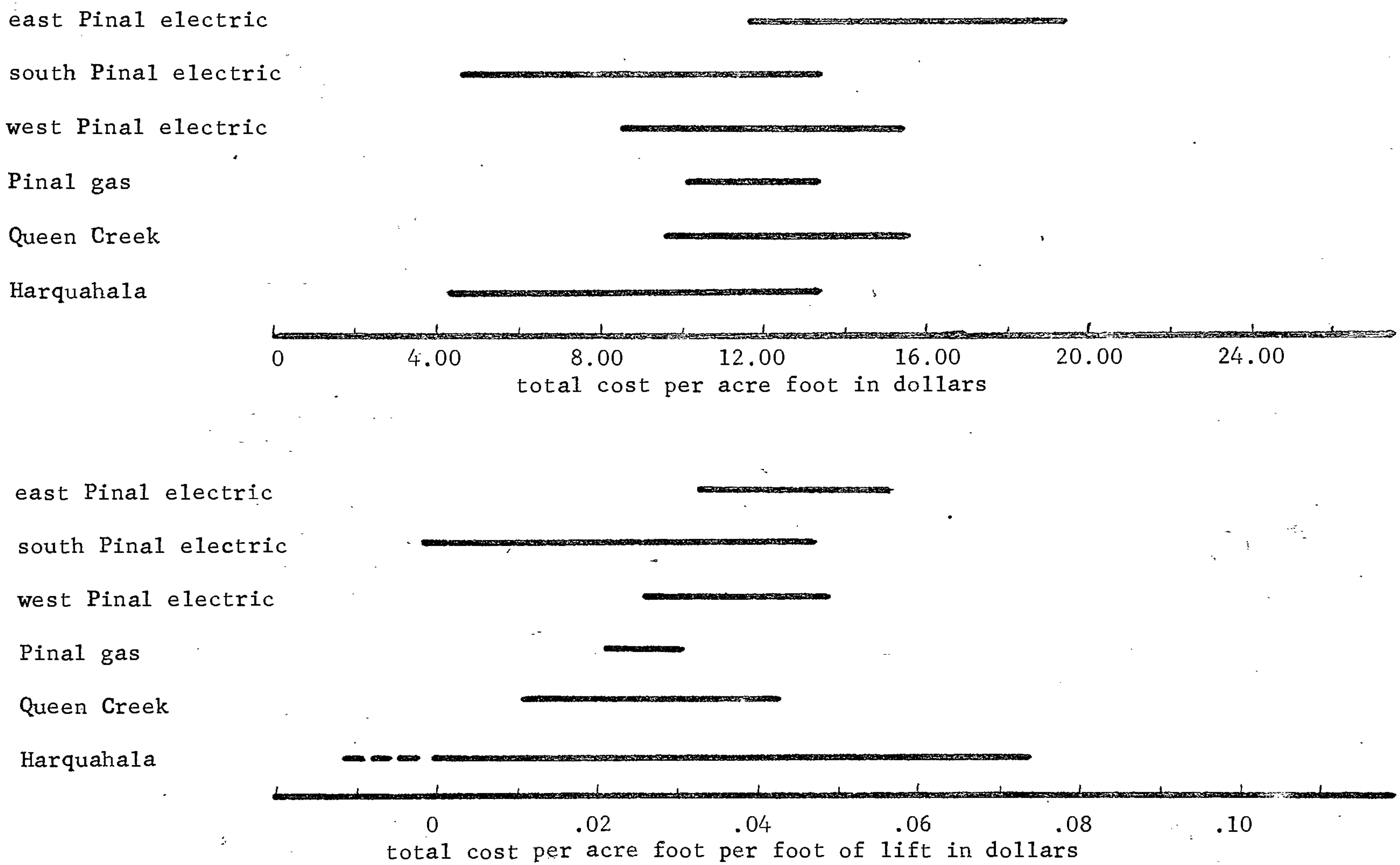

Figure 24. Confidence Intervals of Total Cost for Sampled Areas

per year multiplied by each total cost gives the total cost of water per acre per year for cotton in each area as shown in Table 23.

TABLE 23.--Total cost of water per acre per year for cotton in each sampled area.

East Pinal Electric	South Pinal Electric	West Pinal Electric	Pinal Gas	Queen Creek	Harquahala
$73.70	$43.05	$57.03	$55.91	$60.55	$33.10

It appears that the cost of water differences between areas has no effect upon the amounts of water applied per acre.

The total cash outlay for water given in Table 24 is somewhat less due to subtracting the interest on investment and depreciation. Out of pocket costs for water per acre foot and per year for cotton is shown in Table 24.

TABLE 24.--Total cash outlay for water for cotton per acre per year for each area.

East Pinal Electric	South Pinal Electric	West Pinal Electric	Pinal Gas	Queen Creek	Harquahala
$50.90	$32.10	$41.85	$34.12	$48.64	$23.48

The total costs of water per acre for cotton are averages only. Many farmers apply much more water than 4.78 acre feet per year. Individuals should adjust for their own rates of application. With water costing as much as reported it should be of great concern to farmers to know exactly what the cost is and how much water they are applying. Some farmers report out of pocket water costs in excess of $100 per acre per year on cotton. Chances are that such farmers are wasting their water as well as cutting into their profits.

The Cost of Re-Using Waste Water

The method of surface irrigation employed by most farmers in central Arizona gives rise to water being wasted through over irrigation of the lower end of the field through water leaving the field in waste ditches.

The problem of run-off occurs mainly in areas where the water intake rate of the soil is quite low. Farmers find it necessary to run the water through the rows for a number of hours after the water has reached the bottom of the field. It is not uncommon for 50 percent of the water taken out of the head ditches to run off the bottom of the field. To allow such to continue is both wasteful and expensive. If water were free it wouldn't matter so much, but with the high costs previously outlined, if only one-half of the water pumped is used by the crop, the water really costs the farmer twice as much.

The main advantage of a reuse system is to save the water that can be reused at a low cost. The cost of reuse may be $2.00 per acre foot whereas the underground water may be costing $10.00 an acre foot. A considerable savings can be realized in crop production costs by reusing the waste. In addition to cost savings the facility to store considerable amounts of water for use during the summer when many wells don't actually provide enough water for the crops is worth a great deal. Having extra water so that the crop won't be slighted during peak use can mean considerable additional yield.

This situation is general in the West Pinal area; therefore, the cost of reusing waste water was investigated to see the effect upon the farms there.

Investigations were made on six pumping installations in the west Pinal area: three natural gas and three electrical.

In order to transfer waste water into the irrigation system a farmer needs some nature of a catchment basin (referred to as a sump), a pump and a motor or engine to provide power.

The sump will vary in size and cost depending upon the particular circumstance. It may be a small depression in the corner of a field that provides only momentary storage or it may be as large as a mile long and able to store as much as three or four hundred acre feet. The sumps studied included the smallest possible up to one a quarter of a mile in length. If there is no effective storage capacity the water must be used as it comes from the field.

The pump on a small basin will be of low horsepower (3-10) and the lift only three to five feet. On a large installation the lift may exceed 25 feet and require 50 to 60 horsepower.

The operating costs include power or fuel, attendance, lubrication, and repair. Power or fuel, attendance and lubrication were computed for the six wells. No repairs were made in 1963 on these particular installations.

The variable, fixed and total cost as collected per acre foot of water for each installation is shown in Table 25.

TABLE 25.--Cost of reusing waste water in dollars.

Intallation number	Variable cost/af	Fixed cost/af	Total cost/af
1-PE	$ .614	$ .574	$1.188
2-PE	2.084	7.728	9.812
3-PG	.452	1.690	2.142
4-PG	.462	.642	1.104
5-PG	.633	1.275	1.908
6-PE	1.888	1.341	3.229

Installation 1-PE has an electric motor on a medium-sized pump about 800 feet long. The output was 1441 gallons per minute and 798.6 acre feet were pumped during 1963.

Only 14.6 acre feet were pumped by 2-PE in 1963 which caused the very high fixed costs. Monthly minimums caused the cost of electricity per acre foot to be very high. A very small basin was used which would hold about 15 minutes run of tail water. It pumped 375 g.p.m.

Another small basin setup was 6-PE. It was an electric motor which pumped out of a small area with about a 30-minute inflow capacity. The output was 405 gallons per minute and pumped 96.6 acre feet per year.

The installations 3-PG, 4-PG, and 5-PG were all of similar construction. The sumps were all about 1500 feet in length with natural gas engines used for power. Outputs were 1870, 1570, and 2165 gallons per minute, respectively. The acre feet pumped per year was 675.9, 1814.6, and 895.7, respectively. As was 1-PE, these installations were used quite efficiently.

In comparing these pumping setups we find the costs are quite comparable for those that have large storage capacity. The two with immediate pickup are expected to have a little higher cost because of the irregular and intermittent use. The cost of 2-PE is unusually high and would be much lower if the water pumped was at least 100 acre feet. Because of the high fixed cost involved, the average cost falls quite rapidly with increased use. Complete descriptive data on each installation can be found in Appendix G.

USE OF WATER COST DATA IN DECISION MAKING

To attain maximum profits water should be applied to a crop until its marginal unit cost is equal to the marginal revenue of the product produced.

Marginal unit cost is defined as the change in total cost divided by the change in input.

Marginal revenue of the product produced can best be represented as the value of the marginal product and is defined as the marginal physical product times the price of the product. The marginal physical product is the change in total output divided by the change in the input. Expressed as a formula:

$$\text{Marginal unit cost} = \frac{\Delta TC_x}{\Delta X}$$

$$\text{Marginal physical product} = \frac{\Delta Y}{\Delta X}$$

$$\text{Value of the marginal product} = \text{m.p.p.}_x \times P_y$$

where X is the water input in acre feet,

Y is output per acre,

TC_x is total cost of water, and

P_y is price of output.

Profits can be at a maximum only when the value of the change in input of factor is equal to the value of the change in output of the product. This is where:

$$\text{m.u.c.}_x = \text{value of the marginal product}$$

or:

$$\frac{\Delta TC_x}{\Delta X} = \text{m.p.p.}_x \times P_y$$

which when simplified gives us:

$$\frac{P_x}{P_y} = \frac{\Delta Y}{\Delta X} \ .$$

Cotton will serve as a good illustration of this principle. If we assume a cotton price of 32 cents per pound and a marginal water cost of $10 per acre foot, substituting into the formula we have:

$$\frac{\$10}{\$.32} = \frac{\Delta Y}{\Delta X} \ .$$

If the cost of X and the price of Y remain constant through all ranges of output, this means we should apply water until the m.p.p.$_x$ falls to 31.25 pounds of lint cotton per acre foot of water. If we know our price and costs, then we need only know what level of water application will give us a m.p.p.$_x$ of 31.25 in order to organize for mamximum profits.

Figure 25 shows a total physical product curve, average physical product curve, and a marginal physical product curve for the application of irrigation water to cotton estimated from empirical research.[10] From the figure we can see that with the assumed data the optimum amount of water is at 5.07 acre feet of water per acre per year by following the m.p.p.$_x$ curve until it falls to 31.25 and reading 5.07 off the horizontal axis.

Assuming the relationship shown in Figure 25 is representative of all areas in this study we can ascertain on the basis of the costs computed, whether farmers are over or under irrigating their cotton. Assuming the price of cotton constant at 32 cents per pound of lint, and the marginal cost of water in each area constant at the mean total variable cost values calculated,[11] we can determine optimum water application. Using the formula and data given we obtain values shown in Table 26, which indicate the profit maximizing application of water within the restraints of the given assumptions is not significantly different than presently practiced (presently 4.78 acre feet per acre).

---

[10] Data were synthesized from an unpublished Master's thesis, "Economic Use of Limited Water and Land Resources in Cotton Production," by Yaaqov Goldschmidt at the University of Arizona, 1959, and experimental data developed from studies by Leonard J. Erie to correspond with actual experienced by farmers with higher yields.

[11] When making decisions in the short run, only the variable costs are considered. This is because the fixed costs are already sunk and the decision to produce more has no effect upon the fixed cost. The additional cost incurred by producing one more unit is all variable.

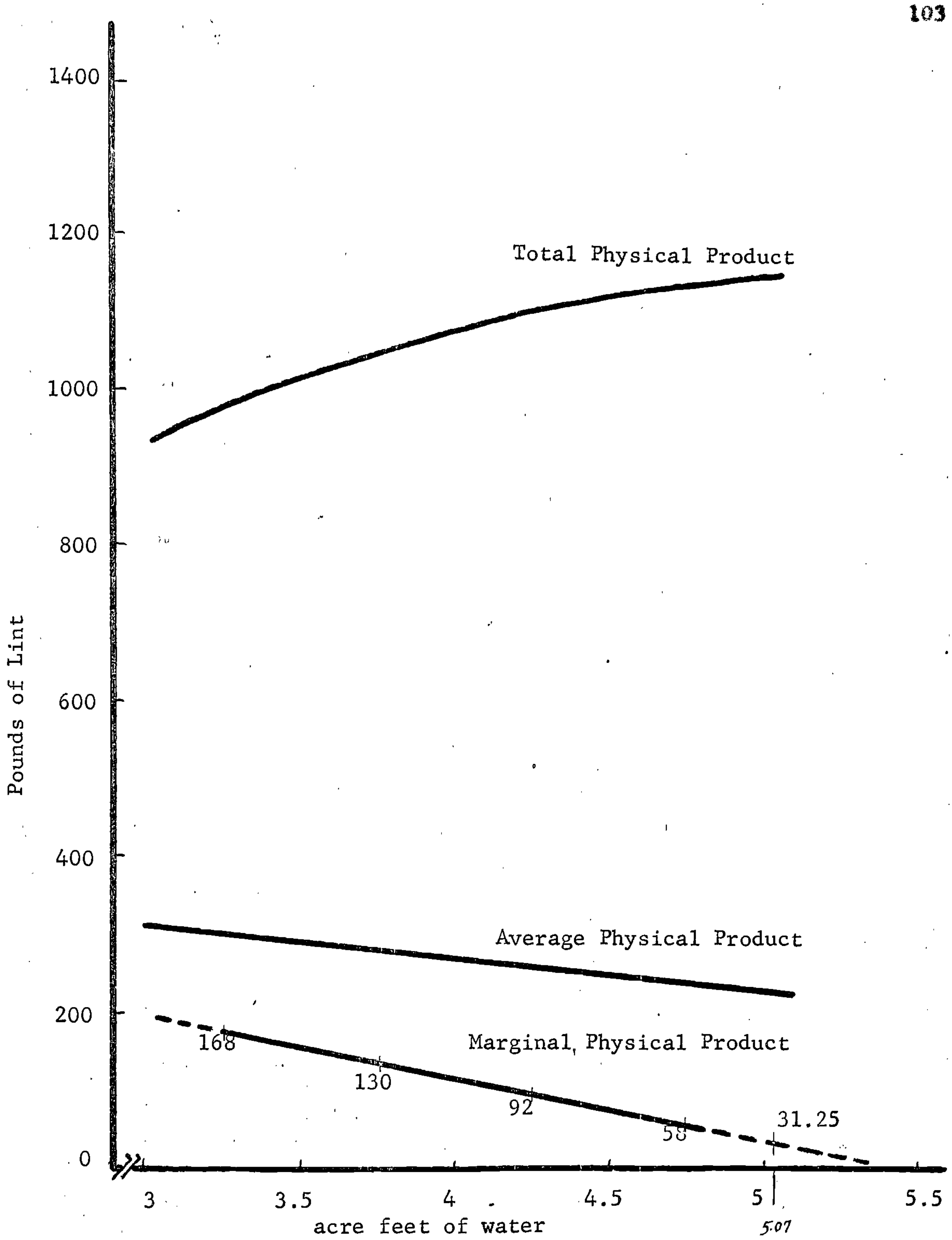

Figure 25. A Water--Yield Relationship for Cotton Production in Central Arizona

TABLE 26.--Profit maximizing application of water on cotton per year in acre feet.[a]

East Pinal Electric	South Pinal Electric	West Pinal Electric	Pinal Gas	Queen Creek	Harquahala
5.13	5.24	5.15	5.24	5.14	5.28

[a] All areas presently using 4.78 acre feet per acre per year.

In actuality the water yield relationship will vary for different soils. Pumping cost will vary from well to well and year to year. Individuals will need to make adjustments of the data to suit their particular circumstance.

In the short run production will continue even if only variable costs are covered; however, in the long run situation all costs must be covered. The long run in pumping water is the life of the well. When the well needs to be replaced the decision must be made as to whether or not a new one will be drilled. If expectations indicate that all costs cannot be covered, economically speaking the investment should not be made. In making the investment decision the cost is generally placed on an annual basis as was done earlier in this analysis. If the long run expected returns over variable costs and all other committed fixed costs is greater than or equal to the expected annual cost of the proposed investment, it will be profitable to invest.

SUMMARY AND CONCLUSIONS

This study pertains to the cost of pumping water in central Arizona. Seventy-four randomly chosen wells in Pinal and Maricopa Counties provide the basis for this analysis. Both electric and natural gas installations were examined.

A substantial portion of the water used by farmers in central Arizona is drawn from underground reservoirs. The cost to the individual farmer is his cost of extraction. In order to withdraw sufficient water for the vast acreages, hundreds of pumping installations have been installed by private users. As a consequence of this use the water table is steadily falling in most areas averaging around ten feet per year. Many pumps lift water in excess of 500 feet. The feet of lift is the most important factor affecting the cost of pumping water.

Irrigation water cost is a major factor of production on farms in central Arizona. The scarcity of reliable, current water cost data makes it difficult for farmers to make decisions that will yield maximum profit. The purpose of this study is to help fill this gap and facilitate more efficient operation of central Arizona farms. The study is based upon data obtained from interviews with farmers, well drillers, pump companies, and power and gas suppliers. Statistical analysis was used extensively in analyzing the data and interpreting the results.

Pumping installations vary from farm to farm but are generally quite uniform for central Arizona. The most typical installation is 1100 feet deep with between 400 and 500 feet of column. If electric power is used, the motor is around 200 horsepower. The average gas installation will have a 325 horsepower engine. The typical well will operate for about 3750 hours per year and throw 1433 gallons per minute. The amount of water pumped in a year will be just less than 1000 acre feet. Capital cost of the well (based upon current cost) will be around $36,000 for electric wells and $46,000 for gas wells, with $21,000 being invested in the well and casing, $7,000 in the pump and column, and $8,000 to $18,000 in the power unit.

Not all farmers purchase power or natural gas from the same supplier. Consequently, differences in rates may affect the profitability of crop production in various districts. Energy is the most important single cost of pumping water.

Average total costs of pumping decline throughout all ranges of production. Average variable and marginal costs are constant as production increases.

The study was conducted on the basis of different areas because it was thought that the costs would be different.

The cost range of area means per acre foot for a typical installation is as follows: taxes, $.14 to $1.12; interest on investment, $.66 to $1.77; depreciation, $1.09 to $3.48, and total fixed cost, $1.91 to $5.89 per acre foot. Added capital cost ranged from $.30 to $1.39 per acre foot. The variable costs per acre foot are: energy, $3.84 to $6.97; pump and well repair, $.21 to $.48; power unit repair, $.03 to $.48; lubrication, $.07 to $.49; attendance, $.05 to $.23, and total variable cost, $4.61 to $8.34. The total cost per acre foot ranged from $6.92 to $15.42. The ranges given cover all areas in the study including costs of natural gas installations. Total cost of pumping water per acre foot did not differ significantly between areas except between the east Pinal electric area and the Harquahala area.

The costs of pumping water were also computed upon the basis of acre foot per foot of lift to adjust for cost differences caused by variations in lift. The cost ranges of area means upon this basis for fixed costs are: taxes, .05 to .33 cents; interest on investment, .205 to .512 cents; depreciation, .345 to .869 cents and total fixed costs from .659 to 1.705 cents per acre foot per foot of lift. Added capital cost per acre foot per foot of lift ranged from .044 to .343 cents. The breakdown of variable costs is: energy, .952 to 1.97 cents; pump and well repair, .08 to .233 cents; power unit repair, .007 to .14 cents; attendance, .012 to .052 cents, and total variable costs ranged from 1.237 to 2.416 cents per acre foot per foot of lift. The total cost of pumping water per acre foot per foot of lift ranged from 2.26 to 4.46

cents. On the basis of cost per acre foot per foot of lift, the only significant differences were between the east Pinal electric area and the Pinal gas area. It appears that no significant difference in total cost exists between the use of electricity and natural gas as an energy source. On the basis of energy cost alone natural gas does have some advantage over electricity, but the higher fixed costs of natural gas engines tend to offset the energy cost differential.

The reuse of waste water appears to be a very cheap source of water, where feasible, not only because of lower cost but also because of a greater volume of water available at critical water use times if considerable storage capacity is available. The cost per acre foot of reusing waste water ranged from $1.10 to $9.81 with the most common cost around $2.00 per acre foot.

The application of economic theory for determining optimum water application on cotton in central Arizona shows that farmers are applying the profit maximizing amount of water to their crop.

It appears the increasing cost of pumping water over time imposes additional restriction upon land use and allocation of crops in central Arizona.

APPENDIX A

WELL AND PUMP DATA INFORMATION FORM

Well no. ____________

Interviewer ____________

Date ____________

Owner ______________________________ Phone ____________

Address ____

Operator ______________________________ Phone ____________

Address ____

Well location: Sect. ____________ Twp. ______ R ______

____

____

____

Approval given to test well and obtain capital and operating costs ______ ____________. Well will be tested 3 times in June, July, and August.

Well

Casing size ______ Inches; Depth ______ feet; Date drilled ____________

Location of access hole ______________________________

____

May we drill hole in outlet pipe to test output?____________________

____

____

Pump

Column size______ inches; Bowl setting______ft.; No. of bowls_____

Make and model of pump____

Installation date____________ Installed by _______________________

Address___________________________

Gallons per minute______________________

Acres well serves_______________________

Other irrigation wells:	Column Size	Gallons per minute	Data Source
Well number			

____

____

____

Crops, summer 1963:	Acres Irrigated	A. ft. applied per acre	Yield per acre

Crops, winter 1962-63:	Acres Irrigated	A. ft. applied per acre	Yield per acre

Power Plant (electric motor or gas engine - check one)

Make and model ____________________

Rated H.P. __________ at __________ R.P.M.

Installation date __________ by __________

Address __________

Power or gas supplier __________ Address __________

Does farmer have repair costs, deepening costs, etc., records, 1952-61? __________

Can operating costs for sample well be obtained for year July 1, 1962 to June 30, 1963? __________

APPENDIX B

EFFICIENCY ANALYSIS INFORMATION FORM

Well No. ____________

Tested by____________

Date_______________

Operator____

Source of Power: Gas________ Electric__________ Meter No. __________

Output Data

Discharge pipe: Diameter______inches Area ________Sq. inches

Approximate Static Water Level ______feet Total lift ________feet

Pressure Head ______ feet Total Pumping Head _________feet

Pitot Reading_______________ Pump Output ___________ G.P.M.

Water H. P. _______________________

Input Data

Electric

Meter_____ Rev. in_____ seconds. Disk K_h____ Multiplier K ______

Kw Input ______________________ H.P. Input ______________________

Gas

Meter Reading ______ dial feet _____ seconds: minutes: _____ line pressure, psi

Gas K __________ cu. ft. per min. __________

______________ cu. ft. per min. x 25.4 = __________ HP Input

Over-all Efficiency __________ %

Water Data

Temperature ______________

Conductivity ______________

Sample No. ______________

APPENDIX C

CAPITAL COSTS INFORMATION FORM

Well No. ____________

Interviewer __________

Date _________________

Owner ______________________________ Tenant __________________________

Location of well: Section _____________ Twp. ________ Range ____________

(Obtain present replacement cost assuming the well were drilled this year and fitted with new equipment comparable to that now in use.)

Item	Cost	Life in Years*	Salvage Value
Well			
Pump			
Motor or engine			
Starter			
Transformers			

*Assuming the item is "new"--see parenthetical statement above.

APPENDIX D

OPERATING COSTS JULY 1, 1962-JUNE 30, 1963

INFORMATION FORM

Well No. ____________

Interviewer ____________

Date ____________

Owner ____________________________ Tenant ____________________________

Location of well: Quarter Quarter and Section ______ Twp. ____ Range ___

			Amount	
	Description, including size	Date	Material	Labor
Repairs[1]				
Well:				
Deepening				
Casing added				
Pump:				
Head				
Discharge pipe				

[1] Include both added capital costs and repair and maintenance costs, but show the items separately if possible.

			Amount	
	Description, including size	Date	Material	Labor
Column assembly				
Bowls				
Impeller				
Suction pipe and strainer				
Power Unit, Gas Wells:				
Engine overhaul (major)				
Engine service (minor)				
Gear head				
Universal joint				
Starter motor				

			Amount	
	Description, including size	Date	Material	Labor
Power Unit, Electric Wells:				
Rewind motor[2]				
Bearings				
Shaft				
Housing				
Starter equipment				
Transformers				
Wiring				

	Description	Amount
Service		
Service charge[3]		
Maintenance		
Attendance: hours		
dollars		
Lubricants		

---

[2] Indicate if the motor was rewound to a higher HP, and how much.

[3] Monthly service charges, if any. Indicate what these charges cover.

	Description	Amount
Taxes		
Real estate		
Chattel		
Insurance		
Fire		

Electricity or gas by months during 1963

APPENDIX E

OPERATION AND RATE STRUCTURING OF ELECTRICAL DISTRICTS

Application of Arizona Power Authority rates to electrical districts in determining average costs in mills per kwh.

A.P.A. rate to districts for hydro energy (Hoover, Parker, Davis Dams)

The rate for hydro power consists of the following:

first block = $.75 per kw of demand

second block = 3.5 mills/ per kwh for the first 250 kwh times the demand

third block = 3.0 mills per kwh for all kwh over the second block.

Demand refers to the demand for power in kw (not kwh) during any peak period. The district might set its monthly demand at 10,000 kw and use 4,000,000 kwh during the month. The demand represents a contract between A.P.A. and the district whereby the district agrees to pay for a stipulated peak demand for power during the period, and A.P.A. agrees to make that amount of power available to the district. When the district pays a demand charge, it pays for the constant availability of a certain amount of power. In other words, the district not only pays for energy used in terms of kwh, but also pays for the maximum power available to it as measured in kw of power demand.

An example of a monthly billing by A.P.A. to a district might be the following:

Let us assume that the district has a demand of 10,000 kw and uses 4,000,000 kwh during the period.

first block = 10,000 kw demand x $.75 = $7,500.00
second block = 250 kwh x 10,000 kw (demand
2,500,000 kwh x 3.5 mills = 8,750.00
third block = 4,000,000 kwh
-2,500,000 kwh
1,500,000 kwh x 3.0 mills = 4,500.00
$20,750.00

Steam Power

The steam power rate to the district is made up of the following:

$1.60 per kw of demand
4.45 mills per kwh
1.00 mills per kwh for wheeling
5.45 mills per kwh

The wheeling charge represents a charge paid to the bureau of reclamation for the use of its line in the transmission of power to the district's substation.

Load Factor and Its Effect on Average Cost per kwh

Each district pays the same rate for its power, but its average cost per kwh is determined by the efficiency and consistency with which it can utilize its kw demand for power in terms of kilowatt hours of energy. This utilization of energy in relation to the minimum demand for power for the billing period is reflected in the district's load factor. The formula for determining load factor is:

$$\text{L. F.} = \frac{\text{kwh}}{\text{Peak demand in kw x no. of hours in period}}$$

By definition a kilowatt hour is one kilowatt used for one hour. Therefore, if a district uses its peak demand in kilowatts for the total number of hours in the billing period, it has a load factor of 100%. It has used 100% of its capacity. If we assume that a district has a peak demand of 10,000 kw and uses 7,300,000 kwh during the billing period of 730 hours we can use the formula $\left(\frac{7,300,000}{10,000 \times 730} = 1\right)$ and observe that its load factor is 100%.

The effect of load factor on the average cost per kilowatt hour can be illustrated by the following examples.

Assume a rate to the district of $1.00 per kilowatt of demand and a single rate of 5 mills per kilowatt hour of energy used. Assume a demand of 10,000 kw at 50% load factor. This is equal to 730 hours at 50% or 365 hours of use. This gives us 365 x 10,000 kw or 3,650,000 kilowatt hours used for the month. When we compute the district's bill for the month, we have:

10,000 kw x $1.00 per kw demand = $10,000.00

3,650,000 kwh x 5 mills = 18,250.00

total bill = $28,250.00

average cost per kwh = 7.7 mills

Next, assume a demand of 10,000 kw at 80% load factor. This gives us 584 hours x 10,000 kw or 5,840,000 kilowatt hours for the period. When we compute the district's bill for this period, we have:

10,000 kw x $1.00 per kw demand = $10,000.00

5,840,000 kwh x 5 mills = 29,200.00

total bill = $39,200.00

average cost per kwh = 6.7 mills

The Effect of Power Rates on the Average Cost of Electric Power to the Farmer

Some suppliers of electric power to the farmer charge a flat rate in mills per kilowatt hour for energy used, and no demand charge is used. Others include a demand charge in their rates to farmers. When a demand charge is used, the farmer's bill is computed by retailer in the same manner in which the retailer is billed by the wholesaler.

Each irrigation pump has its own meter and is billed individually. The billing demand is measured by a demand-hour meter or estimated by the district if no meter reading is available. If a demand meter is used, the peak demand is determined by the average kw supplied during the 15-minute period of maximum use during the month.

The demand meter has a demand portion, which measures peak demand in kilowatts for any given 15-minute period during the month, in addition to a regular watt-hour meter. The demand indicator remains at the highest point reached during the month. The company can reset the indicator to zero at the end of the month. The total kilowatt hours are indicated on the watt-hour portion of the meter.

The demand meter indicates fluctuations of power during any 15-minute period. By finding the period of maximum demand as shown by the indicator, the company can compute the high and low points of the power fluctuations and arrive at an average kw demand for the period.

In the case of Arizona Public Service Company, the kw demand is determined by the average kw supplied during the 15-minute period of maximum use for the month. Salt River Project bases its kw demand on the maximum kw measured during the 12 months ending with the current month, but not less than the kw stated in the service agreement.

If we assume that a farmer has an irrigation pump that has an average peak demand of 100 kw and during the month uses 100,000 kwh, we can compute his power bill for the month. Using Arizona Public Service Company rates, we arrive at the following bill:

flat rate per meter	=	$ .16
275 kwh x 100 kw demand = 27,500 kwh at 1.16¢	=	319.00
all additional 72.500 kwh at .86¢	=	623.50
total bill	=	$942.66

We can compute minimum billing for any period on the same basis, but the effect of minimum billing on average cost of power is negligible. The minimum bill is computed on the basis of the highest kw established during 12 months ending with the current month or the minimum specified in the agreement for service, whichever is greater. Electrical district no. 2 has a minimum bill of $5.00 per month. The absolute minimums for Arizona Public Service and Salt River Project are $101.92 and $100, respectively, per month. Only the retailers of power apply minimum charges to their customer billing. Wholesalers do not have minimum charges. They use the demand charge in their efforts to compensate for fluctuations in power demands.

APPENDIX F

CAPITAL COST OF ESTABLISHING ELECTRIC AND NATURAL GAS WELLS

Well no.	Well cost	Pump cost	Power unit cost	Total cost
		Electric wells		
E-1	$29,065	$ 7,156	$ 7,957	$38,178
E-2	9,352	8,241	4,300	21,893
E-3	7,992	6,051	3,700	17,743
E-4	15,497	6,498	7,957	29,952
E-5	39,242	19,604	25,390	84,236
E-6	7,584	6,661	4,300	18,545
E-7	14,740	7,285	7,957	29,982
E-8	18,340	6,417	5,609	30,366
E-9	13,480	5,116	4,000	22,596
E-10	6,800	7,129	3,520	17,449
E-11	20,662	12,484	12,349	45,495
E-12	11,140	4,267	5,757	21,164
E-13	17,590	8,356	10,505	36,451
E-14	18,340	6,598	7,957	32,895
E-15	25,540	8,540	7,957	42,037
E-16	18,880	4,977	10,505	34,362
E-17	17,364	10,662	10,629	38,655
E-18	21,940	8,398	12,717	43,055
E-19	20,140	9,496	7,957	37,593
E-20	8,052	6,786	5,609	20,447
E-21	6,940	4,154	3,400	14,494
E-22	14,740	7,542	7,957	30,239
E-23	12,794	6,350	4,109	23,253
E-24	18,340	9,662	12,717	40,719
E-25	7,440	6,486	4,109	18,035
E-26	8,926	6,220	5,609	20,755
E-27	21,940	8,959	7,957	38,856
E-28	13,470	6,900	5,757	26,127
E-29	32,740	14,580	14,907	62,227
E-30	16,540	6,349	2,800	25,689

Well no.	Well cost	Pump cost	Power unit cost	Total cost
		Electric wells (continued)		
E-31	$ 7,440	$ 6,072	$ 4,109	$17,621
E-32	27,340	7,014	5,757	40,111
E-33	12,844	7,936	5,757	26,537
E-34	16,090	10,479	5,757	32,326
E-35	19,607	4,946	3,700	28,253
E-36	25,540	7,892	12,717	46,149
E-37	17,468	6,289	5,609	29,366
E-38	17,380	3,870	3,520	24,770
E-39	9,714	3,627	3,280	16,621
E-40	4,922	3,147	4,000	12,069
E-41	15,380	4,588	7,957	27,925
E-42	18,388	9,313	7,971	35,673
E-43	20,809	13,234	10,505	44,548
E-44	17,070	12,194	10,505	39,769
E-45	17,500	13,024	7,957	38,481
E-46	10,890	15,064	12,717	38,671
E-47	17,526	14,969	10,505	43,000
E-48	13,486	12,974	10,505	36,965
E-49	14,200	14,409	12,717	41,326
E-50	25,990	13,600	12,171	52,307
		Natural gas wells		
G-1	19,665	10,764	19,769	50,198
G-2	21,940	12,992	17,909	52,841
G-3	20,340	12,113	21,431	53,884
G-4	17,602	10,928	33,212	61,742
G-5	18,250	11,057	17,095	46,402
G-6	15,820	8,060	19,869	43,650
G-7	19,906	14,130	16,798	50,834
G-8	11,438	7,525	16,798	37,761
G-9	12,540	7,721	17,095	37,356
G-10	16,454	9,104	20,501	46,059
G-11	25,202	8,223	16,798	50,223
G-12	40,622	8,964	17,095	66,681
G-13	18,465	8,657	33,212	60,334
G-14	25,744	14,511	17,095	57,350
G-15	12,040	11,144	17,095	40,279

Well no.	Well cost	Pump cost	Power unit cost	Total cost
Natural gas wells (continued)				
G-16	$16,900	$13,312	$17,095	$47,307
G-17	22,914	10,465	16,798	50,177
G-18	14,110	10,465	16,798	41,373
G-19	19,384	14,106	17,095	50,585
G-20	18,970	8,398	20,501	47,870
G-21	21,840	11,820	19,769	53,429
G-22	13,795	7,068	21,431	42,294
G-23	14,290	10,308	20,501	45,099
G-24	17,840	14,188	16,798	48,826

APPENDIX G

PUMP BACK SYSTEMS: CAPITAL COST IN DOLLARS

	1-PE	2-PE	3-PG	4-PG	5-PG	6-PE
Reservoir	2,394.00	20.00	4,500.00	4,500.00	4,500.00	60.00
Columns	96.80	24.20	193.60	193.60	193.60	24.20
Bowls	381.00	381.00	504.00	504.00	504.00	381.00
Motor	775.00	225.00	4,697.93	4,697.93	4,697.93	225.00
Head	600.00	316.00	872.00	872.00	872.00	467.00
Casing	160.00	None	320.00	320.00	320.00	None
Screen	30.00	25.00	50.00	50.00	50.00	30.00
Discharge	96.00	19.20	580.00	870.00	580.00	32.00
Pump cost	1,363.80	765.40	2,519.60	2,809.60	2,519.60	934.00
Power unit cost	775.00	225.00	4,697.93	4,697.93	4,697.93	225.00
Total capital cost	4,532.80	1,010.40	11,717.53	12,007.53	11,717.53	1,219.20
Power	$ 419.41	$ 25.39	$ 258.80	$ 690.24	$ 513.88	$ 151.55
Attendance	41.25	2.91	27.00	86.36	30.91	17.83
Lubrication	30.09	2.12	19.64	62.81	22.48	12.97
Tot. Var. Cost	490.75	30.42	305.44	839.41	567.27	182.35
Taxes	96.00	32.00	204.80	204.80	204.80	32.00
Interest	135.98	30.31	351.52	360.23	351.52	36.58
Depreciation	226.64	50.52	585.88	600.38	585.88	60.96
Tot. Fix. Cost	458.62	112.83	1,142.20	1,165.41	1,142.20	129.54

	1-PE	2-PE	3-PG	4-PG	5-PG	6-PE
Energy	41225 kwh	306 kwh	648 mcf	1760 mcf	1295 mcf	3504 kwh
Ac. ft./hr.	.2654	.0690	.3442	.2889	.3948	.0745
Hrs. run/yr.	3,009	212	1,963.6	6,281.2	2,248.3	1,297
Ac. ft./yr.	796.6	14.6	675.9	1,814.6	895.7	96.6
Lift (feet)	13.25	3.3	17.0	20.0	20.0	3.0
G.P.M.	1,441	375	1,870	1,570	2,165	405
Eff. (%)	36.2	20.1	6.77	6.7	4.49	8.48
A.F.F.	10,581	48	11,490	36,292	17,914	290
Var./ac. ft.	$ .614	$2.084	$ .452	$ .462	$ .633	$1.888
Fixed/ac. ft.	.574	7.728	1.690	.642	1,275	1.341
Tot. ac./ft.	1.188	9.812	2.142	1.104	1.908	3.229
Var./A.F.F.	.04634	.632	.02659	.0231	.03165	.629
Fixed/A.F.F.	.08966	2.342	.1260	.0552	.0954	.447
Total/A.F.F.	.1360	2.974	.15259	.0783	.12705	1.076

LIST OF REFERENCES

Barr, George W., Editor, Recovering Rainfall, University of Arizona, Tucson, Arizona, 1963.

Bureau of Reclamation, 1962 Crop Report and Related Data, United States Department of Interior, Washington, D. C., 1963.

Cochran, William G., Sampling Techniques, New York: John Wiley and Sons, Inc., 1963.

Cox, P. Thomas, An Economic Analysis of Water Priority Rights and Their Effect on Farm Planning in the San Carlos Irrigation and Drainage District, Unpublished Master's Thesis, University of Arizona, 1963.

Enz, Richard W., Water Supply Outlook for Arizona, U. S. Department of Agriculture, Soil Conservation Service, Phoenix, Arizona, Jan. 15, 1964.

Forbes, R. H., Irrigation and Agricultural Practice in Arizona, Arizona Agricultural Experiment Station Bulletin, June 1911, Number 63, Tucson, Arizona.

Gulley, F. A. and C. B. Collingswood, Agricultural Development in Southwestern and Pumping Water for Irrigation, Arizona Agricultural Experiment Station Bulletin, December 1893, Number 11, Tucson, Arizona.

Nelson, Aaron G., Unpublished survey material from his files, Department of Agricultural Economics, University of Arizona, Tucson, Arizona.

Rehenburg, Rex D., The Cost of Pumping Irrigation Water, Pinal County, 1951, Arizona Agricultural Experiment Station Bulletin, January 1953, Number 246, Tucson, Arizona.

Steel, Robert G. D. and James H. Torrie, Principles and Procedures of Statistics, New York, McGraw-Hill Book Company, Inc., 1960.

Stolbrand, Vasa E., Irrigation in Arizona, Arizona Agricultural Experiment Station Bulletin, October 1891, Number 3, Tucson, Arizona.

Thompson, Ned O. and W. A. Steenbergen, The Cost of Pumping for Irrigation in Pinal County, 1939, Arizona Agricultural Extension Service Report, 1939.

White, Natalie D., R. S. Stulik and others, Annual Report on Groundwater in Arizona Spring 1961 to Spring 1962, U. S. Geological Survey, Phoenix, Arizona, 1962.

________, Annual Report on Groundwater in Arizona Spring 1962 to Spring 1963, U. S. Geological Survey, Phoenix, Arizona, 1963.

Woodward, Sherman M., Cost of Pumping for Irrigation, Agricultural Experiment Station Bulletin, November 38, 1904, Number 49, Tucson, Arizona.