TEXAS BOARD OF WATER ENGINEERS

COST OF PUMPING WATER FOR IRRIGATION TEXAS HIGH PLAINS

FIELD INVESTIGATIONS - 1947 IRRIGATION SEASON

By

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PREPARED IN COOPERATION WITH THE
TEXAS BOARD OF WATER ENGINEERS

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TEXAS HIGH PLAINS

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A large part of the irrigation development in the Texas High Plains occurred during the war and immediate postwar period 1942-47. This was a period of general scarcity in which such critical items as pumps, well casing, engines, motors, and other necessary pump appurtenances were difficult to obtain. Competition for the scant supplies of equipment for irrigation wells was exceptionally keen, with little or no opportunity for selective buying. Under these conditions, prospective irrigators were more concerned with the problem of obtaining equipment than in the suitability of this equipment for the job at hand. The results, as are presently noted, are reflected in the fact that many wells are producing water at a higher cost than would appear to be necessary had this development taken place under less pressing circumstances.

PURPOSE OF STUDY

The cost of water constitutes one of the major items of expense incurred in the practice of irrigation, particularly where water must be pumped from deep wells. As most of the irrigation developments in the High Plains are of recent origin, the subject of water costs has not been extensively investigated. The study upon which this report is based was undertaken, therefore, to determine the cost of pumping water with existing equipment operating under the wide range of conditions found in the Texas High Plains.

1/ Agricultural Economist, Bureau of Agricultural Economics, U. S. Department of Agriculture.

NATURE OF DATA

The data on which this report is based are drawn mainly from the first year of a more comprehensive 3-year study of pump-irrigated farming practices.2/ Included in the field records obtained are reported hours of plant operation, expenditures for fuel or electric energy, lubricants, and repairs incurred in the operation of 172 pumping plants on 134 farms during 1947. Data of some degree of completeness were obtained for 233 pumping plants; consequently, some of the tables contain data from more than 172 plants.

Well-yield and pumping-lift measurements were made during the pumping season.

The pumping plants studied are well distributed throughout the southern and central portions of the main irrigated section, as shown by the location map included in this report. The conditions under which they operate, the type of equipment -- pumps, power units, and fuels -- pumping lifts, and well yields are representative of conditions for the area as a whole.

The range of conditions covered by the pumping plants included in this study is as follows:

Static water levels	25.4 to 193.9 feet
Pumping lifts	44.1 to 226.0 feet
Well yields	250.0 to 1,346.0 gallons per minute
Total pumpage	16.0 to 344.0 acre feet
Power units	Electric motors, Diesel engines, industrial engines, automobile engines
Fuels	Diesel, butane, gasoline, and natural gas

Although the wells studied include a wide range in pumping lift

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2/ A cooperative undertaking by the Texas Agricultural Experiment Station and the Bureau of Agricultural Economics.

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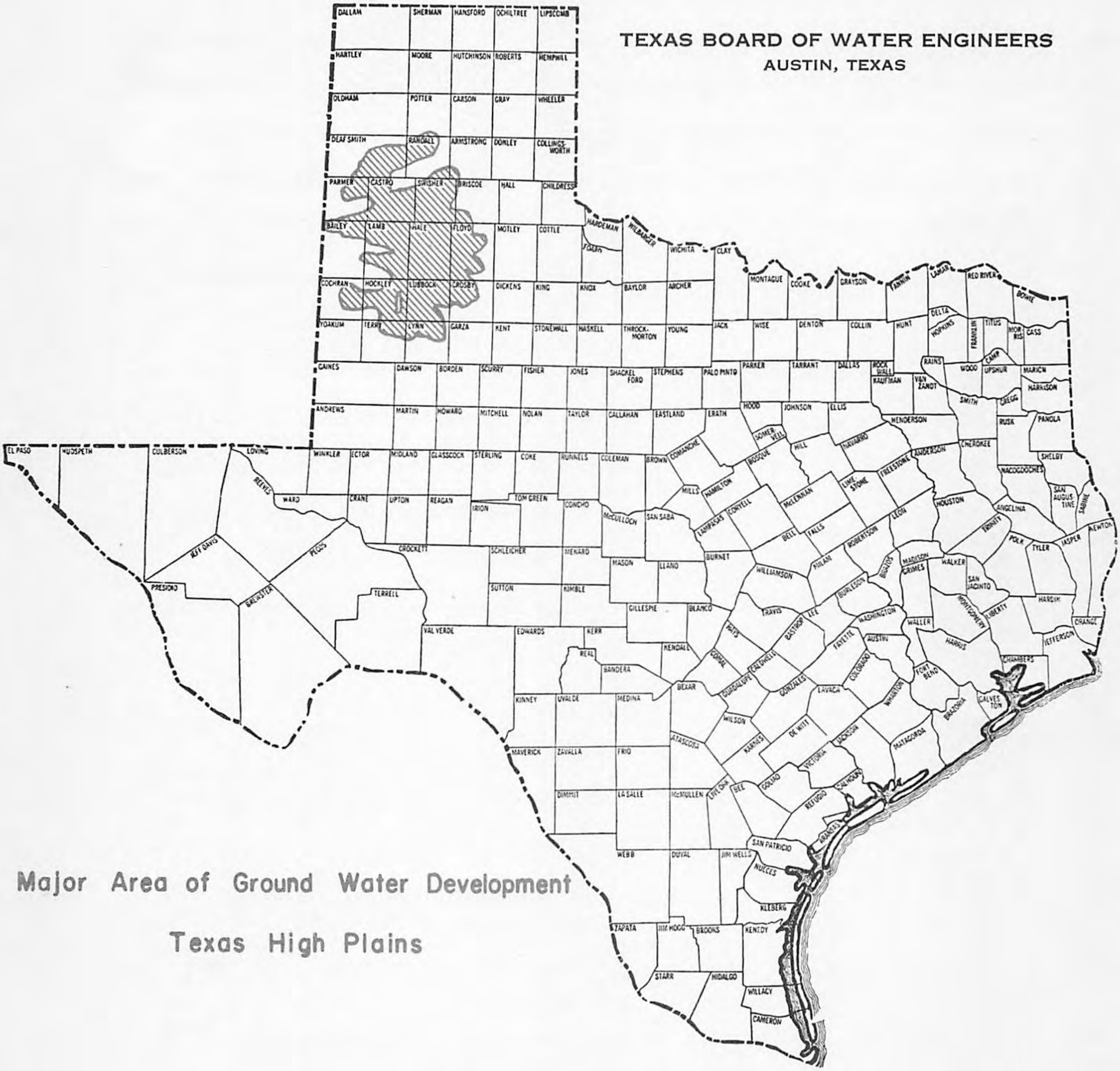

Major Area of Ground Water Development

Texas High Plains

and well yield, there is a striking similarity in the equipment of most pumping plants. Types, makes and horsepower ratings of engines and fuels used often differ from plant to plant, but approximately 85 percent of the pumps are of the same size and rated capacity.

Field work did not include determinations of pump efficiency; consequently, there is no valid basis for direct comparisons between individual pumping plants. 3/ Moreover, in the absence of pump efficiencies, it is not possible to ascertain the brake-horsepower requirement of a particular plant or to relate fuel consumption to these requirements. 4/ Although the data are incomplete in this respect, they are comprehensive enough for the purpose of this report: The determination of the cost of pumping water with existing equipment. What the cost of pumping water should be and how much existing costs could be reduced are matters for further study.

ANALYSIS OF DATA

Investigators are generally agreed regarding the cost items included in the cost of pumping water. This agreement is not so general, however, as to the methods used in the determination of these individual items of cost or in the allocation of charges for particular purposes. As this suggests, there are

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3/ The ratio of the theoretical horsepower represented in lifting water (water horsepower) to the actual horsepower developed at the shaft by the motor or engine (brake horsepower). Because of power losses in the pump, in the transmission, and in overcoming friction, the ratio or efficiency is always less than 100 percent. Under field conditions it seldom exceeds 70 percent on new plants and often falls to 40 percent or lower as the plant becomes worn.

4/ Actual horsepower being developed at the shaft by the motor or engine. Also power input to a pump.

different methods of calculating pumping costs. Because of the many variables and dissimilarities involved, investigators have tended to vary their methods somewhat to meet local conditions. A similar situation obtains in this study; consequently, basic assumptions and methods of cost allocation are presented at appropriate places in the text. For those who might be inclined to use other methods of cost allocation the data on individual wells are presented in appendix table 1.

Pumping costs are composed of two types of cost -- overhead and operating. Each of these types contains several individual cost items which may vary considerably, depending upon the combination of operating circumstances at a particular plant. The way in which the various factors that affect cost combine at a particular plant materially influences the resultant total cost at that plant; consequently, total pumping costs, operating costs, or overhead costs are peculiar to the particular well for which they are calculated. Certain of the cost items included in operation costs, which must be based on reasonable expectancy of occurrence and be distributed throughout the expected life of the facility, can only be derived from mass experience. These individual costs are based on average expenditures for these purposes per hour of operation.

Pumping costs for the 172 plants are presented individually in figures 1, 2, and 3. The range and the more common energy or fuel and lubricant requirements and costs are discussed. However, the individual per acre-foot costs presented in figures 1, 2, and 3 contain the actual expenditures for energy or fuel and lubricants incurred in the operation of the individual plants, plus allowances for the other items of cost, derived as indicated in the text.

In this analysis, the two types of cost, overhead and operating, are considered to be independent of each other and are so calculated.

Overhead Costs

Overhead costs consist of allowances for depreciation, interest, risk, and taxes. The total annual amount of overhead cost depends upon the rate of depreciation adopted, the rate of interest charged, and the amount allocated for risk and taxes on the amount invested in a particular plant. For all practicable purposes, the total annual amount of overnead cost is not affected by total amount of water pumped, hours of plant operation, or changed economic conditions. 5/ Under some circumstances the amount of use could aaversely affect overhead costs, but the operation of these plants is seasonal rather than year-round and few if any of them are used enough for wear to appreciably shorten the life of the plant. Once a plant is installed, overhead becomes a legitimate item of expense that must be charged off whether or not the plant is operated.

The rate of deterioration of wells and depreciation of various items of pumping equipment varies widely, depending on individual circumstances. As a result, there are differences of opinion regarding the expected life of power units and other items of plant equipment. In lieu of the actual useful-life span of the various pumping plant components, which cannot be predetermined, a normal useful-life expectancy for these components is assumed. The expected life and depreciation rates adopted are given in table 1. These estimates are based on the consensus of operators and others familiar with pump operating conditions in the Texas High Plains. Except for a shorter period of expected

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5/ See discussion by: Rohwer, Carl. Design and Operation of Small Irrigation Pumping Plants. U. S. Dept. Agr. Circ. No. 678. Oct. 1943.

life for power units, the estimates given in table 1 are in close agreement with those used by Stanley 6/, Bush 7/, and Wood 8/.

An interest rate of 5 percent and an allowance of 2 percent of the initial investment for risk and taxes are arbitrarily adopted. Inasmuch as the straight-line depreciation principle is used. the annual interest, risk, and tax charge is applied to one-half the initial capital investment.

Table 1.- Estimated years of life and rates of depreciation for wells and various items of pumping equipment

Item	Estimated life (years)	Rate of depreciation (Percent of initial investment)
Well and casing	20	5.00
Pump and appurtenances	15	6.66
Power unit:		
Electric motor	15	6.66
Diesel engine	10	10.00
Industrial engine	8	12.50
Automotive-type engine 1/	5	20.00
Fuel tank or switch box	20	5.00
Housing and installation	20	5.00

1/ Automobile engines adapted for fixed operation.

6/ Stanley, Wyatt R. "Cost of Pumping Water." Water Utilization Planning Service, Bur. Agr. Econ. March 1941 (Mimeo.)

7/ Bush, Clarence J., Assistant Engineer, Rural Electrification Administration, reported in "Special Report on Water Utilization in Chaves and Eddy Counties, New Mexico," Bur. Agr. Econ. March 1941. (Mimeo.)

8/ Wood, Ivan D. "Pumping for Irrigation." Soil Conservation Service, SCS TP-89. Washington, D. C. May 1950.

Annual charges for overhead are based on the rates of depreciation given in table 1, except for three wells equipped with second-hand items of equipment. In these cases, depreciation rates are arbitrarily doubled on the second-hand items. Allowance for risk and taxes along with interest are calculated in the same way in all cases.

The amount invested in the individual plants depends on type and size of power unit, size of pump, depth of the well, depth of pump setting, and the particular year in which the plant was installed. The average investment in plants of all types and depths for the period 1937 through 1940 was about $2,600. Since 1940, the average investment has increased, averaging about $3,000 for the period 1941 through 1943; $3,300, $3,500, $3,800, and $4,200 for the years 1944, 1945, 1946, and 1947, respectively. The range in investment for the 172 plants included in this study is from $881 for a plant powered by an automobile engine and using second-hand equipment to slightly more than $10,100 for a Diesel-equipped plant installed in 1947.

Some of the increase in plant cost may be attributed to the installation of larger engines, a trend that has been under way for some time. But most of it is due to increases in the general price level during the construction period. The net effect of increases in the general price level is reflected in proportionally higher overhead costs. (A 10-percent increase in investment results in a 10-percent increase in overhead costs.)

Increases in the general price level have affected the items making up operating costs also, but, inasmuch as operating costs are mostly annual out-of-pocket costs, the effect is the same for both old and new plants regardless of the amount invested in a plant.

Variations in overhead costs are comparable and proportionate to variations in initial plant costs. They range from $173 on an investment of $1,730 in an electric-powered plant to $1,263 on a $10,100 Diesel-powered plant.

Overhead costs on electric-powered plants approximate 10 percent of the initial investment whereas on engine-powered plants of all types, they approximate 12.5 percent of the initial investment. On individual plants, overhead constitutes 20 to a little more than 80 percent of the total per acre-foot cost of pumping water, depending, first, on the number of acre-feet pumped and, second, on the amount invested in the particular plant.

Operating Costs

Operating costs consist of expenditures for fuel or energy, lubricants, repairs, maintenance, and time spent in attending the plant. Unlike overhead costs, which apply whether or not the plant is used, operating costs are proportionate to the hours of plant operation. As calculated, the first hour of operation costs the same as the last.

Operating cost per acre foot of water pumped, per hour of plant operation, and per acre-foot per foot of lift (hereinafter designated as acre-foot foot) have been calculated for all 172 plants. Expenditures for fuel or energy and lubricants have been obtained from the records of cooperating farmers. Allowances for repairs and maintenance are based largely on these same records.

Energy or Fuel Costs

Expenditures for energy or fuel constitute the largest single item of expense in the cost of operation. In many cases, especially when the plant was operated for upward of 1,000 hours or more, costs of energy or fuel were the largest item of expense in the cost of pumping water. Some idea of the importance of energy or fuel costs in the cost of operation can be obtained from table 2 in which this cost is presented as a percentage of total operating cost.

Table 2.- Percentage average energy or fuel costs are of total operating costs, Texas High Plains, 1947 season

Energy or fuel	Unit	Average cost per unit	Percentage of total operating cost
		Cents	Percent
Electricity	K. W. H.	1.25	80
Natural gas	1,000 cu. ft.	32.00	45
Gasoline	Gallon	11.50	65
Butane 1/	Gallon	8.00	63
Butane 2/	Gallon	9.00	67
Diesel oil	Gallon	9.50	69

1/ Owner furnishes fuel storage tank.
2/ Fuel storage tank provided by fuel distributor.

Because of the wide range in the yield of similarly equipped wells, the per acre foot fuel or energy requirement does not provide as satisfactory a measure for comparison as the fuel or energy requirements per hour of operation.

The over-all range and the more common range in the hourly fuel or energy requirements and costs are presented in table 3.

Table 3.- Range in energy or fuel requirements and costs per hour of operation, by type and size of power unit and fuel or energy used, Texas High Plains, 1947 operating season

Power units and type of fuel or energy used	Number of plants	Energy or fuel requirements and cost per hour of operation: Over-all range: Requirements	Over-all range: Cost	More common range: Requirements	More common range: Cost
	Number	Units	Cents	Units	Cents
Electric motors:		KWH		KWH	
25 hp.	2	20.0 - 22.6	25.0 - 28.3	20.0 - 22.6	25.0 - 28.3
30 hp.	15	23.9 - 35.0	31.9 - 43.7	26.6 - 33.3	33.4 - 41.6
40 hp.	10	26.9 - 37.9	33.6 - 47.4	30.9 - 33.3	38.6 - 41.6
Industrial engines:		Gallons		Gallons	
Gasoline fueled	3	3.04 - 6.01	35 - 69	3.04 - 6.01	35 - 69
Butane fueled	10	3.01 - 7.74	25 - 62	3.50 - 5.00	36 - 44
Automobile engines-(all):					
Gasoline fueled	27	2.15 - 6.72	25 - 76	3.50 - 5.00	40 - 52
Butane fueled	96	2.62 - 8.75	20 - 66	3.50 - 5.00	26 - 37
Natural gas	9	---	10 - 20	---	15 - 18
Diesel engines:					
118 hp.	3	4.00 - 4.75	38 - 45	4.00 - 4.75	38 - 45
50 hp.	2	2.95	28	2.95	28

The number of plants powered by Diesel or industrial engines is perhaps too small to indicate the range in hourly fuel requirements for these types of engines as they are being used. Although the data do not permit direct comparisons between the hourly fuel requirements and costs on Diesel and industrial engines with those of automobile engines, they do permit an approximation of the hourly amounts of fuel these engines require.

For automotive-type engines fueled by gasoline or butane, the hourly fuel requirements tend to be associated with engine size. This is indicated in table 4 where both the range in and the average fuel requirements per hour for the various engine size groups are presented.

Table 4.- Fuel consumption, gallons per hour of operation, automotive-type engines, Texas High Plains, 1947 pumping season

Size of engine (rated horsepower)	Number of plants	Range in fuel consumption (gallons per hour)	Average fuel consumption (gallons per hour)
90 and under	25	2.15 to 5.19	3.72
91 to 100	31	2.62 to 6.38	4.12
101 to 120	28	3.00 to 6.76	4.68
121 to 145	25	3.86 to 7.92	5.15
146 to 187	7	4.50 to 8.75	5.91

Because of the wide range of conditions encompased and the lack of check data or control, it is not possible directly to compare hourly rates of fuel consumption of engines fueled by gasoline and those fueled by butane, The data suggest, however, that factors other than kind of fuel are primarily responsible for differences in the hourly rates of fuel consumption. Then, too, farmers who have recently changed from gasoline to butane, report little if any difference in the amount of fuel consumed in an hour's operation.

Lubricant Costs

Reported expenditures for lubricants varied with type and condition of the power unit. On electric-powered plants, with water-lubricated pumps, the lubricant cost was negligible, seldom exceeding 50 cents for the season. For electric-powered plants, with oil-lubricated pumps, the lubricant costs were higher, ranging from 1 to 2.5 cents per hour of operation.

The cost of lubricants on engine-powered plants approximated 10 percent of the fuel costs. With new engines, presumably in good mechanical condition, the lubricant cost was 5 to 7 percent of the fuel costs, or 1.1 to 3.0 cents per hour of operation. On older engines, the cost of lubricants approached 12 to 15 percent of the fuel costs, or 4 to 7 cents per hour of operation. Hourly lubricant costs ranged from a low of 0.9 to a high of 8.3 cents per hour of operation, with most plants having an hourly lubricant cost somewhere between 1.5 and 4.0 cents.

Lubricant costs on Diesel engine equipped plants ranged from 2.0 to 3.0 cents per hour of operation.

Repair and Maintenance Costs

Two types of charges are included here, repair and maintenance on the plant (power unit and pump) and maintenance on the well itself. Although expenditures for repair and maintenance may not be necessary in a particular year, they must be anticipated sometime during the life of the equipment. Moreover, they must be distributed throughout the life of the equipment or else water costs in a particular year will not adequately reflect their proportionate share of these costs.

No expenditures for repair or maintenance were reported for a number of the plants included in this study, whereas expenditures of several hundred dollars for these purposes were reported for others. The methods used to determine repair and maintenance costs are outlined in the discussion which follows.

Plant repair and maintenance.- Allocations for repair and maintenance have been derived by totaling expenditures for these items by power unit groups -- electric, automotive-type engines, and industrial engines -- and dividing the total expenditures for each group by the total number of hours each group of plants operated. The resultant average hourly cost by groups multiplied by the hours of individual plant operation gives the individual plant repair and maintenance cost.

The number of Diesel engine equipped plants included in this study was too small for this type of treatment. Allocations for repair and maintenance have been based on the procedure suggested by Rohwer -- a lump sum allowance equivalent to 20 percent of the annual fuel bill. 9/

The average repair and maintenance cost per hour of operation for plants powered by different types of power units and fuels is shown in table 5. 10/

9/ Rohwer, Carl. Op. cit., p. 71.

10/ There is reason to believe that the average repair and maintenance costs presented in table 5 are low. Approximately 75 percent of the pumping plants included in this study were relatively new plants being installed during 1944, 1945, 1946, and 1947. As repair costs can be related to the number of hours a plant is operated, this would suggest that the greater part of the plants included have not been used enough to require substantial repairs. The average repair and maintenance cost per hour of operation, given in table 5, should be regarded as the minimum expected cost per hour of operation for plant repairs and maintenance.

Table 5.- Average plant repair and maintenance cost per hour of operation and as a percentage of total fuel or energy bill, Texas High Plains, 1947 season

Type of power unit	Number of plants	Average hours of operation per plant	Average repair and maintenance cost per hour of operation	Percentage R&M costs are of annual fuel bill 1/
	Number	Hours	Cents	Percent
Electric motor	33	1,049	2.00	5.0
Industrial-type engine 2/	19	811	3.25	8.4
Diesel engine	5	1,146	9.00	20.0
Automotive-type engine	(128)	(953)	(6.50)	--
Gasoline-fueled	29	655	6.50	15.0
Butane-fueled	90	983	6.50	16.0
Natural-gas-fueled	9	1,607	6.50	41.0

1/ See table 2 for fuel or energy rates.
2/ 3 gasoline-fueled and 16 butane-fueled plants.

Well maintenance.- Occasionally, for one reason or another, the pump must be removed from the well. The cost for this service depends on the depth of pump setting. The usual charge is a flat fee for the first 100 feet or less of pump setting plus an additional per-foot charge for each foot of setting in excess of 100 feet. Unlike other costs of operation, which have been related to hours of operation, allowances for this service are based on the depth of the individual pump setting.

Assuming that the well itself will require a general overhauling every 5 years, an annual cost of 20 cents per foot of pump setting is charged to operating costs. 11/ This charge covers the cost of pulling the pump and cleaning the well. Repairs on the pump are included in the foregoing plant repair and maintenance costs. Expenditures for the additional pump stages, column pipe or suction pipe that may be required are charged as capital investment.

11/ As calculated, this cost could be properly considered under overhead, but it has been included here under the assumption that it will not be required unless the pump is operated.

Plant Attendance

Allowances for plant attendance are based on an estimated 1 hour of attendance per 24 hours of operation on electric-powered plants and 1 hour per 12 hours operation on engine-powered plants. Labor costs are calculated at $1.00 per hour.

Operating Cost per Hour of Operation

Calculated at the foregoing rates, the cost per hour of operation ranged from a low of 28.6 cents on a plant using a natural-gas fueled, automotive-type engine to 103.8 cents on a butane-fueled, industrial-type engine. Operating costs on most electric-powered plants are in the 40 to 55 cents per hour range, while on automotive-type engines the cost range is around 35 cents per hour for natural gas fueled plants, 55 to 65 cents per hour on butane-fueled plants, and 60 to 70 cents per hour on plants using gasoline. For industrial-type engines, hourly operating costs were about the same as those incurred on automotive-type engines. Diesel engines had operating costs ranging from 50 to 70 cents per hour.

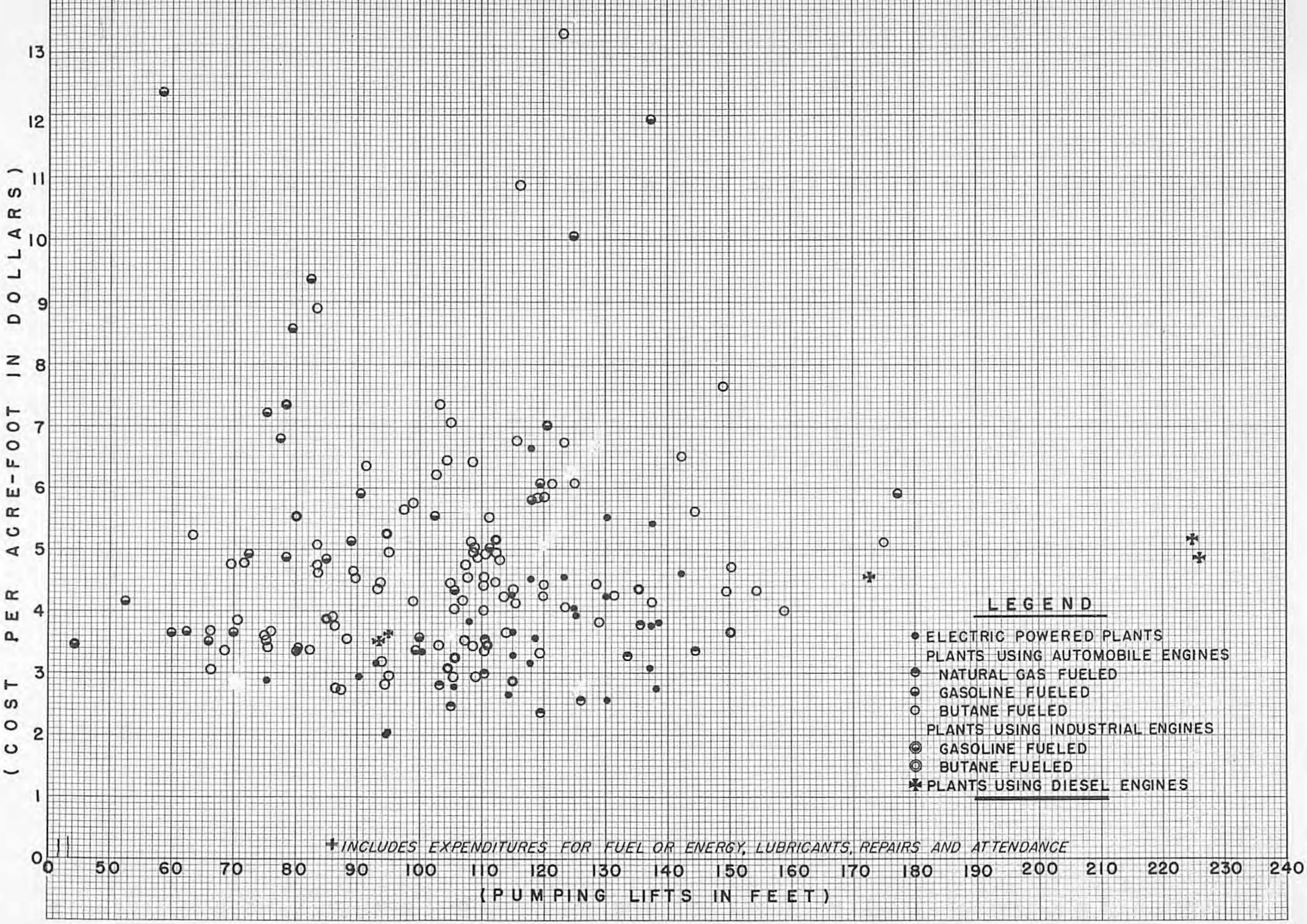
Operating costs per hour are emphasized because, as is pointed out later, the cost per hour of operation materially affects the per acre-foot pumping costs.

Operating Cost per Acre-Foot of Water Pumped

The operating cost per acre-foot of water pumped ranges from a low of $2.02 on an electric-powered plant to $13.30 on a plant using a butane-fueled, automotive-type engine. Approximately three-fourths of the 172 plants in this study are delivering water at an operating cost of $5.00 or less per acre foot (figs. 1 and 2).

Operating costs per acre-foot on the automotive and industrial engine-driven plants included in this study bear little if any relation to the

FIGURE I.- OPERATING COST PER ACRE-FOOT IN RELATION TO PUMPING LIFTS +
TEXAS HIGH PLAINS - 1947 OPERATING SEASON



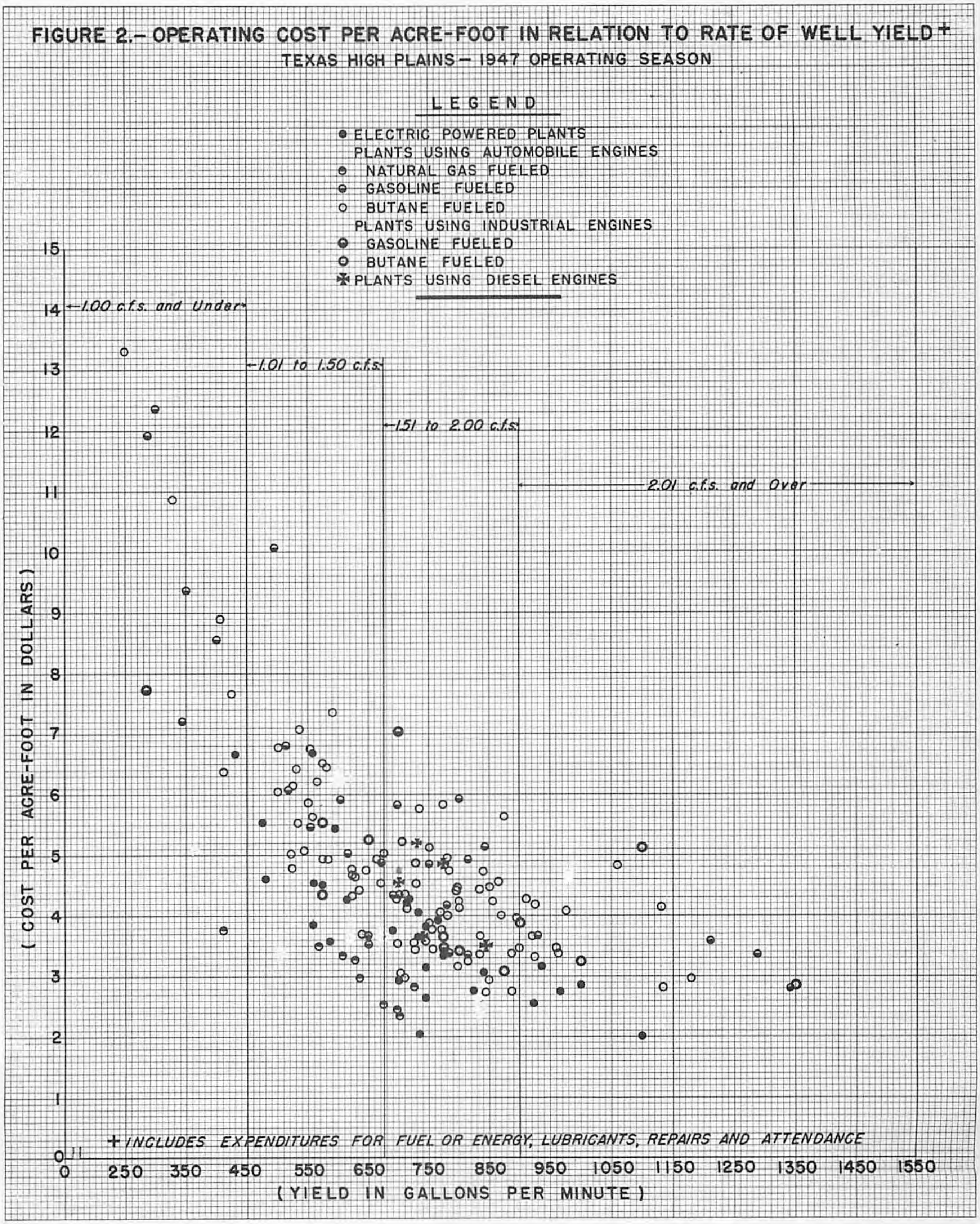


FIGURE 2.- OPERATING COST PER ACRE-FOOT IN RELATION TO RATE OF WELL YIELD+
TEXAS HIGH PLAINS — 1947 OPERATING SEASON
LEGEND
ELECTRIC POWERED PLANTS
PLANTS USING AUTOMOBILE ENGINES
NATURAL GAS FUELED
GASOLINE FUELED
BUTANE FUELED
PLANTS USING INDUSTRIAL ENGINES
GASOLINE FUELED
BUTANE FUELED
PLANTS USING DIESEL ENGINES
←1.00 c.f.s. and Under→
←1.01 to 1.50 c.f.s.
←1.51 to 2.00 c.f.s.
←2.01 c.f.s. and Over→
(COST PER ACRE-FOOT IN DOLLARS)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0
250
350
450
550
650
750
850
950
1050
1150
1250
1350
1450
1550
(YIELD IN GALLONS PER MINUTE)
+ INCLUDES EXPENDITURES FOR FUEL OR ENERGY, LUBRICANTS, REPAIRS AND ATTENDANCE

pumping lifts involved (fig. 1). On electric-powered and Diesel engine plants, these costs tend to increase as the lift increases (fig. 1). Pumping plants operating at the higher lifts (130 feet or more) usually have rather high operating costs. Most of these plants are equipped with engines rated at 120 horsepower or more, but there is no significant difference between their hourly operating costs and the hourly operating costs obtained on engines of similar size driving pumps at lower lifts.

With pump efficiencies unknown the effect of pumping lift on operating costs per acre foot cannot be precisely determined. The persistent way in which hourly rates of fuel consumption tend to be associated with engine size, regardless of the size of well yield or the pumping lift, suggests that if any relationship exists between lifts and operating costs on these plants it is obscured by other factors. There is a possibility that the failure of lift to be reflected in operating costs is due to differences in pump efficiency. The probability appears remote in that it is most unlikely that pumps with low rates of efficiency would be concentrated on wells with low lifts.

The lack or correlation between operating costs per acre-foot and pumping lifts on plants powered by automotive-type engines is not unexpected under the circumstances. As previously indicated, pumping equipment shows a striking similarity from well to well. With uniform pumping equipment, irrespective of pumping lift or size of well yield, and with fuel consumption rates closely related to engine size, the pumping lift could not reasonably be expected to exert much influence on operating costs (fig. 1).

In the absence of pump efficiency rates, direct comparison of costs are of dubious value. Direct comparison will serve to indicate, however, the extent to which differences in pumping lift are not reflected in pumping costs. The data presented in table 6 indicate a wide disparity in the cost of meeting the water-power requirements of the individual wells. 12/ It will be noted that the water-power requirement of the first well listed in table 6 is more than three times greater than that of the last well listed, yet the cost of satisfying the greater power requirement is only $1.72 more per acre-foot than the cost of meeting the smaller requirement.

Table 6.- Operating costs per acre foot pumped for selected plants with similar yield and different lifts, powered by automotive-type engines, Texas High Plains, 1947 operating season

Pumping lift	Well yield (gallons per min)	Water-power requirements	Rated horsepower of engines	Fuel consumption (gallons per hour of operation)	Fuel cost per acre-foot 1/	Total operating cost per acre foot
Feet	Gallons	Horsepower	Horsepower	Gallons	Dollars	Dollars
177.20	800	35.8	155	2/ 5.70	4.44	5.91
137.50	800	27.7	145	4.81	2.77	4.14
131.20	800	26.5	120	5.14	2.96	4.25
110.92	800	22.4	100	3.01	1.73	3.42
110.30	780	21.7	120	4.61	2.73	4.00
108.85	780	21.4	145	5.72	3.38	4.97
105.00	797	21.1	120	5.50	3.18	4.45
93.00	797	18.8	100	3.20	1.85	3.17
93.00	797	18.8	120	4.66	2.70	4.18
82.17	815	16.9	100	3.81	2.16	3.39
80.00	815	16.4	100	2/ 3.17	2.43	3.36
80.05	780	15.7	93	2/ 2.25	1.80	3.40
72.40	815	14.9	120	2/ 4.50	3.45	4.94
69.86	783	13.8	100	6.08	3.59	4.76
52.70	780	10.4	85	2/ 4.05	3.24	4.19

1/ Fuel rates: gasoline, 11.0¢ per gallon; butane, 8.0¢ per gallon.
2/ Gasoline-fueled plants, all others butane-fueled.

12/ Water-power requirement is the theoretical horsepower required. It represents the net horsepower required for the particular load. The actual horsepower required will be greater because of power losses in pump, power transmission, and in overcoming friction.

pumping lifts involved (fig. 1). On electric-powered and Diesel engine plants, these costs tend to increase as the lift increases (fig. 1). Pumping plants operating at the higher lifts (130 feet or more) usually have rather high operating costs. Most of these plants are equipped with engines rated at 120 horsepower or more, but there is no significant difference between their hourly operating costs and the hourly operating costs obtained on engines of similar size driving pumps at lower lifts.

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177.20	800	35.8	155	2/ 5.70	4.44	5.91
137.50	800	27.7	145	4.81	2.77	4.14
131.20	800	26.5	120	5.14	2.96	4.25
110.92	800	22.4	100	3.01	1.73	3.42
110.30	780	21.7	120	4.61	2.73	4.00
108.85	780	21.4	145	5.72	3.38	4.97
105.00	797	21.1	120	5.50	3.18	4.45
93.00	797	18.8	100	3.20	1.85	3.17
93.00	797	18.8	120	4.66	2.70	4.18
82.17	815	16.9	100	3.81	2.16	3.39
80.00	815	16.4	100	2/ 3.17	2.43	3.36
80.05	780	15.7	93	2/ 2.25	1.80	3.40
72.40	815	14.9	120	2/ 4.50	3.45	4.94
69.86	783	13.8	100	6.08	3.59	4.76
52.70	780	10.4	85	2/ 4.05	3.24	4.19

1/ Fuel rates: gasoline, 11.0¢ per gallon; butane, 8.0¢ per gallon.
2/ Gasoline-fueled plants, all others butane-fueled.

12/ Water-power requirement is the theoretical horsepower required. It represents the net horsepower required for the particular load. The actual horsepower required will be greater because of power losses in pump, power transmission, and in overcoming friction.

Within the various fuel groups, the yield of the well materially influences the cost of pumping an acre-foot of water. This is indicated in table 7 and in figure 2, where operating costs per acre-foot for the various types of power and well yields are presented.

Operating costs per acre foot and per acre-foot foot are both affected by the yield of the well. With hourly fuel consumption more or less a constant for a particular engine size, it necessarily follows that the fewer the hours required to pump an acre foot of water, the less the operating cost per acre foot or acre-foot foot will be. This is illustrated in figure 2, where operating costs per acre-foot are plotted against the yield of individual wells.

Table 7.- Average operating cost per acre-foot related to various rates of well yields, Texas High Plains, 1947 season 1/

Type of power or fuel	Yield of well - Gallons per minute: 449 and under: Number of plants	449 and under: Dollars per acre-foot	450 - 675: Number of plants	450 - 675: Dollars per acre-foot	676 - 900: Number of plants	676 - 900: Dollars per acre-foot	901 and over: Number of plants	901 and over: Dollars per acre foot
Electric	1	6.76	8	4.54	14	3.34	5	2.67
Natural gas 2/	1	3.78	5	3.14	3	2.55	-	-
Butane 2/	5	9.42	28	5.47	45	4.10	11	3.73
Gasoline 2/	5	9.89	10	5.79	9	4.66	4	3.37
Total and average all types	12	8.92	51	5.16	71	3.95	20	3.39

1/ Fuel and energy rates as indicated in table 2.
2/ Automotive-type engines only.

Although a number of individual factors combine to affect the per acre-foot operating costs, the persistent decline in these costs as well yields increase, indicates that this factor alone exerts a material if not an overriding influence, particularly for yields up to 675 gallons per minute (fig. 2). For yields of 676 gallons a minute and over, the effect, although still evident, is not so pronounced (fig. 2). Differences in per acre-foot operating cost between plants with comparable yields are largely attributable to differences in mechanical condition of individual plants, types of power unit, and fuel costs.

Operating Cost per Acre-Foot Foot

Operating cost per acre-foot foot (cost of lifting one acre foot of water one foot) ranged from a low of 2.0 cents on two electric-powered and two natural gas fueled, automotive-type, engine-powered plants to 21.2 cents on a gasoline-fueled, automobile engine-powered plant with a pumping lift of 58.4 feet and a yield of 300 gallons per minute.

The lowest acre-foot foot costs were obtained on plants powered by automotive-type engines using natural gas, averaging 2.5 cents, followed by Diesel equipped plants, 2.7 cents; electric plants, 3.2 cents; butane plants, 4.6 cents; and gasoline plants, 6.7 cents.

One reason for the higher cost on gasoline-fueled plants, in addition to the greater fuel cost, is that more than 60 percent of the plants fueled by gasoline had pumping lifts of 90 feet or less (fig. 1). Plants of all types -- fuels and engines or motors -- show greater acre-foot foot costs at pumping lifts of 90 feet or less than they do at lifts above 90 feet.

Disproportionally high acre-foot foot costs on pumping lifts under 90 feet compared with those at greater lifts, suggest that many of the comparatively low-lift plants are not fitted to the conditions under which they are operating.

Total Cost per Acre Foot

The total per acre-foot cost of pumping water on the 172 plants ranged from a low of $3.48 on an electric-powered plant that pumped 218 acre-feet to a high of $27.89 on a gasoline-fueled plant that pumped only 16 acre-feet of water (fig. 3). Most plants, especially those pumping more than 100 acre-feet during the season, delivered water at a total cost somewhere between $5.00 and $9.00 per acre-foot.

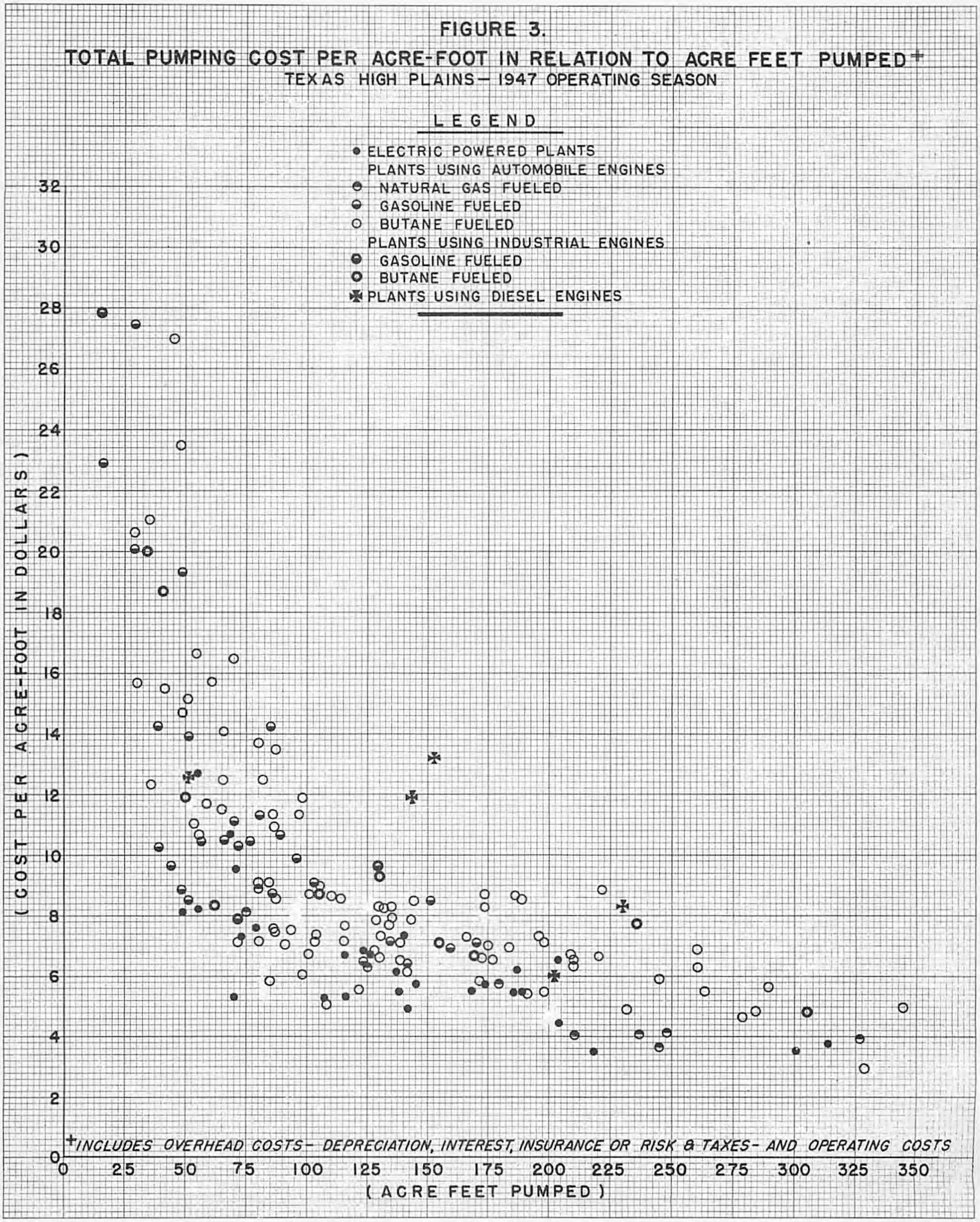
FIGURE 3.
TOTAL PUMPING COST PER ACRE-FOOT IN RELATION TO ACRE FEET PUMPED+
TEXAS HIGH PLAINS — 1947 OPERATING SEASON
LEGEND
ELECTRIC POWERED PLANTS
PLANTS USING AUTOMOBILE ENGINES
NATURAL GAS FUELED
GASOLINE FUELED
BUTANE FUELED
PLANTS USING INDUSTRIAL ENGINES
GASOLINE FUELED
BUTANE FUELED
PLANTS USING DIESEL ENGINES
(COST PER ACRE-FOOT IN DOLLARS)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
(ACRE FEET PUMPED)
+INCLUDES OVERHEAD COSTS — DEPRECIATION, INTEREST, INSURANCE OR RISK & TAXES — AND OPERATING COSTS

The number of acre feet of water pumped influences the total cost more than all other factors combined. This is shown in figure 3, where individual total costs per acre-foot are plotted against total pumpage for the season. Some plants with low per acre-foot operating costs have rather high total costs per acre-foot simply because they are not used enough to spread the overhead costs. Conversely, some heavily used plants with rather high operating costs produce water at a cheaper total cost per acre-foot than the less heavily used plants with lower operating costs. One plant in particular with a low operating cost of $3.42 per acre-foot had a total pumping cost of $18.66 per acre foot. Total operating cost for the season on this plant was $140.28 for 41 acre-feet of pumpage, but the $625.00 overhead cost on the $5,000 plant investment brought the cost of water up materially.

Reference to figure 3 indicates that only 4 out of 50 plants are producing water at less than $8.00 per acre-foot when the pumpage is 75 acre-feet or less for the season. For rates of pumpage in excess of 75 acre-feet per season there is a gradual reduction in the per acre foot costs as the amount of pumpage increases(fig.3). Variations in total cost per acre-foot between plants with similar total seasonal amounts of pumpage reflect: (1) operating costs, as they are affected by the size of well yield, type of fuel or energy used, and plant efficiency; and (2) differences in the amount of fixed costs that result from differences in the amount invested in individual plants.

As a group, natural gas-fueled, automobile-engined powered plants produced the cheapest water both in operating and total cost per acre-foot. Total investment in these plants did not differ much from the investment in similar engine-driven plants using different fuels. Low operating costs combined with fairly high amounts of pumpage account for the favorable showing made by natural gas-fueled plants.

Electric-powered plants as a group produced next to the lowest cost water. Total pumping costs on electric-powered plants ranged from a low of $3.48 to a high of $12.69 per acre-foot. In general, the investment in an electric-powered plant was a little less than that for comparable plants installed in the same year. Overhead costs were less on electric-powered plants and operating costs were generally $1 or more per acre-foot less than operating costs on engine-driven plants using gasoline or butane. Differences in well yields are reflected in operating costs per acre-foot, but the effect is less pronounced than with engine-driven plants.

Plants powered by butane-fueled, automotive-type engines generally produced water at a slightly lower cost than did plants using gasoline. The range in total pumping costs for butane-fueled plants is from $3.99 to $27.00 per acre-foot, whereas with gasoline-fueled plants this range was from $3.99 to $27.49 per acre-foot. The size of well yield and the number of acre-feet pumped in a season's operation have about the same effect on both operating and total cost of pumping.

Industrial-type engines, using either gasoline or butane, did not show to particular advantage in this study. (See figures 2 and 3.) Engines of this type have acre-foot operating costs similar to those obtained on most of the automotive-type engines using similar fuels, but the amount of water pumped was not sufficient to offset the higher overhead cost resulting from their installation.

The five Diesel engine-driven plants had fairly low operating costs but total costs were up somewhat compared to other plants pumping the same amount of water. The low operating cost of the Diesel was offset by the high overhead costs caused by the investment in Diesel engines. Investment in the Diesel plants included in this study is approximately double that of other types of plants installed in the same year.

Only two of the Diesel-equipped plants pumped as much as 200 acre-feet of water during the 1947 season. The resulting total per acre-foot costs on these two plants was $8.31 and $6.00. The other three had costs of $11.83, $12.54, and $13.20, with a total pumpage of 143, 51, and 152 acre-feet, respectively.

DISCUSSION

Inasmuch as several of the individual cost items involved in the cost of pumping cannot be precisely determined, except in retrospect once the plant has been abandoned or replaced, the per acre-foot costs presented herein should be considered as reasonable approximations. Moreover, because of the number of contingencies involved, there is no assurance that these costs could be precisely duplicated, even with the same equipment and the same fuel or energy rates.

Now that the postwar installation pressure has eased, no doubt a number of farmers are interested in a review of their present pumping cost situation. To that end, the foregoing estimates of cost are of value if for no other reason than to highlight the necessity of selecting and installing a pumping plant that will fulfill requirements at the lowest cost. Wide differences in per acre-foot operating costs between plants operating under similar lift and yield conditions, along with the standardized nature of most pumping plants, strongly suggest that this factor was generally overlooked in the postwar expansion.

These cost estimates should be of particular value to individuals who contemplate new wells and to those faced with the necessity of replacing pump or power units. Within certain limits, an individual operator can exercise a degree of control over his pumping costs. Overhead costs can be reduced by keeping the investment to a minimum consistent with the amount of use expected of the plant. In this endeavor, installation of pumps capable of delivering 1,100 gallons a minute in wells yielding only 500 or 600 gallons a minute, powered by engines rated at 120, 145, or 165 horsepower when smaller engines will suffice, may provide a certain pride of ownership, but not the cheapest water.

The installation of larger-than-necessary pumps and engines results in higher-than-necessary water costs. Both overhead and operating costs are increased under these circumstances: Overhead by virtue of the fact that the investment is increased and operating costs through the greater hourly fuel requirement of the larger engines (table 4).

A farmer with a recently installed pumping plant, assuming that he, like many others, has installed a standard pumping plant, will probably not be in position to lower his costs to any great extent. Assuming that his present plant is not well fitted to the conditions at the site, he probably could not recover the cost of effecting the changes required to fit his plant to the particular set of conditions within the expected useful life of the pump or engines as the case may be.

With pumping lifts increasing and with well yields declining, a high degree of plant efficiency probably would be impracticable to maintain. The situation being what it is, it would probably cost more to maintain a plant at a high level of efficiency than could be recovered in subsequent fuel or energy savings. This does not alleviate the desirability of nor the necessity for installing equipment designed to fit the particular set of lift and yield conditions at the site. Subsequent increases in the pumping lift and concomitant decreases in the well yield probably would not affect the setup enough to warrant future changes, provided the plant is properly designed.

It has been common practice to recommend a slight overpowering of plants to provide for expected increases in the pumping lift. Experience to date suggests that this is a contingency that need not be taken into account in the Texas High Plains.

A large number of the wells included in this study have been overhauled or reworked since, or during, 1947. On some of the wells, the reworking was substantial, on others it was minor. Most wells sustained one or more of the following operations: cleaning and deepening, lowering of pump bowls, reworking and at times the addition of more pump stages, new pumps, extension of suction pipes, and the installation of new and usually larger power units. Despite the substantial nature of these operations, many of which might reasonably be expected to increase well yields, little or no improvement in well yield has resulted. This would suggest that plants in this area need not be overpowered as well yields are not likely to be improved.

APPENDIX A

PUMPING COST DATA, TEXAS HIGH PLAINS, 1947 OPERATING SEASON

Well No.	Year of completion 1/ (year)	Cost of plant 1/2/ ($)	Rating of power unit 1/ (horsepower)	Size of pump column 1/ (Inches)	Pump setting 1/ (feet)	Pumping lift 3/ (feet)	Well yield 3/ (gpm)	Hours of plant operation 1/ (Number)	Acre feet pumped 3/ (Number)	Fuel or energy 1/: Units (Total used) (k.w.h.)	Fuel or energy 1/: Cost (Total) ($)	Cost of lubricant 1/ (Total) ($)	Attendance cost 5/ (Total) ($)	Cost of maintenance 5/: Power Unit & Pump (Total) 4/ ($)	Cost of maintenance 5/: Well (Total) 4/ ($)	Total operating costs 4/ ($)	Total overhead costs 4/ 5/ ($)	Total cost of pumping 4/ ($)	Operating costs, per 4/: Acre foot pumped ($)	Operating costs, per 4/: Acre foot foot (cents)	Operating costs, per 4/: Hour of operation ($)	Total cost per acre-foot pumped 4/ ($)
Electric powered plants																						
1	1941	1,723 6/	30	9	90	75.20	1,000	379	70	12,280	153.50	7.00	15.80	7.67	18.00	201.97	172.30	374.27	2.88	3.8	.533	5.35
2	1912	2,400 6/	25	8	132	108.00	558	533	55	12,044	150.66	4.80	22.20	7.50	26.40	211.56	240.00	451.56	3.84	3.6	.396	8.21
3	1942	4,915	40	8	150	105.20	825	1,227	186	32,960	412.00	5.00	51.10	20.60	30.00	518.70	491.50	1,010.20	2.79	2.6	.423	5.43
4	1943	2,530	30	8	100	93.00	936	826	142	28,910	361.37	15.40	34.40	18.07	20.00	449.24	253.00	702.24	3.16	3.4	.544	4.94
5	1947	3,600	30	8	140	114.15	745	2,276	313	54,524	671.50	-	94.80	33.57	28.00	827.57	360.00	1,187.87	2.64	2.3	.363	3.79
6	1930	2,600	40	9	130	117.80	745	703	116	26,620	295.25	-	29.30	14.76	26.00	365.31	260.00	625.31	3.15	2.7	.519	5.39
7	1944	3,000	30	9	140	115.00	736	888	145	29,570	443.55	-	37.00	22.18	28.00	532.73	300.00	832.73	3.67	3.2	.599	5.74
8	1943	2,500	30	8	90	90.30	700	693	107	20,160	252.00	2.40	28.90	12.60	18.00	313.90	250.00	563.90	2.93	3.2	.452	5.27
9	1946	2,339	30	8	110	100.20	775	289	49	9,363	117.04	7.00	12.00	5.85	22.00	163.89	233.90	397.79	3.34	3.3	.567	8.4
11	1938	2,700	25	8	110	118.70	588	672	73	13,440	201.60	.10	28.00	10.08	22.00	261.78	270.00	531.78	3.58	3.0	.389	7.28
12	1942	3,600	30	8	120	118.00	575	672	71	17,024	255.36	.10	28.00	12.77	24.00	320.23	360.00	680.23	4.51	3.8	.476	9.58
13	1938	2,800	40	8	110	115.00	615	1,025	116	31,980	399.75	12.75	42.70	19.99	22.00	497.19	280.00	777.19	4.29	3.7	.485	6.70
14	1947	4,000	30	8	130	115.00	719	1,034	137	28,952	361.90	-	43.10	18.09	26.00	449.09	400.00	849.09	3.28	2.8	.434	6.18
16	1941	3,025	30	8	90	95.00	737	857	174	22,800	285.00	-	35.70	14.25	18.00	352.95	302.50	655.45	2.03	2.1	.412	3.77
17	1943	3,225	40	10	90	94.80	1,100	897	218	28,800	360.00	-	40.40	18.00	18.00	436.40	322.50	758.90	2.00	2.1	.486	3.48
18	1939	2,550	30	8	130	130.10	475	1,600	140	42,850	642.87	5.00	66.70	32.14	26.00	772.71	255.00	1,027.71	5.52	4.2	.483	7.34
19	1944	2,680	40	6	150	118.00	430	854	68	28,800	360.00	16.50	35.60	18.00	30.00	460.10	268.00	728.10	6.76	5.7	.538	10.70
20	1947	4,450	30	8	170	142.17	480	619	55	15,333	184.00	-	25.80	9.20	34.00	253.00	445.00	698.00	4.60	3.2	.408	12.69
22	1935	2,400	30	9	130	137.65	594	1,866	204	63,477	952.15	-	77.70	47.61	26.00	1,103.46	240.00	1,343.46	5.41	3.9	.591	6.58
24	1945	4,000	30	8	120	125.00	732	1,383	187	43,002	645.03	-	57.60	32.25	24.00	758.88	400.00	1,158.88	4.06	3.2	.548	6.20
25	1944	3,273	40	8	130	137.10	690	1,491	189	47,689	596.12	-	62.10	29.81	26.00	714.03	327.30	1,041.33	3.78	2.7	.479	5.51
26	1945	2,910	40	8	140	130.30	923	1,771	301	50,959	636.99	-	73.80	31.85	28.00	770.64	291.00	1,061.64	2.56	2.0	.435	3.53
27	1934	2,800	40	8	150	137.10	840	1,316	204	41,150	514.37	-	54.80	25.72	30.00	624.89	280.00	904.89	3.06	2.2	.474	4.44
28	1947	4,674	40	8	150	138.20	968	943	168	29,864	373.30	-	39.30	18.66	30.00	461.26	467.40	928.66	2.75	2.0	.489	5.53
29	1944	3,730	40	8	160	138.60	744	905	124	30,117	376.47	7.00	37.70	18.82	32.00	471.99	373.00	844.99	3.81	2.7	.521	6.81
30	1937	2,200	30	8	110	125.32	765	984	138	28,760	431.40	25.00	41.00	21.57	22.00	540.97	220.00	760.97	3.92	3.1	.549	5.51
31	1937	3,100	40	8	130	130.00	714	960	126	29,667	445.05	-	40.00	22.25	26.00	533.30	310.00	843.30	4.23	3.2	.555	6.69
32	1934	2,400	30	8	110	123.45	560	768	79	19,456	291.84	.10	32.00	14.59	22.00	360.53	240.00	600.53	4.56	3.7	.469	7.60
Automotive Type Engines																						
Natural gas fueled										cu.ft.												
34	1937	3,285	145	8	140	135.80	410	1,059	80	-	104.00	13.70	88.20	68.83	28.00	302.73	410.62	713.35	3.78	2.8	.286	8.91
35	1934	2,735	125	8	130	133.65	629	603	70	422,100	108.54	6.65	50.00	39.19	26.00	230.38	341.87	572.25	3.29	2.5	.382	8.17
36	1946	3,160	95	8	130	126.00	675	2,001	248	825,000	259.22	51.95	166.70	130.06	26.00	683.93	395.00	1,028.93	2.56	2.0	.317	4.15
37	1943	3,400	125	8	140	144.50	608	1,606	179	-	281.70	46.60	138.80	104.39	28.00	599.49	425.00	1,024.49	3.35	2.3	.373	5.72
38	1946	2,863	100	8	125	110.30	569	1,189	125	654,950	213.90	23.00	99.00	77.28	25.00	438.18	357.87	796.05	3.50	3.2	.368	6.37
39	1925	2,300	135	10	130	110.30	635	2,026	237	-	325.00	56.60	168.80	131.69	26.00	708.09	252.00	960.09	2.99	2.7	.349	4.05
40	1941	2,300	100	8	120	105.00	698	1,905	245	781,000	250.00	45.94	158.70	123.82	24.00	602.46	287.50	889.96	2.46	2.3	.316	3.63
41	1941	2,920	120	8	127	103.20	725	2,449	327	-	490.00	40.88	204.00	159.18	25.40	919.46	365.00	1,284.46	2.81	2.7	.375	3.93
42	1945	2,779	95	8	123	119.50	700	1,633	211	-	245.00	14.53	136.00	106.14	24.60	501.67	347.37	849.04	2.38	2.0	.307	4.02
Gasoline fueled										gallons												
43	1946	3,386	140	8	96	58.40	300	501	28	1,970	246.25	6.79	41.75	32.56	19.20	346.55	423.25	769.80	12.38	21.2	.692	27.49
44	1943	2,199	120	8	100	75.10	343	1,100	70	3,300	330.00	11.20	91.60	71.50	20.00	504.30	274.87	779.17	7.20	9.6	.458	11.13
45	1937	2,128	90	8	90	80.05	780	342	49	770	88.55	9.39	28.50	22.23	18.00	166.67	266.00	432.67	3.40	4.2	.487	8.83
46	1946	2,771	120	8	100	89.00	842	1,096	170	5,975	657.25	32.32	91.30	71.24	20.00	872.11	346.37	1,218.48	5.13	5.8	.796	7.16
47	1947	4,090	120	10	90	70.00	1,346	265	66	1,060	121.90	6.87	22.00	17.22	18.00	185.99	511.25	697.24	2.82	4.0	.701	10.56
48	1947	2,386	85	8	70	52.70	780	111	16	450	49.50	1.08	9.25	7.21	14.00	67.04	298.25	365.29	4.19	7.9	.604	22.83
49	1933	1,395 7/	95	8	60	60.00	650	318	38	730	80.30	3.98	26.50	20.67	12.00	143.45	250.00	393.45	3.76	6.1	.438	10.35
50	1945	3,432	100	8	100	78.70	671	627	77	2,320	255.20	7.83	52.20	40.75	20.00	375.98	429.00	804.98	4.88	6.2	.600	10.45
51	1947	2,922	100	8	100	77.40	513	545	51	2,125	233.75	12.08	45.40	35.42	20.00	346.65	365.22	711.87	6.80	8.8	.636	13.96
52	1937	2,045	90	8	70	66.00	650	426	51	917	96.29	6.05	35.50	27.69	14.00	179.53	255.62	435.15	3.52	5.3	.421	8.53
53	1943	2,098	85	8	70	62.50	930	255	44	835	100.20	10.48	21.25	16.57	14.00	162.50	262.25	424.75	3.69	5.9	.637	9.65
54	1947	2,501 7/	100	8	100	72.40	815	380	57	1,710	196.65	8.55	31.50	24.70	20.00	281.40	312.62	594.02	4.94	6.8	.740	10.42
55	1937	881	85	7	80	79.70	400	533	39	1,865	214.40	25.35	44.40	34.64	16.00	334.79	220.25	555.04	8.58	10.8	.628	14.23
56	1945	3,459	100	8	110	80.00	815	947	142	3,000	300.00	14.75	78.90	61.55	22.00	477.20	432.37	909.57	3.36	4.2	.503	6.40
57	1946	3,755	120	8	130	111.20	617	849	96	2,929	307.55	23.94	70.70	55.18	26.00	483.37	469.37	952.74	5.03	4.5	.569	9.92
58	1945	2,757	120	8	120	118.00	698	829	106	3,778	434.37	35.98	69.00	53.88	24.00	617.23	344.62	961.85	5.82	4.9	.744	9.07
59	1946	3,054	100	8	130	105.70	690	1,057	134	3,198	367.83	32.23	88.00	68.70	26.00	582.76	381.75	964.51	4.35	4.1	.551	7.19
60	1941	2,532	95	9	100	90.40	604	647	72	2,460	282.90	26.95	53.90	42.05	20.00	425.80	316.50	742.30	5.91	6.5	.658	10.30
61	1945	3,050	100	10	100	99.70	1,287	520	123	2,560	294.40	25.35	43.30	33.80	20.00	416.85	381.25	798.10	3.39	3.4	.800	6.48
62	1946	4,300	150	10	110	100.00	1,210	716	159	4,134	434.07	8.57	59.60	46.54	22.00	570.78	537.50	1,108.28	3.59	3.6	.797	6.97
63	1937	2,690	115	8	110	85.00	750	627	86	2,160	270.00	32.24	52.20	40.75	22.00	417.19	336.25	753.44	4.85	5.7	.665	8.76
64	1943	3,677	95	8	120	102.70	554	876	89	3,066	321.93	10.68	73.00	56.94	24.00	486.55	459.62	946.17	5.47	5.3	.555	10.63
65	1944	2,880	100	8	135	119.20	518	1,588	151	6,059	636.20	22.08	132.30	103.22	27.00	920.80	360 00	1,280.80	6.09	5.1	.597	8.48
66	1944	2,814	110	8	120	125.00	495	932	85	6,260	688.60	11.20	77.60	60.58	20.00	857.98	351.75	1,209.73	10.09	8.1	.920	14.23
67	1946	3,450	155	8	170	177.20	800	537	80	3,060	351.90	7.88	44.75	34.90	34.00	473.43	431.25	904.68	5.91	3.3	.881	11.30
68	1945	2,860	100	8-5/8	130	137.20	279	931	48	3,379	388.59	19.38	77.50	60.51	26.00	571.98	357.50	929 48	11.91	8.7	.614	19.36
70	1938	-	85	6	90	86.70	522	612	58	2,400	252.00	6.70	51.00	39.78	18.00	367.48	-	-	6.33	7.3	.600	-
71	1947	2,381	100	8	130	80.25	350	435	28	1,400	168.09	4.38	36.25	28.27	26.00	262.90	297.62	560.52	9.38	11.7	.604	20.02
Butane fueled																						
72	1945	3,670	125	8	120	112.20	850	1,669	261	9,444	850.00	50.10	139.00	108.48	24.00	1,171.58	458.75	1,630.33	4.48	4.0	.702	6.25
73	1945	4,633	145	8	140	137.50	800	1,343	198	6,465	536.81	55.67	111.90	87.29	28.00	819.67	579.12	1,398.79	4.14	3.0	.610	7.06
74	1947	6,093	120	8	170	144.45	873	439	70	2,850	228.00	29.40	73.20	28.53	34.00	393.13	761.62	1,154.75	5.61	3.9	.895	16.49
75	1945	3,877	125	8	155	109.40	729	369	49	1,556	125.28	28.00	30.75	23.98	31.00	239.01	484.62	723.63	4.87	4.4	.647	14.76
76	1946	4,245	160	8	168	150.50	840	328	51	1,640	150.00	8.58	27.33	21.32	33.60	240.83	530.62	771.45	4.72	3.1	.734	15.12
77	1945	2,505	80	8	70	63.40	706	233	30	1,165	104.85	3.35	19.40	15.14	14.00	156.74	313.12	469.86	5.22	8.2	.672	15.66
79	1937	2,778	100	8	120	83.90	625	1,537	177	5,950	535.50	30.04	128.00	99.90	24.00	817.44	347.25	1,164.69	4.62	5.5	.532	6.58
80	1944	3,095	100	8	94	66.20	639	1,172	138	3,510	303.97	13.80	97.70	76.18	18.80	510.45	386.87	897.32	3.69	5.6	.436	6.50
81	1940	1,982	95	9	100	86.50	886	663	108	2,150	172.00	7.28	55.20	43.09	20.00	297.57	247.75	545.32	2.75	3.2	.448	5.05
82	1941	1,881	85	8	90	66.03	703	648	88	1,700	136.00	7.35	54.00	42.12	18.00	257.44	235.12	492.59	3.06	4.6	.397	5.86
83	1944	2,000	85	8	90	75.57	756	707	98	2,600	208.00	8.15	58.90	45.95	18.00	339.00	250.00	589.00	3.45	4.6	.479	6.01
84	1936	2,698	100	8	90	89.40	623	1,138	131	4,825	397.50	25.05	94.80	73.97	18.00	609.32	337.25	946.57	4.65	5.2	.535	7.22
85	1940	2,653	85	10	84	75.00	742	649	87	2,271	181.68	19.18	54.00	42.18	16.80	313.84	331.62	645.46	3.60	4.8	.483	7.42
86	1944	1,932	85	8	90	75.00	725	917	122	3,192	255.36	26.28	76.40	59.60	18.00	436.04	341.50	677.54	3.57	4.8	.475	5.55
87	1942	2,745	120	8	100	68.36	963	570	101	2,760	220.80	15.90	47.50	37.05	20.00	341.25	363.12	704.37	3.38	4.9	.599	6.77
88	1947	2,978	100	8	100	88.15	697	800	103	2,662	213.20	11.88	66.70	52.00	20.00	363.78	372.25	736.03	3.53	4.0	.455	7.14
89	1940	2,192	100	8	90	83.69	644	873	103	3,845	319.20	20.16	72.75	56.74	18.00	486.85	274.00	760.85	4.74	5.6	.557	7.39
90	1935	3,084	100	8	90	69.68	783	1,450	210	8,811	726.91	40.83	120.80	94.25	18.00	1,000.79	385.50	1,382.29	4.76	6.8	.690	6.58
91	1945	3,128	100	8	110	82.17	815	945	142	3,598	287.84	31.35	78.75	61.42	22.00	481.36	391.00	872.36	3.39	4.1	.509	6.14
92	1939	2,410	85	8	90	89.80	729	854	115	4,112	345.32	31.38	71.20	55.51	18.00	521.41	301.25	822.66	4.53	5.0	.610	7.15

APPENDIX A

PUMPING COST DATA, TEXAS HIGH PLAINS, 1947 OPERATING SEASON

Well No.	Year of completion 1/ (year)	Cost of plant 1/ 2/ ($)	Rating of power unit 1/ (horsepower)	Size of pump 1/ column (inches)	Pump setting 1/ (feet)	Pumping lift 3/ (feet)	Well yield 3/ (gpm)	Hours of plant 1/ operation (number)	Acre feet pumped 4/ (number)	Fuel or energy 1/: Units (Total used) gallons	Fuel or energy 1/: Cost (Total) ($)	Cost of lubricant 1/ (Total) ($)	Attendance cost 5/ (Total) ($)	Cost of maintenance 5/: Power Unit & Pump (Total) 4/ ($)	Cost of maintenance 5/: Well (Total) 4/ ($)	Total operating 4/ costs ($)	Total overhead 4/ costs ($)	Total cost of 4/ pumping ($)	Operating costs, per 4/: Acre foot pumped ($)	Operating costs, per 4/: Acre foot foot (cents)	Operating costs, per 4/: Hour of operation ($)	Total cost per 4/ acre-foot pumped ($)
Butane fueled																						
93	1940	1,900	100	8	90	86.50	770	507	72	2,130	170.40	7.58	42.25	32.95	18.00	271.18	237.50	508.68	3.76	4.3	.534	7.06
94	1943	2,529	125	8	110	70.80	750	626	86	2,446	195.68	22.76	52.20	40.69	22.00	333.33	316.12	649.45	3.87	5.5	.532	7.55
95	1937	2,100	85	8	84	83.50	544	360	36	1,260	107.10	5.72	30.00	23.40	16.80	183.02	262.50	445.52	5.08	6.1	.508	12.37
96	1944	3,392	120	8	100	83.30	405	465	35	2,589	207.12	15.46	38.75	30.22	20.00	311.55	424.00	735.55	8.90	10.7	.670	21.01
97	1945	3,108	85	8	80	71.60	527	1,320	128	4,620	392.70	9.80	110.00	85.80	16.00	614.30	388.50	1,002.80	4.79	6.7	.465	7.83
98	1946	3,708	95	8	120	76.00	833	376	58	1,558	125.13	9.14	31.30	24.44	24.00	214.01	463.50	677.51	3.68	4.8	.569	11.68
99	1946	3,550	125	10	114	85.80	897	834	138	4,587	366.96	24.30	69.50	54.21	22.80	537.77	443.75	981.52	3.90	4.5	.644	7.11
100	1946	4,300	120	8	110	87.80	846	1,270	198	3,900	312.00	17.74	105.80	82.55	22.00	540.09	537.50	1,077.59	2.73	3.1	.425	5.44
101	1935	1,925	90	8	90	99.00	713	608	80	2,700	216.00	12.07	50.60	39.52	18.00	336.19	240.62	576.81	4.18	4.2	.549	7.18
102	1947	3,432	100	8	104	91.40	410	1,142	86	3,990	345.53	13.80	95.10	74.23	20.80	549.46	429.00	978.46	6.38	7.0	.482	11.38
103	1944	3,200	100	8	140	108.90	522	1,488	143	5,343	427.44	41.72	124.00	96.72	28.00	717.88	400.00	1,117.88	5.02	4.6	.482	7.81
104	1943	2,781	100	10	130	102.60	567	622	65	3,130	266.05	19.80	51.80	40.43	26.00	404.08	347.62	751.70	6.21	6.0	.649	11.56
105	1941	3,686	95	8	120	111.10	531	675	66	2,610	208.80	31.30	56.20	43.87	24.00	364.17	460.75	824.92	5.52	5.9	.539	12.49
106	1945	4,834	95	8	160	116.30	328	797	48	3,990	358.10	13.94	66.40	51.80	32.00	522.24	604.25	1,126.49	10.88	9.3	.655	23.47
107	1944	3,451	140	8	135	114.00	925	2,025	344	10,900	885.60	49.41	168.70	131.62	27.00	1,262.33	431.37	1,693.70	3.66	3.2	.623	4.92
108	1938	3,000	85	8	120	115.00	621	758	87	2,510	225.90	12.78	63.10	49.27	24.00	375.05	375.00	750.05	4.31	3.7	.494	8.62
109	1945	3,440	120	8	155	107.20	623	959	110	4,003	320.24	29.85	79.90	62.33	31.00	523.32	430.00	953.32	4.76	4.4	.545	8.67
110	1944	4,450	110	8	130	103.20	590	805	87	5,420	474.40	21.09	67.00	52.32	26.00	640.81	556.25	1,197.06	7.36	7.1	.796	13.75
111	1941	3,962	187	9	120	104.42	580	764	82	4,450	378.25	14.74	63.60	49.66	24.00	530.25	495.25	1,025.50	6.46	6.2	.694	12.50
112	1941	3,733	90	8	120	112.10	666	1,601	196	8,305	664.40	43.00	133.40	104.06	24.00	968.86	466.62	1,435.38	4.94	4.4	.605	7.32
113	1945	5,275	90	8	120	110.10	581	1,633	174	7,010	560.80	29.67	135.50	106.14	24.00	856.11	659.37	1,515.48	4.92	4.4	.524	8.70
114	1943	2,847	100	8	120	97.15	558	1,100	113	5,310	443.38	6.70	91.60	71.50	24.00	637.18	355.87	993.05	5.64	5.8	.579	8.79
115	1944	3,059	120	8	120	107.90	671	682	84	3,015	251.75	5.90	56.80	44.33	24.00	382.78	382.37	765.15	4.56	4.2	.561	9.10
116	1947	4,066	125	8	120	93.17	834	863	132	3,334	405.26	20.10	71.90	56.09	24.00	577.35	508.25	1,085.60	4.37	4.7	.669	8.22
117	1937	3,244	140	8	120	108.85	780	943	135	5,395	445.00	62.70	78.50	61.29	24.00	671.49	405.50	1,076.99	4.97	4.6	.712	7.97
118	1945	3,200	120	8	120	113.60	855	2,255	289	9,545	835.22	27.70	187.90	146.57	24.00	1,221.39	400.00	1,621.39	4.23	3.7	.542	5.61
119	1946	3,600	120	8	120	109.00	698	1,470	232	4,874	426.54	17.75	122.50	95.55	24.00	686.34	450.00	1,136.34	2.96	2.7	.466	4.89
120	1945	3,154	120	8	120	103.00	900	1,705	283	7,370	600.00	100.80	142.00	110.82	24.00	977.62	394.25	1,371.87	3.45	3.3	.573	4.84
121	1944	3,344	100	8	130	110.30	886	1,053	172	4,920	393.60	6.60	87.70	68.44	26.00	582.34	418.00	1,000.34	3.38	3.1	.553	5.81
122	1946	5,083	165	8	140	119.16	924	1,448	245	6,516	521.28	45.75	120.60	94.12	28.00	809.75	635.37	1,445.12	3.31	2.8	.559	5.89
123	1937	3,180	145	8	156	108.55	530	287	28	1,108	96.28	9.67	23.90	18.65	31.20	179.70	397.50	577.20	6.42	5.9	.626	20.61
124	1945	3,522	125	8	130	115.30	850	1,216	191	4,109	328.72	24.20	101.00	79.04	26.00	558.96	440.25	999.21	2.93	2.5	.460	5.23
125	1941	3,843	142	9	160	115.00	536	1,000	98	5,696	495.55	15.40	83.30	65.00	32.00	691.75	480.37	1,172.12	7.06	6.1	.692	11.96
126	1946	3,200	90	8	96	93.90	797	634	93	2,030	172.55	9.32	52.80	41.21	19.20	295.08	400.00	695.08	3.17	3.4	.465	7.47
127	1935	2,576	85	8	110	95.00	575	499	53	1,831	154.73	12.35	41.50	32.43	22.00	263.01	322.00	585.01	4.96	5.2	.527	11.04
128	1947	2,375	115	8	120	93.90	797	386	56	1,800	144.00	9.35	32.00	25.09	24.00	234.44	356.25	590.69	4.18	4.4	.607	10.54
129	1943	2,909	93	8	120	110.40	635	684	80	2,736	218.88	9.94	57.00	44.46	24.00	354.28	363.62	717.90	4.82	4.0	.518	8.97
130	1945	3,200	90	8	120	107.20	729	965	130	3,460	276.80	14.80	80.40	62.72	24.00	458.72	400.00	858.72	3.53	3.3	.475	6.60
131	1937	2,805	85	8	110	105.55	770	894	127	4,150	332.00	24.74	74.50	58.11	22.00	511.35	350.62	861.97	4.03	3.8	.571	6.78
132	1944	3,302	120	8	130	110.30	780	1,838	263	8,478	720.63	32.83	153.20	119.47	26.00	1,052.13	412.75	1,464.88	4.00	3.6	.572	5.56
133	1945	3,270	140	8	120	119.00	774	300	42	2,322	185.76	5.49	16.60	13.00	24.00	244.85	408.75	653.60	5.82	4.9	.816	15.56
134	1946	4,116	140	8	160	107.50	925	1,228	209	7,368	626.28	17.88	120.20	79.82	32.00	876.18	514.50	1,390.68	4.19	3.9	.713	6.65
135	1947	5,590	165	10	180	113.10	1,060	964	188	8,435	716.98	15.72	80.30	62.66	36.00	911.66	698.75	1,610.41	4.84	4.3	.945	8.56
136	1941	2,910	95	8	140	115.90	500	946	87	4,730	402.05	20.76	78.80	61.49	28.00	591.10	363.75	954.85	6.79	5.8	.624	10.97
137	1945	4,040 7/	125	8	140	94.50	1,134	1,335	278	6,675	534.00	22.46	111.20	86.77	28.00	782.43	505.00	1,287.43	2.81	3.0	.586	4.63
138	1922	2,700 7/	125	10	90	95.00	1,180	1,507	328	8,288	683.76	46.75	125.50	97.95	18.00	971.96	337.50	1,309.46	2.96	3.1	.644	3.99
139	1941	2,613	95	8	108	118.20	675	1,078	134	4,317	461.72	28.89	89.80	70.07	21.60	672.08	362.62	1,034.70	5.01	4.2	.623	7.72
140	1946	3,635	120	9	120	105.00	797	1,250	183	6,880	581.36	24.15	104.00	81.25	24.00	814.76	454.37	1,269.13	4.45	4.2	.652	6.93
141	1939	2,600	100	8	120	108.68	960	514	91	2,376	190.08	22.69	42.80	33.41	24.00	312.98	325.00	637.98	3.43	3.2	.608	7.01
142	1944	4,000	110	10	100	110.60	864	846	135	5,720	462.25	9.28	70.50	54.99	20.00	617.02	500.00	1,117.02	4.57	4.1	.729	8.27
143	1947	5,679	145	10	130	115.50	1,130	1,250	260	9,896	841.16	19.82	104.00	81.25	26.00	1,072.23	709.87	1,782.10	4.12	3.6	.858	6.85
144	1937	2,585	100	10	120	99.00	734	959	130	6,122	520.37	63.15	80.00	62.33	24.00	749.85	323.12	1,072.97	5.76	5.8	.781	8.25
145	1946	3,513	125	8	130	120.00	910	1,233	210	7,680	672.00	16.81	102.50	80.14	26.00	897.45	439.12	1,336.57	4.27	3.5	.728	6.36
146	1946	4,984	140	8	175	120.00	550	798	80	4,050	303.75	12.73	66.50	51.87	35.00	469.85	623.00	1,092.85	5.87	4.9	.588	13.66
147	1944	4,896	140	8	200	123.30	250	992	45	4,375	390.00	21.45	82.60	69.48	40.00	598.53	612.00	1,210.53	13.30	10.8	.603	27.00
148	1945	3,500	120	8	120	123.50	975	958	172	6,466	517.28	16.80	79.80	62.27	24.00	700.15	437.50	1,137.65	4.07	3.3	.730	6.61
149	1945	4,616	160	8	140	128.67	833	932	143	5,450	436.60	30.75	77.60	60.58	28.00	633.53	577.00	1,210.53	4.43	3.4	.679	8.46
150	1946	4,479	120	8	150	149.50	700	785	101	3,390	271.20	19.29	65.40	51.02	30.00	436.91	559.87	996.78	4.32	2.9	.556	8.69
151	1941	2,810	143	8	150	123.44	554	1,832	186	10,535	895.48	58.52	152.60	119.08	30.00	1,255.68	351.25	1,606.93	6.75	5.5	.685	8.63
152	1946	4,140	143	8	150	142.30	572	2,115	222	12,160	1,033.60	68.30	176.25	137.47	30.00	1,445.62	517.50	1,963.12	6.51	4.6	.683	8.84
153	1945	3,875	100	8	160	149.00	423	695	54	3,440	271.20	7.20	57.90	45.17	32.00	413.47	484.37	897.84	7.65	5.1	.594	16.62
154	1944	4,067	120	8	140	125.00	500	1,056	97	4,855	388.40	16.99	88.00	68.64	28.00	590.03	508.37	1,098.40	6.08	4.9	.558	11.32
155	1944	3,750	135	8	144	120.00	693	1,301	166	5,460	493.92	22.45	108.40	84.56	28.80	738.13	468.75	1,206.88	4.44	3.7	.567	7.27
156	1946	4,150	125	8	144	131.20	800	1,393	220	7,680	653.00	33.80	124.41	97.04	28.80	937.05	518.75	1,455.80	4.25	3.2	.627	6.61
157	1947	5,555	120	8	180	154.78	708	465	61	1,800	145.54	15.08	38.75	30.22	36.00	265.59	694.37	959.96	4.35	2.8	.571	15.74
158	1946	4,716	140	8	160	175.00	750	476	66	2,140	219.25	15.18	39.70	30.94	32.00	337.07	589.50	926.57	5.11	2.9	.708	14.04
159	1947	4,188	143	8	150	159.00	870	660	105	3,300	280.50	11.34	55.00	42.90	30.00	419.74	523.50	943.24	4.00	2.5	.635	8.98
160	1946	3,537	115	8	150	129.00	750	839	116	3,286	279.31	9.98	69.90	54.53	30.00	443.52	442.12	885.64	3.82	3.0	.528	7.63
161	1944	2,978	120	8	120	121.50	522	1,814	174	8,643	734.66	31.86	151.10	117.91	24.00	1,059.53	372.25	1,431.78	6.08	5.0	.584	8.22
Industrial Type Engines																						
Gasoline fueled																						
162	1944	2,700	55	8	130	120.78	700	999	129	6,000	720.00	46.30	83.25	32.47	26.00	908.02	337.50	1,245.52	7.03	5.8	.908	9.65
163	1943	2,582	50	8	70	78.35	284	300	16	640	70.40	4.40	25.00	9.75	14.00	123.55	322.75	446.30	7.72	9.8	.411	27.89
164	1946	2,551	50	8	68	44.10	775	506	72	1,538	169.18	9.62	42.10	16.44	13.60	250.94	318.87	569.81	3.48	7.9	.495	7.91
Butane fueled																						
165	1946	3,910	68	8	140	80.00	575	1,216	129	5,800	522.00	23.80	101.30	39.52	28.00	714.62	488.75	1,203.37	5.53	6.9	.587	9.32
166	1944	3,749	75	10	90	85.00	900	1,017	169	5,895	495.20	24.16	84.75	33.05	18.00	655.16	468.62	1,123.78	3.88	4.5	.644	6.64
167	1945	4,704	94	8	120	94.80	650	1,968	236	10,825	909.30	77.90	164.00	63.96	24.00	1,239.16	588.01	1,827.17	5.25	5.5	.630	7.74
168	1946	5,000	100	8	120	110.95	800	276	41	830	78.52	5.79	23.00	8.97	24.00	140.28	625.00	765.28	3.42	3.1	.508	18.66
169	1937	2,527	63	8	130	105.65	1,000	338	62	1,352	108.16	28.12	28.10	10.98	26.00	201.36	315.87	517.23	3.25	3.1	.595	8.34
170	1946	4,046	55	8	140	112.40	1,100	168	34	1,300	117.00	9.94	19.00	5.46	28.00	174.40	505.75	680.15	5.13	4.6	1.038	20.00
171	1936	3,370	50	8	130	135.30	572	1,474	155	5,095	433.08	46.50	122.80	47.90	26.00	676.28	421.25	1,097.53	4.36	3.2	.459	7.08
172	1946	4,264	90	8	150	150.00	775	734	105	3,670	313.95	18.54	61.20	23.85	30.00	386.34	533.00	919.34	3.67	2.4	.526	8.75
173	1946	3,530	55	8	130	104.50	875	313	50	1,040	83.20	8.76	26.08	10.17	26.00	154.21	441.25	595.46	3.08	2.9	.492	11.91
174	1943	4,740	92	10	120	115.00	1,350	1,230	305	7,450	633.25	36.45	102.50	79.95	24.00	876.15	592.50	1,468.65	2.87	2.5	.712	4.81
Diesel engines																						
175	1937	6,840	115	8	220	172.80	700	1,770	229	7,080	672.60	48.60	147.50	134.52	44.00	1,047.22	855.00	1,902.22	4.57	2.6	.591	8.30
176	1939	7,600	118	10	230	225.00	730	1,068	143	5,073	481.94	28.40	89.00	96.38	46.00	741.72	950.00	1,691.72	5.19	2.3	.694	11.83
177	1947	10,103	118	10	240	226.00	775	1,068	152	5,073	481.94	28.40	89.00	96.38	48.00	743.71	1,262.87	2,006.58	4.89	2.2	.696	13.20
178	1930	3,685	50	9	100	93.70	845	328	51	968	87.12	10.10	27.30	34.84	20.00	179.36	460.62	639.98	3.51	3.7	.546	12.54
179	1934	3,850	50	8	100	95.00	732	1,497	202	4,435	399.15	29.00	124.70	159.66	20.00	632.51	481.25	1,213.76	3.62	3.8	.489	6.00

1/ Reported by cooperating operators. 2/ Initial cost of well, power unit, pump and appurtenances unless otherwise specified. Where original power unit has been replaced, this cost represents the undepreciated initial cost of the complete original plant minus cost of original power unit plus cost of replacement power unit. 3/ Measured during course of study, August 1947. 4/ Calculated. 5/ See text for method of calculation. 6/ Cost of power unit, pump and appurtenances only. 7/ Second hand equipment.