A PROCEDURE FOR EVALUATING THE COST OF LIFTING WATER FOR IRRIGATION IN EGYPT

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Foreword

This paper presents an analytical method of comparing alternative systems for lifting water from tertiary delivery canals to farmers' fields. The method is then illustrated using data sets from two different sources. Then cost functions are tested for sensitivity by altering the magnitude of selected variables such as fuel prices and length-of-day the systems operate.

Policy and decision makers are invited to use the analytical method by placing their own values on variables. Appendix C contains a blank input form which can be used for processing alternative data. The computer program is available at the EWUP offices in Cairo.

Acknowledgements

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by

Hassan Wahby, Gene Quenemoen and Mohamed Helal[1/]

The purpose of this report is to (1) present a procedure for computing water lifting costs for Egyptian farms and (2) identify the most important factors which determine these costs.

These factors may be classified as economic, technical and governmental policy. Economic factors reflect the dynamic world economic situation and are expressed in terms of international prices for such things as energy, machines and food. Technical factors reflect the state of the arts and innovations regarding machines, energy sources, pumps and methods of production. Policy factors refer to such things as government pricing of energy, policies regarding scheduling water among farmers, rotation turns, crop production quotas, and taxes on imported water lifting equipment. Since all these factors tend to change through time and through deliberate action of government it is more important to understand the components of water lifting costs than the absolute values shown in this or any other study.

This report is intended to assist government decision makers evaluate water lifting alternatives. As capital becomes available for implementing new agricultural and irrigation schemes it is important to use it wisely in order to realize the maximum benefit for the Egyptian people. Proposals should be evaluated according to their potential rate of return and how well they fit the values and cultural patterns of Egyptian people.

BACKGROUND

As a general rule irrigation distribution systems in Egypt are designed to deliver water 50 to 60 centimeters below the surface level of fields. Farmers lift the water from the delivery canals. There are exceptions. Some farmers are able to take water from delivery

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canals and apply it directly to their fields by gravity. Some analysis conducted by the Ministry of Irrigation, show that "free flow irrigation has caused an extravagance in the use of irrigation water."[1/] It is currently government policy to design all delivery systems such that farmers must lift the water onto their fields.

At the same time there is interest in the government sector and among farmers in lifting water with machine driven pumps to replace human and animal power.[2/] Because of increasing costs of human labor and animal power, farmers feel economic pressure to consider alternative methods of lifting water to their fields. Some farmers are installing animal driven water wheels to replace human powered tambours while others are shifting to diesel and electric driven pumps.

Human power is used to operate the shadouf (bucket and counter balance weight on a pole) and the tambour (archimedes screw). Only the tambour is currently important in Egypt's commercial agriculture. The shadouf, now virtually obsolete, is used only by gardeners and a few very small farmers. Neither of these systems will be considered further in this report. Although the use of tambours may continue for some years their cost is almost entirely a function of labor wages or value determined by the principle of opportunity costs. Only a few small farmers who assign very low opportunity cost to their own labor find it economically advantageous to use tambours.

Animal power is used to operate various types of sakias (water wheels). In rare cases animals are used to power tambours and other miscellaneous types of pumps. The cow is the most important source of animal power for turning sakias but water buffalo, donkeys, and camels are also used.

Electric and diesel motors are most frequently attached to various types of low pressure pumps. In the lower delta some large sakias are powered by stationery diesel motors and sometimes tractors. Also available is a small electric motor with a transfer reduction system to provide power for sakias.

1/ The Ministry of Irrigation, The Minister's Office, "National Program in Irrigation and Drainage - General Policies," Cairo September 1978, page 16.

2/ Ibid, p. 18

There have been several studies during the past five years to evaluate alternative water lifting systems for Egyptian farms. Various technical relationships and assumptions have been used regarding present and future energy costs, the value of labor, capacity of lifting devices, irrigation frequency, crop requirements and the number of hours per day that farmers can be expected to use any given irrigation system. This study offers a flexible analytical device that decision makers can use now and in the future as more and better data become available. Egyptian planners need such a model to help them make profitable decisions and conversely to help them avoid making commitments to long range capital investment projects which fail to maximize the benefits from scarce resources.

THEORETICAL CONDITIONS

Each system of lifting water has a limited physical capacity to deliver irrigation water to a field. This limit depends on the lift head (vertical distance from the water source to the field distribution system), the capacity of the driver and pump system, the crop needs for water at the peak season of use and the maximum number of hours that farmers will operate the system on any given day.

Each system is subject to annual fixed and variable costs. Total annual costs, fixed and variable, are used to compare alternative systems in this report. Once a decision is made to own any specified lifting system there are annual <u>fixed</u> costs such as taxes, interest on investment, and insurance which accrue each year whether the system is used or not. They are not related to the amount of use the system is given in a year. The total annual <u>variable</u> costs, on the other hand, are directly related to the amount of time the system is operated. For example each unit of output requires some fuel, oil, grease, repairs and wear-out depreciation.[1/] Total annual costs may be expressed algebraically as in equation (1).

[1/] Theoretically every machine has a finite life which is a function of the amount of use given the machine. In some situations machines may be expected to become obsolete before their wear-out life is reached. Then depreciation should be treated as a function of time and the depreciation for one year should be considered as annual fixed costs. However in systems such as water lifting characterized by slow rates of technological change, it is probably appropriate to consider depreciation to be a function only of use since technological obsolescence is unlikely.

$$TC = TFC + TVC \quad (1)$$

where: TC is total annual cost,
TFC is total annual fixed cost,
TVC is total annual variable cost,

This report also uses the concepts of average annual unit fixed and variable costs for comparing alternative systems. They are referred to as "unit costs" in this report since they represent total costs divided by units of output or work done. This is represented algebraically in equation (2).

$$\frac{TC}{X} = \frac{TFC + TVC}{X} \quad (2)$$

where: X is units of output or work done,

$\frac{TC}{X}$ is defined as unit total costs or UTC,

$\frac{TFC}{X}$ is defined as unit fixed costs of UFC,

$\frac{TVC}{X}$ is defined as unit variable costs or UVC,

The general relationship between unit fixed and variable costs are shown in Figure 1. In this report units of work are measured in terms of output horsepower (HP) hours and also, in the Tables 2 through 7, in terms of number for feddans irrigated. Output HP hours is defined in equation 12 on page 13. From this equation we can deduce that one output horsepower hour measures the work required to lift 270 cubic meters of water for one irrigation, lifted one meter, then we know it requires one HP hour of work. With a known irrigation requirement, equation 12 allows easy substitution between "HP hours" and "numbers of feddans irrigated" as a measure of work.

Unit variable cost (UVC) may represent cost per HP hour and it is constant for each HP hour the water lifting system is used. Unit total cost (UTC) represents the unit variable cost per HP hour plus the unit fixed cost per HP hour. The unit fixed cost, for any given number of HP hours, is the vertical distance between the lines UVC and UTC in Figure 1. Since the unit fixed cost per HP hour declines as the number of HP hours increased it can be observed in Figure 1 that the unit total

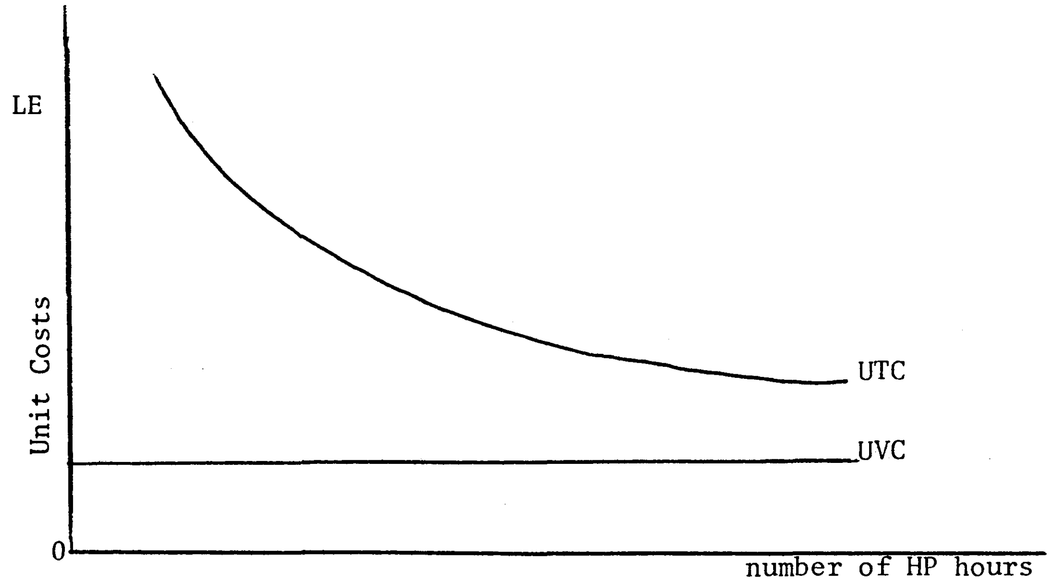

Figure 1. Hypothetical Relationship Between Unit Fixed, Variable and Total Costs.

cost per HP hour also declines. From this we can conclude there is no single unit total cost that can be assigned to any water lifting system without specifying the amount of annual use for which the system is to be employed.

AN ANALYTICAL MODEL

An analytical model for computing water lifting cost functions has been developed to assist in evaluating alternative systems.[1/] Twenty-three variables have been identified and integrated into the model. Each variable is subject to change through time as a result of economic, technical or political considerations.

Each variable, included in the DATA INPUT FORM - WATER LIFTING COSTS, shown on page 6, is discussed below. It is especially

[1/] This model is an adaptation of previous EWUP work reported in McConnen, R. J., Mohamed Helal, Ahmed Bayoumi, Gamal Ayad, James Loftis, and M. E. Quenemoen, "Calculation of Machinery Costs for Egyptian Conditions," Staff Paper #8, Egypt Water Use and Management Project, Cairo, December 1979.

DATA INPUT FORM - WATER LIFTING COSTS

Data prepared by ______________________ Date ______________

Tape ; Track ; File

A$ (*)	
1. Name of machine ....(19)	1. ________
2. Make ....(19)	2. ________
3. Model ....(9)	3. ________
4. Size ....(9)	4. ________
5. Power source (DIES. ELEC. ANIM.)	5. ________
6. Date (day, month, year) DDMMYY ....(12)	6. ________
A *	
1. Present replacement price in Egypt, LE ....(12)	1. ________
2. Wearout life, hours ....(12)	2. ________
3. Expected average repair cost, LE/hour ....(12)	3. ________
4. Fuel consumption, liters/hour ....(12)	4. ________
5. Fuel cost, LE/liter ....(12)	5. ________
6. Oil cost, LE/100 hours ....(12)	6. ________
7. Grease cost, LE/100 hours ....(12)	7. ________
8. Electric energy required, kilowatt hours 2/ ....(12)	8. ________
9. Electricity cost, LE/kilowatt hour ....(12)	9. ________
10. Salvage value at end of wearout life, LE ....(12)	10. ________
11. Taxes, license, permits, rent, etc., LE/year ....(12)	11. ________
12. Interest rate, percent ....(12)	12. ________
13. Operator or labor cost, LE/hour ....(12)	13. ________
14. Discharge of pump, cubic meters/hour ....(12)	14. ________
15. Animal energy cost, LE/hour ....(12)	15. ________
16. Overall efficiency, decimal from .01 to 1.0..........(12)	16. ________
17. Engine efficiency, decimal from .01 to 1.0...........(12)	17. ________
18. Static head, meters 3/ ....(12)	18. ________
19. Dynamic head, meters 4/ ....(12)	19. ________
20. Water duty per year, cubic meters/feddan ....(12)	20. ________
21. Maximum time system will run per day, hours ....(12)	21. ________
22. Minimum irrigation interval, days ....(12)	22. ________
23. Maximum water required per irrigation, cu. meters/fed.(12)	23. ________

1/ Maximum characters allowed.

2/ Kilowatt hours = $\frac{\text{Discharge in } m^3/\text{hr x Dynamic head in m.}}{\text{362 x Overall Efficiency x Engine Efficiency}}$

3/ Static head is defined as the distance between the water level in the delivery canal or pump station well and the water level required in field distribution ditch.

4/ Dynamic head is defined as the difference between the water level in the delivery canal or pump station well at the point of suction and the discharge point of the pump plus losses.

important for policy makers to understand these variables since they are not simply "facts." Considerable latitude exists for assigning values to some of these variables depending on what assumptions one makes and what national policies one wishes to advocate. Consequently policy makers should be involved in determining the values assigned to each variable.

Users of the model may make adaptations to other specifications which they consider important. For example the model does not explicitly consider field irrigation efficiency and design of field ditches. It might be argued that larger flow rates, possible with electric and diesel pumps, result in higher field irrigation efficiency and require less land for field ditches and bunds. This could be accounted for by adjusting water application variables, items 20 and 23 below, and also making a rental charge in item 11 for land devoted to ditches and bunds.

Components of the Model

1. Present replacement cost in Egypt. This is a relatively sensitive variable, especially if high interest rates are used. The "cost" of a water lifting system depends on equipment quality, customs taxes, government subsidies and related infrastructure. In the case of an electric powered system should the initial cost include transformers and transmission lines? Such questions should be considered before assigning capital costs to the analytical model.

2. Wearout life is difficult to determine but not highly sensitive in the total analysis. It is related to maintenance or repair costs and initial quality of the equipment used in the system.

3. Expected average repair cost. Reasonable estimates of repair costs should be used. Records of existing systems provide the best basis for making this estimate. Training programs for machine operators can help to minimize maintenance and repair costs.

4. Fuel consumption is specified by the manufacturer of internal combustion engines. Records from engine users are helpful in determining fuel consumption under field conditions.

5. Fuel cost is often affected by government subsidies. For example diesel fuel presently costs Egyptian farmers L.E. 0.03 per

liter while the international price for diesel fuel is at least L.E. 0.14 per liter.[1/] Policy makers may wish to use projected future energy prices in evaluating alternative systems.

6. Oil cost varies for different types of internal combustion engines. Follow manufacturer's recommendations. Use of adequate, clean lubrication minimizes repair and maintenance costs.

7. Grease cost is usually a minor item but also related to repair and maintenance cost and wearout life.

8. Electric power required to operate a water lifting system is related to the condition of the equipment. It should be consistent with the other parameters of the system. The equation shown as footnote 2 on the data input form, page 6 , is used to determine electrical energy requirements.

9. Electricity cost. In Egypt electricity is produced and distributed by the government. The price charged to farmers does not necessarily reflect the cost of producing and distributing electricity. Currently small consumers are charged L.E. 0.015 per kilowatt hour. One report from 1977 indicates the cost of producing and distributing new power in Egypt with petroleum fuel is L.E. 0.0932 per kilowatt hour.[2/] Increases in the international price for petroleum since 1977 have undoubtedly made thermal generation of electricity more expensive.

The appropriate price to charge for electricity to lift water is debatable. Some argue that daytime use of electricity will help to "...obtain the optimum use of Rural Electrification..." in Egypt.[3/] As in the case of diesel fuel policy makers will perhaps wish to make long run price projections.

1/ For a discussion of the difference between financial and economic costs see Pacific Consultants, "New Lands Productivity in Egypt - Technical and Economic Feasibility," AID Contract No. AID/NE-C-1645, Project No. 263-0042, January 1980, pp. 17-18.

2/ Technical and Economic Feasibility of Electrifying Tertiary Pumping Means in Middle and Upper Egypt, Ministry of Irrigation, Mechanical and Electrical Department, Louis Berger International Inc., 1977, see pages 135-136. Also see Pacific Consultants, op.cit., p. 18.

3/ Nasser, Abdel Hady Bary, "Feasibility Study of Electrification of Irrigation Means: Animal Driven Water Wheels and Diesel Pumps, in Menoufia Governorate," Engineering Research Bulletin, Vol. 1, Part 1 Faculty of Engineering and Technology, Shebin El-Kom, 1978, page 72.

10. Salvage value is included as a variable in the model to handle the wearout life difference in system components. For example a motor may wearout in 10,000 hours while the pump may have a life of 20,000 hours. In this case the value of the pump at the end of 10,000 hours can be considered as salvage value for the total system. Unit costs for long-life water lifting systems are not likely to be highly sensitive to alternative salvage values.

11. Annual taxes, license, permits, land rent, etc., includes all the possible fixed charges that may be imposed or otherwise required for owning a system. In the case of sakias a convenient method of charging for the land occupied by the sakia is to use the annual market rate of land rent for the specified area.

12. Interest rate. Capital usually has alternative uses. The opportunity interest cost of investing in a water lifting system is the rate of return capital would earn in its next best alternative. Although somewhat subjective, this principle can serve policy makers as a guide in assigning a capital charge to investment alternatives. If the capital is available as a loan and other alternatives are not to be considered, then use the interest rate according to the terms of the loan. If, on the other hand, financing is to be provided out of limited funds that could also be used for other purposes, it is important to use an interest rate which reflects the estimated return from the alternative purposes. This is the concept of "opportunity cost."

13. Operator or labor cost. All water lifting systems require some labor. In the case of a sakia a laborer is required to drive the animal. In the case of diesel or electric pumps, labor is required for pump attendants, to keep pipes clean and attend other details necessary for efficient operation. If a highly trained technician serves only one lifting system the hourly cost will be relatively high. If he can serve more than one system and/or perform other labor while operating the system, the cost will be appropriately reduced. There is a relationship between labor cost and other variables such as repairs and wearout life. Well paid, highly trained labor may tend to offset some other costs.

14. Discharge of the pump. An important assumption regarding the discharge of sakias and pumps is that the delivery canal must maintain a uniform water level at the pumping station. Data showing the discharge of sakias often reflects the effects of a fluctuating head. Conversely the discharge assigned to electric and diesel pumps may reflect the manufacturer's specifications at constant head. The delivery canal must be an integral part of any lifting system. In order for any system to operate efficiently and at capacity it must have an adequate supply of water at the point of suction, preferably of a uniform head.

15. Animal power cost is one of the most difficult variables to measure. It is common knowledge that most farmers depend on animals for transportation since field access roads are very limited. They also keep animals for the production of meat, milk, fuel, fertilizers and as a store of wealth or capital. However the measurement of these factors is often quite illusive.

If one assumes animals are kept primarily for power and all animal production costs are assigned to power, then the cost is relatively high. On the other hand if one assumes animals are kept more for the other uses and assigns only the marginal costs to power, then the cost is relatively small. In some cases where the work on a sakia is very light and spread among many animals it may be trivial. Some farmers believe a small amount of work only fulfills normal exercise for the animal and costs nothing.

There is also an assumption made by some that if the work requirement for animals were eliminated they would be replaced by animals specialized in meat and milk production. This could increase meat and milk production from a given feed base but may require a substantial training program to introduce new breeds, new feeding technologies, new marketing systems, etc.

Another possibility is that reducing the work requirements for animals will permit reduction of livestock numbers and production of human food on land formerly used to produce animal feed. Whether this would happen is also, of course, debatable.

Since there are only limited empirical data regarding these issues it is natural that wide variations exist in estimates of animal power costs. EWUP is engaged in further study of this issue. Literature reviews are in progress and research is planned to compare areas of gravity irrigation (where animals are not used for lifting water) with areas that are dependent on animal driven sakias for irrigation.

16. Overall efficiency refers to the pump and the drive (system of coupling between the engine and pump). Pump efficiency is specified by most pump manufacturers but may be adjusted downward to reflect efficiency under average field conditions. Standard engineering references suggest efficiencies for direct drive, right angle drive, vee belts, flat belts, etc. The overall efficiency is the product of the pump efficiency and the drive efficiency.

17. Engine efficiency is usually specified by the manufacturer for electric and diesel engines. It may be adjusted downward to properly reflect average field conditions. In the case of sakias, efficiencies can be calibrated to electric pumps where efficiencies and discharge rates are known. This is shown in Appendix B.

18. Static head is defined, for purposes of this model, as the distance between the water level in the canal or pump station well and the water level in the field distribution ditch.

19. The dynamic head includes the static head plus pumping system losses.

20. The water duty per year is the amount of water that must be lifted from a delivery canal to a field given a particular crop rotation. Of course it can be adjusted for specified locations, cropping sequences, and crop yields during a given year. It should include water needed for evapotranspiration plus leaching requirements under given conditions of field irrigation efficiency.

21. Maximum time the system will run per day should reflect the realities of farm and village cultural patterns. Longer period of operation per day will reduce unit costs of lifting water and will increase maximum area to be served but the system will not operate as planned unless it is compatible with values of farmers. The government of course, may use various methods of coercion or reward system to get farmers to comply with alternative working day lengths.

22. Minimum Irrigation Interval. This variable, expressed in days, effects the size of the area to be served by the system.

If during the peak irrigation season, the system operates at the capacity consistent with its discharge rate, water requirement and time parameters, a certain number of days will be required to cover a specified area. The first area irrigated will then have gone without water for that number of days. This is the concept of "minimum irrigation interval." If the number of days in the interval is lowered then the area served by the system will be reduced accordingly by the program. Under water rotation turns ("off" and "on" periods) the minimum interval should be the same as the days in the "on" period if it is desired that the system have capacity to irrigate all the land served with a "maximum irrigation" during one "on" period.

The cropping pattern and the consumptive use of specified crops during the peak irrigation period also influences the value which should be placed on this variable. For example shallow rooted crops require frequent but light irrigations, especially during July and August.

23. Maximum water required per irrigation. This variable also is part of the equation for setting the limit on the area to be served by the system. It is related to "minimum time between irrigations" in that shallow rooted crops may require less water per irrigation but more frequent irrigations. It is also dependent on water application efficiency.

Equations Utilized in the Model

Before turning to an illustration of the analytical model some readers may wish to examine the equations used in the model. They are shown on page 13.

AN ILLUSTRATION OF THREE SYSTEMS

We shall now examine three alternative systems of lifting water using the analytical model previously described. In order to illustrate the potential application of the model we have selected two sets of data for analysis.

It should be understood that data for this model are of three kinds: (1) primary data collected by observation and enumeration, (2) expert opinion data based on engineering coefficiencts and/or informal collection procedures through years of observation and (3) system design parameters based on judgement, e.g., how many hours per

EQUATIONS FOR WATER LIFTING COST PROGRAM*

1. $K = \text{Hrs. PER FEDDAN PER YEAR} = \dfrac{\text{Water Duty Per Year}}{\text{Discharge of Pump}}$

2. $\text{Annual Fixed Costs} = \left[\dfrac{\text{Present Replacement Price in Egypt + Salvage Value}}{2}\right] [\text{Interest Rate}] + \text{Taxes, etc.}$

3. $\text{Depreciation} = \left[\dfrac{\text{Present Replacement Price in Egypt - Salvage Value}}{\text{Wearout Life}}\right] [K] [\text{No. of feddans}]$

4. Repairs = [Expected Average Repair Cost] [K] [No. of Feddans]

5. Energy Cost if Diesel = [Fuel Consumption] [Fuel Cost] [K] [No. of Feddans]

6. Energy Cost if Electric = [Electric Energy Required] [Electric Energy Cost] [K] [No. of Feddans]

7. Energy Cost if Animal = [Animal Cost] [K] [No. of Feddans]

8. $\text{Grease and Oil} = \left[\dfrac{\text{Oil Cost per 100 hours + Grease Cost per 100 hours}}{100}\right] [K] [\text{No. of Feddans}]$

9. Operator Cost = [Operator or Labor Cost] [K] [No. of Feddans]

10. Total Annual Cost = Annual Fixed Cost + Depreciation + Repairs + Energy Cost + Grease and Oil + Operator Cost

11. $\text{Annual Cost Per Feddan} = \dfrac{\text{Total Annual Cost}}{\text{No. of Feddans}}$

12. $\text{Output Horsepower Hours} = \left[\dfrac{\text{Discharge of Pump x Static Head}}{270}\right] [K] [\text{No. of Feddans}]$ (Work Accomplished)

13. $\text{Cost per HP Hour} = \dfrac{\text{Total Annual Cost}}{\text{Output HP Hours}}$

14. $\text{Max. System Capacity} = \dfrac{\text{Minimum Irrigation Interval x Max. Time per Day x Discharge of Pump}}{\text{Max. Water Required per Irrigation}}$

15. $\text{Brake Horsepower Required at Max. System Capcity} = \dfrac{\text{Discharge of Pump x Dynamic Head}}{\text{270 Overall Efficiency}}$

16. Total Time Required = [Max. System Capacity] [K]

17. Total Energy Required at Max. System Capacity = Brake HP Req. at Max. System Capacity x Total Time Required

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*See DATA INPUT FORM - WATER LIFTING COSTS on page 6 for unit specifications.

day farmers will operate a system and what is the appropriate charge for energy now and in the future?

One set of data is from a report prepared at Menoufia University.[1/] The second set of data was prepared by EWUP. Appendix A contains a discussion and justification for each item of EWUP data. Differences exist between the two data sets concerning energy costs, labor costs and requirements, interest rates, operating hours per day, and discharge rates. The effect of altering these variables will be discussed later.

Table 1 includes data from Menoufia University and from EWUP for three alternative water lifting system, via. (1) sakia, (2) diesel pump, and (3) electricity. Each unit of data has its own justification. One assumption, however, underlying the entire analysis, is that the delivery canal must operate such that the lifting devices can operate at designated capacity.

The data from Table 1 were entered into a computer model to produce Tables 2-7. Examination of Table 2, Water Lifting Costs for 3-Meter Sakia, Data from Menoufia University, shows that costs are reported in annual cost per feddan and cost per horsepower hour. Both values represent the cost of performing a unit of work. In the first case it shows the cost per feddan is L.E. 62.174 when the system is used for only one feddan. This means it costs L.E. 62.174 to lift 6800 m^3, the amount required for one feddan, one meter. These values are included in the data set, i.e., water duty equal 6800 m^3 and static head equal to one meter. Since it requires 25.185 HP hours to do this work we can see the cost per HP hour is L.E. 2.4687. As the use of the system is expanded over more area we notice that both the annual cost per feddan and the cost per HP hour decline. This is due to the fact that fixed costs are spread over more units of work and consequently total cost per unit declines.

Table 2 also indicates that the maximum capacity of this system is 12.88 feddans per year. This is by equation 14 on page 13 and is of course based on specified crop requirements, irrigation frequency, etc. If any of these specifications are relaxed the computed capacity

[1/] Nasser, Abdel Hady Abdel Bary, op. cti., pp. 55-112.

TABLE 1: DATA FOR COST ANALYSES OF PUMPING MACHINES

	MENOUFIA UNIVERSITY DATA			EWUP DATA		
1. Name	SAKIA	DIESEL PUMP	ELECTIRC PUMP	SAKIA	DIESEL PUMP	ELECTRIC PUMP
2. Make	—	—	—	—	IND/CHECK	KSB
3. Model	—	—	—	—	—	—
4. Size	3-METERS	12 HP	12 HP	3-METERS	9 HP	7.5 HP
5. Power Source	ANIMAL	DIESEL	ELECTRICITY	ANIMAL	DIESEL	ELECTRICITY
6. Date, day, month, year	000080	000080	000080	051279	170380	170380
1. Present cost, L.E.	450.	1800.	800.	500.	950.	2325.
2. Life, hrs.	18000.	8161.	28333.	15000.	15000.	15000.
3. Repair cost, L.E.	.013	.221	.035	.008	.060	.010
4. Fuel consumption, liters	.000	1.640	.000	.000	1.429	.000
5. Fuel cost, L.E.	.000	.076	.000	.000	.140	.000
6. Oil cost, L.E./100 hrs.	.000	2.779	.000	.000	1.500	.000
7. Grease cost, L.E./100 hrs	.000	.000	.000	.100	.500	.500
8. Elect. req., kwh	.000	.000	4.806	.000	.000	3.376
9. Elect. cost, L.E.	.000	.000	.015	.000	.000	.050
10. Salvage value, L.E.	.000	300.000	.000	.000	.000	.000
11. Annual taxes, L.E.	.000	.000	.000	2.000	.000	.000
12. Interest rate, percent	6.	6.	6.	15.	15.	15.
13. Labor cost, L.E./Hr.	.056	.794	.318	.050	.300	.300
14. Discharge, m^3/hr.	57.	300.	300.	100.	170.	170.
15. Animal energy cost, L.E.	.314	.000	.000	.300	.000	.000
16. Overall efficiency	.700	.700	.700	.700	.700	.700
17. Engine efficiency	.900	.850	.850	.900	.600	.850
18. Static head, meter	1.	1.	1.	1.	1.	1.
19. Dynamic head, meter	1.	3.500	3.500	1.	3.500	3.500
20. Water duty, m^3/year	6800.	6800.	6800.	6800.	6800.	6800.
21. Max. time/day, hrs.	16.	12.	16.	12.	12.	12.
22. Min. irrig. interval, days	6.	6.	6.	6.	6.	6.
23. Max. water/irrig., m^3	425.	425.	425.	425.	425.	425.

of the system will change. Also we can observe that power required at maximum capacity of the system is 0.30 horsepower as explained by equation 15. The system requires 1536 hours of operation to perform the work required at the maximum system capacity of 12.88 feddans per year. The total energy required to do this work is 463.24 horsepower hours.

Each data set is similarly calculated and reported in Table 2-7. The reader is reminded that the six data sets are shown in Table 1 on page 15.

Cost Curves

To simplify comparison of Tables 2-7 cost curves were plotted to show the relationship between cost per horsepower hour (vertical axis) and the number of feddans which the system serves annually (horizontal axis). Examination of Figure 2 shows that the cost curves slope downward to the right reflecting the declining unit costs of work performed as fixed costs are spread over more units.

The curves do not extend to the right beyond the physical limits of each system's capacity to perform work within the prescribed time and water requirement parameters. The data sets can of course be changed to reflect different parameters and this in turn will affect the shape and relative positions of the cost curves.

Examination of Figure 2, which is based on Menoufia data, will indicate that the cost of a sakia, used at maximum system capacity, is approximately L.E. 2.0 per horsepower hour. From Table 2 we can also observe that this corresponds to approximately L.E. 50.0 per feddan per year.

Similar examination of the diesel pump cost curve and Table 3 will reveal costs of L.E. 1.3 per horsepower hour and L.E. 32.0 per feddan per year. The electricity system reveals costs of L.E. 0.4 per horsepower hour and from Table 4, L.E. 10.6 per feddan per year.

The cost curves in Figure 3 represent data provided by EWUP scientists.[1/] Examination of these curves and corresponding Tables

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[1/] See appendix A for discussion and justification for EWUP data.

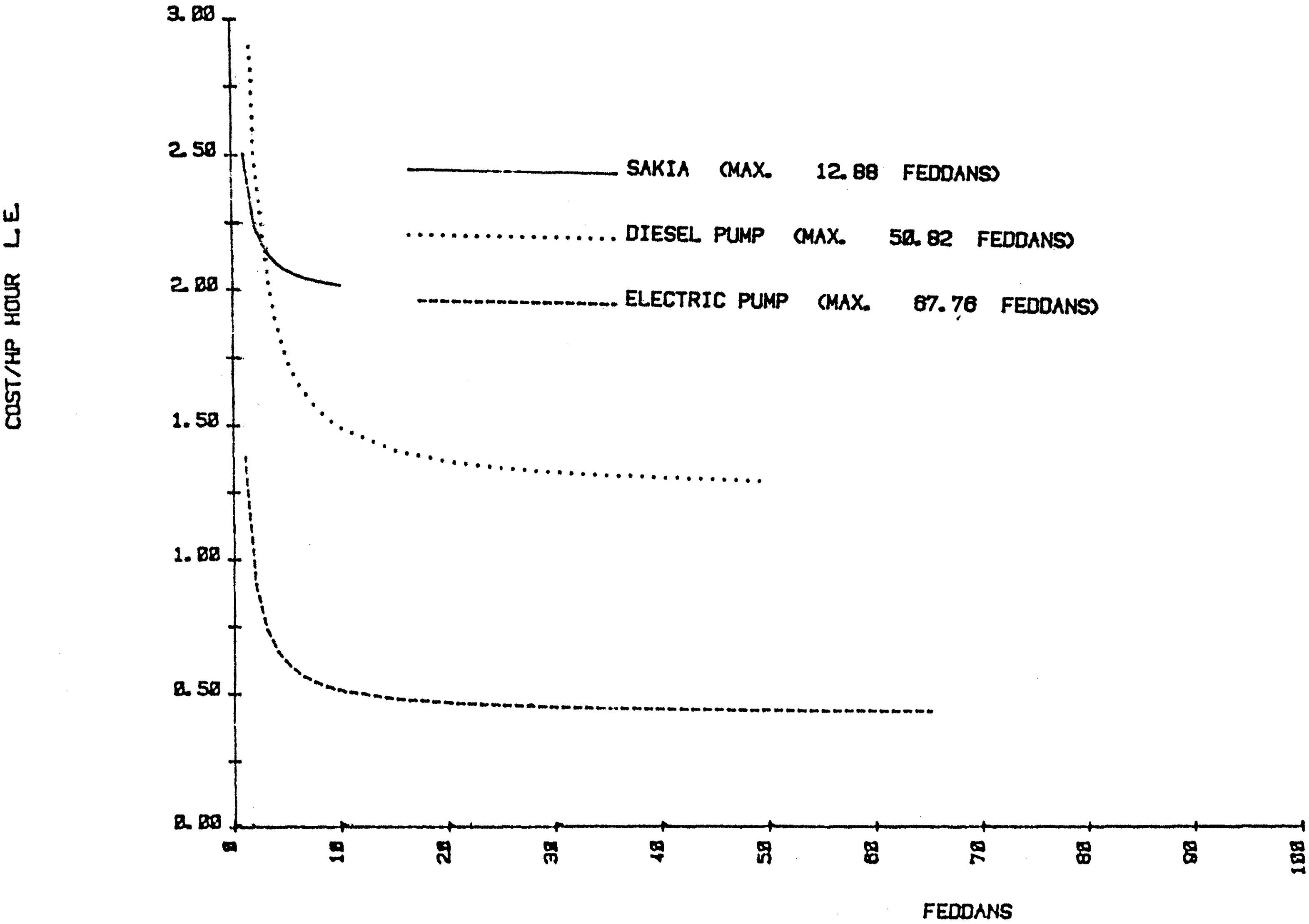

Figure 2. Water Lifting Costs Per Unit of Work Done for Sakia, Diesel Pump and Electric Pump, Menoufia University Data.

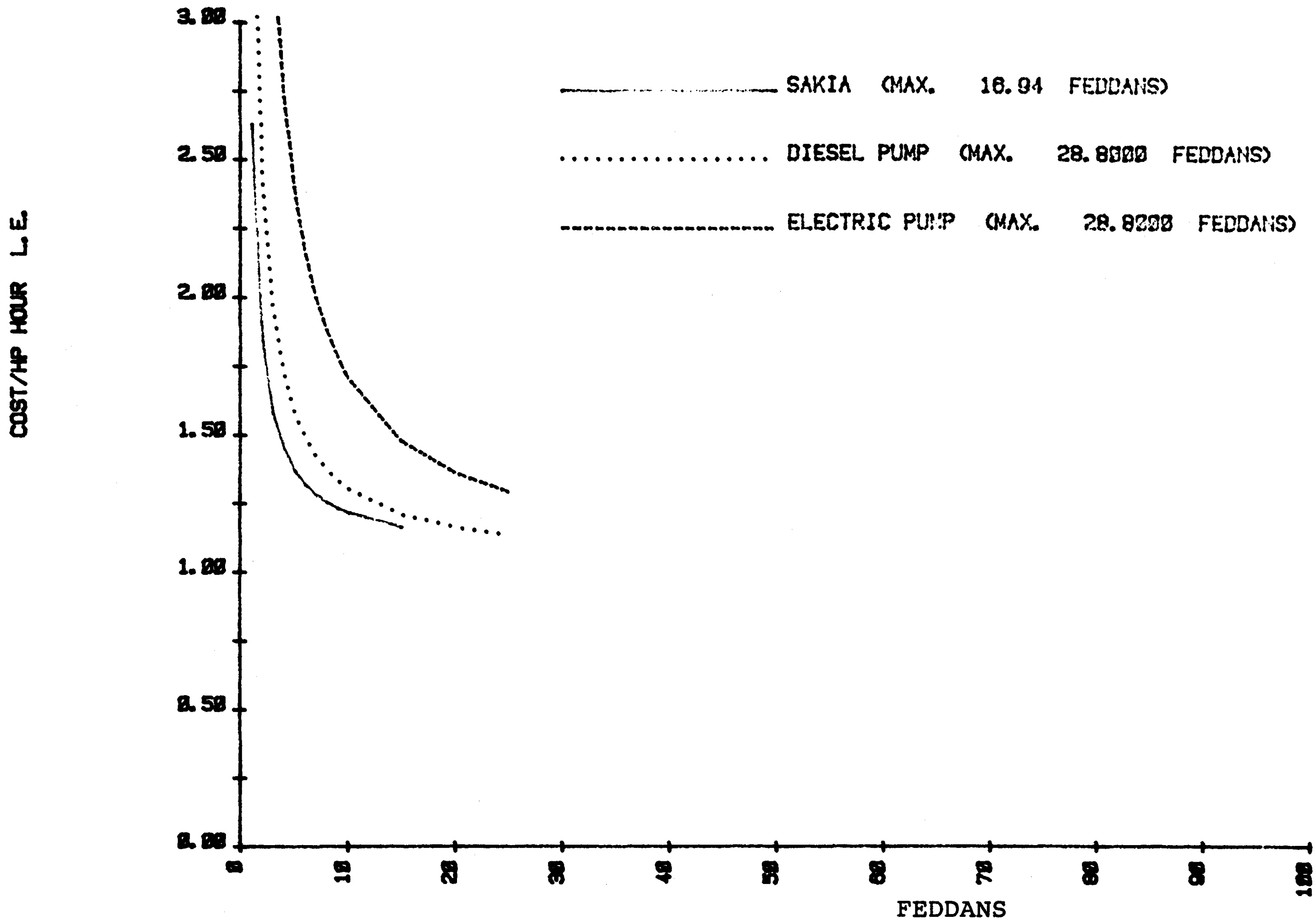

Figure 3. Water Lifting Costs Per Unit of Work Done for Sakia, Diesel Pump and Electric Pump, EWUP Data.

Table 2: Water Lifting Costs for 3-Meter Sakia, Data From Menoufia University

PRESENT REPLACEMENT COST IN EGYPT, LE	450.000
WEAR OUT LIFE ON HOURS	18000.000
EXPECTED AVERAGE REPAIR COST LE /HOUR	0.013
OIL COST LE/ 100 HOURS	0.000
GREASE COST LE /100 HOURS	0.000
SALVAGE VALUE AT END OF WEAR OUT LIFE:LE	0.000
ANNUAL TAXES,LICENSE,PERMIT,RENT,etc.:LE	0.000
INTEREST RATE,PERCENT	6.000 %
OPERATOR COST LE/hr	0.056
Hrs PER FEDDAN PER YEAR	117.298
DISCHARGE OF PUMP,cubic mt./hr	57.000
ANIMAL POWER COST LE/hr	0.314
OVERALL EFFICIONCY	0.700
ENGINE EFFICIENCY	0.900

STATIC HEAD (METERS)	1.000
DYNAMIC HEAD (METERS)	1.000
WATER DUTY PER YEAR,cubic mt/fd	6000.000
MAX. TIME SYSTEM WILL RUN PER DAY,hours	16.000
MIN. TIME BETWEEN IRRIGATION,days	6.000
MAX. WATER REQUIRED PER IRRIG.,cubic mt/fd	425.000

MAX. SYSTEM CAPACITY = 12.80 FEDDANS/YEAR
BHP REQUIRED AT MAX = 0.30 BRAKE HORSPOWER
TOTAL TIME REQUIRED =1536.00 Hrs/YEAR
TOTAL ENERGY REQ. AT MAX = 463.24HP Hrs/YEAR

FEDD.	ANNUAL FIXED COST	DEPRECIA.	REPAIRS	ENERGY COST	GREASE &OIL	OPERATOR COST	TOTAL ANNUAL COST	ANNUAL COST/Fd	OUTPT HP Hrs.	COST HP HOUR
1.00	13.500	2.982	1.551	37.460	0.000	6.681	62.174	62.174	25.185	2.4687
2.00	13.500	5.965	3.102	74.919	0.000	13.361	110.847	55.424	50.370	2.2006
3.00	13.500	8.947	4.653	112.379	0.000	20.042	159.521	53.174	75.556	2.1113
4.00	13.500	11.930	6.204	149.839	0.000	26.723	208.195	52.049	100.741	2.0666
5.00	13.500	14.912	7.754	187.298	0.000	33.404	256.868	51.374	125.926	2.0398
6.00	13.500	17.895	9.305	224.758	0.000	40.084	305.542	50.924	151.111	2.0220
7.00	13.500	20.877	10.856	262.218	0.000	46.765	354.216	50.602	176.296	2.0092
8.00	13.500	23.860	12.407	299.677	0.000	53.446	402.889	50.361	201.481	1.9996
9.00	13.500	26.842	13.958	337.137	0.000	60.126	451.563	50.174	226.667	1.9922
10.00	13.500	29.825	15.509	374.596	0.000	66.807	500.237	50.024	251.852	1.9862
15.00	13.500	44.737	23.263	561.895	0.000	100.211	743.605	49.574	377.778	1.9684
20.00	13.500	59.649	31.018	749.193	0.000	133.614	786.974	49.349	503.704	1.9594
25.00	13.500	74.561	38.772	936.491	0.000	167.018	1230.342	49.214	629.630	1.9541
30.00	13.500	87.474	46.526	1123.789	0.000	200.421	1473.711	49.124	755.556	1.9505
35.00	13.500	104.386	54.281	1311.088	0.000	233.825	1717.079	49.059	881.481	1.9479
40.00	13.500	119.298	62.035	1498.386	0.000	267.228	1760.447	49.011	1007.407	1.9460
45.00	13.500	134.211	69.789	1685.684	0.000	300.632	2203.816	48.974	1133.333	1.9445
50.00	13.500	149.123	77.544	1872.982	0.000	334.035	2447.184	48.944	1259.259	1.9434
55.00	13.500	164.035	85.298	2060.281	0.000	367.439	2690.553	48.919	1385.185	1.9424
60.00	13.500	178.947	93.053	2247.579	0.000	400.842	2733.921	48.899	1511.111	1.9416
65.00	13.500	193.860	100.807	2434.877	0.000	434.246	3177.289	48.881	1637.037	1.9409
70.00	13.500	208.772	108.561	2622.175	0.000	467.649	3420.658	48.867	1762.963	1.9403
75.00	13.500	223.684	116.316	2809.474	0.000	501.053	3664.026	48.854	1888.889	1.9398
80.00	13.500	238.596	124.070	2996.772	0.000	534.456	3707.395	48.842	2014.815	1.9393
85.00	13.500	253.509	131.825	3184.070	0.000	567.860	4150.763	48.833	2140.741	1.9389
70.00	13.500	268.421	139.579	3371.368	0.000	601.263	4394.132	48.824	2266.667	1.9386
95.00	13.500	283.333	147.333	3558.667	0.000	634.667	4637.500	48.816	2392.593	1.9383
$$$$$	13.500	298.246	155.088	3745.965	0.000	668.070	4880.863	48.809	2518.519	1.9380

Table 3: Water Lifting Costs for 12 HP Diesel Pump, Data From Menoufia University

PRESENT REPLACEMENT COST IN EGYPT, LE	1800.000
WEAR OUT LIFE IN HOURS	8161.000
EXPECTED AVERAGE REPAIR COST LE /HOUR	0.221
FUEL CONSUMPTION LITERS PER HOUR	1.640
FUEL COST LE/LITER	0.076
OIL COST LE/ 100 HOURS	2.779
GREASE COST LE /100 HOURS	0.000
SALVAGE VALUE AT END OF WEAR OUT LIFE:LE	300.000
ANNUAL TAXES,LICENSE,PERMIT,RENT,etc.:LE	0.000
INTEREST RATE,PERCENT	6.000 %
OPERATOR COST LE/hr	0.794
Hrs PER FEDDAN PER YEAR	22.667
DISCHARGE OF PUMP,cubic mt./hr	300.000
OVERALL EFFICIENCY	0.700
ENGINE EFFICIENCY	0.850

MAX. SYSTEM CAPACITY	= 50.82 FEDDANS/YEAR
BHP REQUIRED AT MAX	= 5.56 BRAKE HORSPOWER
TOTAL TIME REQUIRED	=1152.00 Hrs/YEAR
TOTAL ENERGY REQ. AT MAX	=6400.00HP Hrs/YEAR

STATIC HEAD (METERS)	1.000
DYNAMIC HEAD (METERS)	3.500
WATER DUTY PER YEAR,cubic mt/fd	6800.000
MAX. TIME SYSTEM WILL RUN PER DAY,hours	12.000
MIN. TIME BETWEEN IRRIGATION,days	6.000
MAX. WATER REQUIRED PER IRRIG.,cubic mt/fd	425.000

FEDD.	ANNUAL FIXED COST	DEPRECIA.	REPAIRS	ENERGY COST	GREASE &OIL	OPERATOR COST	TOTAL ANNUAL COST	ANNUAL COST/fd	OUTPT HP Hrs.	COST HP HOUR
1.00	63.000	4.166	5.009	2.825	0.630	17.997	93.628	93.628	25.185	3.7176
2.00	63.000	8.332	10.019	5.650	1.260	35.995	124.256	62.128	50.370	2.4668
3.00	63.000	12.498	15.028	8.476	1.890	53.992	154.884	51.628	75.556	2.0499
4.00	63.000	16.665	20.037	11.301	2.520	71.989	185.512	46.378	100.741	1.8415
5.00	63.000	20.831	25.047	14.126	3.150	89.987	216.140	43.228	125.926	1.7164
6.00	63.000	24.997	30.056	16.951	3.779	107.984	246.767	41.128	151.111	1.6330
7.00	63.000	29.163	35.065	19.776	4.409	125.981	277.395	39.628	176.296	1.5735
8.00	63.000	33.329	40.075	22.601	5.039	143.979	308.023	38.503	201.481	1.5288
9.00	63.000	37.495	45.084	25.427	5.669	161.976	338.651	37.628	226.667	1.4940
10.00	63.000	41.662	50.093	28.252	6.299	179.973	369.279	36.928	251.852	1.4663
15.00	63.000	62.492	75.140	42.378	9.449	269.960	522.419	34.828	377.778	1.3829
20.00	63.000	83.323	100.187	56.503	12.598	359.947	675.558	33.778	503.704	1.3412
25.00	63.000	104.154	125.233	70.629	15.748	449.933	828.698	33.148	629.630	1.3162
30.00	63.000	124.985	150.280	84.755	18.897	539.920	981.837	32.728	755.556	1.2995
35.00	63.000	145.815	175.327	98.881	22.047	629.907	1134.977	32.428	881.481	1.2876
40.00	63.000	166.646	200.373	113.007	25.196	719.893	1288.116	32.203	1007.407	1.2786
45.00	63.000	187.477	225.420	127.133	28.346	809.880	1441.256	32.028	1133.333	1.2717
50.00	63.000	208.308	250.467	141.259	31.495	899.867	1594.395	31.888	1259.259	1.2661
55.00	63.000	229.139	275.513	155.385	34.645	989.853	1747.535	31.773	1385.185	1.2616
60.00	63.000	249.969	300.560	169.510	37.794	1079.840	1900.674	31.678	1511.111	1.2578
65.00	63.000	270.800	325.607	183.636	40.944	1169.827	2053.814	31.597	1637.037	1.2546
70.00	63.000	291.631	350.653	197.762	44.093	1259.813	2206.953	31.528	1762.963	1.2518
75.00	63.000	312.462	375.700	211.888	47.243	1349.800	2360.093	31.468	1888.889	1.2495
80.00	63.000	333.292	400.747	226.014	50.393	1439.787	2513.232	31.415	2014.815	1.2474
85.00	63.000	354.123	425.793	240.140	53.542	1529.773	2666.372	31.369	2140.741	1.2455
90.00	63.000	374.954	450.840	254.266	56.692	1619.760	2819.511	31.328	2266.667	1.2439
95.00	63.000	395.785	475.887	268.391	59.841	1709.747	2972.651	31.291	2392.593	1.2424
*****	63.000	416.616	500.933	282.517	62.991	1799.733	3125.790	31.258	2518.519	1.2411

Table 4: Water Lifting Costs for 12 HP Electric Pump, Data From Menoufia University

PRESENT REPLACEMENT COST IN EGYPT, LE	800.000
WEAR OUT LIFE IN HOURS	28333.000
EXPECTED AVERAGE REPAIR COST LE /HOUR	0.035
OIL COST LE/ 100 HOURS	0.000
GREASE COST LE /100 HOURS	0.000
ELECTRIC POWER REQUIRED ,Kw hour	4.806
ELECTRICITY COST LE /Kw.hour	0.015
SALVAGE VALUE AT END OF WEAR OUT LIFE:LE	0.000
ANNUAL TAXES,LICENSE,PERMIT,RENT,etc.:LE	0.000
INTEREST RATE,PERCENT	6.000 %
OPERATOR COST LE/hr	0.318
Hrs PER FEDDAN PER YEAR	22.667
DISCHARGE OF PUMP,cubic mt./hr	300.000
OVERALL EFFICIENCY	0.700
ENGINE EFFICIONCY	0.850

STATIC HEAD (METERS)	1.000
DYNAMIC HEAD (METERS)	3.500
WATER DUTY PER YEAR,cubic mt/fd	6800.000
MAX. TIME SYSTEM WILL RUN PER DAY,hours	16.000
MIN. TIME BETWEEN IRRIGATION,days	6.000
MAX. WATER REQUIRED PER IRRIG.,cubic mt/fd	425.000

MAX. SYSTEM CAPACITY = 67.76 FEDDANS/YEAR
BHP REQUIRED AT MAX = 5.56 BRAKE HORSPOWER
TOTAL TIME REQUIRED =1536.00 Hrs/YEAR
TOTAL ENERGY REQ. AT MAX =8533.33HP Hrs/YEAR

FEDD.	ANNUAL FIXED COST	DEPRECIA.	REPAIRS	ENERGY COST	GREASE &OIL	OPERATOR COST	TOTAL ANNUAL COST	ANNUAL COST/Fd	OUTPUT HP Hrs.	COST HP HOUR
1.00	24.000	0.640	0.793	1.634	0.000	7.208	34.275	34.275	25.185	1.3609
2.00	24.000	1.280	1.587	3.268	0.000	14.416	44.551	22.275	50.370	0.8845
3.00	24.000	1.920	2.380	4.902	0.000	21.624	54.826	18.275	75.556	0.7256
4.00	24.000	2.560	3.173	6.536	0.000	28.832	65.102	16.275	100.741	0.6462
5.00	24.000	3.200	3.967	8.170	0.000	36.040	75.377	15.075	125.926	0.5986
6.00	24.000	3.840	4.760	9.804	0.000	43.248	85.652	14.275	151.111	0.5668
7.00	24.000	4.480	5.553	11.438	0.000	50.456	95.928	13.704	176.296	0.5441
8.00	24.000	5.120	6.347	13.072	0.000	57.664	106.203	13.275	201.481	0.5271
9.00	24.000	5.760	7.140	14.706	0.000	64.872	116.478	12.942	226.667	0.5139
10.00	24.000	6.400	7.933	16.340	0.000	72.080	126.754	12.675	251.852	0.5033
15.00	24.000	9.600	11.900	24.511	0.000	108.120	178.131	11.875	377.778	0.4715
20.00	24.000	12.800	15.867	32.681	0.000	144.160	229.508	11.475	503.704	0.4556
25.00	24.000	16.000	19.833	40.851	0.000	180.200	280.885	11.235	629.630	0.4461
30.00	24.000	19.200	23.800	47.021	0.000	216.240	332.261	11.075	755.556	0.4398
35.00	24.000	22.400	27.767	57.191	0.000	252.280	383.638	10.961	881.481	0.4352
40.00	24.000	25.600	31.733	65.362	0.000	288.320	435.015	10.875	1007.407	0.4318
45.00	24.000	28.800	35.700	73.532	0.000	324.360	486.392	10.809	1133.333	0.4292
50.00	24.000	32.000	39.667	81.702	0.000	360.400	537.769	10.755	1259.259	0.4271
55.00	24.000	35.200	43.633	89.872	0.000	396.440	589.146	10.712	1385.185	0.4253
60.00	24.000	38.400	47.600	98.042	0.000	432.480	640.523	10.675	1511.111	0.4239
65.00	24.000	41.600	51.567	106.213	0.000	468.520	691.900	10.645	1637.037	0.4227
70.00	24.000	44.801	55.533	114.383	0.000	504.560	743.277	10.618	1762.963	0.4216
75.00	24.000	48.001	59.500	122.553	0.000	540.600	794.654	10.595	1888.889	0.4207
80.00	24.000	51.201	63.467	130.723	0.000	576.640	846.030	10.575	2014.815	0.4199
85.00	24.000	54.401	67.433	138.893	0.000	612.680	897.407	10.558	2140.741	0.4192
90.00	24.000	57.601	71.400	147.064	0.000	648.720	948.784	10.542	2266.667	0.4186
95.00	24.000	60.801	75.367	155.234	0.000	684.760	1000.161	10.528	2392.593	0.4180
*****	24.000	64.001	79.333	163.404	0.000	720.800	1051.538	10.515	2518.519	0.4175

Table 5: Water Lifting Costs for 3-Meter Sakia, Data From EWUP

PRESENT REPLACEMENT COST IN EGYPT, LE	500.000	
WEAR OUT LIFE IN HOURS	15000.000	
EXPECTED AVERAGE REPAIR COST LE /HOUR	0.008	
OIL COST LE/ 100 HOURS	0.000	
GREASE COST LE /100 HOURS	0.100	
SALVAGE VALUE AT END OF WEAR OUT LIFE:LE	0.000	
ANNUAL TAXES,LICENSE,PERMIT,RENT,etc.:LE	2.000	
INTEREST RATE,PERCENT	15.000	%
OPERATOR COST LE/hr	0.050	
Hrs PER FEDDAN PER YEAR	68.000	
DISCHARGE OF PUMP,cubic mt./hr	100.000	
ANIMAL POWER COST LE/hr	0.300	
OVERALL EFFICIENCY	0.700	
ENGINE EFFICIENCY	0.900	

STATIC HEAD (METERS)	1.000
DYNAMIC HEAD (METERS)	1.000
WATER DUTY PER YEAR,cubic mt/fd	6800.000
MAX. TIME SYSTEM WILL RUN PER DAY,hours	12.000
MIN. TIME BETWEEN IRRIGATION,days	6.000
MAX. WATER REQUIRED PER IRRIG.,cubic mt/fd	425.000

MAX. SYSTEM CAPACITY = 16.94 FEDDANS/YEAR
BHP REQUIRED AT MAX = 0.5291 BRAKE HORSEPOWER
TOTAL TIME REQUIRED =1152.00 Hrs/YEAR
TOTAL ENERGY REQ. AT MAX = 609.52 HP Hrs/YEAR

FEDD.	ANNUAL FIXED COST	DEPRECIA.	REPAIRS	ENERGY COST	GREASE &OIL	OPERATOR COST	TOTAL ANNUAL COST	ANNUAL COST/Fd	OUTPT HP Hrs.	COST HP HOUR
1.00	39.500	2.2667	0.5440	20.4000	0.0680	3.4000	66.1787	66.1787	25.1852	2.6277
2.00	39.500	4.5333	1.0880	40.8000	0.1360	6.8000	92.8573	46.4287	50.3704	1.8435
3.00	39.500	6.8000	1.6320	61.2000	0.2040	10.2000	119.5360	39.8453	75.5556	1.5821
4.00	39.500	9.0667	2.1760	81.6000	0.2720	13.6000	146.2147	36.5537	100.7407	1.4514
5.00	39.500	11.3333	2.7200	102.0000	0.3400	17.0000	172.8933	34.5787	125.9259	1.3730
6.00	39.500	13.6000	3.2640	122.4000	0.4080	20.4000	199.5720	33.2620	151.1111	1.3207
7.00	39.500	15.8667	3.8080	142.8000	0.4760	23.8000	226.2507	32.3215	176.2963	1.2834
8.00	39.500	18.1333	4.3520	163.2000	0.5440	27.2000	252.9293	31.6162	201.4815	1.2553
9.00	39.500	20.4000	4.8960	183.6000	0.6120	30.6000	279.6080	31.0676	226.6667	1.2336
10.00	39.500	22.6667	5.4400	204.0000	0.6800	34.0000	306.2867	30.6287	251.8519	1.2161
15.00	39.500	34.0000	8.1600	306.0000	1.0200	51.0000	439.6800	29.3120	377.7778	1.1639
20.00	39.500	45.3333	10.8800	408.0000	1.3600	68.0000	573.0733	28.6537	503.7037	1.1377
25.00	39.500	56.6667	13.6000	510.0000	1.7000	85.0000	706.4667	28.2587	629.6296	1.1220
30.00	39.500	68.0000	16.3200	612.0000	2.0400	102.0000	839.8600	27.9953	755.5556	1.1116
35.00	39.500	79.3333	19.0400	714.0000	2.3800	119.0000	973.2533	27.8072	881.4815	1.1041
40.00	39.500	90.6667	21.7600	816.0000	2.7200	136.0000	1106.6467	27.6662	1007.4074	1.0985
45.00	39.500	102.0000	24.4800	918.0000	3.0600	153.0000	1240.0400	27.5564	1133.3333	1.0942
50.00	39.500	113.3333	27.2000	1020.0000	3.4000	170.0000	1373.4333	27.4687	1259.2593	1.0907
55.00	39.500	124.6667	29.9200	1122.0000	3.7400	187.0000	1506.8267	27.3968	1385.1852	1.0878
60.00	39.500	136.0000	32.6400	1224.0000	4.0800	204.0000	1640.2200	27.3370	1511.1111	1.0854
65.00	39.500	147.3333	35.3600	1326.0000	4.4200	221.0000	1773.6133	27.2864	1637.0370	1.0834
70.00	39.500	158.6667	38.0800	1428.0000	4.7600	238.0000	1907.0067	27.2430	1762.9630	1.0817
75.00	39.500	170.0000	40.8000	1530.0000	5.1000	255.0000	2040.4000	27.2053	1888.8889	1.0802
80.00	39.500	181.3333	43.5200	1632.0000	5.4400	272.0000	2173.7933	27.1724	2014.8148	1.0789
85.00	39.500	192.6667	46.2400	1734.0000	5.7800	289.0000	2307.1867	27.1434	2140.7407	1.0778
90.00	39.500	204.0000	48.9600	1836.0000	6.1200	306.0000	2440.5800	27.1176	2266.6667	1.0767
95.00	39.500	215.3333	51.6800	1938.0000	6.4600	323.0000	2573.9733	27.0945	2392.5926	1.0758
100.00	39.500	226.6667	54.4000	2040.0000	6.8000	340.0000	2707.3667	27.0737	2518.5185	1.0750

Table 6: Water Lifting Costs for 9 HP Diesel Pump, Data From EWUP

PRESENT REPLACEMENT COST IN EGYPT, LE	950.000
WEAR OUT LIFE IN HOURS	15000.000
EXPECTED AVERAGE REPAIR COST LE /HOUR	0.060
FUEL CONSUMPTION LITERS PER HOUR	1.429
FUEL COST LE/LITER	0.140
OIL COST LE/ 100 HOURS	1.500
GREASE COST LE /100 HOURS	0.500
SALVAGE VALUE AT END OF WEAR OUT LIFE:LE	0.000
ANNUAL TAXES,LICENSE,PERMIT,RENT,etc.:LE	0.000
INTEREST RATE,PERCENT	15.000 %
OPERATOR COST LE/hr	0.300
Hrs PER FEDDAN PER YEAR	40.000
DISCHARGE OF PUMP,cubic mt./hr	170.000
OVERALL EFFICIENCY	0.700
ENGINE EFFICIENCY	0.600

STATIC HEAD (METERS)	1.000
DYNAMIC HEAD (METERS)	3.500
WATER DUTY PER YEAR,cubic mt/fd	6800.000
MAX. TIME SYSTEM WILL RUN PER DAY,hours	12.000
MIN. TIME BETWEEN IRRIGATION,days	6.000
MAX. WATER REQUIRED PER IRRIG.,cubic mt/fd	425.000

MAX. SYSTEM CAPACITY = 28.80 FEDDANS/YEAR
BHP REQUIRED AT MAX = 3.15 BRAKE HORSPOWER
TOTAL TIME REQUIRED =1152.00 Hrs/YEAR
TOTAL ENERGY REQ. AT MAX =3626.67HP Hrs/YEAR

FEDD.	ANNUAL FIXED COST	DEPRECIA.	REPAIRS	ENERGY COST	GREASE &OIL	OPERATOR COST	TOTAL ANNUAL COST	ANNUAL COST/Fd	OUTPT HP Hrs.	COST HP HOUR
1.00	71.250	2.533	2.400	8.002	0.800	12.000	96.986	96.986	25.185	3.8509
2.00	71.250	5.067	4.800	16.005	1.600	24.000	122.721	61.361	50.370	2.4364
3.00	71.250	7.600	7.200	24.007	2.400	36.000	148.457	49.486	75.556	1.9649
4.00	71.250	10.133	9.600	32.010	3.200	48.000	174.173	43.548	100.741	1.7291
5.00	71.250	12.667	12.000	40.012	4.000	60.000	199.929	39.986	125.926	1.5877
6.00	71.250	15.200	14.400	48.014	4.800	72.000	225.664	37.611	151.111	1.4934
7.00	71.250	17.733	16.800	56.017	5.600	84.000	251.400	35.914	176.296	1.4260
8.00	71.250	20.267	19.200	64.019	6.400	96.000	277.136	34.642	201.481	1.3755
9.00	71.250	22.800	21.600	72.022	7.200	108.000	302.872	33.652	226.667	1.3362
10.00	71.250	25.333	24.000	80.024	8.000	120.000	328.607	32.861	251.852	1.3048
15.00	71.250	38.000	36.000	120.036	12.000	180.000	457.286	30.486	377.778	1.2105
20.00	71.250	50.667	48.000	160.048	16.000	240.000	585.965	29.298	503.704	1.1633
25.00	71.250	63.333	60.000	200.060	20.000	300.000	714.643	28.586	629.630	1.1350
30.00	71.250	76.000	72.000	240.072	24.000	360.000	843.322	28.111	755.556	1.1162
35.00	71.250	88.667	84.000	280.084	28.000	420.000	972.001	27.771	881.481	1.1027
40.00	71.250	101.333	96.000	320.096	32.000	480.000	1100.679	27.517	1007.407	1.0926
45.00	71.250	114.000	108.000	360.108	36.000	540.000	1229.358	27.319	1133.333	1.0847
50.00	71.250	126.667	120.000	400.120	40.000	600.000	1358.037	27.161	1259.259	1.0784
55.00	71.250	139.333	132.000	440.132	44.000	660.000	1486.715	27.031	1385.185	1.0733
60.00	71.250	152.000	144.000	480.144	48.000	720.000	1615.394	26.923	1511.111	1.0690
65.00	71.250	164.667	156.000	520.156	52.000	780.000	1744.073	26.832	1637.037	1.0654
70.00	71.250	177.333	168.000	560.168	56.000	840.000	1872.751	26.754	1762.963	1.0623
75.00	71.250	190.000	180.000	600.180	60.000	900.000	2001.430	26.686	1888.889	1.0596
80.00	71.250	202.667	192.000	640.192	64.000	960.000	2130.109	26.626	2014.815	1.0572
85.00	71.250	215.333	204.000	680.204	68.000	1020.000	2258.787	26.574	2140.741	1.0551
90.00	71.250	228.000	216.000	720.216	72.000	1080.000	2387.466	26.527	2266.667	1.0533
95.00	71.250	240.667	228.000	760.228	76.000	1140.000	2516.145	26.486	2392.593	1.0516
*****	71.250	253.333	240.000	800.240	80.000	1200.000	2644.823	26.448	2518.519	1.0502

Table 7: Water Lifting Costs for 7.5 HP Electric Pump, Data From EWUP

PRESENT REPLACEMENT COST IN EGYPT, LE	2325.000	
WEAR OUT LIFE IN HOURS	15000.000	
EXPECTED AVERAGE REPAIR COST LE /HOUR	0.010	
OIL COST LE/ 100 HOURS	0.000	
GREASE COST LE /100 HOURS	0.500	
ELECTRIC POWER REQUIRED ,Kw hour	3.376	
ELECTRICITY COST LE /Kw.hour	0.050	
SALVAGE VALUE AT END OF WEAR OUT LIFE:LE	0.000	
ANNUAL TAXES,LICENSE,PERMIT,RENT,etc.:LE	0.000	
INTEREST RATE,PERCENT	15.000	%
OPERATOR COST LE/hr	0.300	
Hrs PER FEDDAN PER YEAR	40.000	
DISCHARGE OF PUMP,cubic mt./hr	170.000	
OVERALL EFFICIENCY	0.700	
ENGINE EFFICIENCY	0.850	

STATIC HEAD (METERS)	1.000
DYNAMIC HEAD (METERS)	3.500
WATER DUTY PER YEAR,cubic mt/fd	6800.000
MAX. TIME SYSTEM WILL RUN PER DAY,hours	12.000
MIN. TIME BETWEEN IRRIGATION,days	6.000
MAX. WATER REQUIRED PER IRRIG.,cubic mt/fd	425.000

MAX. SYSTEM CAPACITY = 28.00 FEDDANS/YEAR
BHP REQUIRED AT MAX = 3.15 BRAKE HORSPOWER
TOTAL TIME REQUIRED =1152.00 Hrs/YEAR
TOTAL ENERGY REQ. AT MAX =3626.67HP Hrs/YEAR

FEDD.	ANNUAL FIXED COST	DEPRECIA.	REPAIRS	ENERGY COST	GREASE &OIL	OPERATOR COST	TOTAL ANNUAL COST	ANNUAL COST/Fd	OUTPT HP Hrs.	COST HP HOUR
1.00	174.375	6.200	0.400	6.752	0.200	12.000	199.927	199.927	25.185	7.9383
2.00	174.375	12.400	0.800	13.504	0.400	24.000	225.477	112.740	50.370	4.4764
3.00	174.375	18.600	1.200	20.256	0.600	36.000	251.031	83.677	75.556	3.3225
4.00	174.375	24.800	1.600	27.008	0.800	48.000	276.583	69.146	100.741	2.7455
5.00	174.375	31.000	2.000	33.760	1.000	60.000	302.135	60.427	125.926	2.3993
6.00	174.375	37.200	2.400	40.512	1.200	72.000	327.687	54.615	151.111	2.1685
7.00	174.375	43.400	2.800	47.264	1.400	84.000	353.239	50.463	176.296	2.0037
8.00	174.375	49.600	3.200	54.016	1.600	96.000	378.791	47.349	201.481	1.8800
9.00	174.375	55.800	3.600	60.768	1.800	108.000	404.343	44.927	226.667	1.7839
10.00	174.375	62.000	4.000	67.520	2.000	120.000	429.895	42.990	251.852	1.7069
15.00	174.375	93.000	6.000	101.280	3.000	180.000	557.655	37.177	377.778	1.4761
20.00	174.375	124.000	8.000	135.040	4.000	240.000	685.415	34.271	503.704	1.3608
25.00	174.375	155.000	10.000	168.800	5.000	300.000	813.175	32.527	629.630	1.2915
30.00	174.375	186.000	12.000	202.560	6.000	360.000	940.935	31.365	755.556	1.2454
35.00	174.375	217.000	14.000	236.320	7.000	420.000	1068.695	30.534	881.481	1.2124
40.00	174.375	248.000	16.000	270.080	8.000	480.000	1196.455	29.911	1007.407	1.1877
45.00	174.375	279.000	18.000	303.840	9.000	540.000	1324.215	29.427	1133.333	1.1684
50.00	174.375	310.000	20.000	337.600	10.000	600.000	1451.975	29.040	1259.259	1.1530
55.00	174.375	341.000	22.000	371.360	11.000	660.000	1579.735	28.722	1385.185	1.1405
60.00	174.375	372.000	24.000	405.120	12.000	720.000	1707.495	28.458	1511.111	1.1300
65.00	174.375	403.000	26.000	438.880	13.000	780.000	1835.255	28.235	1637.037	1.1211
70.00	174.375	434.000	28.000	472.640	14.000	840.000	1963.015	28.043	1762.963	1.1135
75.00	174.375	465.000	30.000	506.400	15.000	900.000	2090.775	27.877	1888.889	1.1069
80.00	174.375	496.000	32.000	540.160	16.000	960.000	2218.535	27.732	2014.815	1.1011
85.00	174.375	527.000	34.000	573.920	17.000	1020.000	2346.295	27.603	2140.741	1.0960
90.00	174.375	558.000	36.000	607.680	18.000	1080.000	2474.055	27.490	2266.667	1.0915
95.00	174.375	589.000	38.000	641.440	19.000	1140.000	2601.815	27.388	2392.593	1.0874
*****	174.375	620.000	40.000	675.200	20.000	1200.000	2729.575	27.296	2518.519	1.0838

5, 6 and 7 reveals substantial differences from Figure 2 and Tables 2, 3 and 4. The difference in unit costs at maximum system capacity for the alternative data sets are shown clearly in Table 8.

SENSITIVITY ANALYSIS

It is not likely that many readers will accept the data presented here without modification. For various reasons there will be a desire to make some adjustments.

Obviously it is not practical to test all combinations of variables, for each system, and at different levels of magnitude for each variable. This would require many hours of computer time and a very large book to report the results. It is possible and practical, however, to examine a few variables, at different levels of magnitude, in order to assess the impact of each on cost functions. Such analyses will provide the reader with a basis for selecting combinations for further testing.

Present Replacement Price in Egypt

There is room for honest difference of opinion about how much of the nation's electrical infrastructure should be charges to electrification of water lifting. The effect on the cost curve for an electric pump, EWUP data, is shown in Figure 4. The initial cost is reduced from L.E. 2325 to L.E. 800 while holding all other factors constant. The resulting cost curves are shown in Figure 4. The L.E. 800 cost curve would be appropriate if the cost of transformers and transmission lines are omitted from the analysis.

Interest Rate

The cost curves are especially sensitive to interest rates when the system has high capital costs. Figure 5 shows the difference between 6 and 15 percent interest, electric pump, EWUP data with all other factors constant.

Energy Costs

Diesel fuel and electricity prices to Egyptian farmers are subsidized by government. The cost of animal energy is difficult to assess and subject to many different estimates. Figure 6 shows the effect of three different electricity rates on the electric pump costs

Table 8. Comparitive Unit Costs of Work Performed for Water Lifting Systems when Operated at Maximum System Capacity

System	Menoufia		EWUP	
	Cost per Output Horsepower Hour	Cost per Feddan Per Year	Cost per Output Horsepower Hour	Cost per Feddan Per Year
	L.E.	L.E.	L.E.	L.E.
Sakia	2.0	50.0	1.2	29.3
Diesel	1.3	32.0	1.1	28.1
Electricity	.4	10.6	1.2	31.4

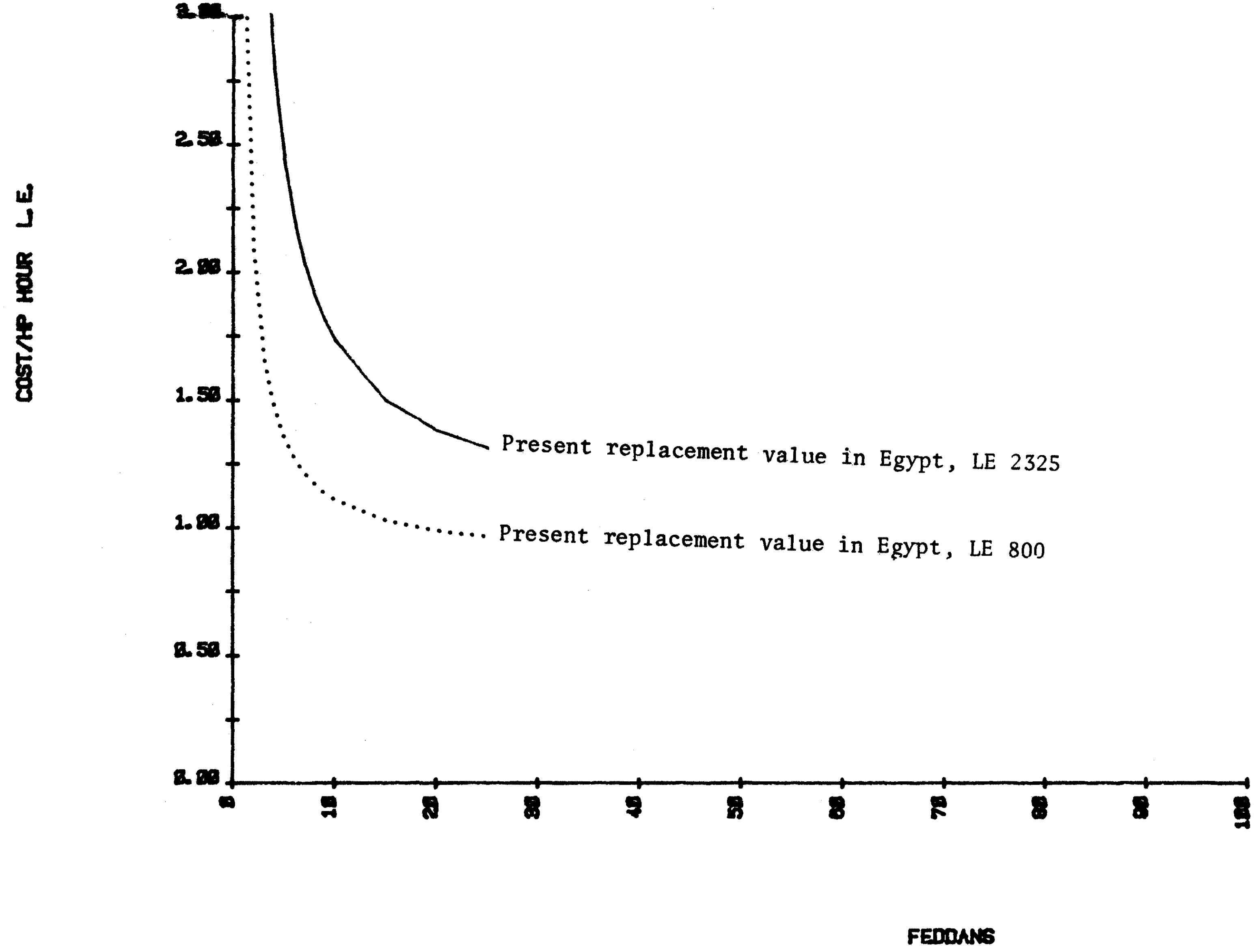

Figure 4: Cost Curve for Electric Pump, EWUP Data, for Replacement Costs of L.E. 2325 and L.E. 800.

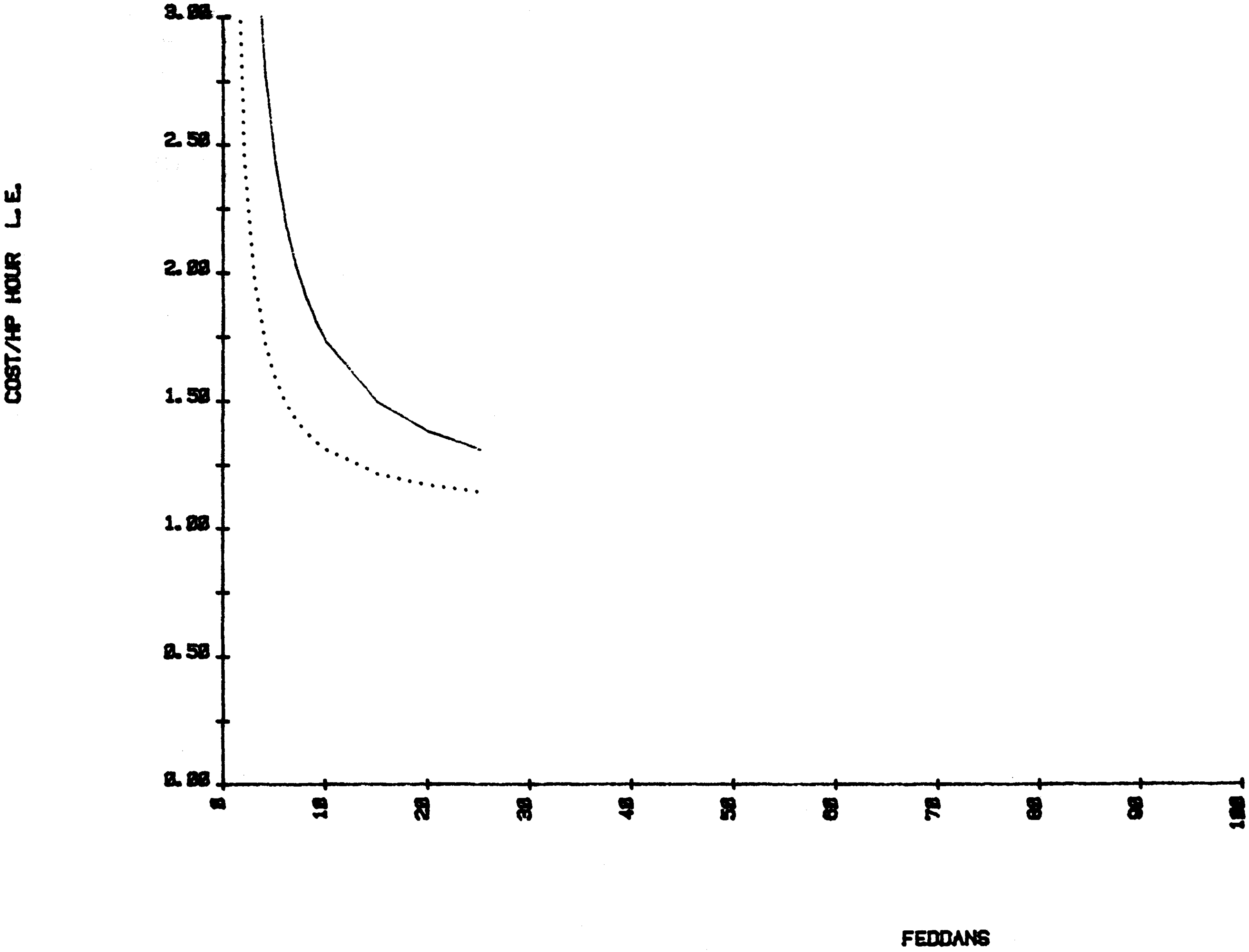

Figure 5: Cost Curves for Electric Pump, EWUP Data, for Interest Rates of 6 Percent and 15 Percent.

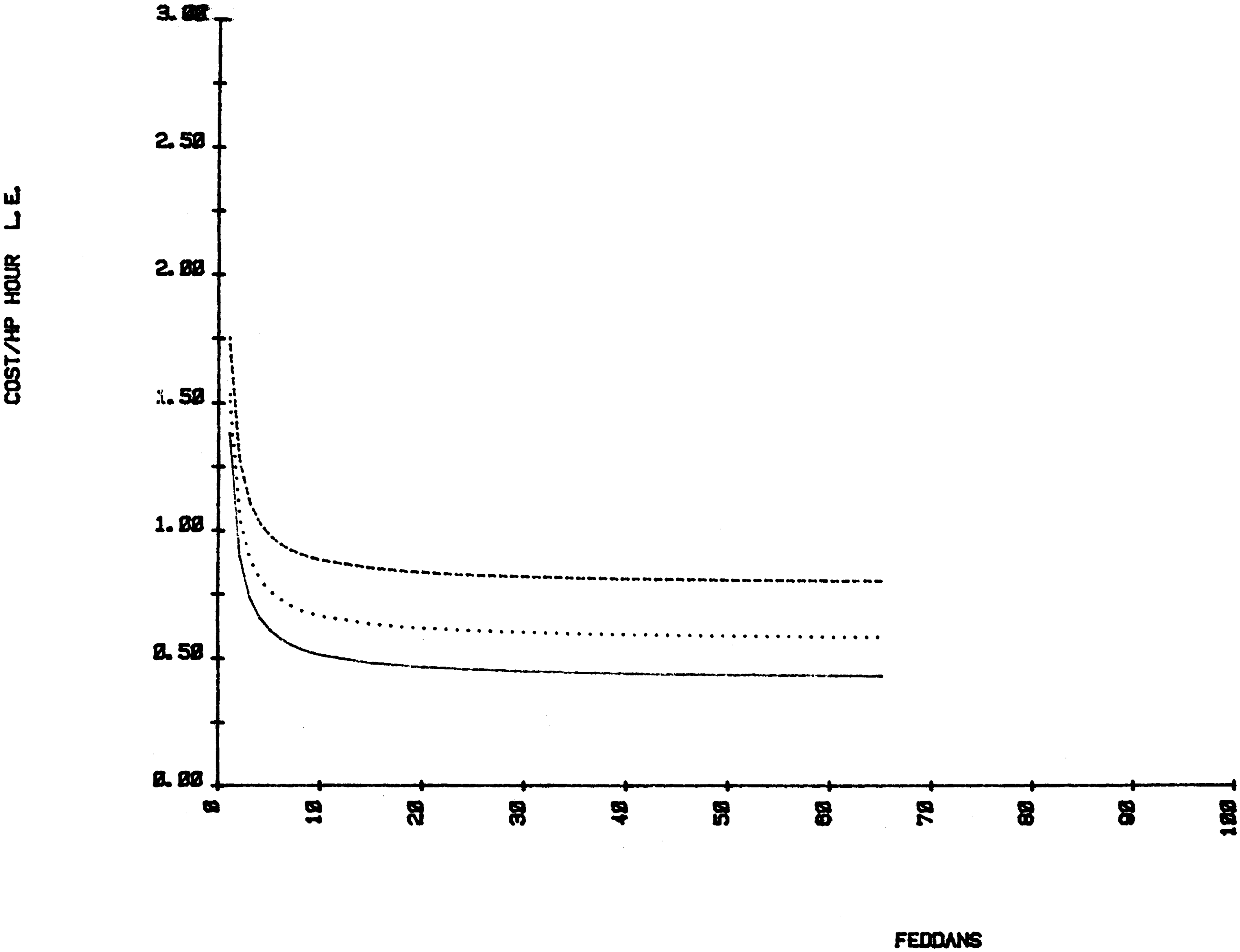

Figure 6: Cost Curves for Electric Pump, for Electricity Rates of L.E. 0.015, 0.05 and 0.10 per Kilowatt Hour.

from Menoufia University. Figure 7 shows the effect on sakia costs of reducing animal power costs from L.E. 0.314 to L.E. 0.15 per hour using the Menoufia University case.

Examination of Figures 6 and 7 suggests that energy prices are of major importance in evaluating water lifting costs and should be given serious attention by policy makers. World energy prices are increasing rapidly. Even if Egypt remains self sufficient in energy she will sacrifice opportunities for obtaining valuable foreign exchange if energy is used domestically rather than exported. The case of animal power is even more complicated due to strong dependence by rural people on animals for numerous products including transportation. If agricultural resources are used to feed animals to produce power this obviously affects output of food for human use. The magnitude of this relationship needs to be given careful study in order to have a rational basis for assigning costs to animal power.

Discharge of Pump

Pumps will operate at rated capacity only if delivery canals are adequate to supply the pump intake with sufficient water. Empirical data regarding sakia discharge rates shows wide variation but this is largely attributed to the availability of water in canals. Also the design of sakias makes them especially sensitive to the level of water in the sakia well. Their rate of discharge depends on the speed of an animal, which because of habit tends to be more or less constant. It is unlikely that a declining head in the sakia well will be offset by higher revolutions per minute by the animal.

Consequently a fluctuating head is likely to be correlated closely with fluctuating discharge.

The affect on the cost curve for a sakia is shown in Figure 8. Using Menoufia data the discharge rates of 57 m^3/hr. is compared with double that rate, 114 m^3/hr., while holding other factors constant. Notice that unit costs are greatly reduced primarily because less animal power time is required for the same quantity of irrigation water delivered to the fields. Also maximum system capacity is increased in direct proportion to the increase in the discharge rate.

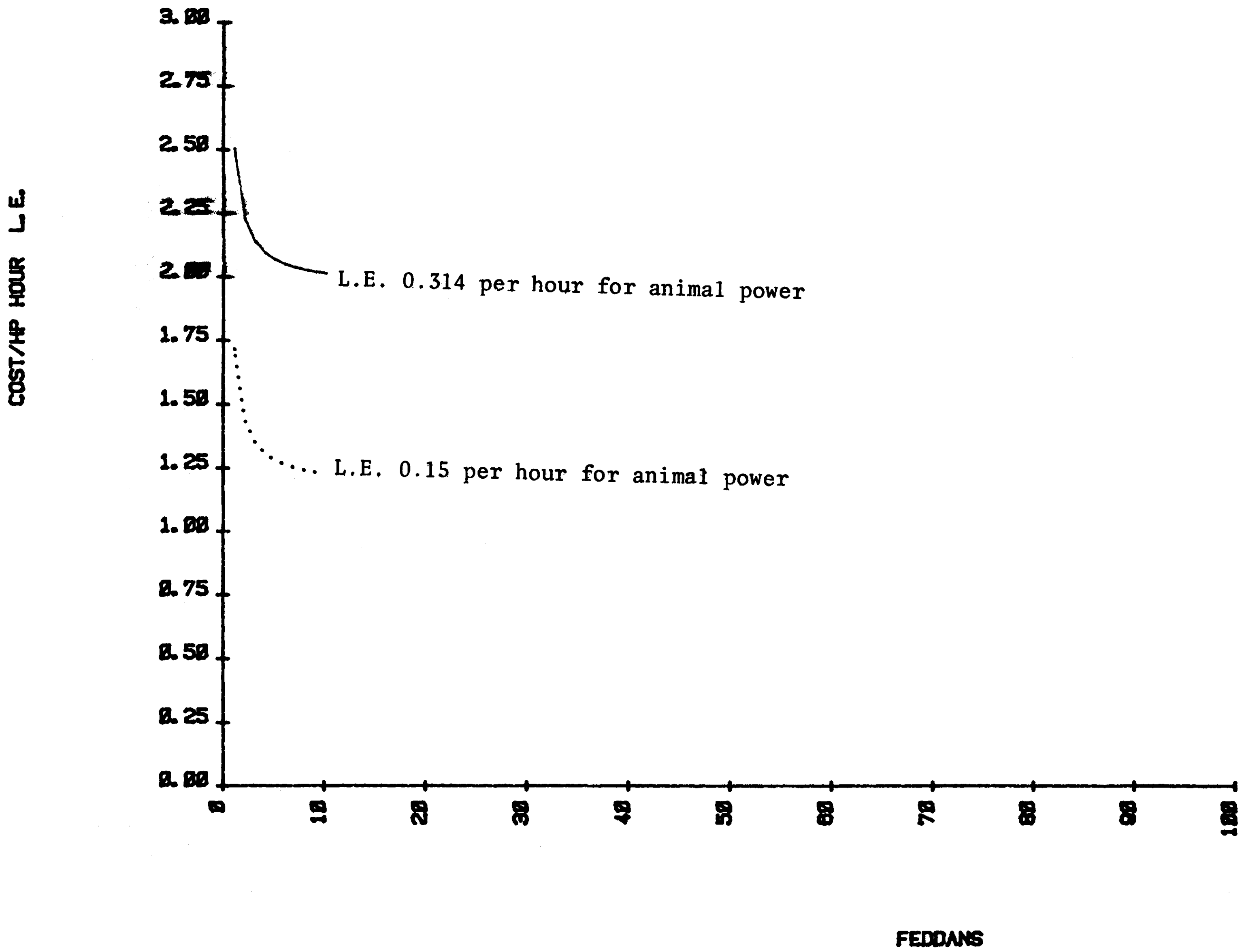

Figure 7: Cost Curves of Sakia, Menoufia Data, for Animal Power Rates of L.E. 0.314 and L.E. 0.15 Per Hour.

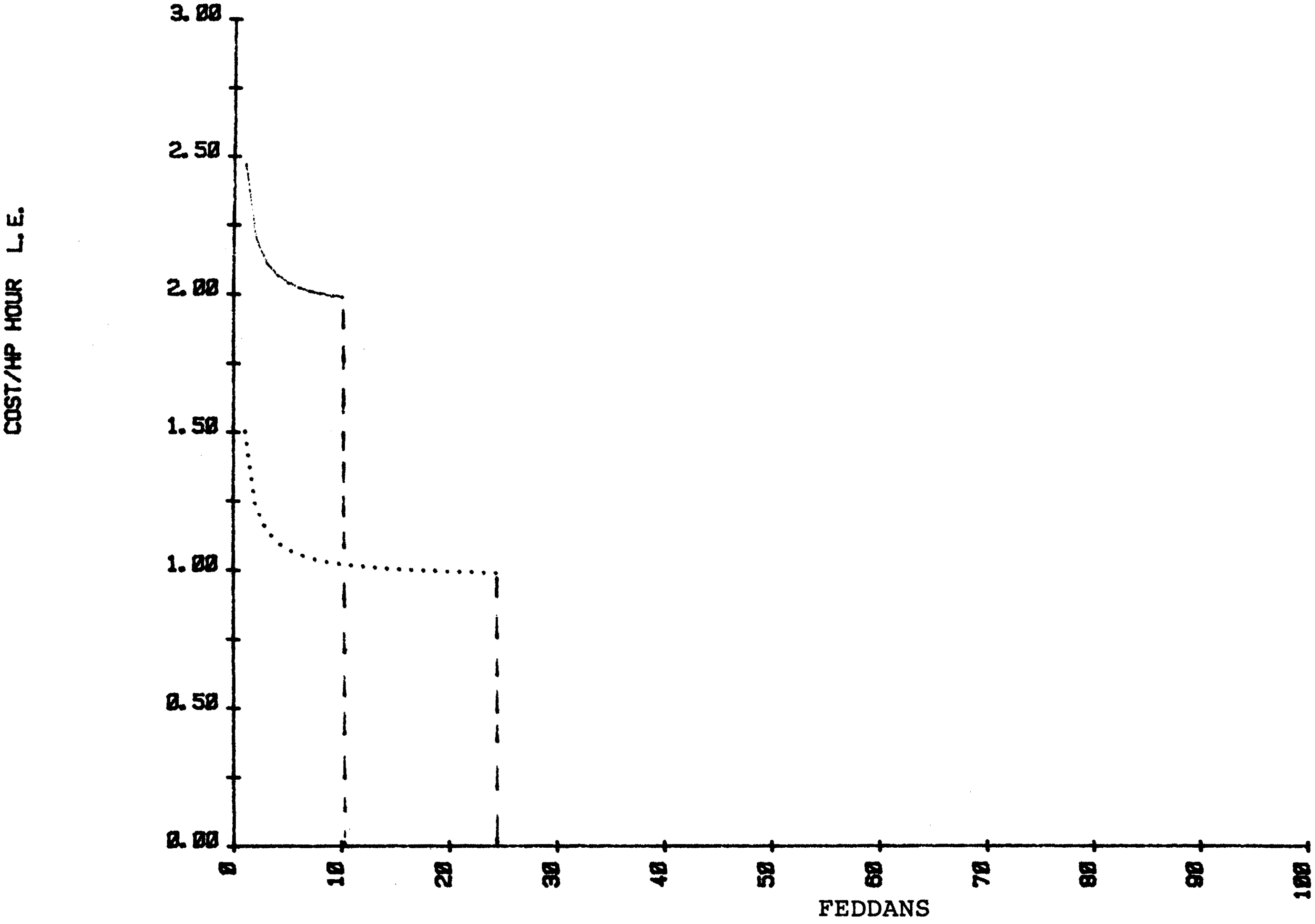

Figure 8. Cost Curves for a Sakia, Menoufia Data, for Discharge Rates of 57 m^3/hr. and 114 m^3/hr.

Operator Labor Cost

The amount and price of labor used to operate water lifting systems has an important effect on cost curves. This factor is also difficult to quantify. Empirical studies from Western market oriented economies are probably not valid sources of data. A more useful approach is likely to be a judgement made by an individual farmer regarding the opportunity cost of his own labor or by government policy makers. Questions about wage rates, working conditions, numbers of pumps served by one technician, training provided to pump technicians, are likely to be answered in the public sector. Consequently policy judgements rather than empirical market studies are more likely to be appropriate for assigning operator labor costs.

Figure 9 shows the effect of different operator labor rates on electric pumping costs for EWUP data holding other costs constant. It should be pointed out that changing labor wage rates have more impact on cost curves for low discharge pumps (170 m^3/hr.) than on the higher discharge pumps (300 m^3/hr.) used in the Menoufia study.

Maximum Time System Will Run Per Day

Not only are the cost curves sensitive to the amount of time the system will operate per day but his is a politically sensitive parameter The area to be served by a system could be maximized and unit costs could be minimized if the system operated 24 hours per day. It may be difficult however, to convince farmers they should adapt to such a system. If not 24 hours then what length of working day is acceptable?

The maximum system capacity increases in direct proportion to hours worked per day while costs per unit of work performed decrease. Figure 10 illustrates this point. Maximum system capacity is, of course, reached when the system operates 24 hours per day.

SUMMARY AND CONCLUSIONS

Cost curves for water lifting systems have been developed using 23 variables. Some of these variables are primarily technical. Their appropriate magnitude depends on physical measurement which can be verified through empirical observation. Other variables depend on subjective judgement about future price relationships, economic conditions and public policy considerations.

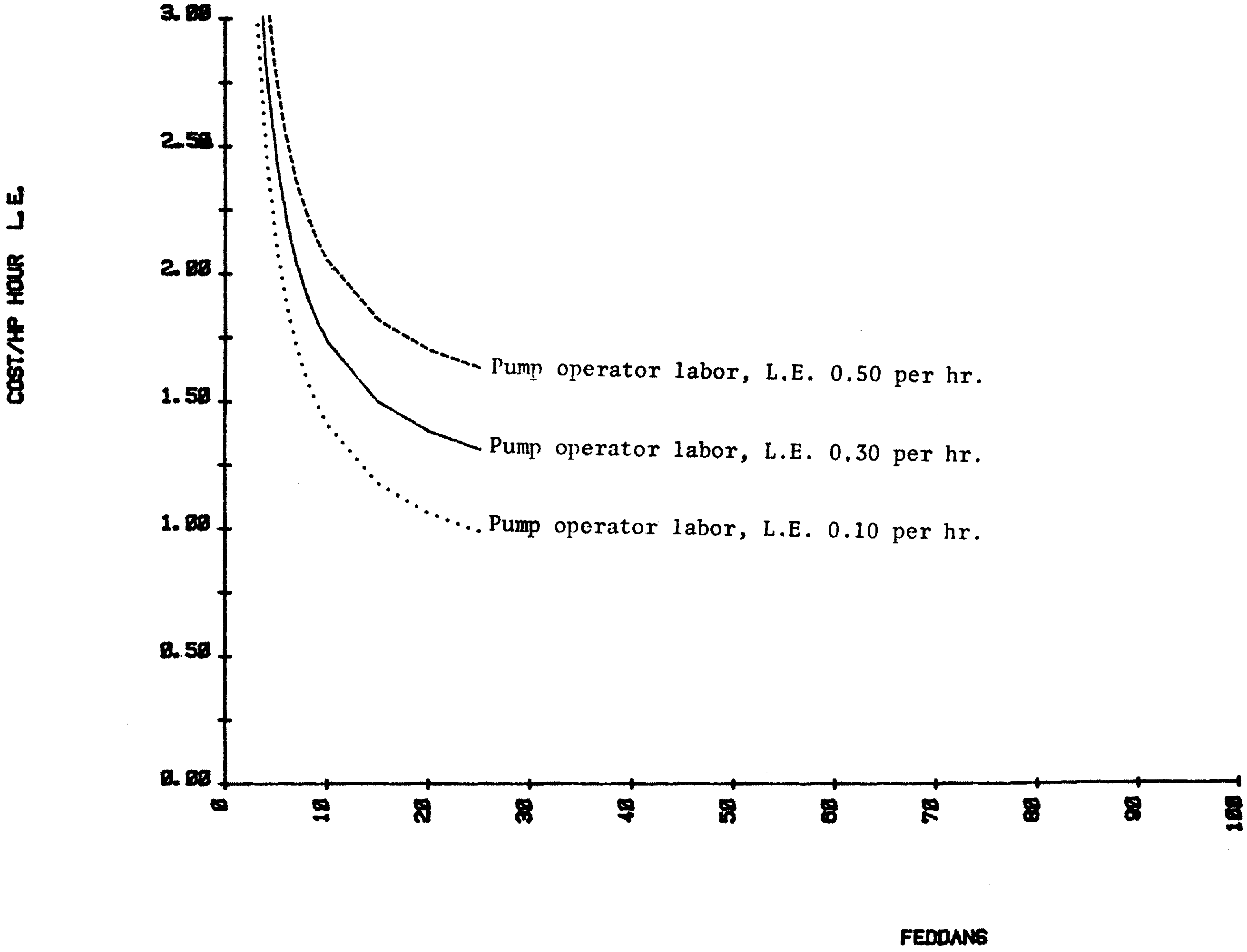

Figure 9: Cost Curves for an Electric Pump, EWUP Data, for Operator Labor Cost of L.E. 0.10 0.30 and 0.50 Per Hour.

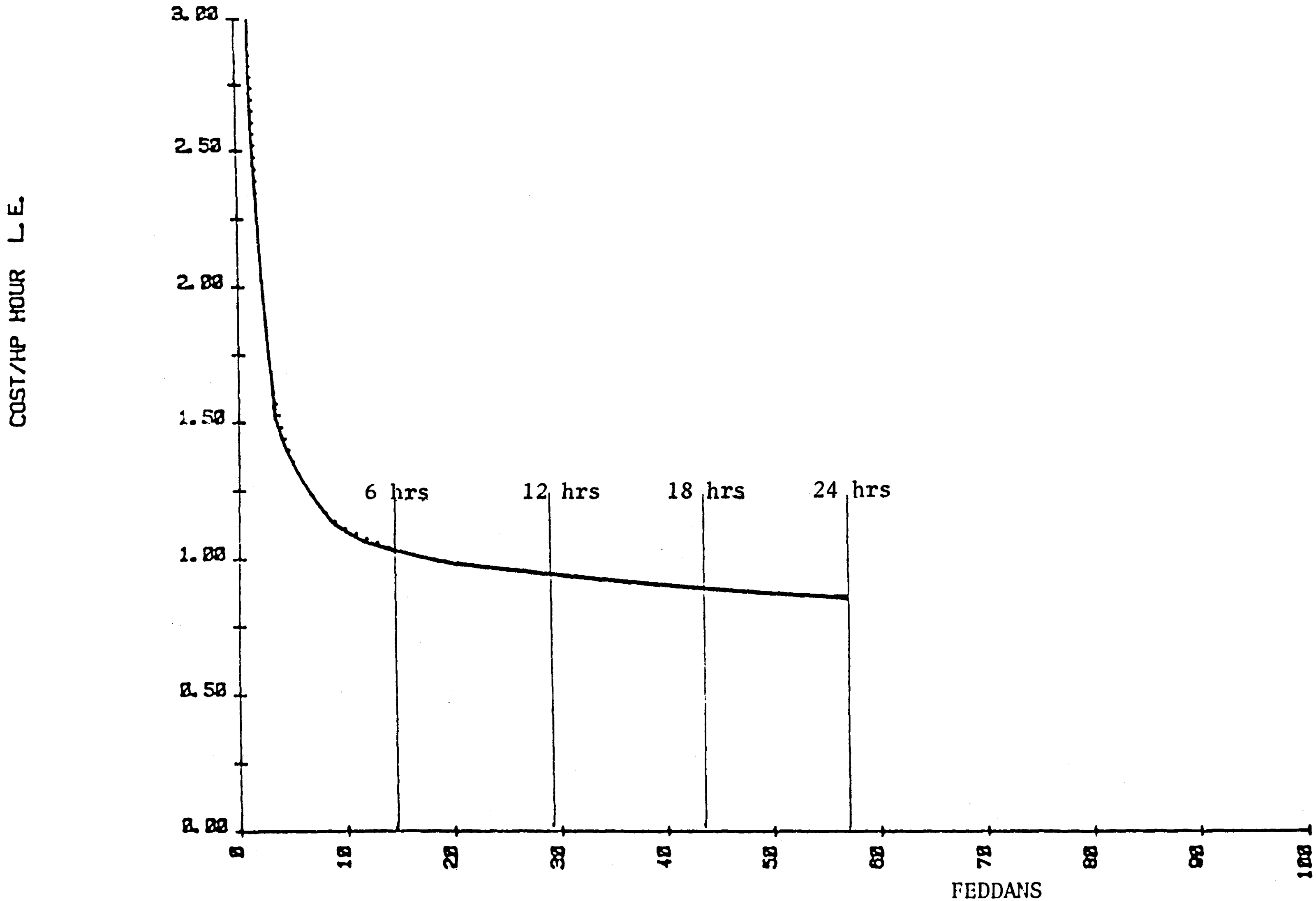

Figure 10. Cost Per Unit of Work Done Decreases and System Capacity Increases as Number of Hours per Day the System Operates Increases.

Cost curves have been illustrated for sakias, diesel pumps and electric pumps using data sets from two different sources, viz. Menoufia University and EWUP. It has been shown that the cost curves from these two sources suggest contradictory conclusions regarding public policy decisions. If the Menoufia University data and judgements are acceptable to decision makers, then it should be appropriate to encourage electrification of water lifting systems in Egypt. If the EWUP data and judgements are perceived to be practical and consistent with Egyptian national interests, then it would appear more appropriate to leave the existing sakia system as they are now.

The model lends itself to use by policy and decision makers. Selection of alternative values to be tested in the model could be made by persons responsible for making decisions. If it is agreed to delay decisions pending more evidence for a specified variable, then research efforts could be authorized to improve the basis for assigning values.

Individual entrepreneurs may use the model to test alternative investment opportunities. Minimizing the cost of performing work should lead the entrepreneur to higher profits. He can use values for each specified variable that are appropriate to his circumstances. Comparision of the resulting cost curves should result in better entrepreneurial decision.

The national implications of this report are significant. Decisions to mechanize water lifting may lead to substantial capital investments which reduce flexibility for future policy alternatives. For example it would be difficult to shift to gravity irrigation in the future if heavy investments were already committed to an electrified lifting system. Consequently the policies related to water lifting are of major significance and should be studied carefully. The model illustrated in this report can be extremely useful in studying alternatives and reaching sound decisions.

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APPENDIX A

EXPLANATION OF EWUP DATA

The data to be used in the analytical model should be realistic from a technical point of view and appropriate with respect to current and future needs of the Egyptian nation. EWUP data, which may require special explanation, documentation or clarification are discussed below.

1. Present replacement price in Egypt. Cooperating farmers and equipment companies provided information used in the estimates for sakias, diesel pumps and electric pumps. Cairo dealers reported the present price of 7.5 horsepower electric pump and motor sets to be L.E. 992 for a unit of good quality. According to the Rural Electrification Authority, Ministry of Electricity, the cost of a 25 KVA transformer is L.E. 4,000. Assuming this would be shared by 3 pumps, one-third cost is added to the cost of the pumpset for a total initial cost of L.E. 2325. It should be noted that this amount does not include the cost of transmission and distribution lines. Although the cost of major transmission lines are usually amortized and included in the user price of electricity it is not clear whether the secondary and tertiary distribution lines to field location transformers should be charged to pumping. If they are the initial cost of an electric pump station should be increased accordingly.

2. Wearout life for each unit is based on the judgement of reliable manufacturers and on the experience of pump users. It assumes good maintenance and ample allowance for spare parts.

3. Expected average repair cost is a judgement reached after interviewing pump users. The reliability of these data could be improved by keeping records on different pump systems through time.

4. Fuel consumption is based on manufacturers specifications. It may be higher under field conditions but again, records or tests under field conditions are needed.

5. Fuel cost is based on Pacific Consultants, op. cit, page 18. One may wish to use projected prices for long range planning. The current subsidized price for diesel fuel is L.E. 0.03 per liter.

6. Oil cost is based on manufacturer's recommendation to change oil each 100 hours of use.

7. Grease cost is estimated from interviews with farmers.

8. Electrical energy required is computed by use of the formula on the Data Input Form, page . This formula considers the pump unit's discharge rate, dynamic head and the efficiency of the pump, drive and motor.

9. Electricity cost is based on Pacific Consultants, *op. cit.*, page 17. The present subsidized price for electrical energy is L.E. 0.015 per kilowatt hour. Projected prices for long range planning should also be considered. According to one report Egypt's hydro-electric energy potential is "almost completely exploited."[1/] This leaves one to conclude electric energy for future projects will be based on scarce resources at world prices.

10. Salvage value at end of wearout life is considered to be zero. One could assign a wearout life to each component of the system and then place a "salvage value" on all longer lived components based on their estimated values when the shortest lived component wears out. Such refinements are unlikely to have much effect on the analytical results.

11. Taxes, license, permits, rent, etc. The only annual cost in this category which seemed relevant to water lifting was the cost of land occupied by the sakia. The amount of land required varies from 50 to 175 square meters or more depending on whether the site contains shade trees and feeding space for animals. Since the market value of annual land rent is about L.E. 2.0 per year for 175 square meters, this value was assigned.

12. Interest rate. In view of world interest rates and potential returns from Egyptian investment alternatives 15 percent seems to be a reasonable rate for determining the cost of capital of water lifting systems. Pacific Consultants, *op. cit.*, Table 1 following Annex G, list nine agricultural projects in Egypt which have projected internal rates of return in excess of 15%.

[1/] U.S. Department of Energy "Joint Egypt/United States Report on Egypt/United States Cooperative Energy Assessment," Vol. 1, April, 1979, page ES-5.

13. Operator or labor cost is difficult to assess. The amount L.E. 0.05 per hour for a sakia seems consistent with other studies and is perhaps adequate unless one considers the cost of the young boys driving animals turning sakias in terms of their foregone opportunity of going to school. Given the work habits of rural laborers L.E. 0.30 per hour for overseeing mechanical pumps seems realistic and consistent with information obtained by farmer interviews.

14. Discharge of pump. Data from EWUP observations indicate a 3-meter sakia, lifting water one meter from a well with an adequate flow into the well, is capable of discharging 100 m^3 per hour (see Appendix E). The discharge rates for diesel and electric driven pumps are taken from the respective manufacturer's specifications.

15. Animal energy cost is one of the most sensitive variables associated with sakia costs. EWUP data, based on farmer interview, indicate L.E. 0.30 per hour is realistic. This assumes cows are worked, in rotation with other cows, not more than three hours per day. This achieves normal discharge from a sakia assuming adequate head in the sakia well. The rationale for asking farmers about the rental rate of cows for returning a sakia is that they will, on the average, correctly evaluate the cost of extra feed and the reduction in meat and milk associated with working the animals.

This value is verified by Nasser[1/] in a report where he accounts for extra feed, milk losses and cow depreciation. He reports a cost of animal power of L.E. 37.6 per feddan per year. It is deduced from his report that 120 hours are spent each year to irrigate one feddan which results in L.E. 0.314 per hour as the cost of using a cow on a sakia. Some studies support the point of view that animal production is traditional among villages and the relationship between mechanization and animal production is very loose.[2/] The latter point of view suggests assigning a low cost to animal produced energy.

There are long run and short run considerations regarding the replacement of animal power with machines. With respect

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[1/] Nasser, Abdel Hady Abdel Bary, op. cit. pp. 63-64.

[2/] See for example Hopkins, Nicholas S., "Imposed Utilization of Feed Resources for the Livestock Sector - Rural Sociology Segment." Unpublished draft of a report to USAID, January 1980.

to long run considerations a recent study reports improved ruminant livestock would enable the annual meat and milk offtake to increase by nearly 3 fold in areas where ruminant livestock are no longer required for draft power.[1/] The report indicates such an increase would require a comprehensive program of improved animal breeding, forage production and nutrition. Such a program would take time to establish but could generate long run gains which would contribute to justification of mechanization. As stated earlier the short run gains from releasing animals from providing energy to turn sakias appears to be of lower magnitude. Further EWUP research is aimed at providing more information on this subject.

16. Overall efficiency, relating input horsepower to the amount of work performed, is not especially important in the case of diesel pumps or sakias since their energy source is priced in terms of fuel and animal power per hour. It is important in the case of electric pumps when energy is priced in terms of kilowatt hours. Manufacturer's specifications are used.

17. Engine efficiency. The discussion above (16) also pertains to the engine efficiency.

18. Static head simply reflects the amount of lift from the farms source of water to the field distribution ditches. It is believed that one meter reflects most conditions in Egypt but his value can easily be adjusted to accommodate special situations. It is important in the calculation of output horsepower hours required to irrigate a given area.

19. Dynamic head has been previously defined. It is taken from manufacturers specifications for low pressure pumps.

20. Water duty per year is based on typical conditions at field sites of EWUP. It can also be easily adjusted to fit special conditions.

[1/] Winrock International Livestock Research and Training Center, "Improved Utilization of Feed Resources for the Livestock Sector," Preliminary Draft, United States Agency for International Development, Catholic Relief Service, Cairo, A.R.E., January 1980.

21. Maximum time system will run per day is an important parameter in establishing the size of area a system can serve. If farmers pay the full cost they will have maximum incentive to use the system for long periods each day. If the government pays the costs it will be more difficult to convince farmers to operate the system beyond their normal working hours. The EWUP data assumes typical daylight working hours.

22. Minimum irrigation interval can be computed if crop patterns, consumptive use for each crop, and soil characteristics are known. The EWUP data assumes a cropping pattern which requires frequent irrigation.

23. Maximum water required per irrigation can be computed with the above information plus information about water application efficiency. The EWUP data assumes typical water application efficiency with a liberal margin of safety.

APPENDIX B

COMPUTATIONS OF POWER REQUIREMENTS AND EFFICIENCIES

Pumps used for lifting water from delivery canals to fields should be of low pressure design. The maximum design head should not exceed 4.0 meters.

The equation for computing water horsepower (WHP) in metric units is:

$$WHP = \frac{W \cdot H}{75} \qquad (1)$$

where: W is discharge flow in liters per second,
H is the total dynamic head in meters

or

$$WHP = \frac{Q \cdot H}{270} \qquad (2)$$

where: Q is discharge flow in cubic meters per hour.

The equation for computing brake horsepower (BHP) required to operate a pump is:

$$BHP = \frac{WHP}{\text{Overall Efficiency}} \qquad (3)$$

where: overall efficiency is pump efficiency x drive efficiency

<u>Power Requirements for Electric Motors</u>

The BHP of the motor is determined by combining equations (2) and (3), that is:

$$BHP = \frac{Q \cdot H}{270 \text{ Overall Efficiency}} \qquad (4)$$

To compute the input to the motor the efficiencies of electric motors must be considered. In determining the consumption in kilowatt hours (KWH), the following formula is applied:

$$KWH = \frac{Q \cdot H}{270 \text{ Overall Efficiency}} \times \frac{0.7457}{\text{Motor Efficiency}} \qquad (5)$$

For small electric motors running at full speed (1760 rpm), motor efficiency is about 85 percent. Then equation (5) becomes:

$$KWH = \frac{Q \cdot H}{270 \text{ Overall Efficiency}} \times \frac{0.7457}{0.85}$$

or

$$KWH = \frac{Q \cdot H}{307.76 \cdot \text{Overall Efficiency}}$$

Power Requirements for Internal Combustion Engines

Equation (4) can be applied, with necessary corrections for temperature, continuous operation and altitude.

Power Requirements for Sakia

Power requirements for sakias can be calculated by comparing work done by either electric or internal combustion engine driven pumps.

The time ratio between a pump and a sakia to deliver a specific amount of flow can be used to determine the brake horsepower of the sakia as follows:

$$(BHP)_S = (BHP)_P x \frac{t_P}{t_S} \times \frac{H_S}{H_P}$$

where: $(BHP)_S$ is the break horsepower of a sakia.

$(BHP)_P$ is the break horsepower of a pump.

t_P is the time required for a pump to lift a specified amount of water.

t_S is the time required for a sakia to lift the same specified amount of water.

H_S is the dynamic head of sakia.

H_P is the dynamic head of pump.

APPENDIX C

DATA INPUT FORMS - WATER LIFTING COSTS

DATA INPUT FORM - WATER LIFTING COSTS

Data prepared by ______________________ Date ______________

Tape ; Track ; File

A$ (*)	
1. Name of machine ....(19)	1. ________
2. Make ....(19)	2. ________
3. Model ....(9)	3. ________
4. Size ....(9)	4. ________
5. Power source (DIES. ELEC. ANIM.)	5. ________
6. Date (day, month, year) DDMMYY ....(12)	6. ________
A *	
1. Present replacement price in Egypt, LE ....(12)	1. ________
2. Wearout life, hours ....(12)	2. ________
3. Expected average repair cost, LE/hour ....(12)	3. ________
4. Fuel consumption, liters/hour ....(12)	4. ________
5. Fuel cost, LE/liter ....(12)	5. ________
6. Oil cost, LE/100 hours ....(12)	6. ________
7. Grease cost, LE/100 hours ....(12)	7. ________
8. Electric energy required, kilowatt hours 2/ ....(12)	8. ________
9. Electricity cost, LE/kilowatt hour ....(12)	9. ________
10. Salvage value at end of wearout life, LE ....(12)	10. ________
11. Taxes, license, permits, rent, etc., LE/year ....(12)	11. ________
12. Interest rate, percent ....(12)	12. ________
13. Operator or labor cost, LE/hour ....(12)	13. ________
14. Discharge of pump, cubic meters/hour ....(12)	14. ________
15. Animal energy cost, LE/hour ....(12)	15. ________
16. Overall efficiency, decimal from .01 to 1.0...........(12)	16. ________
17. Engine efficiency, decimal from .01 to 1.0............(12)	17. ________
18. Static head, meters 3/ ....(12)	18. ________
19. Dynamic head, meters 4/ ....(12)	19. ________
20. Water duty per year, cubic meters/feddan ....(12)	20. ________
21. Maximum time system will run per day, hours ....(12)	21. ________
22. Minimum irrigation interval, days ....(12)	22. ________
23. Maximum water required per irrigation, cu. meters/fed.(12)	23. ________

1/ Maximum characters allowed.

2/ Kilowatt hours = $\frac{\text{Discharge in } m^3/\text{hr} \times \text{Dynamic head in m.}}{362 \times \text{Overall Efficiency} \times \text{Engine Efficiency}}$

3/ Static head is defined as the distance between the water level in the delivery canal or pump station well and the water level required in field distribution ditch.

4/ Dynamic head is defined as the difference between the water level in the delivery canal or pump station well at the point of suction and the discharge point of the pump plus losses.

APPENDIX D

Development of the Water Wheel Design for Field Irrigation

Introduction

Due to large increase in the cultivated area in the U.A.R., it was necessary to adopt a new system of field irrigation by lifting the water from distributary canals to the field instead of raising the water levels of the canals and discharging the water by gravity to the land.

The Hydraulic Research and Experiment Station at the Delta Barrage is requested to study and develop the design of the water wheels. The Tanabish water wheels have become the most popular means of lifting water in the last years. This is due to the simplicity of its operation, the low initial and running costs and the durability of the machine. The Tanabish can either be driven by animals or by mechanical power.

The Hydraulic Research and Experiment Station carried out a test program on five different designs of the Tanabish which were 6 cm thick and 75 cm in diameter. The different bucket shapes tested were:

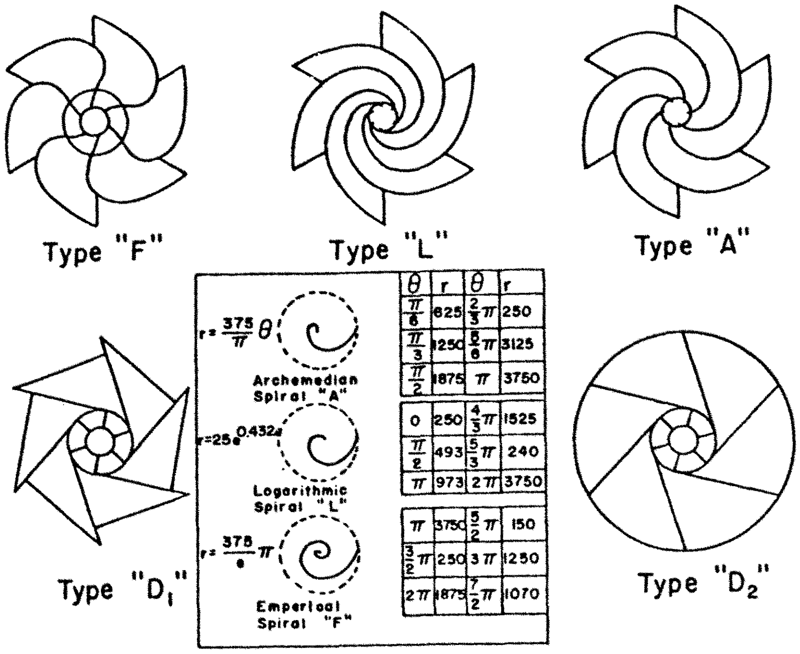
1. The archimedian spiral curve (A).
2. The empirical design according to Professor Ali Fathi's suggestion (F).
3. The logarithmic spiral curve (L),
4. The first design suggested by the HRES "D_1".
5. The second design suggested by the HRES "D_2".

Figure (1) shows the different designs tested.

The Model and the Measuring Devices

Figure (2) shows the experimental setup. It consists of:

1. A glass flume 1.00 x 1.00 x 80 cm. The sides were made of glass. Water is discharged to and from the flume through circular pipes in the concrete base. This flume simulates the prototype sump from which the Tanabish lifts the water.
2. The outlet channel: It consists of a wooden channel which collects the water discharging from the water wheel.
3. The discharge measurement: The California pipe method was used for measuring the discharge from the Tanabish. The method is most suitably for small discharges. It consists of a 4 inch pipe



θ	r	θ	r
$\frac{\pi}{6}$	625	$\frac{2}{3}\pi$	250
$\frac{\pi}{3}$	1250	$\frac{5}{6}\pi$	3125
$\frac{\pi}{2}$	1875	π	3750
0	250	$\frac{4}{3}\pi$	1525
$\frac{\pi}{2}$	493	$\frac{5}{3}\pi$	240
π	973	2π	3750
π	3750	$\frac{5}{2}\pi$	150
$\frac{3}{2}\pi$	250	3π	1250
2π	1875	$\frac{7}{2}\pi$	1070

Figure 1

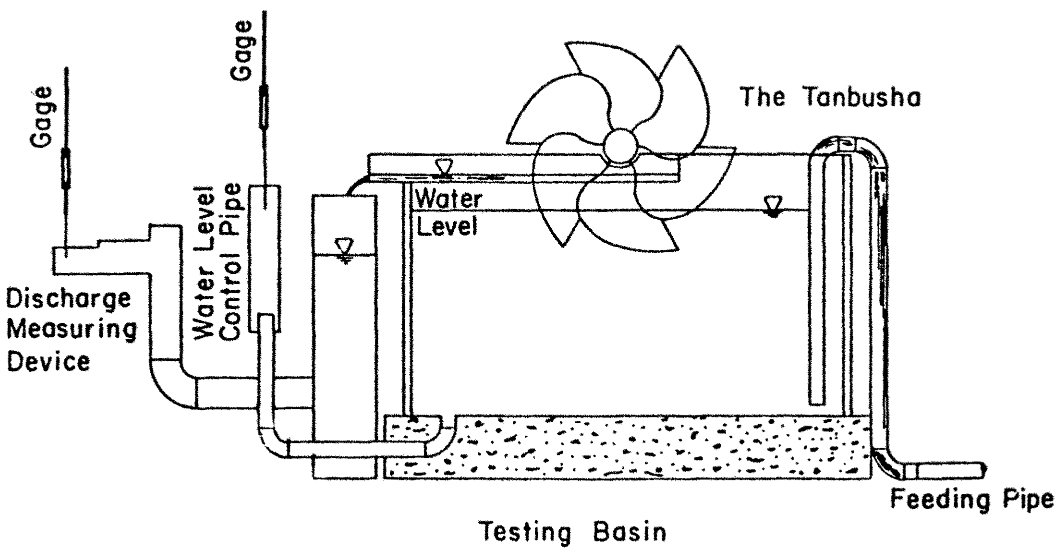


Figure 2

equipped with a point gauge for measuring the water levels in the pipe. This set was calibrated and the following equation was found to fit the calibration data:

$$Q = 0.165\ (d - a)^{1.974}$$

where (d - a) is the water head at the end of the pipe in cms and Q is the discharge in liters per second.

4. The skimming weir: It consists of a 4" pipe connected to the flume on which slides a 6" pipe used as an overflow weir to ensure a constant level in the flume. It is also fitted with a point gage for water level recording.

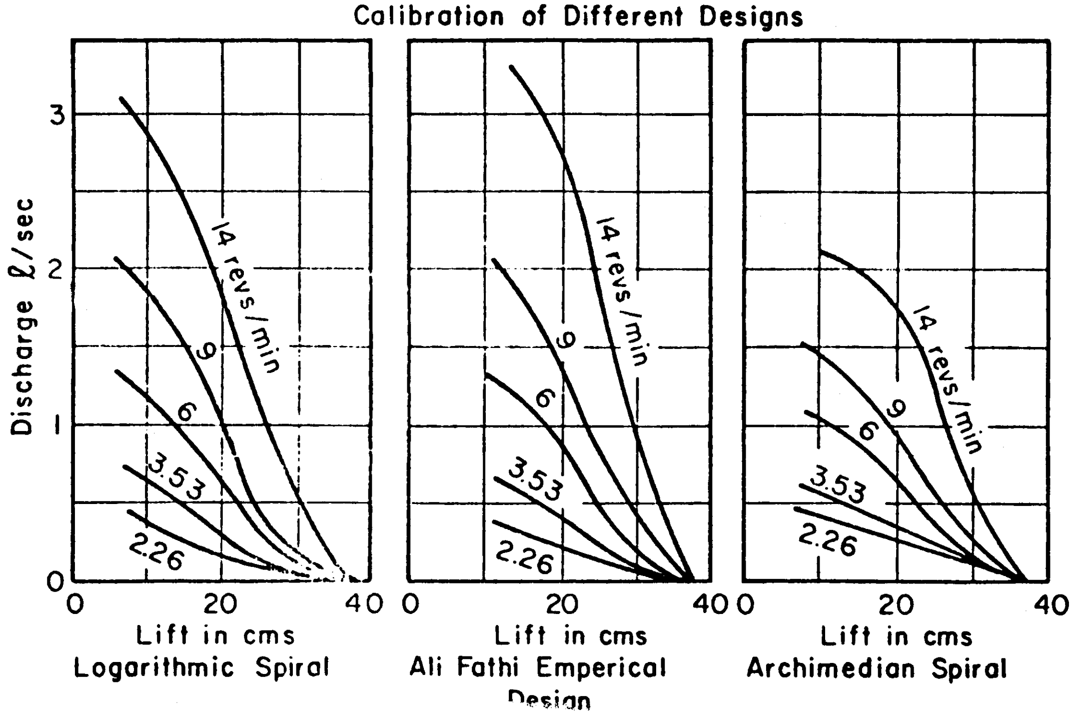
5. The feeding pipe: The flume is supplied with water through a 2" pipe. The amount of discharge was adjusted by a valve. A screen mesh was also placed at the pipe exit to avoid surface disturbances in the water. The pipe was supplied with water from an overhead constant head bank.

6. The driving equipment: The wheel was driven by an electric motor equipped with a gear box to adjust the rpm which varied between 2 and 14 rpm.

Results of the Calibration of the Three Types of Tanabish Used Currently in the Prototype

Several experiments were carried out on each of these three types. It includes Tanabish having 6, 8, 10 and 12 buckets. The following diagrams show the results of this test.

Calibration of Different Designs



It was observed in these tests that there is interference between adjacent buckets, i.e., some of the water discharging from one bucket did not discharge to the next channel but it fills again the following bucket. This reduced the efficiency of the machine considerably (Figure A).

Other losses are also due to the overflow of water through the entrance of the bucket as it turns out of the water. The amount of this loss was found to be less then 0.5%. This loss also decreased with the decrease of the number of revolutions per minuted (Figure B).

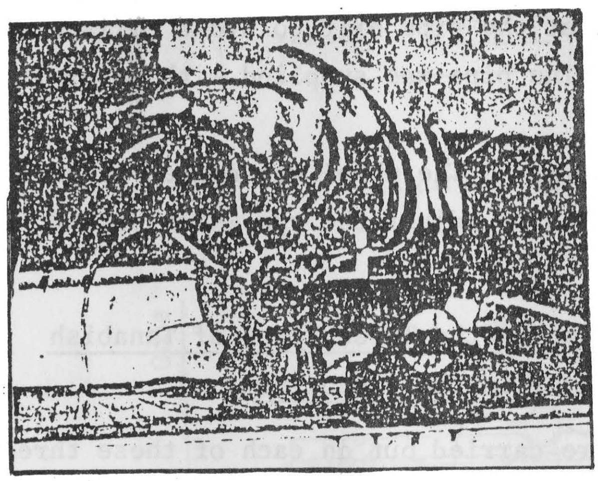


Figure A

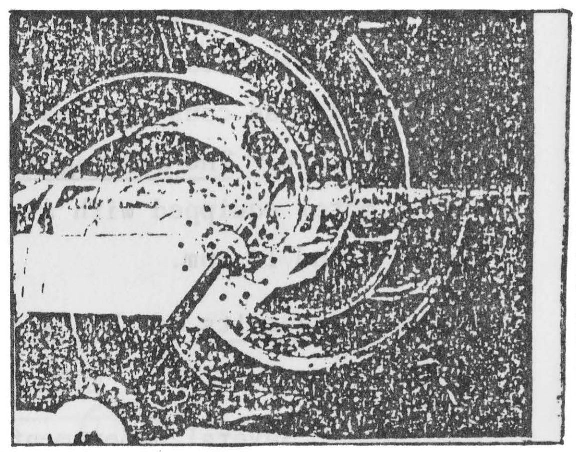


Figure B

The Design of the Bucket Exit and the Relationship Between the Discharge and the Number of Buckets

Guide vanes were used in the bucket exits to separate the water paths through the bucket completely. By this method, the discharge from the wheel will be equal to the product of the discharge through one bucket by the number of the buckets. Figure (3) and (4) show the increase in the total discharge due to the separation of the buckets.

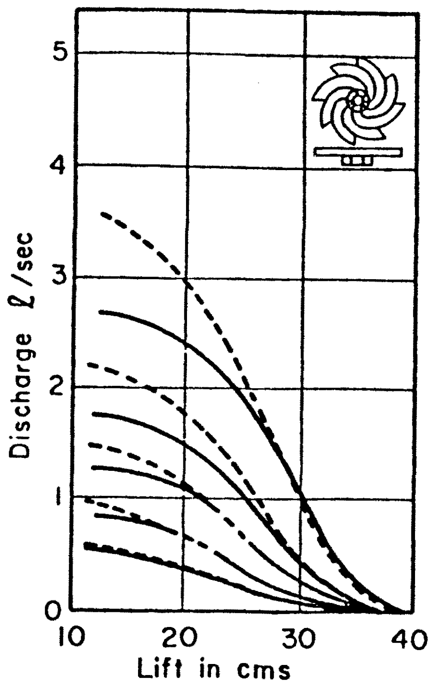


Figure 3

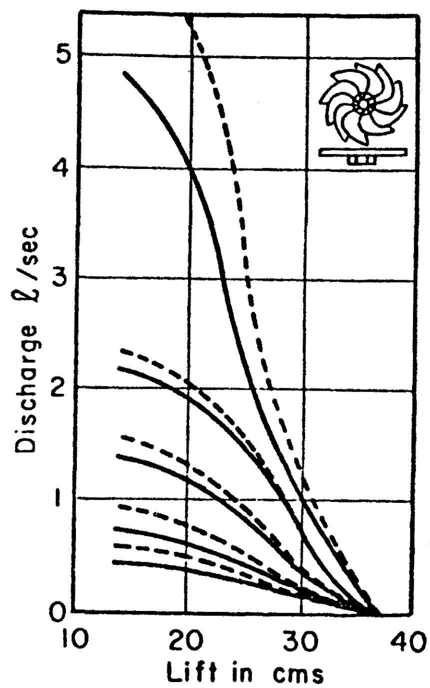


Figure 4

The Empirical Discharge Results

A relationship between the amount of water discharged by the Tanabish and the lift was derived. Figure (5) shows this relationship for the different types of Tanabish at the very low speed of rotation. Assuming that N is the number of buckets, t is the time during which the water of one Tanabish is discharged and L is the lift, the equation is given as:

$$Q = C_d \frac{V N}{t}$$

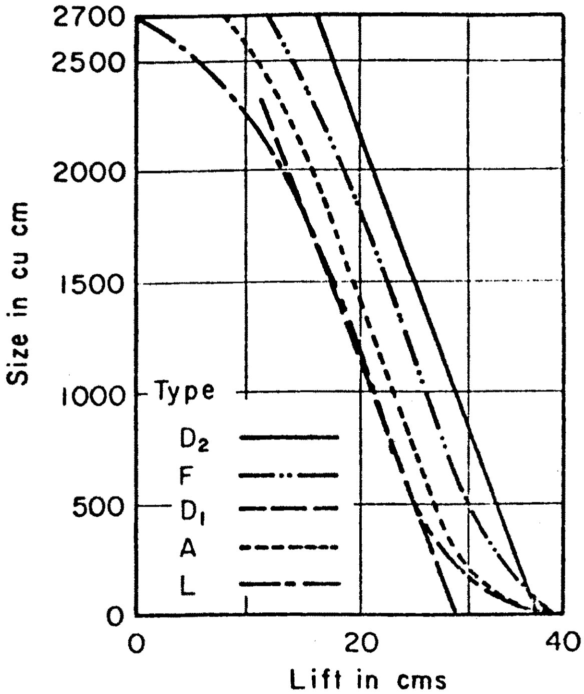


Figure 5

Where C_d is the coefficient of discharge,

V is the volume of one bucket.

It was observed that the values of C_d is not constant for the three types which shows that C_d depends upon the shape of the bucket.

For the D_1 -6 design, the relation between V and L is linear although C_d is varied considerably. Modification of this type gave the D_2 -5 design in which C_d proved to be constant for each speed of revolution but it does not depend upon L. The following equations show the calibration for this design,

$$Q = \frac{1}{t} (16.4 - 0.456\ L) \qquad \text{for } 3.53 \text{ rpm}$$

$$Q = \frac{1}{t} (32.4 - 0.9\ L) \qquad \text{for } 6 \text{ rpm}$$

$$Q = \frac{1}{t} (50.3 - 14.\ L) \qquad \text{for } 9 \text{ rpm}$$

The advantages of this design are:

1. The simplicity of the design and the easiness of the manufacture.

2. The increase of discharge varied between 125% and 295% as compared to the best of the previous three designs.

3. The relationship between Q and L is linear.

4. It is easy to find both C_d and t experimentally. They do not depend upon any other factors. Figure (6) shows a comparison between the different design of Tanabish.

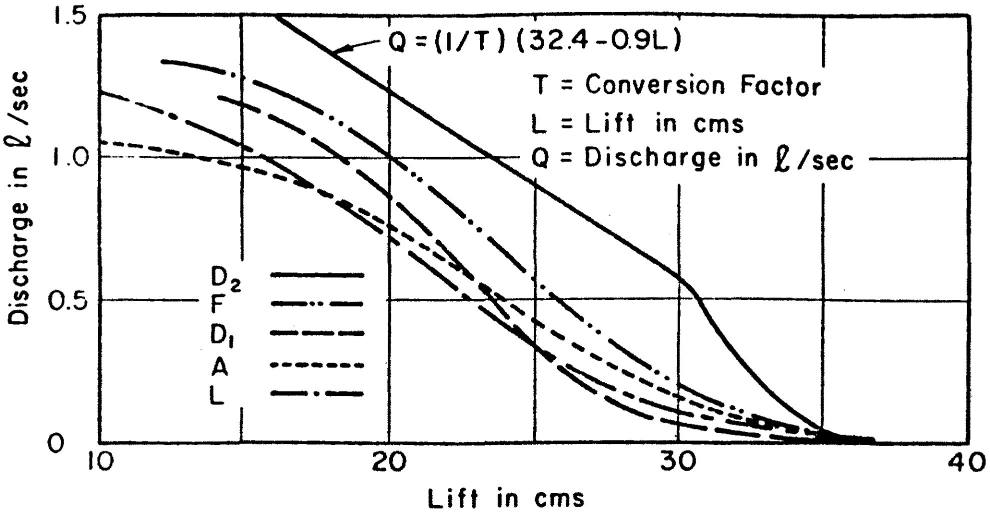

1.5
1.0
0.5
0
10
20
30
40
Q = (I/T) (32.4 - 0.9L)
T = Conversion Factor
L = Lift in cms
Q = Discharge in ℓ/sec
D2
F
D1
A
L
Discharge in ℓ/sec
Lift in cms

Figure 6

APPENDIX E

EWUP ANALYSIS OF SAKIA DISCHARGE DATA

Data were collected on discharge, lift head, speed in revolutions per minute and total time of irrigation at a dozen sakia locations in 1978 and 1979. The discharge was measured by use of cutthroat flumes.

Several functions were fitted to the data by standard statistical methods. The function giving the best fit is:

$$Q = k\ n\left(\frac{r - h}{r}\right)^{Z}$$

where: Q is discharge in cubic meters per hour,

K = 50.7

n = revolution per minute

r = radius of a sakia in meters

h = lift head in meters

Z = .6252

The data indicated the simple arithmetic average of revolutions per minute is 3.3 r.p.m. This included observations where animals were not driven actively, sometimes topping completely for various reasons.

The average discharge (Q), under such conditions for a sakia of 1.5 meters radius (3 meter diameter) and lifting water 1 meter is:

$$Q = 50.7 \times 3.3\left(\frac{1.5 - 1.0}{1.5}\right)^{.6252} = 83.7\ mt^3/hr$$

If we assume animals can be managed in such a way as to achieve 3.9 revolutions per minute the discharge increases to 100 m^3/hour. Based upon field research and experience this appears to be feasible but of course requires good management of the animal as a source of power. It also depends on the desire of the farmer to achieve high rates of irrigation.

See next page for sakia discharge observations and regression function.

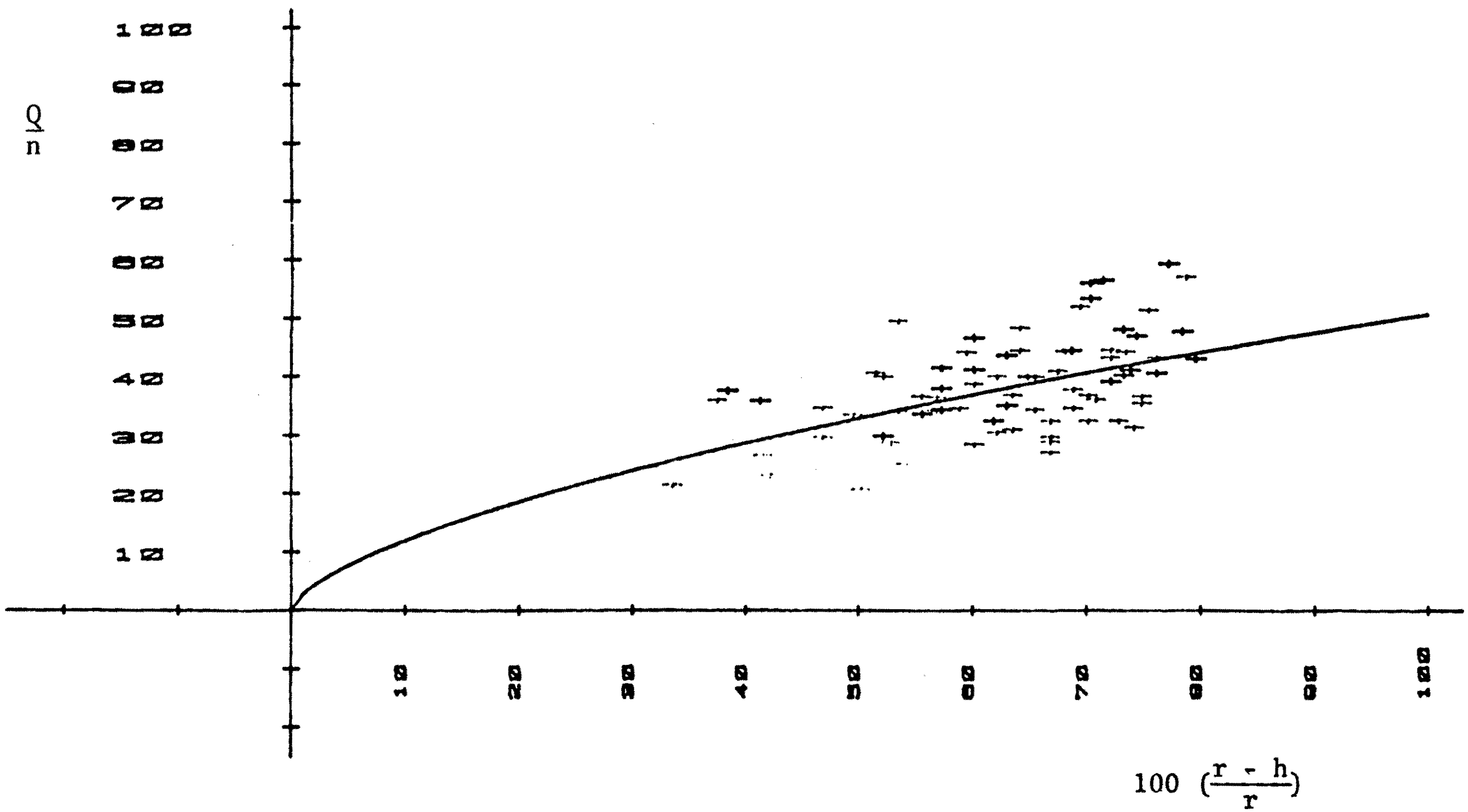


Figure E.1: Sakia Discharge Observations and Regression Function

$$\frac{Q}{n} = 2.8492 \left[\frac{100\ (r-h)}{r}\right]^{.6252}$$