PROJECT TECHNICAL REPORT NO. 7

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

By:

H. Wahby, M. Quenemoen, Mohamed Helal

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EGYPT WATER USE AND MANAGEMENT PROJECT

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EWUP PROJECT TECHNICAL REPORT NO. 7

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# AMERICAN EQUIVALENTS OF EGYPTIAN ARABIC TERMS AND MEASURES COMMONLY USED IN IRRIGATION WORK

| LAND AREA | IN SQ METERS | IN ACRES | IN FEDDANS | IN HECTARES |
|---|---|---|---|---|
| 1 acre | 4,046.856 | 1.000 | 0.963 | 0.405 |
| 1 feddan | 4,200.833 | 1.038 | 1.000 | 0.420 |
| 1 hectare (ha) | 10,000.000 | 2.471 | 2.380 | 1.000 |
| 1 sq. kilometer | $100 \times 10^4$ | 247.105 | 238.048 | 100.000 |
| 1 sq. mile | $259 \times 10^6$ | 640.000 | 616.400 | 259.000 |

| WATER MEASUREMENTS | FEDDAN-CM | ACRE-FEET | ACRE-INCHES |
|---|---|---|---|
| 1 billion $m^3$ | 23,809,000.000 | 810,710.000 | |
| 1,000 $m^3$ | 23.809 | 0.811 | 9.728 |
| 1,000 $m^3$ /Feddan (= 238 mm rainfall) | 23.809 | 0.781 | 9.372 |
| 420 $m^3$ /Feddan (= 100 mm rainfall) | 10.00 | 0.328 | 3.936 |

| OTHER CONVERSION | | METRIC | U.S. |
|---|---|---|---|
| 1 ardab | = | 198 liters | 5.62 bushels |
| 1 ardab/feddan | = | | 5.41 bushels/acre |
| 1 kg/feddan | = | | 2.12 lb/acre |
| 1 donkey load | = | 100 kg | |
| 1 camel load | = | 250 kg | |
| 1 donkey load of manure | = | 0.1 $m^3$ | |
| 1 camel load of manure | = | 0.25 $m^3$ | |

## EGYPTIAN UNITS OF FIELD CROPS

| CROP | EG. UNIT | IN KG | IN LBS | IN BUSHELS |
|---|---|---|---|---|
| Lentils | ardeb | 160.0 | 352.42 | 5.87 |
| Clover | ardeb | 157.0 | 345.81 | 5.76 |
| Broadbeans | ardeb | 155.0 | 341.41 | 6.10 |
| Wheat | ardeb | 150.0 | 330.40 | 5.51 |
| Maize, Sorghum | ardeb | 140.0 | 308.37 | 5.51 |
| Barley | ardeb | 120.0 | 264.32 | 5.51 |
| Cottonseed | ardeb | 120.0 | 264.32 | 8.26 |
| Sesame | ardeb | 120.0 | 264.32 | |
| Groundnut | ardeb | 75.0 | 165.20 | 7.51 |
| Rice | dariba | 945.0 | 2081.50 | 46.26 |
| Chick-peas | ardeb | 150.0 | 330.40 | |
| Lupine | ardeb | 150.0 | 330.40 | |
| Linseed | ardeb | 122.0 | 268.72 | |
| Fenugreek | ardeb | 155.0 | 341.41 | |
| Cotton (unginned) | metric qintar | 157.5 | 346.92 | |
| Cotton (lint or ginned) | metric qintar | 50.0 | 110.13 | |

## EGYPTIAN FARMING AND IRRIGATION TERMS

fara = branch
marwa = small distributer, irrigation ditch
masraf = field drain
mesqa = small canal feeding from 10 to 40 farms
qirat = cf. English "karat", A land measure of 1/24 feddan, 175.03 $m^2$
qaria = village
sahm = 1/24th of a qirat, 7.29 $m^2$
saqia = animal powered water wheel
sarf = drain (vb.), or drainage. See also masraf, (n.)

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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

During the past two years a number of people have contributed conceptual ideas, empirical data and computer programming assistance to this work. The authors especially recognize assistance from their EWUP colleagues Gamal Ayad, Yusef Yusef, Shinnawi Abdel Ati, and Dr. Mona El Kady. Dr. R. J. McConnen, Montana State University, assisted in many ways but was particularly helpful in conceptualizing alternatives for computer analysis. Mr. Niel Dimick, USAID offered many suggestions as well as contributing information and encouragement. Drafts of the reports were reviewed by Drs. E. V. Richardson and Melvin Skold, Colorado State University, Dr. Royal Brooks, EWUP Technical Director and Mr. Any Koval, Director of Catholic Relief Service in Cairo. Grateful thanks and acknowledgement is extended to all those who assisted in this work. The authors alone accept responsibility for errors and omissions.

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

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

1/ Dr. Hassan Wahby is Director of the Egypt Water Use and Management Project. Dr. Gene Quenemoen is Agricultural Economist and Mr. Mohamed Helal is Research Engineer for the same organization.

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.

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[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.

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

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).

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

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

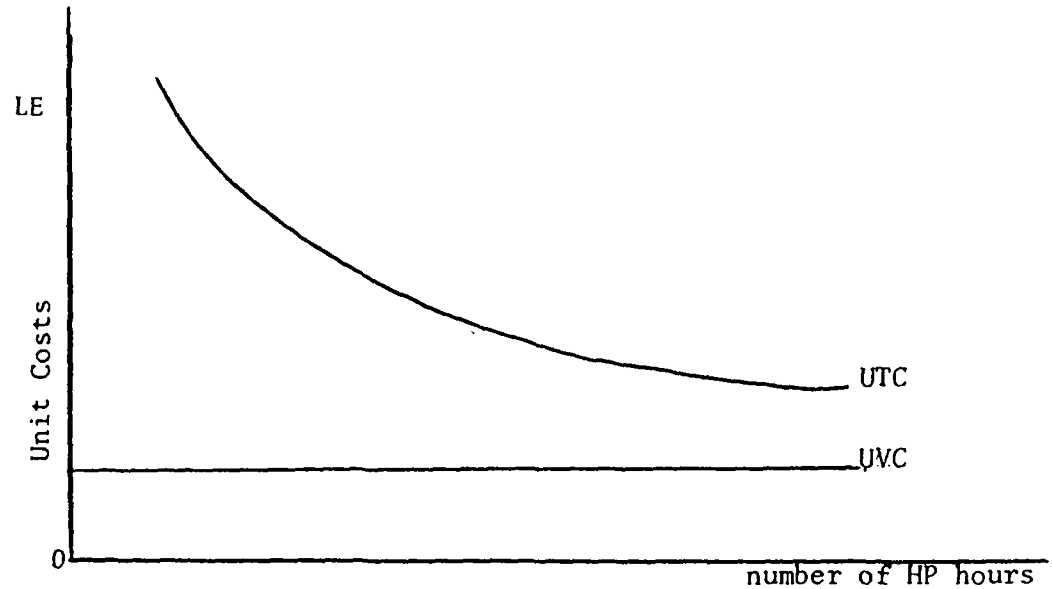


Figure 1. Hypothetical Relationship Between Unit Fixed, Variable and Total Costs.

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

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.

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[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. <u>Maximum water required per irrigation</u>. 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.

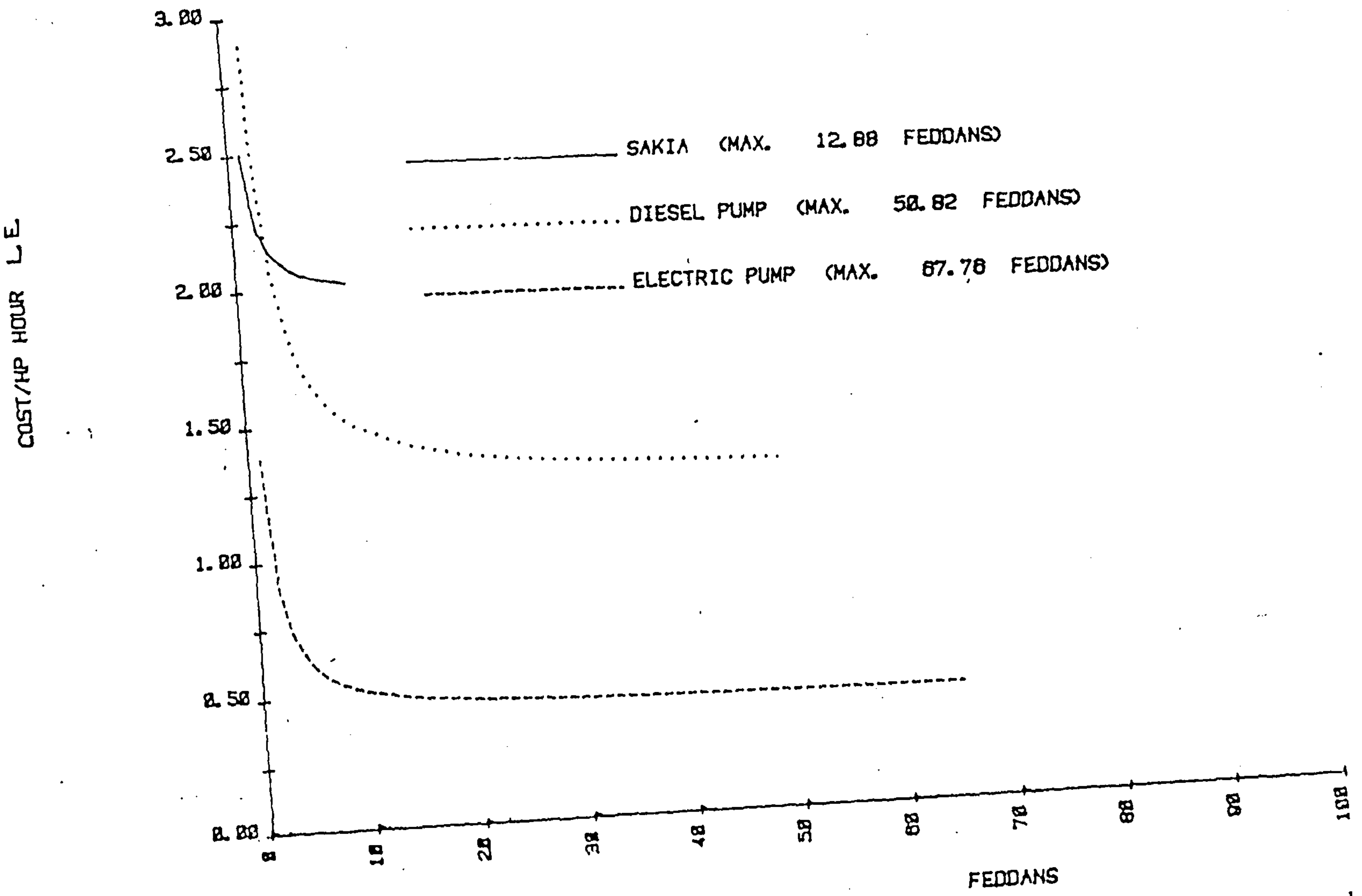


Figure 2. Water Lifting Costs Per Unit of Work Done for Sakia, Diesel Pump and Electric Pump, Menoufia University Data.

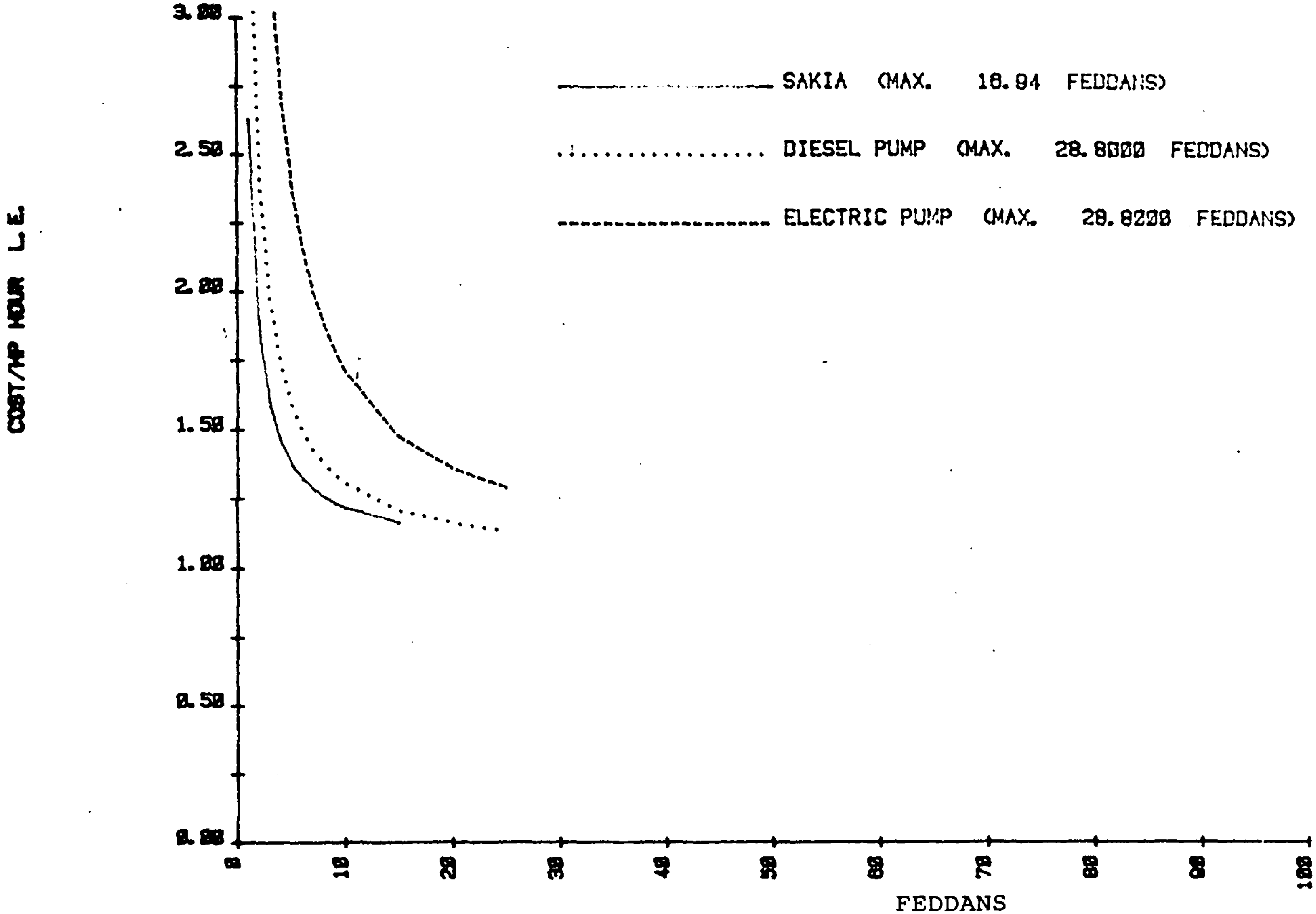


Figure 3. Water Lifting Costs Per Unit of Work Done for Sakia, Diesel Pump and Electric Pump, EWUP Data.

**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 | 119.298 |
| DISCHARGE OF PUMP,cubic mt./hr | 57.000 |
| ANIMAL POWER COST LE/hr | 0.314 |
| 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 | 16.000 |
| MIN. TIME BETWEEN IRRIGATION,days | 6.000 |
| MAX. WATER REQUIRED PER IRRIG.,cubic mt/fd | 425.000 |

MAX. SYSTEM CAPACITY = 12.88 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 | 986.974 | 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 | 89.474 | 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 | 1960.447 | 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 | 2933.921 | 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 | 3907.395 | 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 |
| 90.00 | 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 | 4880.868 | 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
OHP REQUIRED AT MAX = 5.56 BRAKE HORSEPOWER
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 | 10.017 | 5.650 | 1.260 | 35.995 | 124.256 | 62.128 | 50.370 | 2.4668 |
| 3.00 | 63.000 | 12.498 | 15.026 | 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 |
| 7.80 | 63.000 | 29.163 | 35.065 | 19.776 | 4.409 | 125.981 | 277.395 | 39.628 | 176.296 | 1.5735 |
| 8.00 | 63.000 | 33.327 | 40.075 | 22.601 | 5.037 | 143.977 | 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 =8533.3BHP 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 | 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 | 49.021 | 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 | 6000.000 |
| 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 = 28.00 FEDDANS/YEAR
BHP REQUIRED AT MAX = 3.15 BRAKE HORSEPOWER
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 | 174.193 | 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 | OUTPUT 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 | 225.479 | 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 | 67.146 | 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 |

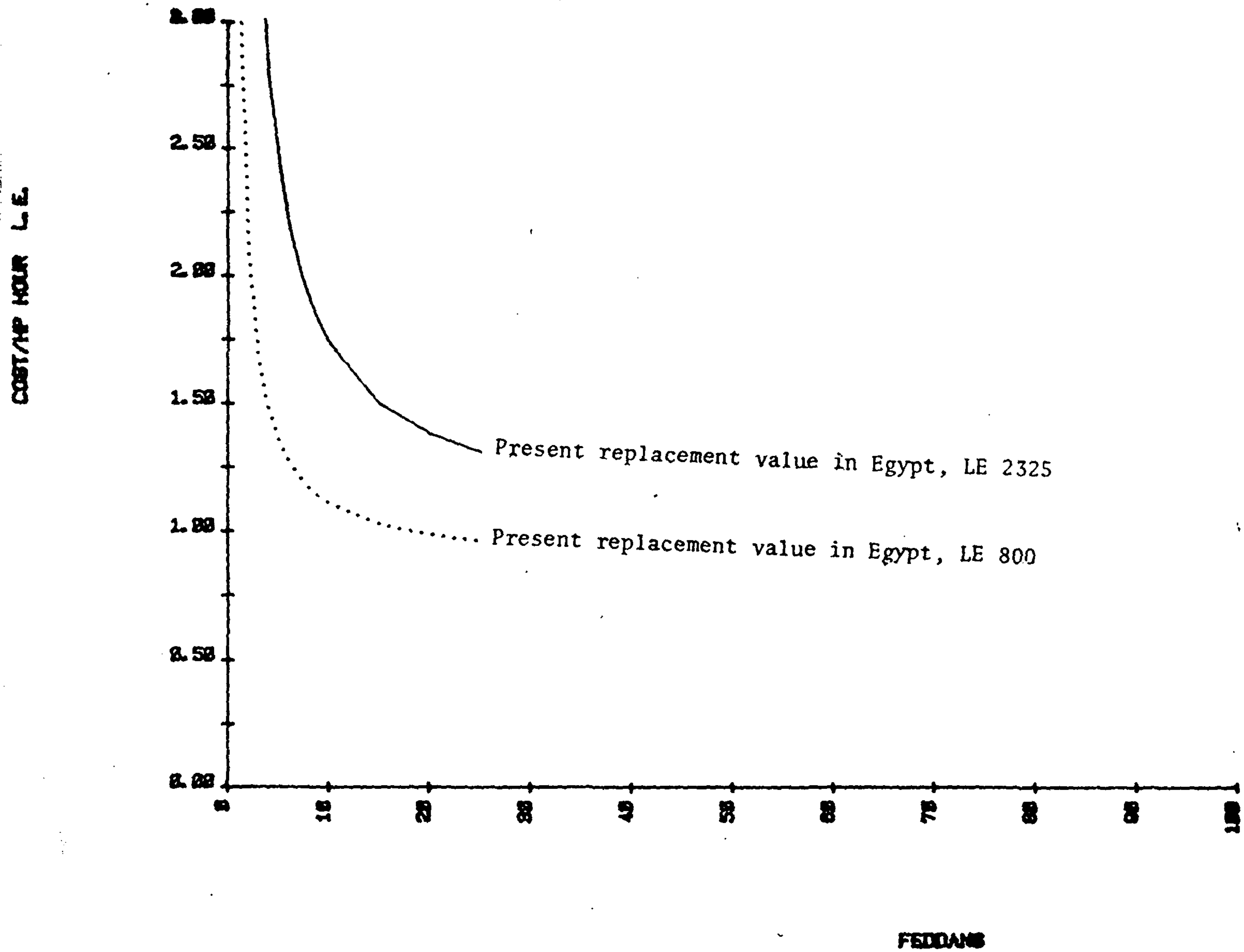


Figure 4: Cost Curve for Electric Pump, EWUP Data, for Replacement Costs of L.E. 2325 and L.E. 800.

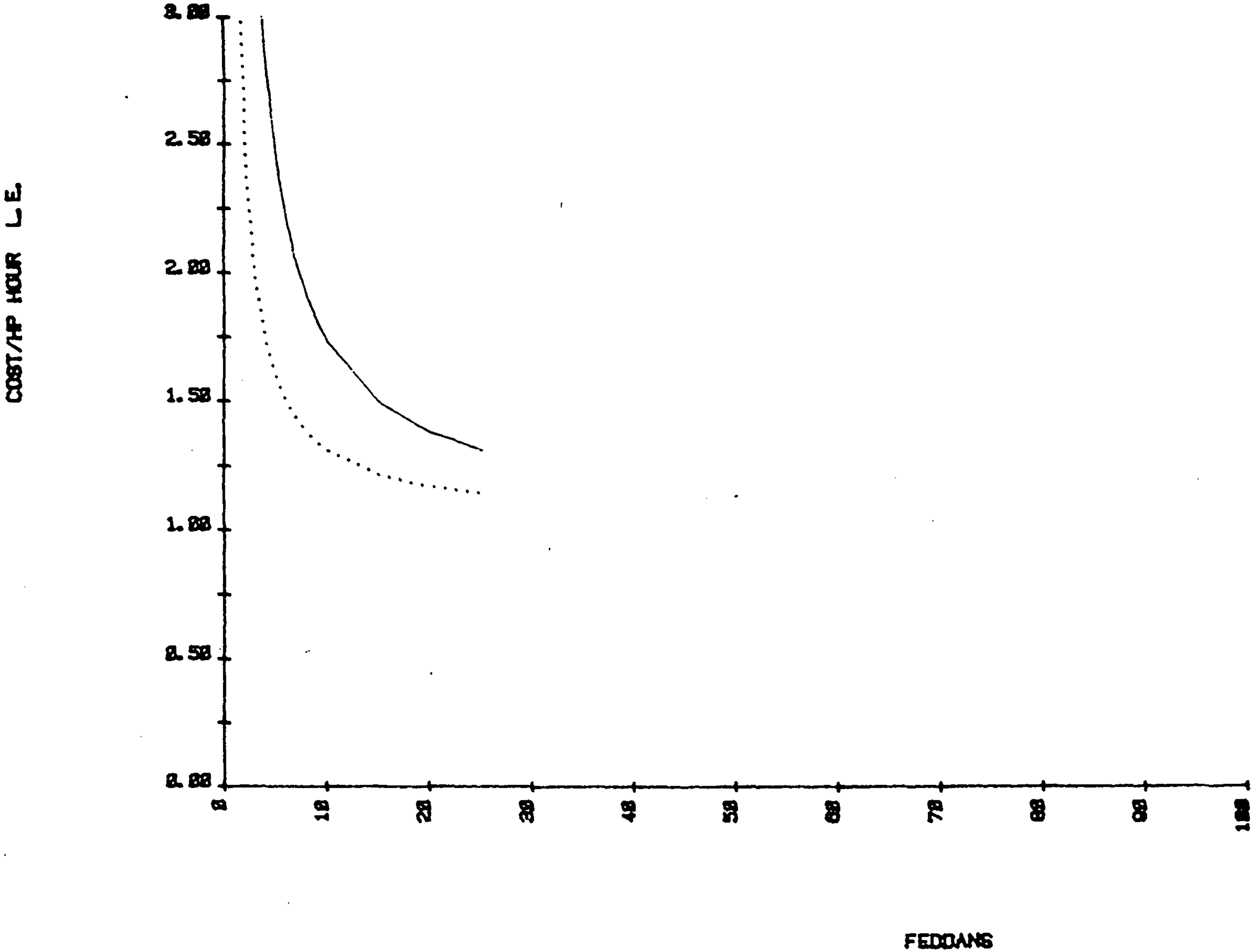


Figure 5: Cost Curves for Electric Pump, EWUP Data, for Interest Rates of 6 Percent and 15 Percent.

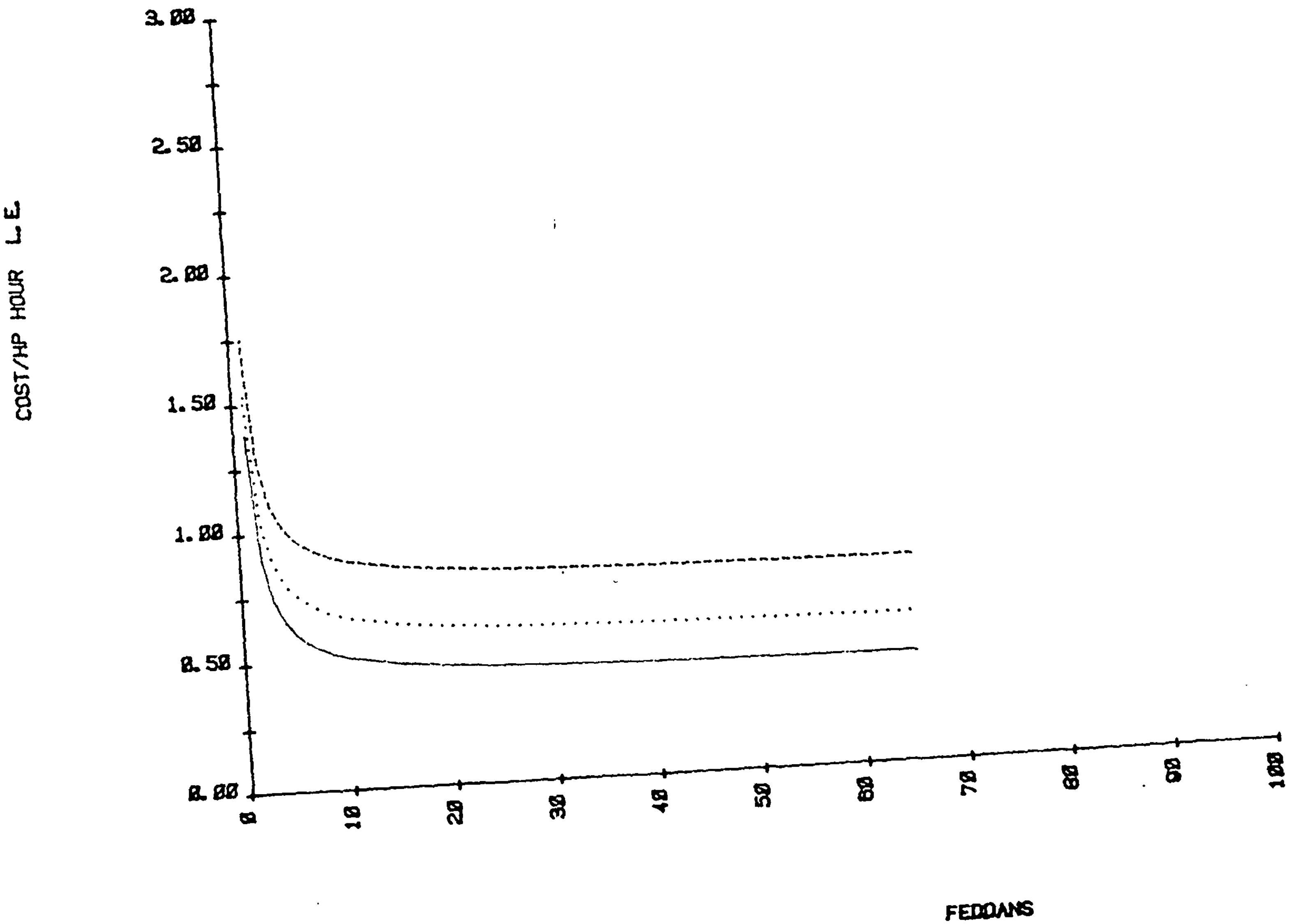


Figure 6: Cost Curves for Electric Pump, for Electricity Rates of L.E. 0.015, 0.05 and 0.10 per Kilowatt Hour.

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.

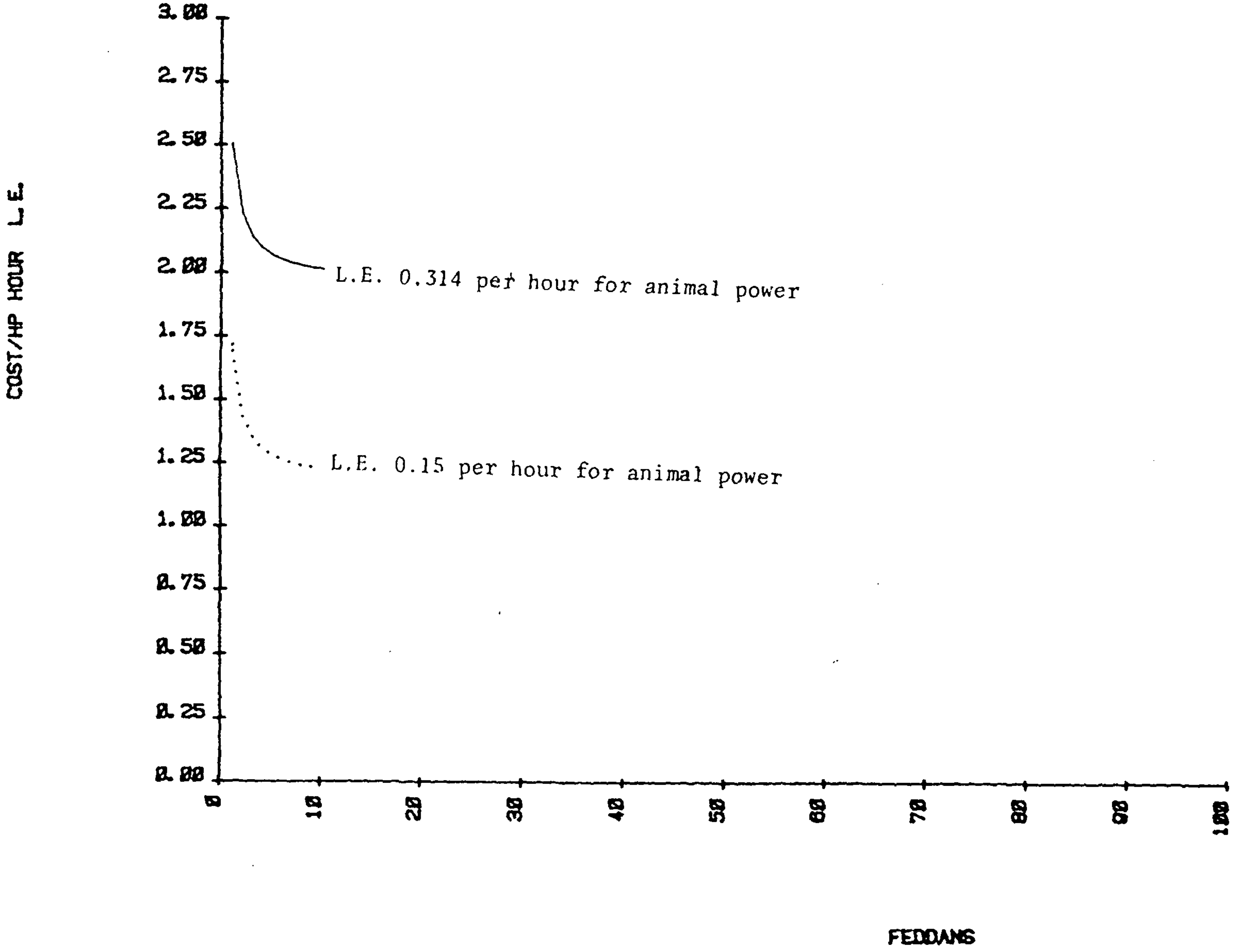


Figure 7: Cost Curves of Sakia, Menoufia Data, for Animal Power Rates of L.E. 0.314 and L.E. 0.15 Per Hour.

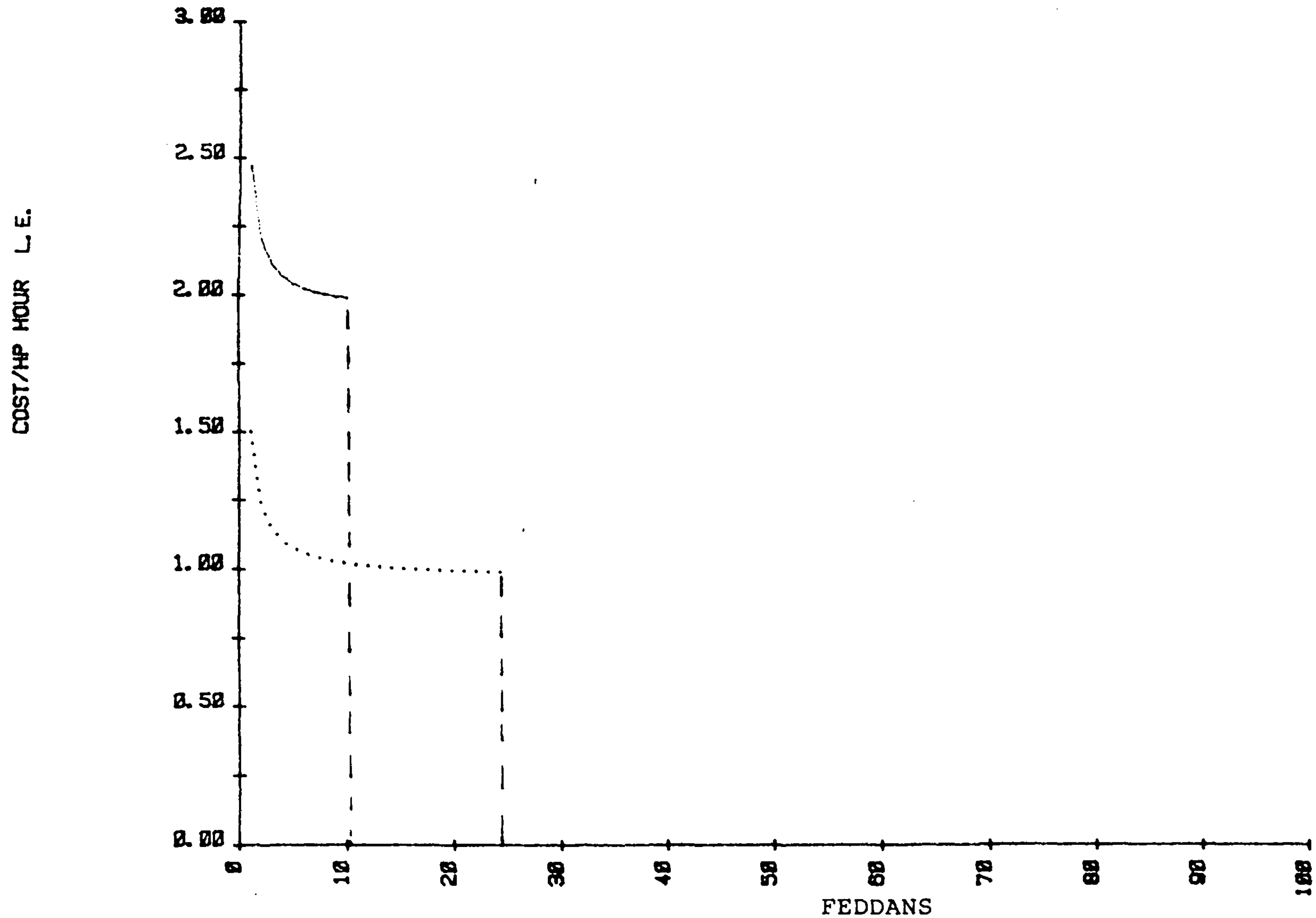


Figure 8. Cost Curves for a Sakia, Menoufia Data, for Discharge Rates of 57 $m^3$/hr. and 114 $m^3$/hr.

## 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.

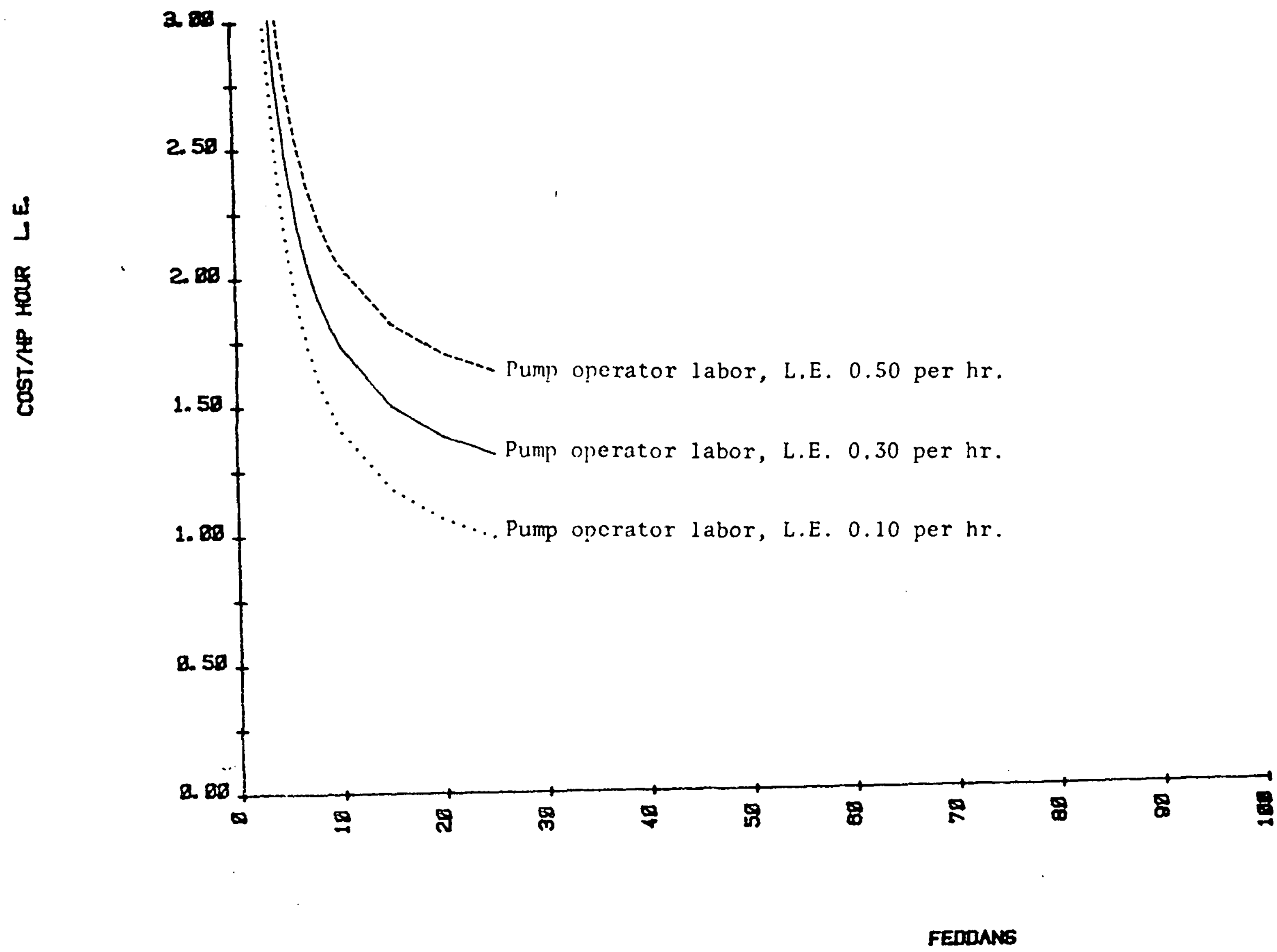


Figure 9: Cost Curves for an Electric Pump, EWUP Data, for Operator Labor Cost of L.E. 0.10, 0.30 and 0.50 Per Hour.

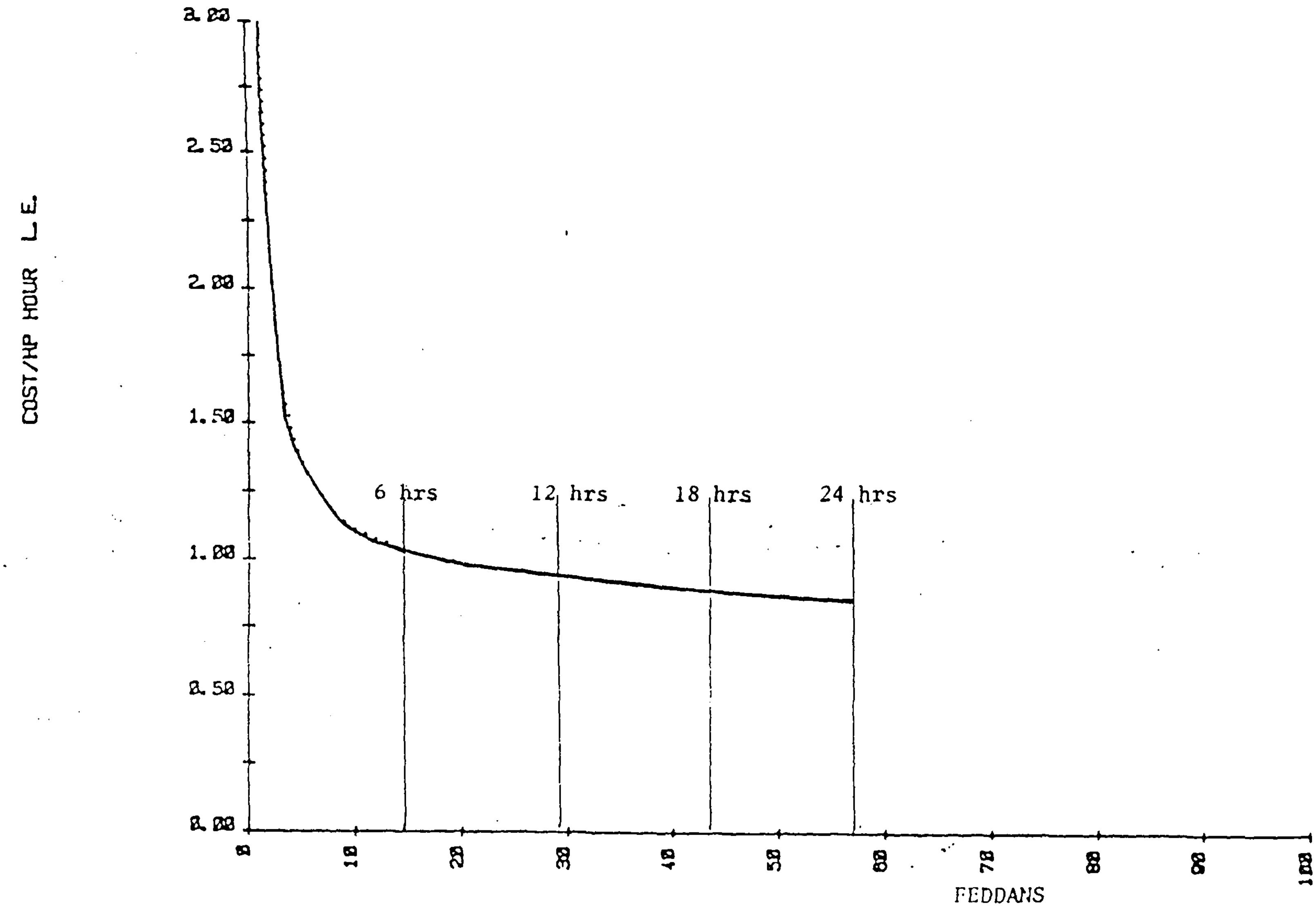


Figure 10. Cost Per Unit of Work Done Decreases and System Capacity Increases as Number of Hours per Day the System Operates Increases.

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%.

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[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.

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[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.

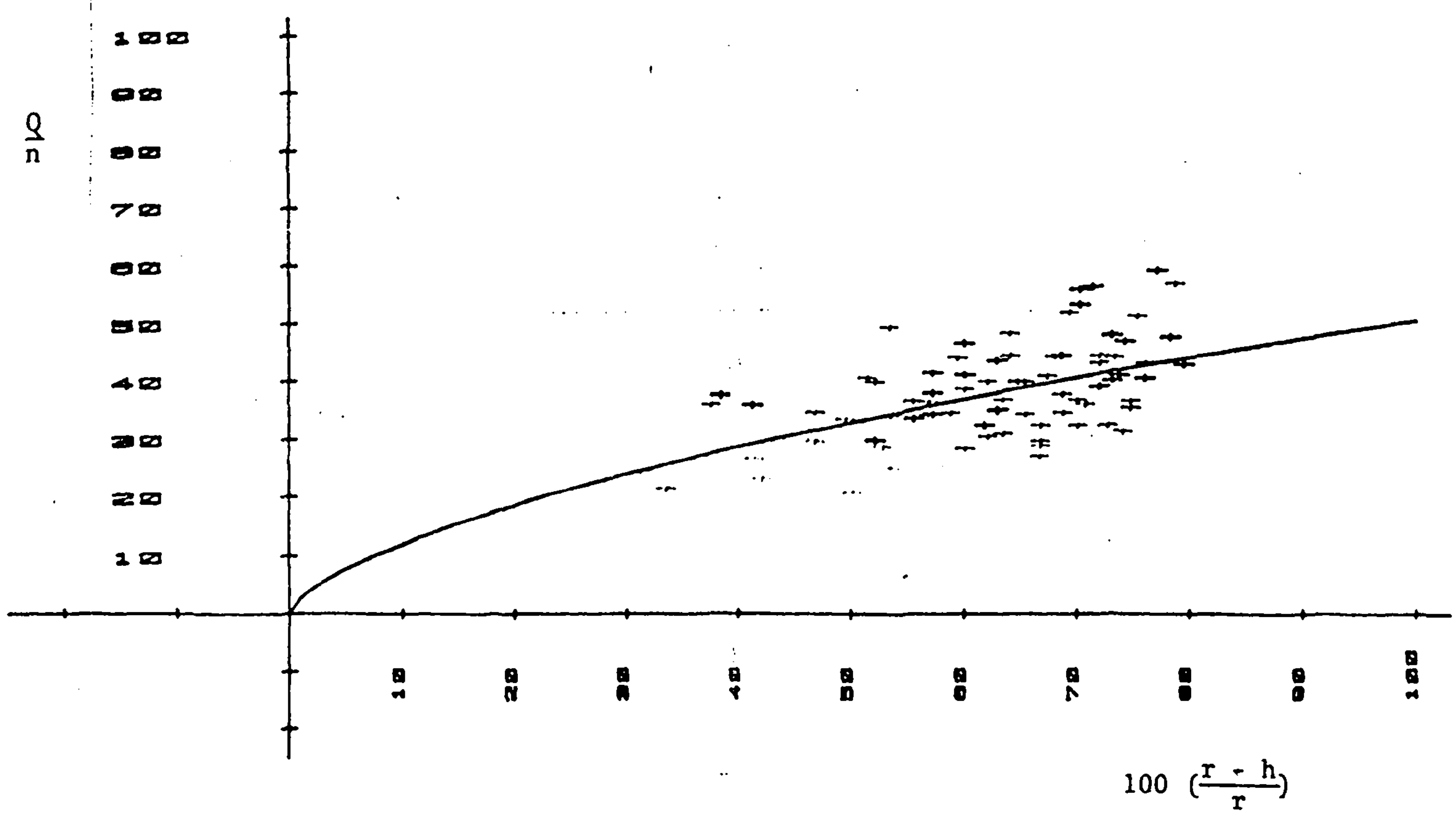



Figure E.1: Sakia Discharge Observations and Regression Function

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

## 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

### Power Requirements for Electric Motors

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:

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

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

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.

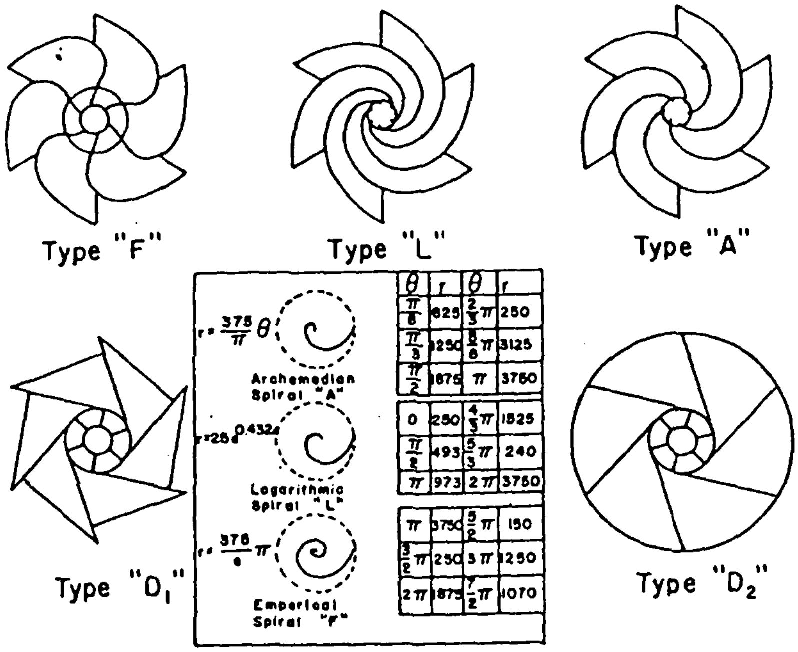
## The Model and the Measuring Devices

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




| $\theta$ | r | $\theta$ | r |
|---|---|---|---|
| $\frac{\pi}{6}$ | 625 | $\frac{2}{3}\pi$ | 250 |
| $\frac{\pi}{3}$ | 1250 | $\frac{5}{6}\pi$ | 3125 |
| $\frac{\pi}{2}$ | 1875 | $\pi$ | 3750 |
| 0 | 250 | $\frac{4}{3}\pi$ | 1525 |
| $\frac{\pi}{2}$ | 493 | $\frac{5}{3}\pi$ | 240 |
| $\pi$ | 973 | $2\pi$ | 3750 |
| $\pi$ | 3750 | $\frac{5}{2}\pi$ | 150 |
| $\frac{3}{2}\pi$ | 2500 | $3\pi$ | 1250 |
| $2\pi$ | 1875 | $\frac{7}{2}\pi$ | 1070 |

Figure 1

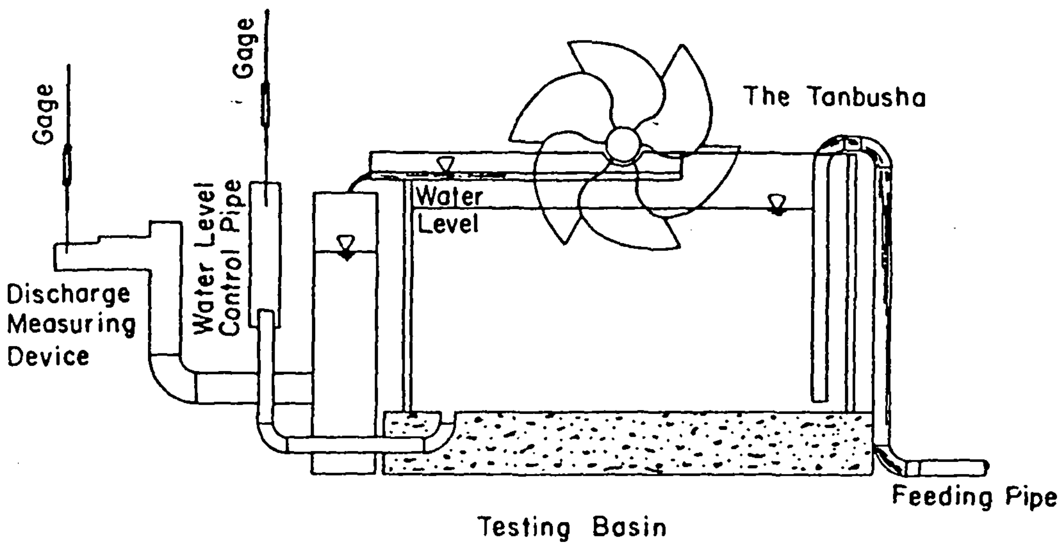



Figure 2

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.

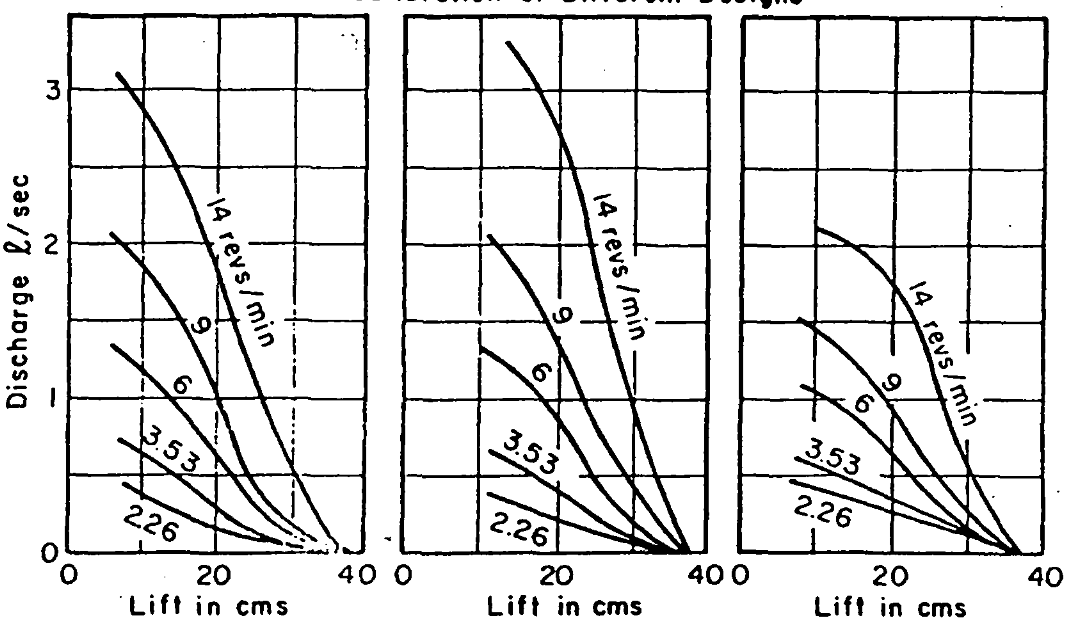
5. The feeding pipe: The flume is supplied with water through a 2" pipe. The amount of discharge was adjusted by a valve. A screen mesh was also placed at the pipe exit to avoid surface disturbances in the water. The pipe was supplied with water from an overhead constant head bank.

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




Logarithmic Spiral

Ali Fathi Emperical Design

Archimedian Spiral

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).

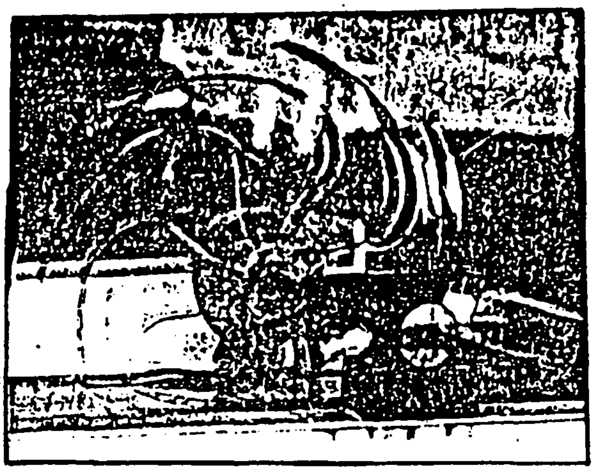


Figure A

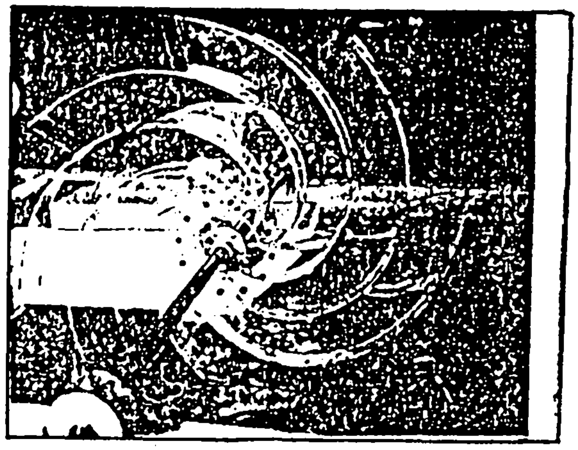


Figure B

## 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.

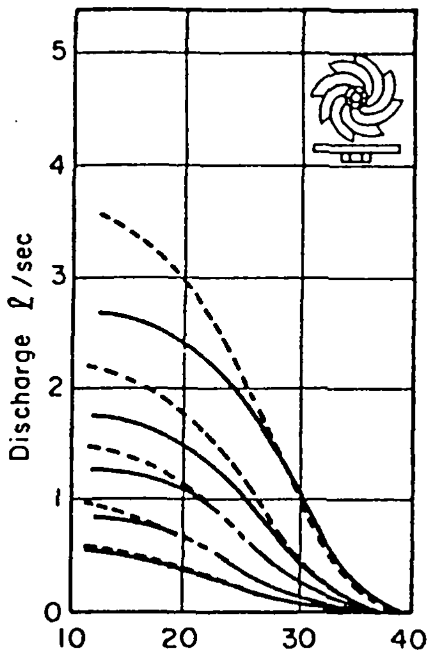


Figure 3

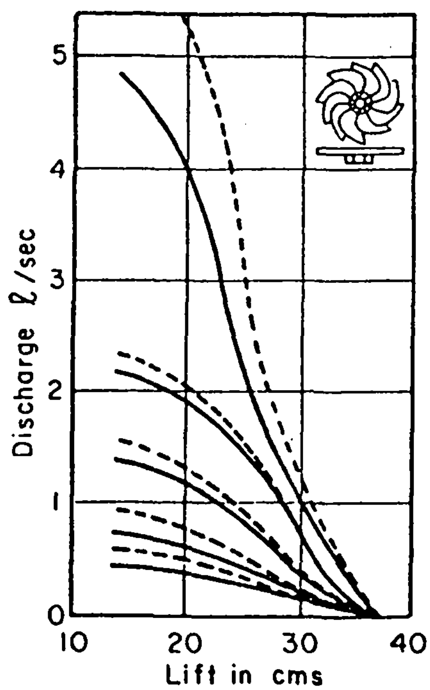


Figure 4

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:

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

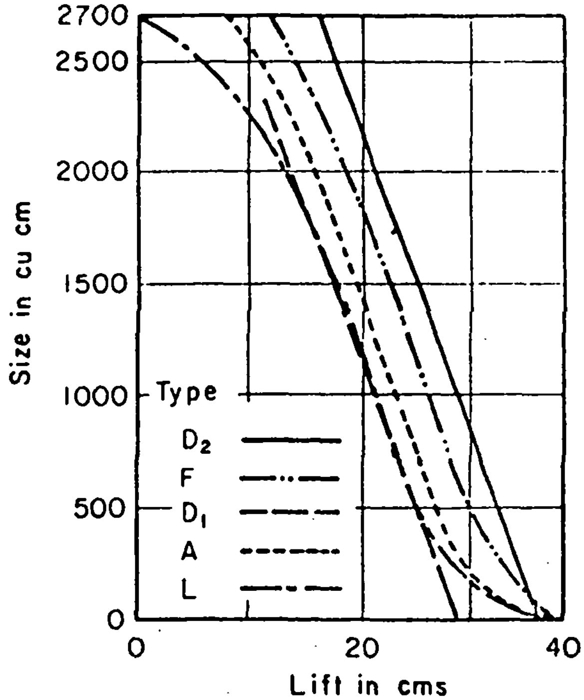



Figure 5

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.

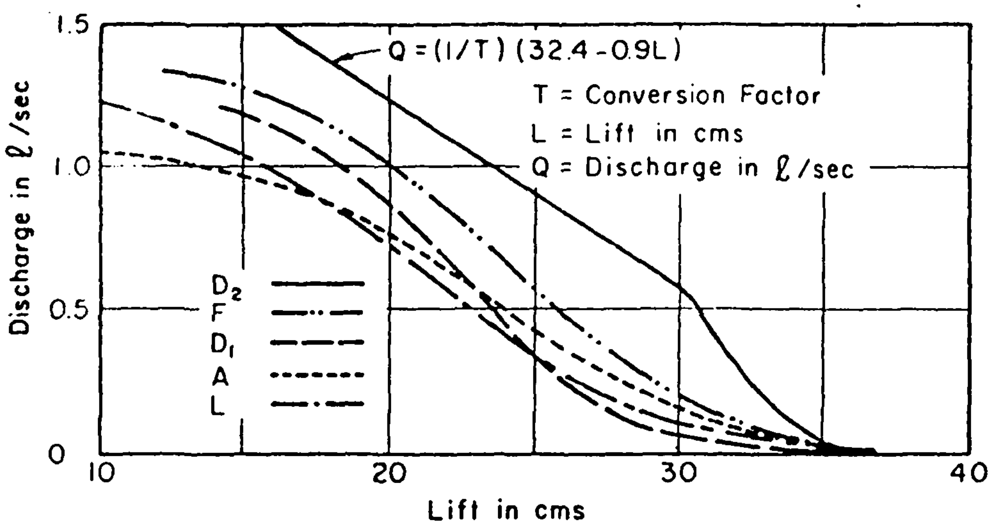
$$Q = \frac{1}{t}(16.4 - 0.456\ L) \qquad \text{for } 3.53 \text{ rpm}$$

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

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

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.



Q = (1/T) (32.4 - 0.9L)
T = Conversion Factor
L = Lift in cms
Q = Discharge in ℓ/sec
Discharge in ℓ/sec
1.5
1.0
0.5
0
10
20
30
40
Lift in cms
D2
F
D1
A
L


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.