Research Report No.,79

An Analysis of Private Tubewell Costs

by

Edwin H. Clark II and Mohammad Ghaffar

March 1969

Pakistan Institute of Development Economics
Old Sind Assembly Building
Bunder Road,
Karachi-1
Pakistan

Mr. Edwin H. Clark II is associated with Williams College, Williamstown, Mass., USA and was formerly a Research Associate at the Pakistan Institute of Development Economics.

Mr. Mohammad Ghaffar is a Research Assistant at the Pakistan Institute of Development Economics.

AN ANALYSIS OF PRIVATE TUBEWELL COSTS

by

Edwin H. Clark, II

Mohammad Ghaffar

INTRODUCTION

The growth in private tubewell installations in the Punjab has come to be recognized as one of the more significant developments to have occurred in a "traditional" agricultural economy. It has been a completely indigenous and primarily private development. Although the first private tubewells were being installed at least 30 years ago it was not until about 1955 that most of the Bari and Upper Rechna Doabs reached an average tubewell concentration of one tubewell per 20,000 acres, that the development began to "take off" [1/]. At the present time there are probably at least 60,000 of these tubewells in operation[2/].

Few people appreciated how significant this growth was until Ghulam Mohammad published his classic article in 1965 /̅17_/. Since then it has become a subject of a great interest to many economists concerned with questions of

---

[1/] The history of the development will be presented in more detail in a forthcoming monograph to be published by the PIDE. The statistical details of the growth since 1945 are available in /̅7,8_/.

[2/] The fourth survey of private tubewells conducted during the third quarter of 1967 showed 51,400 tubewells in operation and an installation rate of about 10,000 tubewells per year. See /̅7_/.

agricultural development and the ability of the developing countries like Pakistan to develop indigenous technology for growth. It has also, of course, become a central point in the discussions of how West Pakistan can most efficiently develop her limited water resources to expand agricultural production.

In spite of this interest and in spite of the several analyses of private tubewells which have been undertaken since 1965, there has been no comprehensive study of the development since Ghulam Mohammad wrote his original paper. The Agricultural Section of the Pakistan Institute of Development Economics (PIDE) is presently in the process of making such a study. In this paper we present some of our results pertaining to private tubewell costs. In this study we have used published and unpublished data from studies conducted by other organizations as well as reprocessing several of our own surveys.3/

The paper is organized into four sections followed by a short conclusion. Section II includes a general description of a tubewell and then investigates how the design varies between regions, and what is known about such factors as discharge and efficiency. In Section III we consider the costs - investment, operation and maintenance -- of the tubewells to the country, adjusting prices to take account

---

3/ See the bibliography at the end of the paper for a complete list of sources.

of such factors as the use of foreign exchange and labour and the incidence of taxes and subsidies. In Section V we discuss the conclusions of the first three sections, investigate how the costs have been changing over time, and consider various means by which the economic and technical efficiency of the tubewells might be improved.

II. THE PRIVATE TUBEWELL

The term 'tubewell' is used in Pakistan to distinguish the type of well in which the water is lifted from the groundwater aquifer through pipe or tube to the surface by a mechanically operated centrifugal or turbine pump. As with any such well the tube is composed of two parts - blind pipe and strainer. The blind pipe, which is mild steel pipe with solid walls, is fitted in that part of the well running from the ground surface down to the groundwater aquifer. The strainer, a pipe which allows the water to seep into it while holding back the soil, is fitted in the remainder of the well where it passes through sand or gravel aquifers.

In most of the private tubewells the water is lifted by a centrifugal pump which is placed at the bottom of a pit as close to the watertable as possible. For the tubewells operated by electric motors, the motor is coupled directly with the pump at the bottom of the pit; and for those operated by diesel engines, the engine is at the ground surface and the pump is driven via a long belt.

Tubewell Components

The sizes of the various tubewell components will depend upon the quantity of water pumped, the overall efficiency of the well, the depth to the groundwater table, and the permeability of the groundwater aquifer. In Table I we show how the sizes and dimensions vary among eight major tubewell districts in the Punjab.

The changes in the depth to groundwater are indicated by the variations in the average depth of the pit - from almost nothing in Gujranwala down to 25 feet or more in Sahiwal and Multan. Similarly, the average depth of the tubewell (depth of bore) varies from about 90 feet in Gujrat and Sialkot to 188 feet in Sahiwal. The average length of blind pipe varies from about 40 feet to almost 100 feet, and the average length of strainer from 44 feet to over 100 feet in the same areas.

The motors and engines in Sahiwal and Multan are also somewhat larger on the average than those in the Gujranwala area because of the higher lifts required in these more southern districts. In all districts the average size of the motors - supposedly because of the less efficient driving mechanism of the engine. The most common diameters of the tubewell (this is the diameter of the blind pipe) are 5 inches and 6 inches. Smaller diameters may be used on smaller farms when there is no plan to sell surplus water, and bigger diameters may be used on farms greater than 100 acres.

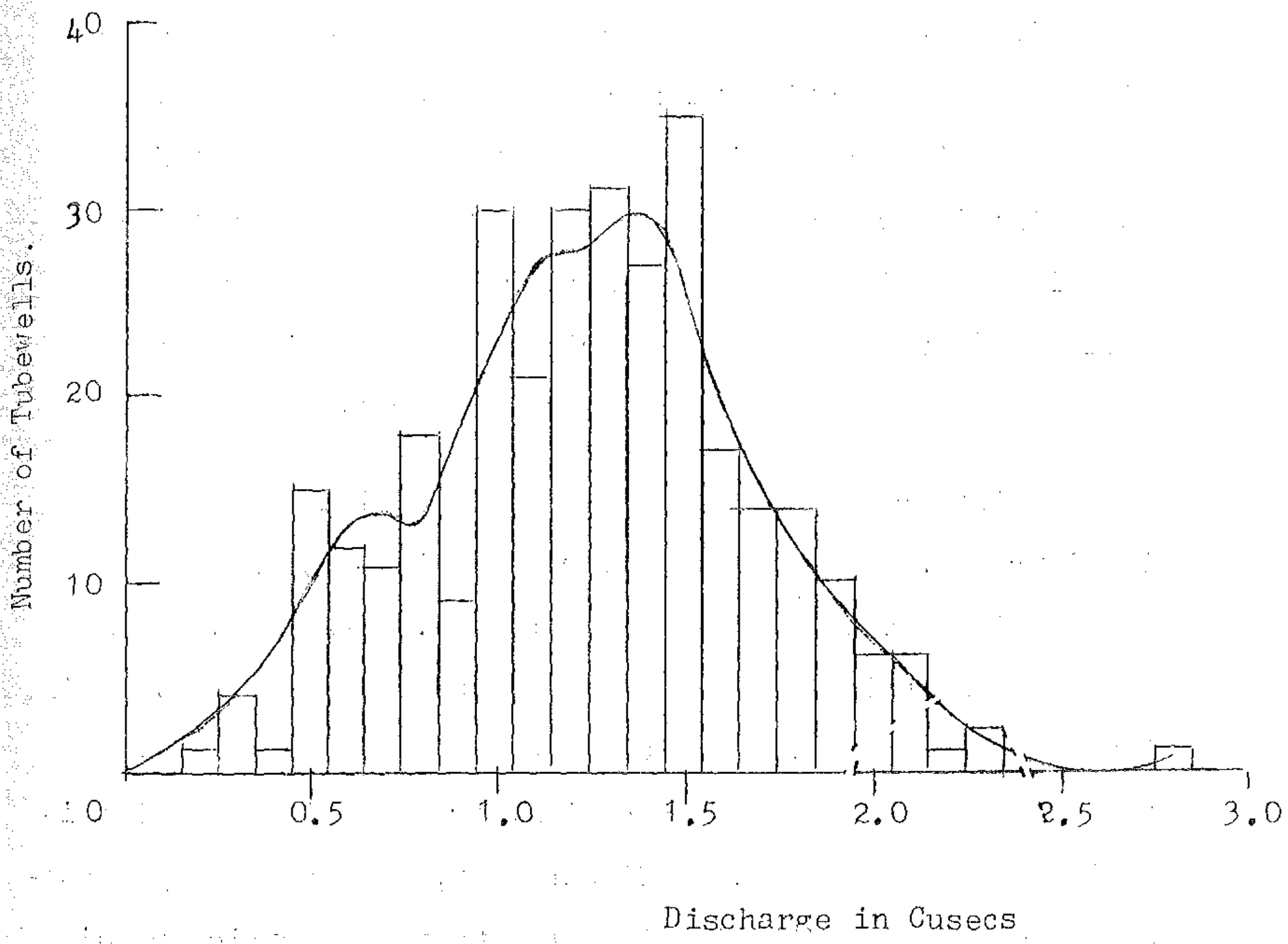
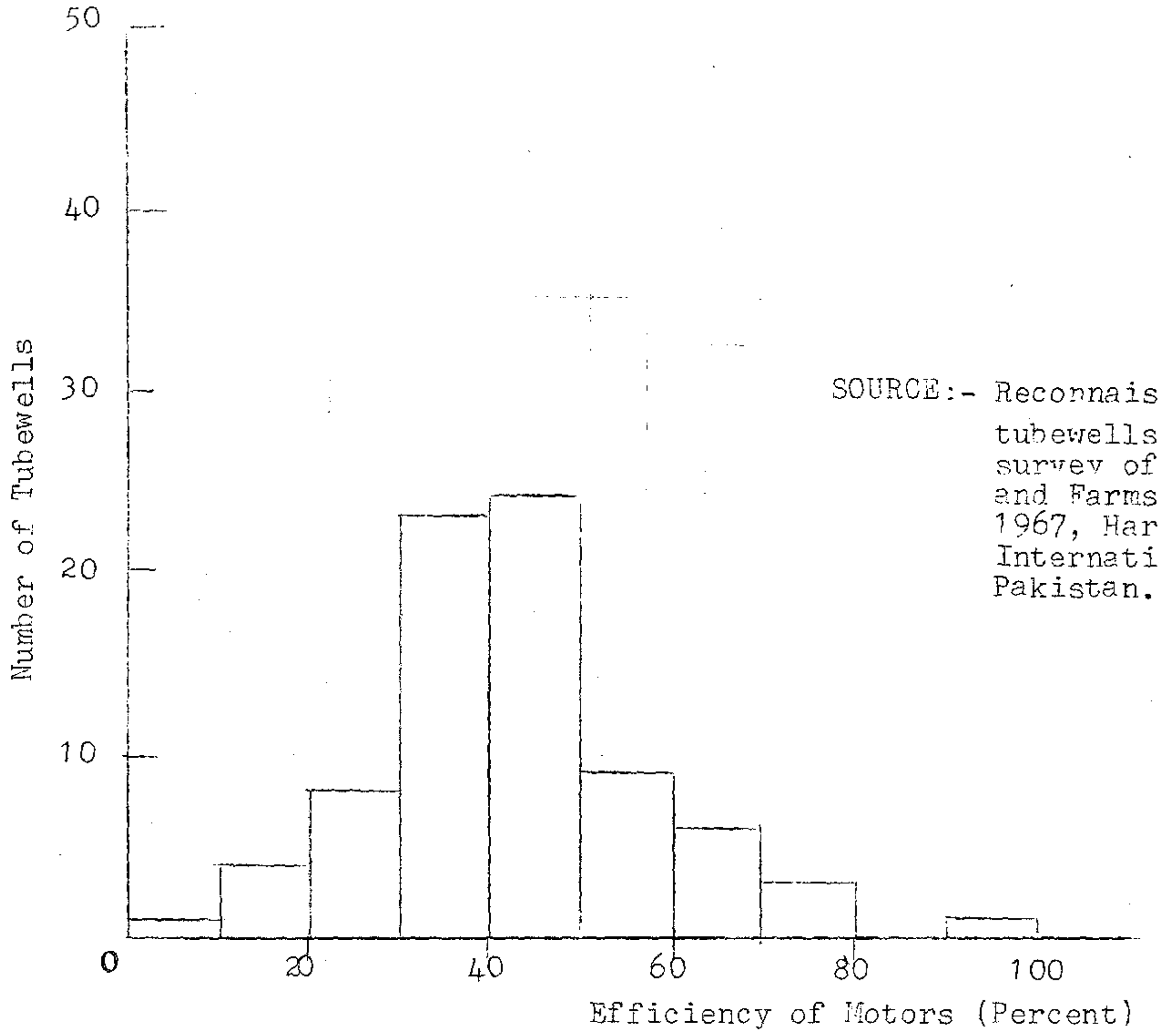


FIGURE:- 1, showing Discharge variations and Number of Tubewells.

it is computed by dividing the work output of the pump by the power consumption. For diesel engines it is computed by dividing the work output of the pump by the rate of diesel oil consumption times the energy content per unit of diesel oil. The efficiency computed for the electric tubewells is probably more accurate than that computed for the diesel engines since the measurements of the rate of fuel consumption cannot be precise, and there is no way of knowing whether the fuel has been adulterated or not.

Histograms showing the computed efficiencies are given in Figures 2.A and 2.B. The overall efficiency of diesel engines is much less, averaging about 9.5 per cent, than that for electric motors, averaging about 44 per cent. It is interesting to note, however, that if the efficiency of the combined electrical generation, transmission and distribution system is as low as 21 per cent, from an energy standpoint the overall efficiencies of both the electric and diesel systems would be the same (neglecting the energy required to transport the diesel oil to the tubewell). The heat rates of various thermal generating stations which are already in operation or are proposed for various locations in West Pakistan vary from 10,000 Btu/net kwh to over 24,000 Btu/net kwh /‾29,pp.29-30_7. The median value is about 12,000 Btu/ net kwh. This is equivalent to a generating efficiency of 29 per cent. Distribution losses are expected to be reduced to about 17.5 per cent by 1975 /‾27, p. 44_7. Thus, the overall



SOURCE:- Reconnaissance of private tubewells 1965 and a simple survey of private tubewells and Farms Gujranwala area 1967, Harza Engineering Co. International, Lahore West Pakistan.

Figure 2-A Electric Motor efficiency.

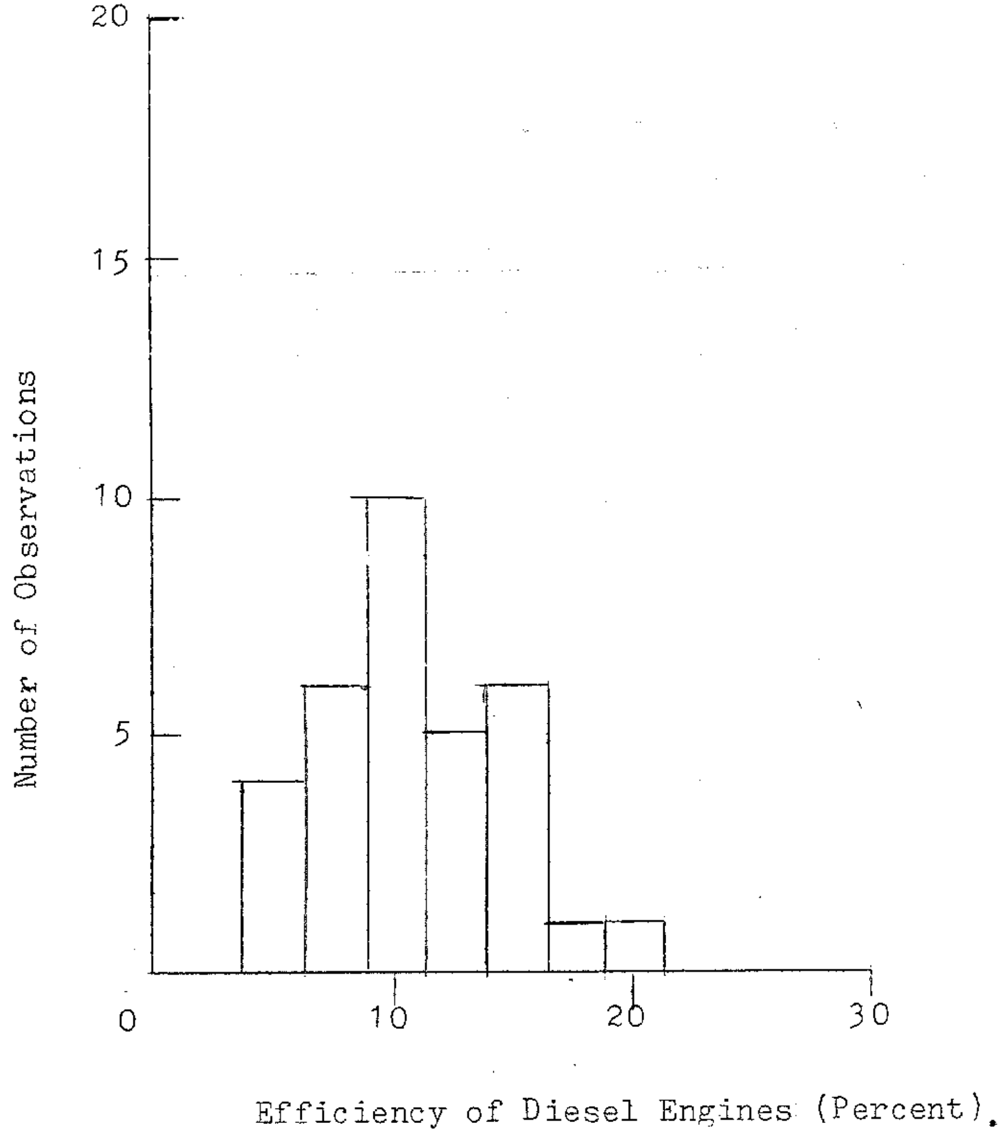


FIGURE:- 2-B Diesel Engine Efficiency.

system efficiency of the electric tubewell about 10.5 per cent - almost the same as that for the diesel-engine tubewells excluding the transportation of diesel fuel.

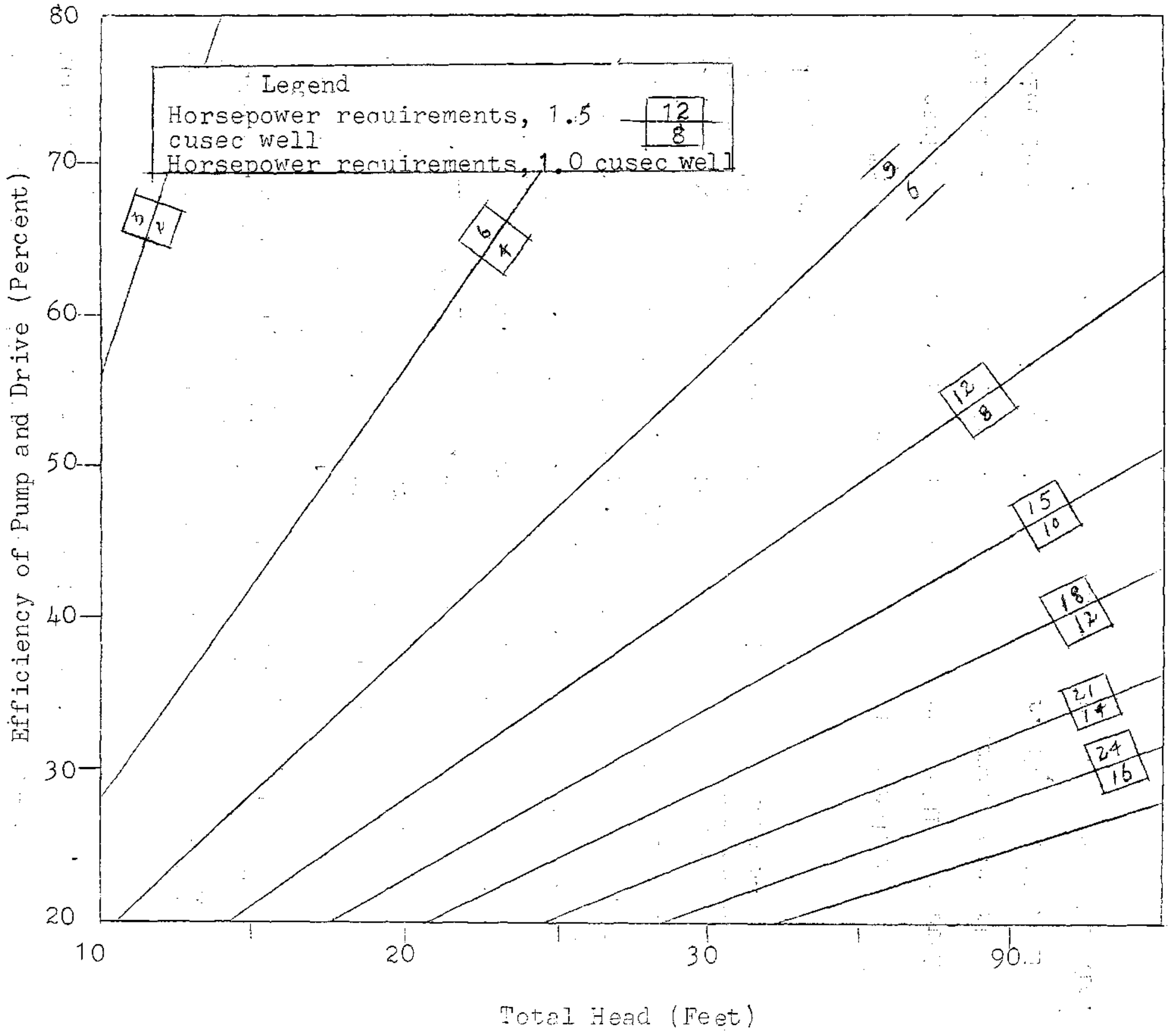
One reason that both diesel and electric tubewells are inefficient is that the engines and motors seem to be substantially over sized. Figure 3 shows the horsepower required to lift 1.0 cusecs and 1.5 cusecs at various heads and pump efficiencies. In Gujranwala the average total head is about 31 feet (including drawdown, velocity head, pipe losses, etc.) [9]. The pumps are probably about 50 to 60 per cent efficient. The average discharge of these wells was measured at 1.31 cusecs. Therefore, a rated horsepower of 8.4 H.P. should be adequate. In fact, the average horsepower of the motors is 14.1 H.P. and of the engines is 17.1 H.P. We must conclude that either the rated horsepowers are grossly inaccurate or the pumps and engines are substantially oversized.

There may be good reasons for using an oversized electrical motor. Motors are designed to operate with a certain voltage - usually 440 volts - and to draw a certain current which is a function of the size of the motor. The relationship is most simply expressed by the standard direct current formula.

$$P = IV$$

where P is power, I is current, V is voltage.

Theoretical Power Requirements



If the voltage falls below the designed level, the motor will have to draw more current to produce the same power. If the voltage drops to 70 per cent of its designed value, the current will have to increase by slightly over 40 per cent to compensate. If the motors were designed for the power output actually being used, this current overload would probably burn them out. As protection against this, motors designed for the larger current and thus a higher horsepower output are used. This same reasoning, however, does not apply to diesel engines. It is not clear why these should be as oversized as they appear to be.

III. The Cost of Private Tubewells to the Farmer

From the figures presented in Table 1 there appear to be two distinct regions for tubewell development. One is the Lower Bari Doab composed of Sahiwal and Multan Districts where the tubewells are 170 to 220 feet deep, and the other is the Upper Rechna Doab region composed of Gujranwala, Sialkot and Gujrat Districts. This is the same distinction which Ghulam Mohammad made in his original paper. The other districts fall somewhere between these two extremes. Therefore, in the remainder of this paper we will consider only the extremes in order to bracket the range of private tubewell costs. Data from Sahiwal and Multan will be combined and compared with those from Gujranwala, Sialkot and the few data from Gujrat.

Investment Costs

Even within one of these regions, of course, investment costs may differ significantly from one tubewell to the next. There are differences in the quality and quantity of materials used. A farmer using imported components will invest more than a farmer using all indigenous components. Or one farmer may want a bigger tubewell, or perhaps just a fancier one. By taking the averages within each of our two regions we hope to have eliminated all such variations.

As Table II indicates, both electric and disel tubewells are about 3,150 rupees more expensive in Multan than in the Gujranwala/ Sialkot area. The increased depth to the ground-water aquifer in the former region increases the cost of all components. The biggest cost differences are for the increased length of blind pipe, increased size of motor or engine, and increased masonry work. The latter item results from the fact that the pits for the pump (and motor) average 25 feet deep in Multan/Sahiwal and therefore have to be lined with cement masonry to prevent them from caving in. Miscellaneous costs are also somewhat higher in Multan/Sahiwal. This item inclides such factors as transportation, some labour charges, and materials not included elsewhere. These items may cost less in Gujranwala/Sialkot because this region is the centre of the tubewell industry and perhaps because there is more competition among tubewell suppliers.

TABLE II

DETAILS OF PRIVATE INVESTMENT COSTS

Items	Gujranwala-Sialkot and Gujrat	Multan-Sahiwal
Bore or drilling	306 (74)	543 (55)
Pit digging	70[a] (1)	340 (48)
Blind pipe	427 (75)	1,166 (55)
Strainer	489 (75)	895 (55)
Masonry work	675 (74)	1,146 (55)
Pump	696 (132)	841 (48)
Miscellaneous	629 (66)	980 (53)
Sub-total	3,292	5,911
Electric motor & appurtenances	2,708 (50)	3,253 (28)
Diesel engine & appurtenances	6,030 (82)	6,553 (27)
Total cost of electric tubewells	6,000	9,164
Total cost of diesel tubewells	9, 322	12,464

Note: [a] Most of the farmers in Gujranwala and Sialkot Districts either do not dig or dig out the pits with their own family labour.

Whether the tubewell is electric or diesel, the power source with its appurtenances is the single most expensive component, being over 50 per cent of the total cost for diesel engines, and about 40 per cent for electric motors. However, electric tubewells in either location are consistently about 3,300 rupees less expensive than the diesel tubewells. This is because the engine is basically more expensive, and it also, requires more appurtenances such as pulleys and belts in order to drive the pump. An engine also requires housing.

The low cost of the drilling is an important factor in the economics of private tubewells. This is generally less than five per cent of the total investment cost. In only very rare occasions is any mechanical power used in this operation. It is mostly done by a "percussion" method using a hand winch. The low cost of drilling permits the tubewell owner to inexpensively move his tubewell if its discharge begins to decrease or the strainer suffers some damage.

The strainer is also relatively inexpensive, being manufactured by hand with indigenous materials. It is made by winding coir string (string made out of coconut fiber) tightly around a round steel cage constructed out of iron strips.

Operation and Maintenance

For either type of tubewell, annual operating and maintenance costs depend upon the discharge of the well, the total depth to the groundwater acquifer, the amount of water pumped, and the efficiency of the engine or motor. In all respects, the diesel tubewell, which was a more expensive investment for the farmer, is also more expensive to operate and maintain. Much of this difference is due to inconsistent pricing policy by the government, as will be discussed later. However, diesel engines are also basically more costly to operate. The comparative costs, as they appear to the farmers, are shown in Table III.

Diesel Tubewells

About 75 per cent of the total annual operation and maintenance costs for diesel engines is spent on fuel oil. The rest is primarily taken up by the wages of the operator (which average about 400 rupees per year) and lubrication (which averages about 14 per cent of total operation and maintenance costs). The price of the low speed diesel oil used in almost all private tubewells averages 1.71 rupees per gallon and the cost of lubricating oil about 4.90 rupees per gallon to the farmer. The dealer's controlled price for light diesel oil is 1.67 rupees per gallon The difference is apparently taken up by transportation and some scarcity premium.4/

Electrict Tubewells

Electric tubewells have both lower operating and lower maintenance costs. The power cost to the farmer is about 0,08 rupee per kilowatt hour which corresponds to about 0.63 rupee per operating hour in Multan/Sahiwal. The actual cost is 13 to 24 per cent higher than this because of such additional charges as meter rent, minimum consumption guarantees, etc. In either case, the per hour cost to the farmer is 47 to 56 per cent cheaper for the electrical tubewell.

4/ The annual fuel consumption for diesel tubewells in the Multan/Sahiwal area shown in Table III is about 15 per cent less than that reported in Ghulam Mohammad's study [17 p 52]. The figures given here include the results of a study by the Punjab Board of Economic Enquiry which was conducted in 1963/1964[30], a year earlier than Ghulam Mohammad's. The differences may be either a result of different samples from the same universe, or it may be that utilization rate did increas Support for the second explanation is given by the fact that the Harza study in the Gujranwala Area[9] which was conduct a few months after Ghulam Mohammad's gives a slightly higher utilization rate.

The similarity in the total cost of fuel consumption in the two areas is misleading. The cost per hour in Multan/sahiwal is greater, about 2.20 rupees compared to 1.67 rupees but the number of hours of operation is higher in Gujranwala/etc. 2051 hours compared to 1678 hours. One would expect the number of hours to be higher in the Gujranwala area because of the importance of rice in the *Kharif* cropping-pattern. However, the difference may also result from the fact that the surveys were undertaken in the different regions at different times.

TABLE III

ANNUAL COST OF OPERATION AND MAINTENANCE OF PRIVATE TUBEWELLS

Tubewell	Gujranwala, Sialkot, Gujrat.	Multan Sahiwal
Diesel Tubewell		
Diesel oil	2,505 (79)	2,683 (54)
Lubrication	465 (56)	520 (54)
Other costs (operators' pay, broza, etc.)	464 (63)	485 (52)
Total cost per annum	3,433	3,687
Hours worked per annum	2,051	1,678
Electric Tubewells		
Electricity	1,507 (57)	2,105 (57)
Other cost (lubrication, operators, etc.)	198 (41)	94 (52)
Total cost per annum	1,705	2,199
Hours worked per annum	1,923	2,269

Note: Figures in peranthesis indicate , the number of observations.

Electrict tubewells also do not require as high expenditure for lubrication and other maintenance, and operators are only occasionally retained. The Harza study[9] shows a higher proportion of wells with operators in Gujranwala than any of the other studies for that region or elsewhere. This is why the "other costs" in Table III are twice as high in the Gujranwala area as they are in Multan/Sahiwal.

Repairs, Replacements, and the Tubewell's Economic Life

One of the major uncertainties about private tubewells has been their expected life and their annual repair costs. Surveys report tubewells which have been operating for fifteen to twenty years - although most of the original components may have been replaced. Whether or not this is the same tubewell depends upon one's definition of repairs.

In this study we have initially chosen to define the life of a tubewell as the number of years it stays in one pit. During this time there are probably several different bores drilled, which we take to be repairs. Similarly, engine reboring, motor rewinding, pump impeller replacing and other such major items are taken as repairs rather than marking the end of the life of the machine.

Starting from this basic definition, we have used the following method for computing the frequency or repairs. We start with the sample of tubewells on which we have repair data 5/

5/ Frequency tables showing (by year of tubewell installation) the time to repair and time since repair for the major types of repairs are given in appendix Table A-1 to A-5.

Some of these have needed repairs and some have not. Taking those which have required repairs, we compute the average time between the initial installation and the first repair or between one repair and a subsequent repair. These computations are given in Column (3) of Table IV. We are then left with a number of observations on the time since the last repair or, if no repair has been required, the time since installation. The average of these observations is shown in Column (4) of Table IV. All we know about these observations is that no repair has been required yet. Presumably, one will be required at some time in the future. It would be incorrect to ignore these observations since, as Table IV incidates, the average time since the last repair is longer than the average time between repairs. This is true even though the majority of the tubewells in our sample were less than three years old.

TABLE IV

AVERAGE FREQUENCY OF REPAIRS

Component	Average age of sample	Average time to repair	Average time since last repair	Computed frequency of repair
1	2	3	4	5
	years			
Engine	2.83	1.70	1.71	2.4
Motor	3.14	1.94	2.06	2.9
Pump	2.97	2.19	2.40	3.9
Redrilling	2.97	2.47	2.39	4.1
Others	2.97	1.79	2.57	4.3

To combine these two sets of observations we begin by taking the average time to repairs as a first approximation of the average repair frequency. Then from the samples used in computing Column (4) we eliminate all those tubewells for which the time since the last repair (or installation) is less than the average time to repairs. We combine the remaining observations with those giving the time to repair, and compute a second approximations of the average frequency of repairs. This is a longer interval than the average time to repairs. We eliminate all those observations for which the time since the last repair or installation is less than our second approximations and combining the remainder with the observations on time to repairs, compute a third approximation of repair frequency. After several such iterations, the recomputed frequency does not increase enough to cause the elimination of any further tubewells from the sample (tubewell ages were measured in one year increments) and we take this as the frequency of repairs.[6/] These computed frequencies are given in Column(5) of Table IV. Since perhaps half of the observations used in computing these frequencies were tubewells which had not yet needed a repair, our computed frequencies are probably still too low. Nevertheless, we will use them in our further calculations. On this basis we can take the average cost of each type of repair and divide it by the frequency of repairs to determine the average annual repair cost as is done in Table V.

[6/] If time had been measured continuously rather than in increments, this method would produce a series of computed frequencies which would approach some value asymptotically.

TABLE V

ANNUAL ^VERaGE COST OF REPAIRS ^ND REPL^CEi E NTS

Components	Average cost per repair	Computed frequency of repairs	Average repair cost per annum
	Rupees	Years	Rupees
Repairs to:			
Engine	397	2.4	165
Motor	465	2.9	160
Pump	214	3.9	55
Other parts	216	93	50
Redrilling Cost:			
Gujranwala/Sialkot/ Gujrat	947	4.1	231
Multan/Sahiwal	1344	4,1	328
Average annual cost of repairs per well:			
Gujranwala/Sialkot/Gujrat			499
Multan/Sahiwal			596

Repairs to engines and motors and tubewell redrilling hav the highest annual costs. The most common engine repair is th reboring of the cylinder which is required every three years or so. The most common repair to the motor is for rewinding the armature or replacing the bearings. Armatures often burn out either because of faulty manufacture or because of low voltage. It is interesting to note that the cheaper but more frequent engine repairs have almost the same annual costs as the less frequent but more expensive motor repairs.

The highest cost item is for redrilling. Redrilling is necessary either because the strainer has been damaged, allowing sand to flow into the well, or because of the strainer has become clogged. Redrilling involves jacking the old well out of the ground and drilling a new bore in the bottom of the same pit.7/ The same blind pipe that was pulled out of the old well can be used in the new, and it may be possible to re-use the same strainer cages after rewinding them with coir string (some are pulled out of the old well undamaged and unclogged and can be used in the new well as they are). In such a way only a small amount of the reboring costs are taken up by materials, the major proportion being for labour.

Many wells require redrilling during their first year of operation (see, Appendix Table A-1) apparently because the strainer is damaged during the initial installation. If the strainer is installed undamaged it will only need replacement if it becomes clogged or if the coir string is broken. Coir string when wet looses only 15 to 30 per cent of its strength and elongates slightly. It neither rots in water nor is significantly affected by dissolved salts.8/ However, rusting iron apparently does affect the string's strength /̲4, pp. 2A-17̲7,

---

7/ The pit may be deepened if the watertable had declined since the last reboring.

8/ Personal communication from Dr. Nazir Ahmad of the Irrigation Research Institute in Lahore. See also /̲4̲7.

either because of some chemical reaction or because the rusted strips are apt to have sharpened corners. This is thought to be the reason for strainer failures which occur after several years. One significant advantage coir string has over such traditional strainer materials as iron and brass, is that it doesn't corrode [4, p.24-19 : 6, pp. 2,3].

Given the frequency with which wells are redrilled, one determinant of a tubewell's life according to our definition is how many bores can be made from the same pit. This number seems to vary from four to six including the original bore. By this criterion the life of a tubewell would be from sixteen to twenty-four years. However, there are various other factors which dictate the use of a life around fifteen years. One is the number of times the original blind pipe can be re-used. Everytime the pipe is jacked out of the ground for redrilling, it is weekened. Three or four re-uses would probably be the effective limit for this item. Similarly, there are only so many times an engine can be rebored before it requires a major overhaul in the factory. Engine reboring is required about once every three years (the higher frequency of reported engine repairs results from the inclusion of repairs to bearings and other parts) and can be done four or five times to the same cylinder head. These two factors would dictate a life of about fifteen to twenty years. In our further calculations we will use the shorter life.

Though we have only rarely found an instance when an engine or motor was replaced because it was too old to operate properly, many believe that eight to ten years or less is the effective life of these components. For this reason we will also include an alternative calculation in which the engine or motor, pump and "other" items are assumed to have a life of ten rather than fifteen years.

Summary of Private Costs

A summary of the private tubewell costs to the farmer is presented in Table VI. Variable costs include operation, maintenance, and repairs. Fixed costs are the amortized costs of the initial investment. Since we are dealing with costs as they appear to the individual, we have used two different discount rates in our computations. In the first computation, A, we assume the farmer has borrowed the entire investment cost from the Agricultural Development Bank for seven years at 6 per cent interest. Fixed costs will be highest during these first seven years while he is paying the loan back. After that, assuming that the life of all components is fifteen years (Case A-i) fixed costs will be zero. If, however, the life of the engine or motor, pump, and other parts is taken to be only 10 years (Case A-ii), the fixed costs will be zero from years seven to ten and then will reappear again from years ten to fifteen. We have assumed that the farmer replaces these components out of his retained earnings for which he has an implicit discount rate of 15 per cent. In the second calculation we assume that the original investment is made out of savings for which the farmer has an implicit discount rate of 15 per cent. The same alternative assumptions are made about the life of the various components as under A. We have also computed the variable cost per hour and per accre-foot of water pumped. The ratio of fixed to variable costs will be the same as they are for annual costs. These ratios are also shown in Table VI.

In Table VII we have computed the cost to the farmer of irrigating the major crops grown in the Punjab. Two sets of figures are given for each crop. The figure on top is the cost if the tubewell supplies only the water requirements which are not satisfied by the (average) rainfall. The figure below, in parenthesis, is the cost if the tubewell supplies the entire water requirements. Fixed costs are computed on the basis of fifteen year life for all components and discount rate of 15 per cent. The costs to the farmer of irrigating these same crops by canal water are also shown in Table VII. The cost of irrigation from a tubewell is up to four to eight times as expensive as the cost of irrigation from a canal.

IV. SOCIAL COSTS OF PRIVATE TUBEWELLS

The cost of any resource to society may differ significantly from its cost to the individual. Governments often control market prices (through an official exchange rate, imposing taxes on/ subsidies, restricting the availability

SUMMARY OF PRIVATE TUBEWELL COSTS TO THE FARMER

					Ratio of Fixed Costs to Variable Costs			
	Gujranwala Area		Multan/Sahiwal		Gujranwala Area		Multan/Sahiwal	
	Diesel	Electric	Diesel	Electric	Diesel	Electric	Diesel	Electric
I. Annual Costs								
Variable costs	3860	2155	4240	2735				
Fixed costs								
A. Loan at 6% for 7 years								
(i) 15-year life[a]								
1 to 7 years	1670	1075	2235	1640	.43	.50	.53	.60
7 to 15 years	0	0	0	0	0	0	0	0
(ii) 10 to 15-year lives[b]								
1 to 7 years	1670	1075	2235	1640	.43	.50	.53	.60
7 to 10 years	0	0	0	0	0	0	0	0
10 to 15 years	1475	805	1665	1015	.38	.37	.39	.37
B. Discount rate of 15%								
(i) 15-year life[a]	1640	1030	2130	1570	.41	.48	.50	.57
(ii) 10 & 15 year lives	1810	1140	2370	1710	.47	.53	.56	.67
II. Variable costs per hour [c]	1.88	1.12	2.53	1.21				
III. Variable costs per Acrefoot[c]	1.80	10.3	24.3	11.6				

Notes: a) All components assumed to have 15-year life.
b) Engines, motors, pumps and 'miscellaneous parts' assumed to have life of 10 years, other components 15 years.
c) To determine fixed costs per hour on per acrefood, multiply variable costs by ratio of fixed to variable cost given on right-hand side of table.

Table VII

COSTS OF IRRIGATING SELECTED CROPS BY PRIVATE TUBEWELLS AND CANAL

	Gujranwala Area a/		Multan/Sahiwal b/		Canal
	Diesel	Electric	Diesel	Electric	
Rice: variable costs	42 (58)	25 (36)	-	-	
Total costs	59 (82)	37 (53)	-	-	10.4
a/ Sugarcane: Variable costs	74 (92)	45 (55)	121 (140)	58 (67)	
Total costs	104 (130	67 (81)	183 (210)	91 (105)	21.6
b/ Cotton: variable costs	-	-	59 (66)	28 (31)	
Total Cost	-	-	88 (99)	44 (49)	10.4
a/ Wheat: variable cost	20 (24)	12 (15)	30 (33)	14 (16)	
Total costs	28 (34)	18 (22)	45 (50)	22 (25)	6.4

Notes: Figures in parentheses show costs if there were no rainfall. Other figures show costs assuming average rainfall. Computations based on data contained in [15;21;22].

a) All figures apply to Upper Rechna Doab.

b) Cotton figures apply to area near Multan; sugarcane and wheat to area near Sahiwal.

of a resource by licensing, etc.) and do not always use that control to establish the most "rational" system of prices. Therefore, particularly in developing countries, it is usually necessary to compute two measures of cost, one the cost to the individual (as was done in the previous section) and the other the cost to society.

When computing social costs, one has to determine which resources are being consumed in any process and to estimate their "real" value. Their real value is often measured by their "opportunity" cost, the highest marginal revenue product these resources would produce if used in some alternative manner. Sometimes these opportunity costs may be below the market price. This is usually thought to be the case with unskilled labour in a surplus-labour economy. For other resources - foreign exchange for instance- the controlled price appears to be substantially below the opportunity cost. In either case, choosing the "correct" price for an economic analysis is apt to be an arbitrary process. Faced with such uncertainty, the best policy is usually to do some sort of 'sensitivity' analysis so that the effects of alternative assumptions on the results are made clear.

The Resource for which the official price is most obviously inappropriate is the price of foreign exchange, Pakistani importers are forced to pay up to 13.5 rupees per US dollar escluding duties, or up to over 20 rupees per US dollar including duties and taxes, whereas the official price is maintained at 4.76 rupees. The former prices are probably too high, the latter price undoubtedly too low to measure the true value of foreign exchange to the country. We will hope to bracket this true value by using various prices from 7.14 rupees (1.5 times the official price) to 14.28 rupees (3.0 times the official price) per US dollar in our computations.

The appropriate price for labour is more difficult to determine. Skilled labours probably are not surplus (although there may be some evidence of their being treated as if they were so). This makes it necessary to define skill levels. However, with unskilled labour there is a need for close administrative or managerial talent which may also be in short supply. Furthermore, it is impossible to determine the entire amount of value added to any resource within the country resulting from its being handled by unskilled labour. We have investigated the proportion of value added paid to labour at certain steps in the processing of goods for use in private tubewells.[9] We will show these costs separately so they may be added to the other costs at whatever shadow price is thought to be appropriate.

We will treat taxes and subsidies as if they are only internal transfer payments and thus do not represent a real cost to the nation. It has been questioned whether this is

---

9/ We include here the cost of labour which may presently have skills, but who were unskilled until they began their present occupation.

an appropriate treatment of taxes in developing countries. However, it is by far the most straight forward method and we will use it here. It has also been suggested that since developing countries often have difficulty raising sufficient income through taxation to finance the desired development expenditures, government receipts should be given some weight higher than their face value. Certainly, anyone living in Pakistan has observed numerous situations in which highly productive investments have had to be postponed or cancelled because of inadequate availability of public funds. Such observations would support the view that additional income to government would indeed have a high value. On the other hand, the same observer has seen many more situations in which government expenditures would seem to have a very low or even negative value. One could of course argue that the non-monetary (political, psychological, prestige) income of these latter expenditures gives them as high a real value as the economically measurable income of the foregone productive investments.[10/] We are obviously in no position to make any judgement on this argument. Even if it were valid, it would still have to be proven that the 'value' of the tax receipts to the state is higher than their social value in what ever use would have been made of them if they had been left with the individual.

[10/] One could also argue that for various institutional reasons traditional expenditures which may have a lower social value have first claim to tax receipts and after they are satisfied expenditures will be made on the more valuable development investments this giving marginal tax receipts a higher value than the average.

For these reasons, we will not attempt to directly determine the value of income to the state.

Investment Costs

Cost breakdowns for all the major tubewell components have been collected from various manufactures and importers, and are summarized in Tables VIII through XI. In collecting these data we have attempted specifically to identify (or at least estimate) foreign-exchange costs for imported raw materials, duties and taxes, the proportion of value added in manufacturing paid out to labour, and other manufacturing costs, and to eliminate any scarcity premiums resulting from foreign-exchange scarcities. (Such premiums have existed for blind pipe because the amount which could be imported under licence has been inadequate to meet the demand, and for many raw materials which have to be purchased on bonus or each-cum-bonus). Because we have eliminated these scarcity premiums, the C & F costs we give for raw materials are apt to be quite unrepresentative of their cost to the manufacturer.[11]

---

[11] This is particularly true for iron and steel imports for which we have used the C & F cost of these commodities when purchased on the free-world market. Most of Pakistan's iron and steel is obtained under tied aid from the United States at a substantially higher cost than the world-market prices.

Table VIII

ESTIMATED BREAKDOWN OF DRILLING COSTS
(Rupees per well)

Item	Gujranwala Area	Multan/ Sahiwal
Investment cost for drilling rig	9,000	9,000
Amortized cost (assume 15-year life and interest rate of 10%)	1,200	1,200
Annual repair costs (15% of amortized cost)	180	180
Number of wells drilled per year	10	6
Fixed cost per well	140	230
Set-up costs (including transport)	20	40
Other overhead expenses	20	20
Subtotal	180	290
Labour	126	253
Total costs	306	543
Social costs		
Foreign exchange (20%)	30	45
Other capital costs (less duties & taxes)	100	170
Other overhead	20	20
Labour (including set up)	146	293
Total	296	528

Table IX

COST BREAKDOWN FOR ENGINES, MOTORS, AND PUMPS

Item	18 H.P. Engine	15 H.P. Motor	6 inch pump
Raw Materials			
C&F cost	1000	360	120
Duties & taxes	800	230	80
Actual cost to manufacturer	2500	1125	300
Labour	600	120	80
Other manufacturing cots	1850	855	270
Selling price	4950	2100	650
Social Cost			
Imported raw materials	1000	360	120
Indigenous value added to raw materials inc.	300	100	50
Labour costs (at market prices)	600	120	80
Estimated foreign-exchange Component of manufacturing costs	260	150	50
Other manufacturing costs	1590	705	220
Distribution costs	300	100	100
Total	4050	1535	620

Source: Data given in [22;25]plus personal communication from Siemens Pakistan Engineering Co. Ltd. plus other personal enquiries.

Table X

BLIND PIPE COST BREAKDOWN

(Cost in Rupees per foot)

	Diameter of pipe		
	4 inch	5 inch	6 inch
Imported pipe			
C & F cost[a/]	3.27	4.68	5.73
Duties and taxes[b/]	2.38	3.41	4.17
Transportation handling etc.	.72	.87	1.00
TOTAL	6.40	8.96	10.90
Locally manufactured[c/]			
Imported raw materials	2.10	2.88	3.47
Duties and taxes	2.28	3.16	3.68
Labour costs	.04	.05	.06
Other manufacturing costs	2.86	3.85	4.44
Ex-factory price	7.28	9.94	11.65
Transportation & handling	.52	.67	.80
Octroi charges	.12	.17	.20
TOTAL	7.92	10.78	12.65
Social Costs			
Imported pipe			
C & R cost	3.27	4.68	5.73
Transportation, etc.	.72	.87	1.00
TOTAL	3.99	5.55	6.73
Locally Manufactured pipe			
Imported raw materials	2.10	2.88	3.47
Labour costs (at market price)	.04	.05	.06
Variable manufacturing costs	.70	.95	1.10
Transportation, etc.	.52	.67	.80
TOTAL	3.36	4.55	5.43

Note: a) Ref. [24]

b) This is the difference between landed costs and C&F cos given in [24] plus Octroi charges.

c) The imported raw material costs and the ex-factory pipe are given in [24]. The breakdown of other costs was obtained during discussion with Hyesons Indust. Ltd.

d) Because of substantial excess capacity in pipe manufacturing plants, we have only taken an estimate of the variable manufacturing costs for the social costs.

Table XI

STRAINER COST BREAKDOWN
(Rupees per Foot for 6" Strainer)

Item	Quantity	Market price	Manufacturer's cost	C & F price	Foreign-exchange cost
	(lbs.)	(Rs/lb.)	(Rs.)	(Rs/lb.)	(Rs)
Raw Materials					
Iron strips	4	.65	2.60	.14	.56
Coir string	0.8	2.60	2.05	-	-
End fittings, etc.	-	-	.70	-	.10
			5.35 (Rs. per Foot)		
Total cost imported raw materials			.66		
Duties and taxes			.50		
Manufacturer's cost			5.35		
Labour cost					
Manufacturing cage			.30		
Winding coir string			.22		
Other manufacturing costs			.63		
Selling price			6.50		
Social Cost					
Imported raw materials			.66		
Value added to raw material costs in Pak.			3.00		
Labour cost (at market prices)			.52		
Estimated foreign-exchange components of the manufacturing costs			.06		
Other manufacturing costs			.57		
Distribution costs			.05		
TOTAL:			4.86		

The difference between selling price and the manufacturer's raw material cost is assumed to be the manufacturing cost (including the cost of labour). Thus, we have made no attempt to adjust for any excess profits which might exist in manufacturing. We have also tried to estimate the foreign-exchange component (representing imported capital equipment) of the manufacturing costs. This has been assumed equal to 15 per cent of the cost of buildings, 80 per cent of the cost of imported machinery, and 20 per cent of the cost of indigenously manufactured machinery.12/

We have also attempted to distinguish between variable manufacturing costs and fixed manufacturing costs. Variable manufacturing costs include the cost of raw materials, fuel and power, profit, etc. Fixed manufacturing costs, of course, represent fixed overhead expenses. We have tried to make the distinction in such a way as to provide answers to two different economic questions. The first is what is the average cost of the private tubewell development? In computing this it is appropriate to include all fixed costs. The second is what will be the cost of a continued private tubewell development. In answering this question some of the already sunk costs

---

12/ These data presented are not supposed to be representative of any one particular firm manufacturing the component in question. Where we have had to rely heavily on the information given us by one firm, as is the case with motors and blind pipe, we have adjusted the data to make the information more representative of the industry as a whole For this purpose we have made use of our own observations as well as data contained in the CMI's (Census of Manufacturing Industries), surveys of small-scale industries, and the input-output calculations by Khan & MacEwan/16;23;25/.

should probably be ignored. How much of these costs should be ignored will depend, among other things, upon the value of the equipment in alternative uses (on producing the same component for alternative functions), and its salvage value.

In Table XII-A and B we have summarized our findings and computations to show for each component of the investment the variable, fixed and labour costs associated with its production,. The variable and fixed costs have also been divided into local and foreign-exchange costs. The results of Table XII-A and B have then been used to estimate the social cost of private-tubewell investments evaluating foreign exchange at 1.5 to 3.0 times the official exchange rate, and labour at one-half its market price.

In our computations showing the cost of private tubewells to the farmer, the cost of electricity has been taken as a variable operating cost since this is how the farmer pays for it. However, when considering costs to the society, the total cost of providing electricity is comprised of substantial capital investments in facilities for generator, transmission and distribution, which must be amortized over their economic life, and recurring costs for fuel, operation, maintenance, *etc.* In a system which has a large component of hydro-electric power, such as is the case in West Pakistan, the capital investment costs will be relatively high, and the recurring costs will be relatively low.

Table XII-B

Breakdown of Tubewell Investment Costs

Breakdown	Multan/Sahiwal						
	Variable Costs		Labour	Fixed Costs		Total Costs	
	Ind. l… l	F. E.		Ind. l	F. E.	Ind.	F.E.
Drilling	24	6	293	166	39	483	45
Pit-digging	0	0	340	0	0	340	0
Blind pipe	152	278	5	107	160	264	438
Strainer	356	68	54	10	6	420	74
Masonry work	1031	0	115	0	0	1146	0
Pump	230	133	90	180	56	500	189
Miscellaneous	356	97	178	91	53	625	150
Subtotal	2149	582	1075	554	314	3778	896
Electric motor	552	534	177	785	222	1514	756
Diesel engine	1250	1250	750	1490	326	3490	1516
Total costs: electric tubewells	2701	1116	1252	1339	536	5292	1652
diesel tubewells	3399	1832	1825	2044	640	7268	2472

Table XII-A

Breakdown of Tubewell Investment Costs

Breakdown	Gujranwala/Sialkot/Gujrat						
	Variable Costs		Labour	Fixed Costs		Total Costs	
	local	F. E.		local	F. E.	Ind.	F. E.
Drilling	14	4	146	186	26	266	30
Pit-digging	0	0	0	0	0	70	0
Blind pipe	90	163	3	63	94	156	257
Strainer	260	49	39	7	4	306	53
Masonry work	607	0	68	0	0	675	0
Pump	190	110	74	150	46	414	156
Miscellaneous	278	75	90	75	40	443	115
Subtotal	1439	401	490	401	210	2330	611
Electric motor	460	445	148	655	185	1263	630
Eiesel engine	1150	1150	690	1370	300	3210	1450
Total costs: electric tubewells	1899	846	638	1056	395	3593	1241
diesel tubewells	2589	1551	1180	1771	510	5540	2061

Table XIII

ALTERNATIVE VALUATION OF SOCIAL INSTALLATION COST FOR PRIVATE TUBEWELLS

Alternative Valuation	Gujranwala Area		Multan/Sahiwal	
	Diesel	Electric	Diesel	Electric
CaseI - Foreign-exchange valued at 1.5 times official rate				
Variable costs	4916	3168	6147	4375
Fixed costs	2536	1649	3004	2143
Subtotal	7452	4817	9151	6518
Labour*	590	319	913	626
Total	8042	5136	10064	7144
Case II-Foreign exchange valued at 2.0 times official rate				
Variable coss	5691	3591	7063	4933
Fixed costs	2791	1846	3324	2411
Subtotal	8482	5437	10387	7344
Labour*	590	319	913	626
Total	9072	5756	11300	7970
Case III-Foreign exchange valued at 3.0 times official rate				
Variable costs	7242	4437	8895	6049
Fixed costs	3301	2241	3964	2947
Subtotal	10543	6678	12859	8996
Labour*	590	319	913	626
Total	11133	6997	13772	9622

Notes* : Labour valued at 0.5 times its market price.

The Irrigation and Agriculture Consultants Association (IACA) have given the following estimates of the capital costs for the electrification of private tubewells:

Table XIV

IACA ESTIMATES OF CAPITAL COSTS OF PRIVATE TUBEWELL ELECTRIFICATION

	Total	Foreign Exchange
	-Rs-	-Rs-
Generation	6,200	4,960
Transmission	1,800	1,100
Distribution	11,300	6,890
Total	19,300	12,950

Source: /̲16, p.54̲7.

These are apparently supposed to be some sort of average cost for tubewells throughout the Punjab. The cost of generation capacity will depend upon the demand of the tubewell during the time of the peak load on the entire electrical system. Since tubewells in Multan/Sahiwal are deeper and larger than tubewells in the Gujranwala area, we would expect them to have a higher generating cost. The measured demands of 62 electric tubewells in the Gujranwala area and 45 electric tubewells in the Sahiwal/Multan area were averaged; giving an average tubewell demand of 7.9 kw in the former and 10.3 kw in the latter area. Not all the tubewells would be operating simultaneously at the time of peak system load. Therefore, some diversity factor has to be applied before computing their requirement for generation capacity. The Bank Group recommends a diversity factor of .837 for both private and public tubewell pumping loads [28, p.22]. Applying this factor results in an estimated diversified demand of 6.6 kw and 8.6 kw in the Gujranwala and Multan/Sahiwal areas respectively. This is the demand at the tubewell. The demand at the generating station includes transmission and distribution losses. These have been assumed to vary from 19 per cent up to 100 per cent of energy sales for private tubewells [28, pp. 22, 39]. It is reasonable to expect them to be somewhat higher than the average losses in the system. These are presently about 20 per cent, and are expected to decrease to 17.5 per cent by 1975 and 15.7 per cent in 1985 [27, p.44]. Therefore, a figure of 25 per cent losses for private tubewells would seem to be reasonable. This increases the average tubewell peak load demand to 8.25 kw and 10.75 kw at the generating station. The cost per kilowatt of generation capacity is stated by the World Bank Group to be 509 rupees (excluding duties and taxes) of which about 98 per cent is in foreign exchange [27, p. 39]. This brings the generation cost to 4,200 rupees for the Gujranwala area and 5,470 rupees for the Multan/Sahiwal area. Similarly, the Bank Group estimates the distribution costs per tubewell to be about 8,500 rupees excluding duties and taxes of which 3,400 rupees are in foreign exchange [27, p.36]. The Bank Group makes no estimate of transmission costs per tubewell, so we will use the estimate given in Table XV after deducting 25 per cent for duties and taxes. This gives a total capital cost for electrification per tubewell as :

Table XV

REVISED ESTIMATES OF CAPITAL COSTS FOR PRIVATE TUBEWELL ELECTRIFICATION

(in rupees)

Item	Gujranwala, etc.		Multan/Sahiwal	
	Total	Foreign exchange	Total	Foreign exchange
Generation	4,200	3,570	5,470	4,650
Transmission	1,350	1,100	1,350	1,100
Distribution	8,500	3,400	8,500	3,400
Total	14,050	8,070	15,320	9,150

Note: Generation capacity has an assumed economic life of 20 years, and distribution and transmission facilities an assumed life of 30 years [27, pp.38-39].

Power or Fuel Costs

The major portion of the cost of electricity covers the amortization of capital expenditures - for generation, transmission and distribution - which we have already included in the investment cost for electrified tubewells. The remainder covers such items as fuel for the generators (for thermal gas turbine or diesel generators) and operation and maintenance of the entire electrical system. The Bank Group estimates these recurring costs to be approximately 0.045 rupee per kwh /‾28, p.39_7. Although it is not clear from their report this presumably is 0.045 rupee per kwh generated. Thus, the cost per kwh consumed would have to be somewhat higher than this to take account of losses in the system. Using our previous estimate of 25-per-cent losses brings the economic cost per kilowatt hour to 0.056 rupee. We will arbitrarily assume that about 10 per cent of these costs will represent foreign-exchange expenditures for maintenance equipment and replacements.

Most of the private diesel tubewells are slow-speed affairs which use a light diesel oil (IDO). The price of this oil from the dealers is fixed throughout West Pakistan at 1.67 rupees per gallon including all central and provincial taxes as well as transportation costs from Karachi to Rawalpindi and octroi charges of about 0,03 rupee per gallon.13/ Assuming the costs of transportation from the dealer to the farm about 0.03 rupee per gallon we have a total cost to the farmer of about 1.70 rupee per gallon.

13/ The authors are indebted to Mr. W.C.F. Bussink of the West Pakistan Planning and Development Department for supplying these data on the cost of diesel fuel. These figures are essentially as supplied by him after verification by the authors with several petroleum firms and adjusting them to a dealer base rather than an agent base. The IBRD also reports similar figures in /‾29, p.37_7.

Out of this price approximately 0.67 rupee represents taxes. The difference between the actual transportation cost to the Punjab (0.19 rupee) and that charged to Rawalpindi (0.25 rupee) is 0.06rupee per gallon. Thus, the cost of the diesel fuel less taxes and excess transportation charges is about 0.97 rupee per gallon. The domestic value added for transportation and handling is about 0.50 rupee (Rs.0.31 + Rs. 0.19) and for refining cost is an estimated 0.12 rupee.[14/] This leaves an import component of 0.35 rupee per gallon. These are the figures used in our calculations.

Maintenance and Repair Costs

For maintenance and repairs we have not been able to obtain a detailed cost breakdown. However, labour charges are apt to form a higher proportion of these costs than they do of the investment costs. For redrilling, we will assume the same breakdown as for the original drilling and strainer charges. For lubrication we will assume that the cost breakdown is the same as that given for light diesel oil above. For motor, engine, pump, and miscellaneous repairs, we will assume that labour costs form twice the proportion of total costs that they do in the original investment, and that foreign exchange requirements form the same proportion. The figures we have assumed are shown in Table XVI.

[14/] Light diesel oil is, of course, a joint production of the refining and so there is no precise method of computing its refining cost. However, Rs.0.12 was considered to be reasonable by representatives of one of the local petroleum companies.

Table XVI

BREAKDOWN OF REPAIR COSTS

	Variable Costs		Fixed Costs		Labour
	Total costs	Foreign exchange	Total cost	Foreign exchange	
Redrilling					
Gujranwala Area					
Per repair	251	63	104	36	440
Per annum	61	15	25	9	107
Multan/Sahiwal					
Per rapir	334	69	154	42	648
Per annum	81	17	38	10	158
Pump Repairs					
Per repair	38	34	31	14	58
Per annum	10	9	8	4	15
Engine Repairs					
Per repair	55	76	66	20	90
Per annum	23	32	28	8	38
Motor Repairs					
Per repair	69	76	97	32	51
Per annum	24	26	33	11	17
Miscellaneous Repairs					
Per repair	72	26	19	14	62
Per annum	17	6	4	3	14

Amortization of Investment

We have again made alternative assumptions about the economic life of the various components. The first is that all components have a fifteen year life (Table XVII-A). The second is that engines, motors, pumps, and miscellaneous parts have a ten year life whereas the rest of the investment has a fifteen year life (Table XVII-B). In each case we have amortized private investment at 8 per cent and public investment at 12 per cent. The reason for the differential discount rate is as follows: Public funds, once they are allocated to development expenditure, probably have a fairly high rate of return (even if that for the average public expenditure is low). Twelve per cent would seem to be a reasonable estimate of the value of public development expenditures. Some of the savings used by the farmers for their private investment, however, have, have most probably been induced by the apportunity to invest in the tubewell. If this investment opportunity had not existed, these savings would not have been made and the money used for present consumption to which society gives a low value. The adjustment which should be made to take account of the aggregate opportunity cost of the private investment funds depends upon the relative importance of the different sources of finance for private tubewells. A crude analysis of data collected on this subject by the PIDE has indicated that if the opportunity cost of public development funds is 12 per cent, then the average opportunity cost of the funds invested in private tubewells would be somewhat under 8 per cent.

Summary of Social Costs

Summaries of the estimated cost of private tubewells to society are presented in Tables XVII-A, XVII-B, XVIII-A and XVIII-B. In both sets of tables, the A-table presents the computations assuming that the life of all tubewell components is fifteen years, and the B-table presents the computations assuming that some of the components have only a ten-year life. The first set of tables summarises all of the computations presented in this section without using any shadow prices, but maintaining the distinction between those investment costs representing variable manufacturing expenses, and those representing sunk or fixed manufacturing expenses. This same distinction is used for repair costs. All electrification costs have been included as variable investment costs since these represent the average expenditure that will be required for every additional tubewell. Even if the tubewell population were to remain constant, most of the electrification costs would better be included as variable rather than sunk costs because they represent capital (such as generation capacity) which obviously has a high apportunity cost.

The second set of tables presents alternative valuations of the social cost of private tubewells with foreign exchange period at half its market wage rate. In both sets of tables computations have been given both on a annual basis and on a per acrefoot basis. The running costs have been computed on the assumption that the tubewells will operate on an average of

Table XVII-A[a]

Summary of Social Costs of Private Tubewells
(Official Prices)

	Gujranwala Area					
	Diesel Tubewells			Electric Tubewells		
	Rupee costs	F.E. costs	Labour costs	Rupee costs	F.E. costs	Labour costs
Running Costs:						
Operation[b]	930	530	400	1000	110	160
Maintenance	200	110	-	20	10	-
Repairs	110	60	170	110	60	150
Subtotal	1240	700	570	1130	180	310
Variable Investment Costs:						
Tubewell	300	180	140	220	100	70
Electrification	-	-	-	750	1040	-
Subtotal	300	180	140	970	1140	70
Total Annual Variable Costs	1540	880	710	2100	1320	380
Sunk Investment Costs	210	60	-	120	50	-
Maintenance & Repairs	70	20	-	70	30	-
Total Annual Costs	1820	960	710	2290	1400	380
Cost Per Acre Foot						
Running costs	5.9	3.3		5.4	0.9	
Total variable costs	7.3	4.2	3.4	10.0	6.3	1.8
Variable plus fixed costs	8.7	4.6		10.9	6.7	

Notes: a) All tubewell components assumed to have a life of fifteen years.
b) Operation costs based on assumed 2000 hours of operating time a year which is equivalent to approximately 210 acrefeet of water pumped.

(Cont'

Table XVII-B[a/] (1)

SUMMARY OF SOCIAL COSTS OF PRIVATE TUBEWELLS
(Official Prices)

	Gujranwala Area					
	Diesel Tubewells			Electric Tubewells		
	Rupee costs	F.E. costs	Labour costs	Rupee costs	F.E. costs	Labour costs
Running Costs						
Operation[b/]	930	530	400	1000	110	160
Maintenance	200	110	-	20	10	-
Repair	110	60	170	110	60	150
Subtotal	1240	700	570	1130	180	310
Variable Investment Costs						
Tubewell	350	220	170	250	120	80
Electrification	-	-	-	750	1040	-
Subtotal	350	220	170	1000	1160	80
Total Annual Variable Costs	1590	920	740	2130	1340	390
Sunk Investment Costs	260	70	-	150	50	-
Maintenance & Repair	70	20	-	70	30	-
Total Annual Costs	1920	1010	740	2350	1420	390
Cost Per Acrefoot						
Running costs	5.9	3.3		5.4	0.9	
Total variable costs	7.6	4.4	3.5	10.1	6.4	1.9
Variable plus fixed costs	9.1	4.8		11.2	6.8	

Notes: a) Engines, motors, pumps, and miscellaneous items assumed to have a life of ten years. All other components assumed to have a life of fifteen years.

b) Operation costs based on assumed 2000 hours of operating time a year which is equivalent to approximately 210 acrefeet of water pumped.

(Cont'd..P.Next)

Table XVII-A[a/] (2)

Summary of Social Costs of Private Tubewells
(Official Prices)

	Multan/Sahiwal Area					
	Diesel Tubewells			Electric Tubewells		
	Rupee costs	F.E. cost	Labour costs	Rupee costs	F.E. costs	Labour costs
Running Costs:						
Operation[b/]	1240	700	400	1300	140	40
Maintenance	270	150	-	20	10	-
Repairs	130	60	230	130	60	200
Subtotal	1640	910	630	1450	210	240
Variable Investment Costs:						
Tubewell	400	210	210	320	130	150
Electrification	-	-	-	770	1180	-
Subtotal	400	210	210	1090	1310	150
Total Annual Variable Costs	2040	1120	840	2540	1520	390
Sunk Investment Costs	240	70	-	160	60	-
Maintenance & Repairs	80	20	-	80	30	-
Total Annual Costs	2360	1210	840	2780	1610	390
Cost Per Acre Foot						
Running costs	7.8	4.3		6.9	1.0	
Total variable costs	9.7	5.3	4.0	12.1	7.2	1.9
Variable plus fixed costs	11.2	5.8		13.2	7.7	

(Footnote same Table XVII-A)

SUMMARY OF SOCIAL COSTS OF PRIVATE TUBEWELLS
(Official Prices)

	Multan/Sahiwal Area					
	Diesel Tubewells			Electric Tubewells		
	Rupee costs	F.E. costs	Labour costs	Rupee, costs	F.E. costs	Labour costs
Running Costs						
Operation b/	1240	700	400	1300	140	40
Mainrenance	270	150	-	20	10	-
Repair	130	60	230	130	60	200
Subtotal	1640	910	630	1450	210	240
Variable Investment Costs						
Tubewell	460	260	250	350	150	160
Electrification	-	-	-	770	1180	-
Subtotal	460	260	250	1120	1330	160
Total Annual Variable Costs	2100	1170	880	2570	1540	400
Sunk Investment Costs	300	90	-	190	70	-
Maintenance & Repair	80	20	-	80	30	-
Total Annual Costs	2480	1280	880	2840	1640	400
Cost Per Acrefoot						
Running costs	7.8	4.3		6.9	1.0	
Total variable costs	10.0	5.6	4.2	12.2	7.3	1.9
Variable Plus fixed costs	11.8	6.1		13.58	7.8	

Notes: a) Engines, Motors, pumps, and miscellaneous items assumed to have a life of ten years. All other components assumed to have a life of fifteen years.

b) Operation costs based on assumed 2000 hours of operating time a year which is equivalent to approximately 210 acrefeet of water pumped.

Table XVIII-A

ALTERNATIVE GALUATIONS FOR SOCIAL COST OF PRIVATE TUBEWELLS[a]

	Gujranwala Area		Multan/Sahiwal	
	Diesel	Electric	Diesel	Electric
Case I. Foreign exchange value at 1.5 times the official rate				
Annual Costs				
Running costs	2290	1400	3000	1760
Total variable costs	2860	4080	3720	4820
Variable plus fixed cost	3260	4390	4170	5200
Variable plus fixed plus labour	3610	4580	4590	5390
Cost per acre foot				
Running costs	10.9	6.7	14.3	8.4
Total variable costs	13.6	19.4	17.7	23.0
Variable plus fixed costs	15.5	20.9	19.9	24.8
Variable plus fixed plus labour costs	17.2	21.8	21.9	25.7
Case II. Foreign exchange value at 2.0 times the official rate				
Annual Costs				
Running costs	2640	1490	3460	1870
Total variable costs	3300	4740	4280	5580
Variable plus fixed costs	3740	5090	4780	6000
Variable plus fixed plus labour costs	4100	5280	5200	6200
Cost per acrefoot				
Running costs	12.5	7.1	16.5	8.9
Total variable costs	15.7	22.6	20.4	26.6
Variable plus fixed cost	17.8	24.2	22.8	28.8
Variable plus fixed plus labour costs	19.5	25.1	24.8	32.4

(Cont'd on next page)

Table XVIII-A Contd:

	Gujranwala Area		Multan/Sahiwal	
	Diesel	Electric	Diesel	Electric
Case III. Foreign exchange value at 3.0 times the official ra				
Case III Foreign exchange value at 3.0 times the official rate				
Annual Costs				
Running costs	3340	1670	4370	2080
Total variable costs	4180	6060	5400	7100
Variable plus fixed costs	4700	6490	5990	7610
Variable plus fixed plus labour cost	5050	7190	6410	7800
Cost per acrefoot				
Running costs	15.9	8.0	20.8	9.9
Total variable costs	20.0	28.9	25.7	33.8
Variable plus fixed costs	22.4	30.9	28.5	36.2
Variable plus fixed plus labour cost	24.0	34.2	30.5	37.1

Notes: [a]/all assumptions same as in Table XVII-A.

Table XVIII-B

ALTERNATIVE VALUATION FOR SOCIAL COST OF PRIVATE TUBEWELLS[b]

	Gujranwala Area		Multan/Sahiwal	
	Diesel	Electric	Diesel	Electric
Case I. Foreign exchange value at 1.5 times the official rate				
Annual Costs				
Running cost				
Running cost	2290	1400	3000	1760
Total variable cost	2970	4140	3850	4880
Variable plus fixed cost	3430	4480	4400	5300
Variable plus fixed plus labour cost	3800	4670	4840	5500
Cost per acrefoot				
Running cost	10.9	6.7	14.0	8.4
Total variable cost	14.1	19.7	18.3	23.2
Variable plus fixed cost	16.3	21.3	21.0	25.2
Variable plus fixed plus labour cost	18.1	22.2	23.0	26.2
Case II. Foreign exchange value at 2.0 times the official rate				
Annual Costs				
Running cost	2640	1490	3460	1870
Total variable cost	3430	4810	4440	5650
Variable plus fixed cost	3940	5190	5040	6120
Variable plus fixed plus labour cost	4310	5380	5480	6320
Cost per acrefoot				
Running costs	12.6	7.1	16.5	8.9
Total variable cost	16.3	22.9	21.1	26.9
Variable plus fixed cost	18.8	24.7	24.0	29.1
Variable plus fixed plus labour cost	20.5	25.6	26.1	30.1

(Cont'd on next page)

Table XVIII-B Cont

	Gujranwala Area		Multan/Sahiwal	
	Diesel	Electric	Diesel	Electric
Case III. Foreign exchange value at 3.0 times the official rat				
Annual Costs				
Running cost	3340	1670	4370	2080
Total variable cost	4350	6150	5610	7190
Variable plus fixed cost	4950	6610	6320	7760
Variable plus fixed plux labour cost	5320	6800	6760	7960
Cost per acrefoot				
Running cost	15.9	8.0	20.8	9.9
Total variable cost	20.7	29.3	26.7	34.2
Variable cost plus fixed cost	23.6	31.5	30.1	37.0
Variable plus fixed plus labour cost	25.3	32.4	32.2	38.0

Notes: b) All assumptions same as in Table XVII-B.

of 2000 hours a year which is equivalent to about 210 acrefeet of water pumped.

V. CONCLUSIONS

In this paper we have investigated private and social costs of the private tubewells which have been such a significant aspect of West Pakistan's agricultural development. The data we have used in this analysis have come from several different studies, undertaken at different times and including tubewells installed over a ten to fifteen year period. In results presented in this paper we have grouped all the observations together regardless of when they were made or when the tubewell was installed. In doing so, we were ignoring any trend in costs which might be taking place over time. A sharp upward trend in costs might vitiate any application of our conclusions to policy decisions or what future private tubewell development would be desirable. Preliminary investigations indicated that such a trend might be occurring although in a statistical test, the year of installation provided very little expelanation of the variations in tubewell costs. On further investigation it was found that changes in the cost of blind pipe seemed to be responsible for most of these variations in average costs. When this possibility was investigated by obtaining price quotations for various years from dealers and manufacturers, the suspected importance of the price of blind pipe was confirmed, and it was found that the price of the other component had remained constant (except when there were certain improvements in quality) or decreased over time. The price of diesel engines, for instance, has shown a definite downward trend since 1960. To some extent this may reflect real reductions in costs, although reduced profits resulting from increased - perhaps excessive - competition would also seem to be an important cause. In any case, there is no indication of their being any trend towards higher prices which might affect our conclusions.

The most important conclusion to be drawn from our results is that there is a substantial divergence between the social and private costs of the two types of private tubewells, and that this divergence can be considered perverse in that it offers the investor substantial savings if he invests in the more expensive type of tubewell. Taking the Multan/Sahiwal area as an example. The total cost for the farmer per acrefoot of water pumped (using a discount rate of 15 per cent) is 18.2 rupees. The total cost to society, even without using any shadow price for foreign exchange, is 20.9 rupees (excluding labour). If a reasonable price were placed on foreign exchange, the social cost would be from 24.8 upto 36.2 rupees. Assuming the real value of foreign exchange is twice the official exchange rate, then water pumped from an electric tubewell in the Multan/Sahiwal area costs the farmer 63 per cent of what it costs the society.

For the diesel tubewell, however, the situation is just the reverse. The farmer's variable cost per acrefoot is

24.3 rupees and his full costs are 36.4 rupees. The full cost of the water to society evaluating foreign exchange at twice the official rate, is only 22.8 rupees less than the farmer's variable cost and about 63 per cent of his total costs. The government, particularly through the imposition of various taxes and subsidies, has created a pricing structure whereby the type of tubewell which is actually 25 per cent more expensive to it, appears to the farmer to be 50 per cent cheaper. This situation seems to be even more unreasonable when one considers the fact that over the past few years there have been a shortage in the supply of electricity in the Northern zone, so that the social cost of using electricity to pump water has probably been even higher than is indicated by considering only its foreign-exchange requirements. It would appear as if the government might consider methods of adjusting the relative prices of inputs into the diesel and electric tubewells so that the cost to the farmer more accurately reflected the cost to society.

A second question worth investigation is whether there are any way in which the costs of both diesel and electric tubewells can be reduced. This study has indicated at least two ways. The first would be to use engines and motors which are not so oversized as these presently in use. Although it would not appear to be a particularly rational pricing policy, diesel engines are priced (both in Pakistan and in England) at so much per horse power. Assuming that the rated horse powers are accurate, engines costing half as much as those now being installed would seem to be perfectly adequate. The same would be true of motors except that the savings would not be quite as great (from one large manufacturer, a ten-horse-power motor costs about 60 per cent as much as a 20-horse-power motor) and it would probably not be economical to make this change until voltage levels in rural distribution lines can be maintained at their proper level.

Another straight forward saving would be to protect the iron strips from which the coir string strainers are made from rusting. An easily applied inexpensive bitumen coating should do the job quite adequately [4, p.17]. Since the coir string doesn't rot or crack, this simple addition would most likely extend the tubewell's life substantially.

A third saving which is not so obvious, but could be quite important, involves the possibility of shutting off private electric tubewells during the periods of peak system load. This is known as load shedding. In Table XV, we estimated the cost of providing generation capacity for private tubewells to be about 5,500 rupees in Multan/Sahiwal and 4,200 rupees in Gujranwala/Sialkot/Gujrat. Eighty-five per cent of this cost is in foreign exchange. If some mechanism could be devised for shedding private tubewells during times of peak system load, this investmnt could be saved. The peak system load normally occurs during a certain time of day during a specific part of the year. In the Northern grid zone, the crucial period of the year is as much a function of the generating capacity as it is of the load on the system.[15/] Because there is a large component of hydroelectric power in the generating system, generation capacity will be at a minimum in the late Spring or Early Summer when the reservoirs are drawn down to their lowest level. If private tubewells could be shut off for two to four hours a day during the month of two of lowest generating capacity there would be no need to invest in extra generation capacity to supply them with electricity. At times other than these few hours a day during this period, generation capacity is surplus and therefore has no economic cost.

Of course for the past couple of years at least, private tubewells have been shed from the system - often for much longer than a couple of hours - by the simple expedient of cutting off whole rural distribution lines. In the longer run, however, this may be thought to be undesirable, for it requires shutting off all the other residential, commercial and industrial loads on the feeder as well.

Private tubewells could, off course, be fitted with devices which would automatically shut them off individually during peak hours, allowing the other loads to continue uninterrupted. Since the private tubewell has substantial excess capacity, there would be no need to worry about this reducing

---

15/ The authors wish to thank Mr.W.C.F. Bussink for bringing this point to their attention.

the amount of water pumped. Such devices might take one of several forms. They could be simple timers which would shut off the power for these four hours. Due to the present unreliability of the power supply, however, such timers would rapidly swing out of adjustment - leaving the tubewell on during the peak hours and shutting it off at non-peak hours unless some special precaution were taken, The timers could be readjusted once a month by the meter reader or by some automatic means such as a photoelectric cell or singals sent over the power wires. The latter method is proposed by the Bank's power consultants as a feasible and economic means of shedding public tubewells /̄28, p.25_7. There is no reason why it couldn't be used for private tubewells as well. The cost of any of these regulators wouldmost certainly be less than the 4,200 to 5,500 rupees estimated as the cost of providing generation capacity for a private tubewell. If such a device for instance, cost 500 rupees per well, the savings resulting from its use would amount to 500 to 670 rupees per year, most of which would be in foreign-exchange costs of the private electric tubewell, and about one-seventh of the total annual cost. Such a saving would reduce the cost per acrefoot of water three to six rupees (depending upon the shadow price used for foreign exchange).

A final conclusion that can be reached from this study is that given the nature of the industries supplying parts for private tubewells, it really isn't very important if sunk costs are included or excluded from total costs. There is only about a 10-per-cent difference between total variable plus sunk costs. This is probably less than the margin of error in our computations. Nevertheless, it is clear that in making decisions about future policy in groundwater expolitation, society should carefully consider the size and composition of the industry which has been built up in support of private tubewells. If private tubewells were to be suddenly superseded by public tubewells, for instance, the effects would not be limited to the farmer alone. This problem, of course, can be taken into account in any reasonable economic analysis. It should only be kept in mind that the decision about how to proceed from here may differ from the conclusion about how one should have started in the beginning.

REFERENCES

1. Ahmad, Dr. Nazir — Measuring Discharge of Tubewell Water. (Lahore,Scientific Research Stores,nd).

2. Ahmad, Dr. Nazir — "Some Experience with Tubewells in the Alluvium ofthe Indus Plains", The Pakistan Engineer, April 1968.Pp 160-196.

3. Ahmad, Dr. Nazir — Tubewell Pumping Machinery and their Trouble Shooting. Reprinted from Engineering News, Quarterly Journal of West Pakistan Engineering Congress, Volume 12, No. 1, March 1967 Issue Lahore.

4. Ahmad, Dr. Nazir — Utilization of Ground Water - Its Technique. (Lahore; Scientific Research Store, Akhari Road, n.d.).

5. Ahmad, Dr. Nazir & Sh. Mohd Sadiq — Performance Data of Private Coir String Strainers Tubewells. Publication No. 317-PH/T.W.-77/66. (Lahore; Irrigation Research Institute, West Pakistan, n.d.).

6. Ahmad, Dr. Nazir & Sh. Mohd Sadiq — Performance of Tubewells in Gaja Area. Special Report No:314-PH/T.W.-76/66. (Lahore: Irrigation Research Institute, West Pakistan, n.d.).

7. Ghaffar, Mohammad & Edvin H.Clark-II — Installation of Private Tubewells in West Pakistan 1964-67. Statistical Series on Private Tubewell Development in West Pakistan.Mineographed Research Report No.71. (Karachi: Pakistan Institute of Development Economics, July 1968).

8. Ghaffar, Mohammad, Amir Mohammad, & Edvin H. Clark-II — Size of Holdings of Private Tubewell Owners. Statistical Series on Private Tubewell Development in West Pakistan. Mimeographed Research Report No.69. (Karachi: Pakistan Institute of Development Economics).

9. Harza Engineering Company International, A Sample Survey of Private Tubewells and Farms - Gujranwala Area (Lahore: West Pakistan WAPDA, April 1967).

10. Harza Engineering Company International, Reconnaissance Survey of Private Tubewells. (Lahore: West Pakistan, WAPDA, February 1965).

11. Harza Engineering Company International, Unpublished data from Private Tubewell Survey.

12. Irrigation and Agricultural Consultants Association(IACA), Programme for the Development of Irrigation and Agriculture in West Pakistan, Volume 5, Water Supply and Distribution. London & Arnhem: International Bank for Reconstruction and Development, May 1966).

13. IACA: Programme for the Development of Irrigation and Agriculture in West Pakistan, Volume 9, Farm Surveys. I.B.R.D., (London and Arnhem; International Bank for Reconstruction and Development, May 1966).

14. IACA: Programme for the Development of Irrigation and Agriculture in West Pakistan, Volume 10, Water Course Studies, (London and Arnhem: International Bank for Reconstruction and Development, May 1966).

15. IACA: Programme for the Development of Irrigation and Agriculture in West Pakistan, Volume 12, Annexure-15-B, Bari Doab Project Reports. (London and Arnhem: International Bank for Reconstruction and Development, May 1966).

16. Khan A.R. & Arthur MacEwan, "A Multi-Sectoral Analysis of Capital Requirements for Development Planning in Pakistan",The Pakistan Development Review, Vol. VII, No.4, Winter, 1967. Pp. 445-484.

17. Mohammad, Ghulam "Private Tubewells Development and Cropping Pattern in West Pakistan", Pakistan Development Review, Volume V, No. 1, Spring 1965. Pp. 1-53.

18. Mohammad, Ghulam & Ecvin H. Clark "Ground Water Development in West Pakistan, An Analysis of the IBRD's Recommendations" unpublished Article.

19. Pakistan Institute of DevelopmentEconomics Unpublished Data from the Surveys on Cropping Pattern 1965 and source of Finance of 1967.

20. Tipton and Kalmbach Inc., Engineers *Salinity Control and Reclamation Programme, Project No.4, Upper Rechna Doab.* (Lahore: West Pakistan WAPDA June 1965).

21. Tipton and Kalmbach Inc. Engineers) *Ground Water and Reclamation Programme, Project No.5, Lower Rechna Doab,* (Lahore: West Pakistan WAPDA, August 1966).

22. Weston, J.W. *Small Scale Production of Slow Speed Diesel Engines: Results of Technical Survey of the Privately owned Factories in Lahore.* Revised Issue. (Lahore: Superintendent, Government Printing for West Pakistan Department of Industries, 1962).

23. West Pakistan Bureau of Statistics "Census of manufacturing Industries in West Pakistan. 1963/64". Unpublished.

24. West Pakistan, Planning and Development Department (Projects Wing), *Implementation Plan for the West Pakistan Food Self-Sufficiency Programme (1965-70).* (Lahore: Superintendent, Government of Pakistan, West Pakistan, August 1967).

25. West Pakistan Small Industries Corporation. Unpublished data from Survey and Evaluation Wing, (Lahore WPSIC).

26. World Bank Staff, Headed by Dr, P. Licftinck *Study of the Water and Power Resources of West Pakistan, Volume II, Programme for the Development of Irrigation and Agriculture.* (London IBRD, July 28, 1967, Pp. 1-88).

27. World Bank Staff, Group Headed by Dr. P. Licftinck *Study of the Waterand Power Resources of West Pakistan, Volume IV, Programme for the Development of Power,* (IBRD, July 28, 1967).

28. World Bank Staff, Group Headed by Dr. P. Lictinck: *Study of the Waterand Power Resources of West Pakistan Volume IV, Programme forthe Development of Power, Annex. I*, (IBRD, July 28, 1967).

29. World Bank Staff, Group Headed by Licftinck: *Study of the Waterand Power Resource of West Pakistan, Volume IV, Programme for the Development of Power, Annexure 4*, (IBRD, July 28, 1967).

30. Yasin, M. Ghulam *The Economics of Tubewell Irrigation.* Publication No. 133 (Lahore: The Board of Economic Engineering, Punjab (P).

APPENDIX A

FREQUENCY OF REPAIRS

The data on the frequency of the various types of private tubewell repairs are fragmentary and difficult to interpret. We have had to devise a method of analysis which would permit the quoted to be made of the specific data available. The method is based on the frequency of repair table presented in the appendix. In these tables the vertical axis shows the number of years between the time of installation of the tubewell and the time the survey was made. The column on the far right, then, shows the total number of tubewells in each age group. The horizontal axis indicates three things: the number of years between installation and the first repair, the number of years between any repair and a subsequent repair, and the number of year since the last repair. The number of observations on the time to repairs and the time between repairs are combined and enterred above the horizontal line in each cell. The number of observations giving the time since the last repair are enterred between the horigontal line. As an example, Table A-I indicates that there were thirteen tubewells that were six years old. None of these tubewells required redrilling in the same year, a new bore had been made, but one required it after one year, five after two years, two after three years, one after four years, and one after six years. Eight of the tubewells had never required redrilling. For the other five, three had required their most recent redrilling the year the survey was made, one had last required it one year previously, and the other one two years previously. Thus five tubewells had required a total of ten redrilling and eight had required none.

The total of each column is given at the bottom. The average of the tubewell is computed from the age distribution of all tubewells (far right column) by the following formula:

$$\bar{T} = \frac{\sum_{t=o}^{T^*} tn_t}{N}$$

Where $\bar{T}$ = average age of tubewells in sample

T^*= age of oldest tubewell

t = age of tubewell measured in years

n_t= number of tubewell of age t

$N = \sum_{t=o}^{T^*} n_t$: total number of observations

The average time to repairs was computed in the same manner from the time distribution of all repairs (the number above the horizontal line in the last row); and the average time since repairs from the time distribution of the sum of these observations (the numbers below the horizontal line in the bottom row). The average frequency of repairs was when computed by the method explained in the text of this paper.

APPENDIX TABLE A-1 FREQUENCY OF REDRILLING

Number of Years to and since Redrilling

Age of the well - years	0	1	2	3	4	5	6	7	8	9	10	11	12	13	Total Observations
0	0/21														21
1	0/0	0/31													31
2	2/2	2/2	2/39												43
3	0/0	3/5	4/1	0/28											34
4	1/1	0/1	5/3	1/0	0/7										12
5	0/2	3/2	3/1	2/1	2/0	0/5									11
6	0/3	1/1	5/1	2/0	1/0	0/0	1/8								13
7	0/0	1/0	0/1	0/0	0/0	1/0	0/0	0/6							7
8	0/0	0/0	0/0	0/1	0/0	1/0	0/0	0/0	0/3						4
9	0/1	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/0					1
10	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/3				3
11	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0			0
12	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/1		1
13	0/0	0/0	0/1	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/0	0/0	0/0	1
Total	3/30	10/42	19/47	5/30	3/7	2/5	1/8	0/6	0/3	1/0	0/3	1/0	0/1	0/0	45/182

Average age of well = 2.99 years Average time to repairs = 2.47 years

Average time since Ist repair = 2.39 years
Computed average time between repairs = 4.10 years

APPENDIX TABLE A-2 FREQUENCY OF ENGINE REPAIRS

Number of years to andsince repair of engine

Age of the engines = years

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
0	$\frac{2}{3}$														13
1	$\frac{3}{2}$	$\frac{2}{18}$													20
2	$\frac{3}{3}$	$\frac{7}{7}$	$\frac{3}{17}$												27
3	$\frac{6}{5}$	$\frac{5}{4}$	$\frac{4}{0}$	$\frac{3}{15}$											24
4	$\frac{0}{0}$	$\frac{0}{1}$	$\frac{0}{0}$	$\frac{1}{0}$	$\frac{0}{2}$										3
5	$\frac{1}{0}$	$\frac{3}{2}$	$\frac{1}{0}$	$\frac{0}{0}$	$\frac{1}{1}$	$\frac{0}{1}$									4
6	$\frac{0}{0}$	$\frac{2}{1}$	$\frac{0}{0}$	$\frac{2}{1}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{2}$								4
7	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{1}{1}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{1}{1}$	$\frac{0}{0}$	$\frac{0}{2}$							4
8	$\frac{0}{1}$	$\frac{7}{0}$	$\frac{1}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{1}$						2
9	$\frac{0}{0}$	$\frac{2}{0}$	$\frac{0}{1}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{1}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$					1
10	$\frac{0}{0}$	$\frac{0}{1}$	$\frac{4}{1}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{1}{0}$	$\frac{0}{0}$				2
11	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$			0
12	$\frac{0}{0}$	$\frac{0}{1}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{1}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{1}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$		1
13	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{1}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{1}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	1
Total	$\frac{15}{24}$	$\frac{28}{35}$	$\frac{14}{21}$	$\frac{6}{16}$	$\frac{2}{3}$	$\frac{2}{2}$	$\frac{0}{2}$	$\frac{1}{2}$	$\frac{0}{1}$	$\frac{1}{0}$	$\frac{0}{0}$	$\frac{1}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{70}{106}$

Average age of engine = 2.83 Average time to repairs = 1.70
Average time since last repair = 1.71 Computed average time between repairs = 2.39

APPENDIX TABLE A-3 FREQUENCY OF MOTOR REPAIRS

Age of the motor - years	Number of years to and since repairs of Motor														
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
0	0/6														6
1	1/0	0/11													11
2	1/0	2/2	0/12												14
3	1/3	2/2	2/0	2/5											10
4	4/1	2/3	1/0	3/0	0/4										8
5	3/3	1/0	0/1	1/0	1/0	2/2									6
6	0/1	2/1	0/1	1/0	1/0	0/0	1/3								6
7	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/2							2
8	0/1	0/0	1/0	0/0	0/0	0/0	0/1	0/0	1/0						2
9	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0					0
10	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/1				1
11	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0			0
12	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/00		0
13	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0
Total	10/15	9/19	4/14	7/55	2/4	2/2	1/4	0/2	1/0	0/0	0/1	0/0	0/0	0/0	36/66

Average age of motor = 3.14 Average time to repairs = 1.94 Average time since last repair = 2.06 Computed average time between repairs = 2.86

Appendix Table A-5 FREQUENCY OF OTHER REPAIRS

Number of years to or since repair of other parts

Age of other parts - years	0	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
0	20/1														21
1	2/1	1/30													31
2	1/2	3/3	2/38												43
3	4/3	7/4	2/1	2/25											33
4	0/0	0/0	0/0	0/0	0/11										11
5	0/1	0/0	0/0	0/0	0/0	1/10									11
6	0/2	2/0	0/0	0/0	1/0	0/0	1/11								13
7	0/0	2/1	2/1	0/1	1/0	1/0	0/0	0/3							6
8	0/0	2/1	0/0	0/0	0/0	1/0	0/0	0/0	0/3						4
9	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/1					1
10	0/0	0/0	0/0	0/0	0/1	0/0	1/0	0/0	0/0	0/0	0/2				3
11	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0			0
12	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/1		1
13	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/1	11 179
Total	7/30	17/39	6/40	2/26	2/12	3/10	2/11	0/3	0/3	0/1	0/2	0/0	0/1	0/1	39/179

Average age of other parts = 2.97 years
Average time to repairs = 1.79 years
Average time since last repair = 2.57 years
Computed average time between repairs = 4.32 years

APPENDIX TABLE A-4 FREQUENCY OF PUMP REPAIRS

Number of years or since repairs of replacement of pumps

Age of the pump - years	0	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
0	$2\frac{3}{1}$														21
1	$\frac{1}{0}$	$\frac{0}{31}$													31
2	$\frac{4}{5}$	$\frac{4}{4}$	$\frac{3}{33}$												42
3	$\frac{0}{5}$	$\frac{0}{6}$	$\frac{6}{0}$	$\frac{4}{22}$											33
4	$\frac{0}{0}$	$\frac{0}{1}$	$\frac{1}{1}$	$\frac{1}{0}$	$\frac{0}{9}$										11
5	$\frac{0}{1}$	$\frac{2}{1}$	$\frac{2}{0}$	$\frac{0}{1}$	$\frac{0}{0}$	$\frac{1}{8}$									11
6	$\frac{0}{0}$	$\frac{0}{1}$	$\frac{1}{0}$	$\frac{1}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{12}$								13
7	$\frac{0}{0}$	$\frac{2}{2}$	$\frac{3}{0}$	$\frac{0}{0}$	$\frac{1}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{4}$							6
8	$\frac{0}{1}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{1}{3}$						4
9	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{1}$					1
10	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{1}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{1}{0}$	$\frac{0}{0}$	$\frac{0}{2}$				3
11	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$			0
12	$\frac{0}{0}$	$\frac{0}{1}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{1}{0}$	$\frac{0}{0}$		1
13	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{0}$	$\frac{0}{1}$	1
Total	$\frac{8}{33}$	$\frac{8}{47}$	$\frac{16}{35}$	$\frac{6}{23}$	$\frac{1}{9}$	$\frac{1}{8}$	$\frac{0}{12}$	$\frac{0}{4}$	$\frac{2}{3}$	$\frac{0}{1}$	$\frac{0}{2}$	$\frac{1}{0}$	$\frac{0}{0}$	$\frac{0}{1}$	$\frac{43}{178}$

Average ave·of pump = 2.97 years
Average time to repairs = 2.19 years
Average time since last repair = 2.40 years
Computed average time between repairs = 3.94 years.