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Egypt Water Use & Management Project
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A TECHNICAL AND ECONOMIC ANALYSIS OF LOW LIFT IRRIGATION PUMPING IN EGYPT

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EGYPT WATER USE AND MANAGEMENT PROJECT
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ABSTRACT

The need for small, efficient, low lift pumping devices is being recognized throughout the world. Small efficient pumps lifting irrigation surface water 1/2 to 3 meters are needed in many developing countries. Likewise, the need for similar pumps is increasing in the United States with the introduction of tail water pumpback systems. However, little information is available comparing the technical and economic aspects of such pumps.

The technical and economic characteristics of a variety of low lift pumping devices were analyzed. Water wheels and both portable and fixed axial flow pumps were considered. Animal, electric, and fossil fuel drivers were investigated. The analysis was performed specifically for pumping conditions in Egypt where discharges of 14 to 100 litres/sec (220 to 1585 gpm) are required at static lifts ranging from 1/2 to 3 meters. Both the economic costs of pumping based upon international market prices and the on farm pumping costs in Egypt were determined. A computer model was developed to aid in pump selection and to perform the economic calculations.

A six-inch axial flow pump developed by the International Rice Research Institute (IRRI) was found to be the most efficient low lift pump (efficiencies for this pump as high as 70% have been reported) at heads of 1/2 to 3 meters. Data from field tests indicate that discharges range from 46 litres/sec (729 gpm) at a static lift of 1 meter; to 27 litres/sec (427 gpm) at a static lift of 2.8 meters.

The six-inch IRRI pump driven by a 3 horsepower electric motor provided the lowest pumping costs. Where electricity is unavailable, the animal powered water wheel resulted in the least expensive pumping

costs. However, if the opportunity time of the farmer's labor is included and the opportunity cost is greater than three cents an hour, the cost of pumping with a diesel powered IRRI pump was less than with the water wheel.

مستخلص

حظيت ضرورة الحاجة إلى طلمبات الرفع الصغيره ذات الكفاءه العاليه والتى تعمل لرفع المياه إلى مستوى إرتفاع منخفض باهتمام عالمى . وقد إتضح أن الطلمبات الصغيره ذات الكفاءه العاليه والتى ترفع المياه السطحيه إلى ارتفاع يتراوح بين ½ إلى ٢ متر. أصبحت مطلوبه فى كثير من البلاد الناميه . وبالمثل فان الاحتياج إلى مثل هذه الطلمبات يتزايد فى الولايات المتحده الأمريكيه وخاصة مع استخدام نظام إعادة إستعمال المياه المتجمع فى نهايات الحقول للرى ، بالرغم من أنه ليست هناك مواصفات فنيه واقتصاديه كافيه عن مثل هذه الطلمبات

هذا وقدم دراسه وتحليل المواصفات الفنيه والإقتصاديه لأنواع مختلفه من هذه الطلمبات كالطلمبه المنقوله على عجل وكذلك المثبته وخاصه النوع ذو الدوار المحورى. كذلك تمت دراسه عدة أنواع من الطاقة المتوفره كالحيوانات والكهرباء والمواد البتروليه (كالديزل والجازولين) ، كما أجريت دراسه خاصه لطبيعة الرفع فى مصر على كمية تصرف للمياه تتراوح من ١٤ إلى ١٠٠ لتر/الثانيه (٢٢٠ إلى ١٥٨٥ جالون فى الدقيقه) والتى تتطلب حالات رفع ثابت (إستاتيكي) يتراوح بين ½ إلى ٢ متر. كما تم دراسه كل من التكلفه الإقتصاديه للرفع طبقا للأسعار العالميه وطبقا للتكلفه المحليه فى مصر مع عمل نموذج لإستخدام الحاسب الإلكترونى لإختيار الطلمبه وسعر التكلفه المناسب

وقد تم إنتاج طلمبة محورية (٦ بوصة) بواسطة مؤسسة الأرز العالمية ووجد أنها ذات أعلى كفاءة ممكنة للرفع على ارتفاعات منخفضة تتراوح بين ½ إلى ٣ متر (وكانت كفاءتها المسجلة هي ٧٠ ٪) . كما أظهرت البيانات الخاصة بالتجارب الحقلية على أن كمية المياه المرفوعة تتراوح من ٤٦ لتر/الثانية (٧٢٩ جالون في الدقيقة) .. لارتفاع واحد متر ، إلى ٢٧ لتر/الثانية (٤٢٧ جالون في الدقيقة) .. لارتفاع ٢,٨ متر

وقد وجد أن الطلمبة ذات المواصفات الـ ٦ بوصة والمعروفة بـ I R R I تحتاج إلى محرك بطاقة ٣ حصان كهربائي لتشغيلها وهو الأمثل لخفض تكاليف التشغيل ، وفي حالة عدم توفر التيار الكهربائي يكون تشغيل المواشي هو الأقل تكلفة للرفع . وعلى كل حال ، فإنه إذا كان الوقت وتكاليف العمالة الحقلية يزيد عن ٣ قروش في الساعة .. فإن تكاليف الضخ عن طريق استعمال طلمبات الديزل والمعروفة IRRI وجد أنها تقل في التكلفة عن استخدام الرفع بالآلات الدوارة

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

Symbol	Definition
A	Annual Cost
AC	Uniform Annual Cost
BHP	Brake Horsepower
B_t	Value of Benefits occuring at time t
C_t	Value of Costs occuring at time t
D	Drawdown
D_a	Diameter of a pump impeller
d	Discount rate
EFF	Efficiency
EFFa	Overall Efficiency of the Pumping System
g	Gravitational Constant
H	Head
H_T	Total Dynamic Head
HP	Horsepower
h_b	Barometric Pressure Head
h_d	Static Discharge Head
h_f	Friction Head
h_p	Pump Energy Head
h_s	Static Suction Head
h_v	Velocity Head
h_{vp}	Vapor Pressure Head
ht_s	Pump Impeller Speed

Symbol	Definition
NPSH	Net Positive Suction Head
NPSHA	Net Positive Suction Head Available
NPV	Net Present Value
n	Economic Life
P	Pressure
PC	Present Cost
Q	Discharge
V	Velocity
WHP	Water Horsepower
Z	Elevation
γ_w	Unit Weight of Water

ACKNOWLEDGEMENTS

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Chapter I

INTRODUCTION

Irrigated agriculture is in a state of flux in the Old Lands of Egypt. Problems with the development of the New Lands and a demand for increased food production has refocused attention on the possibility of increasing the agricultural productivity of the Old Lands. Farmer agricultural patterns have changed with the introduction of mechanization, improved crop hybrids and chemical fertilizers. Further improvement in the agricultural productivity of the Old Lands appears to be limited by the present irrigation water delivery system.

A general concensus is emerging that the water delivery system must be rebuilt. How it should be rebuilt remains an open question. Should the new system design be a duplicate of the old system? Should it be a subgrade system requiring the farmers to lift water to their fields? If so, where will the lifting point be and what type of lifting device should be used? Should the water be delivered to the farmers above grade? Rational answers to these questions can not be formulated without a careful scientific analysis of the entire irrigated agriculture system. Only then can an optimum policy for the rebuilding of the water delivery system be generated.

The first step in an analysis of a system is the collection of data on the various components of the system. For example, present and potential water lifting devices must be examined as part of a scientific analysis of the Old Lands irrigated agricultural system. The technical and economic implications of different water lifting devices can significantly influence the design and rebuilding of an optimal irrigation delivery system.

This paper will examine the costs and the technical implications of various low head water lifting devices that are presently in use or could be used in Egypt. The national costs in Egypt of lifting water with a sakia, the most prevalent water lifting device, will be determined. This cost will then be compared with the projected national costs of operating other mechanized low lift pumps. Finally, the on farm or farmer costs of operating these pumps will be examined.

Various aspects of these questions have been covered by previous papers published by the Egypt Water Use and Management Project and other projects and individuals involved in irrigation development in the developing world. Throughout this paper the work of authors including Dr. Hassan Wahby, Dr. Gene Quenemoen, Dr. Everett Richardson, Dr. Forrest Walters, Dr. Melvin Skold, Roger Slack and Richard Dyer will be referred to. The foundations upon which this paper was written were built by these gentlemen. However, this paper is unique in that it synthesizes the work of these and other authors, it introduces and examines several new low lift pumping devices, and examines not only the national but also on farm pumping costs.

Underlying Assumptions

This analysis assumes that any change in lifting mechanization will occur gradually, and so a sudden demand for a particular product or type of products will not create shortages, distort the market, and in turn raise the costs of these products. If a major crash program to mechanize water lifting were to be initiated, great care would have to be taken to eliminate the type of market distortions which would significantly increase the cost of such a program.

Equal benefits are assumed to accrue to each of the pumping systems analyzed and therefore only the costs of the various systems will be considered. Technically, this assumption is questionable. Varying discharge rates and system configurations can affect a wide range of variables including conveyance losses, irrigation application efficiency, requirement efficiency, drainage problems, and erosion. In turn crop yields would be affected. However, the lack of data and the limited scope of this paper necessitates the inclusion of this assumption. The error that this assumption might introduce into this study is small when compared to the range of values of many other of the system parameters.

Chapter II

IRRIGATION IN EGYPT

Egypt is a land of 40 million people living in a river valley and delta of 350000 square kilometers, approximately the size of Connecticut. Deserts surround this valley where rainfall is measured in years per inch instead of inches per year. The Nile, Egypt's only major river, floods annually from August to October during which 80% of the annual discharge occurs. The soil of the valley and delta is a level, deep, dark brown alluvial, deposited by the annual floods over thousands of years.

The Development of a Water Delivery System

A growing population, and the urge to modernize spurred Egypt in the 1800's to expand her agricultural production. As land was limited and the climate subtropical, agricultural production could only be increased by growing multiple crops in one year. But multiple cropping required a dependable water supply throughout the year. Consequently in 1836 construction began on the first of a series of barrages across the Nile, and in 1890 the first barrage was fully functional. (1) During the low flow period these barrages raised the upstream water level of the river high enough to feed a system of gravity flow irrigation canals which carried water to the fields.

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(1) Baedeker, Karl, Baedeker's Egypt 1929, David & Charles, Newton Abott Devon, 1974, pg. 131.

Having solved the problem of distributing water to the fields during the low flow periods, attention shifted to augmenting the Nile flow during these periods. The discharge of the Nile during the non-flood portion of the year was insufficient to support the planned increases in perennial irrigation and the introduction of high water consuming crops. In 1898 construction began on the Aswan Dam in upper Egypt. This dam, completed in 1902 and later heightened several times, trapped the last of the annual flood behind its 180 iron sluice gates. Beginning in March, the stored water would begin to be released to augment the low river flow, and consequently increase the amount of irrigated acreage that could be cropped perennially.

However, the high silt and sediment load of the annual flood of the Nile still limited the amount of the flood that could be seasonally stored. If the Aswan dam was closed and began to fill before the peak of the sediment load had passed through, it was feared that the reservoir would be filled to capacity with sediment in a matter of years.

Periodic low floods and the continuing need for increased agricultural production resulted in a series of proposals for over year water storage. This storage system was envisage to be large enough to store several annual floods and accompanying sediment. The surplus water of a high flood year could then be stored for a year when the flood was not large enough to meet the country's irrigation needs. The over year storage scheme would thus eliminate the periodic water shortages caused by low floods and allow an additional 1,000,000 feddans in middle and upper Egypt to be cropped continuously. A multitude of projects were proposed and debated for 40 years. Finally in 1963, the debate was effectively ended with the commencement of the construction of the Aswan High Dam.

This dam, located several kilometers upstream of the old Aswan dam, created a reservoir that stretches for hundreds of kilometers upstream into the harsh Sahara desert. Yet today, despite the most extensive irrigation system in the world and significant over year storage, Egypt desperately needs to further increase her agricultural production.

The Challenge Facing Egypt

The challenge facing Egyptian agriculture is enormous. It was estimated in 1975 that the ratio between Egypt's cultivated land and population was only 0.15 feddans per person. A population that is increasing at 2.4% per annum and an annual loss of 40,000 feddans of cultivated land to urban development suggest that this ratio is smaller still today. (2) With less than 0.15 feddans of agricultural land per capita Egypt is forced to import food. The population growth and urban development exacerbate this problem. Further compounding the problem is that the yield increases of major crops have not been as high as envisioned. In fact the yields of some crops including cotton have actually decreased. (3)

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(2) El-Tobgy, H. A., Contemporary Egyptian Agriculture, Second Edition, 1976, pgs. 1, 43.

(3) Cuddihy, W., Agriculture Price Management in Egypt. Staff Working Paper No. 388, The World Bank, Washington, D. C., 1980, pg. 1.

Egypt in 1976 imported L.E. 1.2 billion of basic food products to feed her people. (4) (5) This is an enormous food bill for a country whose total agricultural income in 1976 was only L.E. 870 million. (6)

The construction of the High Dam allowed perennial irrigation, multiple cropping, and net water surpluses throughout Egypt's agricultural lands. Unfortunately, the introduction of country wide perennial irrigation and net water surpluses, when combined with inadequate drainage facilities and poor farm water management, has increased the problems of excessively high water tables and salinity. Poor conveyance systems have restricted the access of a significant minority of farmers to the additional water.

One of the most promising methods of quickly realizing that increase is through improving farm water management. However before on farm water management can be effectively practiced, two necessary prerequisites are required. (1) An irrigation delivery system which provides the farmer with the required quantities of water when it is needed, and (2) a drainage network to carry from the fields the leaching fraction of the irrigation application.

Past economic and military crises forced Egypt to re-allocate funds destined for the maintenance and improvement of her irrigation and drainage systems to what were more immediate problems. Today, the

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(4) Berger, Louis, Irrigation Pumping Study in Middle and Upper Egypt, U.S. AID, May 1977.

(5) Bailey, Charles, Final Report, Water Management Consultancy, Egypt and Sudan, Ford Foundation, October 1981.

(6) Cuddihy, W., Agriculture Price Management in Egypt, Staff Working Paper No. 388, The World Bank, Washington, D.C., 1980, pg. 10.

repercussions of such exigencies are beginning to be manifest. Years of deferred maintenance in concert with poor irrigation practices has reduced the productivity of the Egyptian soil and consequently agricultural productivity has not keep pace with population growth. (7)

Planning for the Future

Egypt's irrigation system is designed upon two central premises. The first, is that farmers must be forced to lift water to their fields in order to induce water conservation. The second premise is that centralized control of all aspects of irrigation is necessary in order to promote the most efficient use of Egypt's most precious resource. Both premises were first authored by the British in the late 1800's and early twentieth century. They were products of their age and perhaps were appropriate when first conceived. A century later Egypt, a vital independent nation facing new challenges in a new age, must reexamine these premises and decide if they continue to best meet her needs.

Over the last few years scientific data has been acquired which challenges the first premise, that forcing farmers to lift their irrigation water results in water conservation. Furthermore estimates of the annual cost of this lifting range as high as L.E. 160 million. (8) The impact of a cost of this magnitude is best understood when compared with the total income of agricultural land owners and/or workers in 1976 of L.E. 870 million. (9) These estimates suggest that the cost of lifting

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(7) <u>Strategies for Accelerating Agricultural Development: A Report of the Presidential Mission on Agricultural Development in Egypt</u>, United States Agency for International Development, Washington, D. C., July 1982.

(8) Personal Communication with Dr. Everett Richardson

Egypt's agricultural water approximately one meter is almost one fifth of Egypt's total annual agricultural income.

The second premise, that centralized control of all aspects of irrigation is necessary in order to promote the most efficient utilization of the Nile, is not as easily analyzed. The complex interactions of human beings and social institutions render the delineation of individual/institutional relationships much more difficult than the delineation of technical relationships. Little investigation of this premise has occurred even though enormous investments have been spent to study and improve both on farm water management and the entire water delivery system in Egypt.

Significantly greater investments are being contemplated by both the Government of Egypt and other institutions and countries. The tasks of restoring the water delivery system to its prewar operational condition (overcoming the years of deferred maintenance) and then extending it to meet Egypt's near future needs are enormous. Some estimate that the cost will be 5.8 x 10^9 United States dollars. (10) Tasks and costs of this magnitude can not be initiated lightly. The social and economic implications of such a project could be staggering. The recent events in Iran are a singular example of the social turmoil that can be initiated by massive economic intervention in a developing nation. Additionally, there is a host of technical questions which must be answered by Egypt if Egypt is to get the "best system" for the money.

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(9) Cuddihy, W.; Agriculture Price Management in Egypt, Staff Working Paper No. 388, The World Bank, Washington, D. C., 1980, pg. 10

(10) Richardson, personal communication.

Planning for such a system is difficult because of the lack of information on the costs of the various alternative methods for improving Egypt's water delivery system. For instance, how much more expensive would it be to install an above grade free flow water delivery system than to carry out the extensive corrective maintenance program proposed for the present below grade system? Is an above grade free flow system more costly than a mechanized pumping system? Under what conditions is mechanized pumping a better option than animal powered pumping? Could the present sakia rings be converted into small pump partnerships? Not all options are likely to be equally cost effective and socially acceptable. The political implications of some proposals include income redistribution and the restructuring of social institutions. Unfortunately, the people who will ultimately plan, design, finance, implement, and manage these agricultural development projects have little of the information needed to properly evaluate and implement the proposed alternative investments. (11)

The policy questions that these proposals introduce must be addressed by Egypt if Egypt is to improve her agricultural production. Are the individual farmers going to have to repay the costs of restoring the water delivery system? If so, will credit be available? From whose perspective are the alternative projects going to be evaluated? Will the projects be selected in terms of their benefit to the state or the private benefit they would engender? There is a need for information on

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(11) Moya, Piedad F., Herdt, and Bhuiyan; Returns to Irrigation Investment in Central Luzon, The International Rice Research Institute, Los Banos, Philippines, September 5, 1981.

the impacts of these various proposals upon the agricultural labor pool, food prices, land fragmentation, and rural capital accumulation.

This paper will consider only one small facet of the investigation that must be mounted if irrigation investments are to be optimally allocated. This paper will examine both the present national and financial costs of lifting agricultural water in Egypt and will in turn compare this cost with the costs of several different mechanized low lift pumping schemes. Hopefully this paper will spark the curiosity and interest of others who in turn will investigate this and the many other aspects of Egypt's irrigated agricultural system.

Successful development is the result of skillfully combining careful thought and research with accessible material resources. The material means appear to be available. The knowledge and research necessary to fully exploit these means is not. If this knowledge is not quickly accumulated a great opportunity will be lost.

Chapter III

PUMP FUNDAMENTALS

The accurate modeling of the costs of pumping systems and an understanding of the technical implications of these puming systems requires an understanding of certain pump fundamentals. In this chapter the concept of head, power, efficiency, and the affinity laws will be discussed.

A pump is a device which imparts energy to a fluid. The addition of this energy in the fluid results in a change in velocity, pressure or elevation of the fluid. A pump adds energy to a fluid in one of two ways. The first method, commonly called the dynamic method, continuously adds energy "to increase the fluid velocities within the machine to values in excess of those occurring at the discharge such that subsequent velocity reduction within or beyond the pump produces a pressure increase." The second method, the positive displacement method, periodically adds energy to the fluid "by application of force to one or more movable boundaries of any desired number of enclosed, fluid-containing volumes, resulting in direct increase in pressure up to the value required to move the fluid through valves or ports into the discharge line." (1)

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(1) Krutzsch, W. C.,"Introduction and Classification of Pumps", <u>Pump Handbook</u> ,edited by Karassik, Krutzsch, Fraser, Messina, McGraw-Hill, New York, 1976, pgs. 1-3,1-4

Basic Pump Variables

Regardless of the kind of pump utilized, there is a set of general terms with which we can describe the common characteristics of all pumps and their pumping tasks.

Discharge (Q)

Discharge (Q) is the volume of liquid per unit time that a pump delivers. Discharge is usually expressed metrically as cubic meters per hour or liters per second. In the United States the common unit for pump discharge is gallons per minute.

Head (H)

Head (H) represents the net work done on a unit weight of fluid as it passes through the pump. Head can be expressed as a pressure, e.g. kilograms per meter squared, or as the height of a column of water which would exert the required pressure, due to its weight (potential energy). Often, in irrigation and drainage pumping applications, the second notation of head is more convenient than pressure because it allows both the lift and the needed pressure increases to be expressed in units of length.

This work or head can be manifested as a change in velocity, a change in pressure, or a change in elevation. The Bernoulli equation combines these different manifestations of work into a single expression which states that the change in total energy content of the fluid between two points is equal to the energy added by a pump minus the energy lost due to friction and form losses.

$$\frac{P_1}{\gamma_w} + \frac{V_1^2}{2g} + Z_1 + h_p = \frac{P_2}{\gamma_w} + \frac{V_2^2}{2g} + Z_2 + h_f$$

where:

P = water pressure

γ_w = specific weight of water

V = water velocity

Z = water elevation

h_p = energy added by the pump

h_f = friction in the pumping system

g = gravitational constant

Subscripts 1 and 2 indicate the state of flow before (upstream) and after (downstream) the pump.

A classification of head components has occurred within the context of pump design and sizing. This method of classification is identical to the Bernoulli equation with somewhat different notation, as all the energy components are expressed in terms of meters of water. (See Figure 3.1)

Static suction head (h_s) or lift is the vertical distance from the surface of the water to the centerline of the pump when the system is at rest. If the water surface is above the centerline of the pump a negative value is assigned to the suction head by convention; if below, a positive value is assigned to the suction lift again by convention.

Static discharge head (h_d) is the vertical distance from the centerline of the pump to the centerline of the discharge head or outlet pipe.

Velocity head (h_v) is the amount of kinetic energy contained in the flow through the pump. It is the distance water must fall, subject only to gravity, to obtain the velocity of the water flowing through the pump.

$$h_v = \frac{V^2}{2g}$$

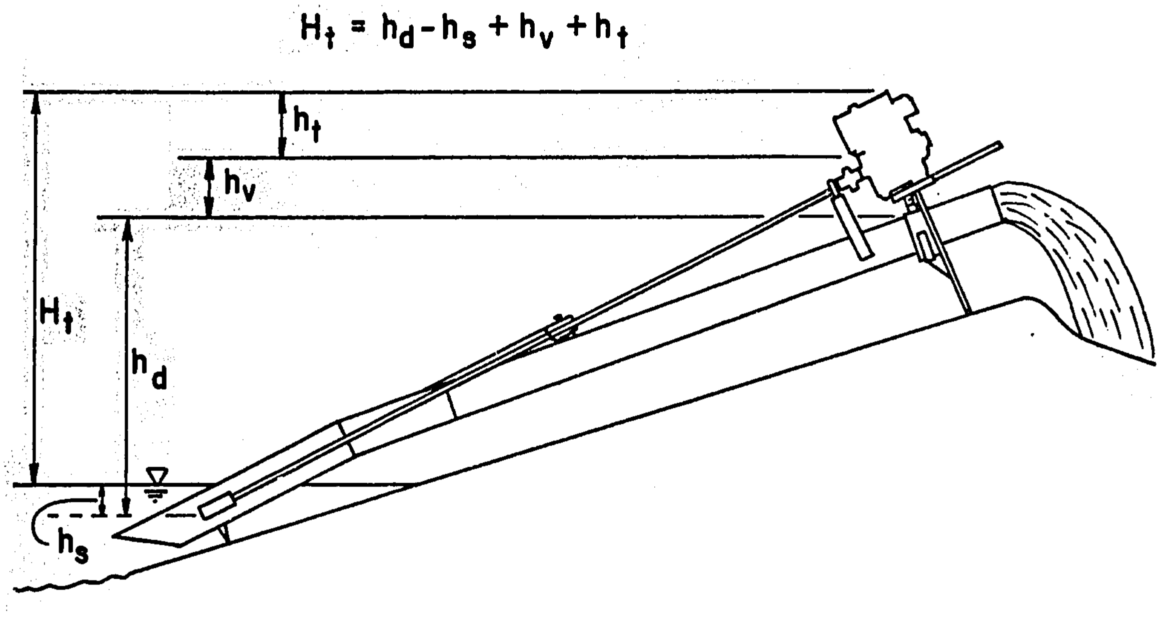

Figure 3.1. Components of head in a pumping application.

The velocity head can usually be ignored in most pumping applications because it is of such small magnitude.

Friction head (h_f) is the amount of head needed to overcome friction in the pumping system caused by resistance, fittings, suction tubes, and discharge heads. Various methods for determining the friction in a pumping system include the Darcy Weisbach equation and empirically derived charts found in many fluid mechanics and hydraulics texts. The calculation of the friction head in a pumping system will be discussed in greater detail in a later section of this paper.

Pressure head (h_p) is the pressure required at the outlet of the pump. In most low lift pump applications a free discharge (atmospheric) condition exists at the pump outlet. In such a case the pressure head would be zero.

Drawdown (D) is the vertical distance that the water surface in the suction bay falls during the course of the pumping operation. Drawdown is most common in wells, but can occur in canals and lakes where the recharge water source is not adequate.

Total Head (H_t), often called the total dynamic head, is the "entire energy potential of the system against which the water lifter or pump must operate." (2) The total head is the sum of the heads of the pumping system plus any drawdown that occurs. (See Figure 3.2)

$$H_t = h_d + h_s + h_v + h_f + h_p + D$$

Most pumps require that the fluid entering the impeller be under some minimum pressure. If the fluid does not have sufficient pressure

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(2) Wood, Alan D., "Water Lifters and Pumps for The Developing World", Masters Thesis, Colorado State University, Spring, 1976, pg. 36

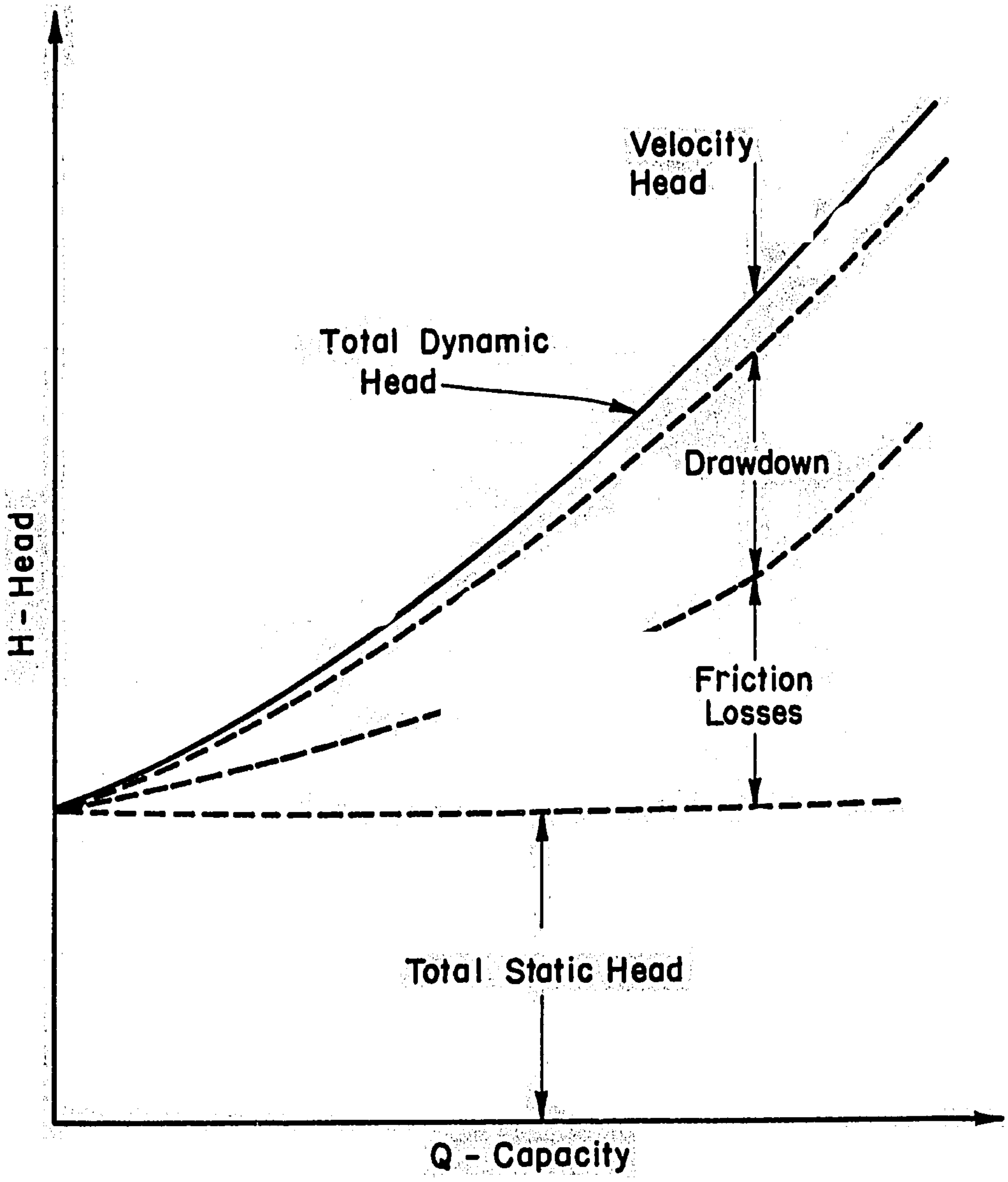

Figure 3.2. Head versus discharge curve.

as it enters the eye of the impeller the pressure drop which the fluid experiences as it is radially accelerated by the impeller will drop the pressure of the fluid below its vapor pressure. As the vaporized fluid leaves the impeller it's velocity decreases, the pressure increases and these vapor pockets suddenly collapse. This phenomenon is called cavitation and will severely stress the components of the pump. Pitting, excessive wear, and early failure of pump components are caused by cavitation.

The pressure that a pump requires at the eye of its impeller is a function of the pump's design. This required pressure which is often less than atmospheric pressure is called the net positive suction head required (NPSHR). The NPSHR must always be less than the net positive suction head available (NPSHA) or cavitation may occur.

The net positive suction head available (NPSHA) is the head at the eye of the impeller. It is the head that causes the fluid to flow up the suction tube of the pump and into the eye of the impeller. If the NPSHA is larger than the NPSHR the fluid will not vaporize as it crosses the impeller. Barometric pressure (h_b) and the suction head (h_s) are the two primary components of NPSH. In addition, the friction losses in the suction piping (hf_s) and the fluids vapor pressure (h_v) must also be included in the definition of NPSHA.

The equation for the net positive suction head available (NPSHA) is:

$$\text{NPSHA} = h_b - h_s - h_v - hf_s$$

Power (HP)

The third variable which we use to describe a pump is the quantity of power that the pump provides and the quantity of power required to drive the pump.

A pump was previously described as a device which added energy to a fluid and the Bernoulli equation was presented as one method of quantifying the energy added.

Another method of describing the energy the pump imparts to the fluid is the water horsepower (WHP) or useful work done by the pump.

$$\text{WHP} = \frac{\text{lbs. of liquid raised per min. x H in feet}}{33000}$$

The water horsepower can also be expressed as

$$\text{WHP} = \frac{Q \times H \times SG}{3960}$$

where:

Q = gpm

H = feet

SG = specific weight of water

A pump, like all mechanical devices, is not totally efficient. Because of problems such as internal friction, slippage, and turbulence more energy or horsepower will be required by the pump than the amount of horsepower the pump adds to the fluid. The horsepower required by the pump is called the brake horsepower (BHP) and is related to the water horsepower of the pump by a term called the pump efficiency.

Efficiency (EFF)

The efficiency of the pump is the fourth parameter that is used to describe pumps and pumping applications. The efficiency of a pump is the ratio of the energy added to the fluid by the pump over the energy input into the pump.

$$\mathrm{EFF} = \frac{\mathrm{Whp}}{\mathrm{BHP}}$$

A pump with no energy losses would have an efficiency of 100%. A good pump has an efficiency of 65% to 70%. The energy losses in a pump include those due to friction, and to turbulence as the radial flow of the fluid passing across the impeller is redirected vertically.

Prime movers and transmissions are also subject to mechanical losses. Each has an efficiency which is a measure of their own mechanical losses. The efficiency of a pumping system which includes a motor, a transmission, and a pump is the product of the efficiencies of each of the components. The overall efficiency of a pumping system (EFF_a) is:

$$\mathrm{EFF}_a = \mathrm{EFF}_{\mathrm{pump}} \times \mathrm{EFF}_{\mathrm{transmission}} \times \mathrm{EFF}_{\mathrm{motor}}$$

Performance Curves

Four variables; discharge (Q), head (H), power (BHP), and efficiency (EFF) are often combined in a graphical presentation of the characteristics of a pump. Such graphical presentations are called performance curves. Specifically, these parameters are plotted for a specified pump operating at a specified speed with discharge (Q) as the common abscissa as shown in Figure 3.3.

The head-discharge curve in Figure 3.3 indicates the head the pump will produce at a specific discharge and vice versa. The efficiency curve indicates at what discharge the pump operates most efficiently. Similarly, the brake horsepower curve and the net positive suction head required curve indicate those characteristics of the pump as a function of discharge.

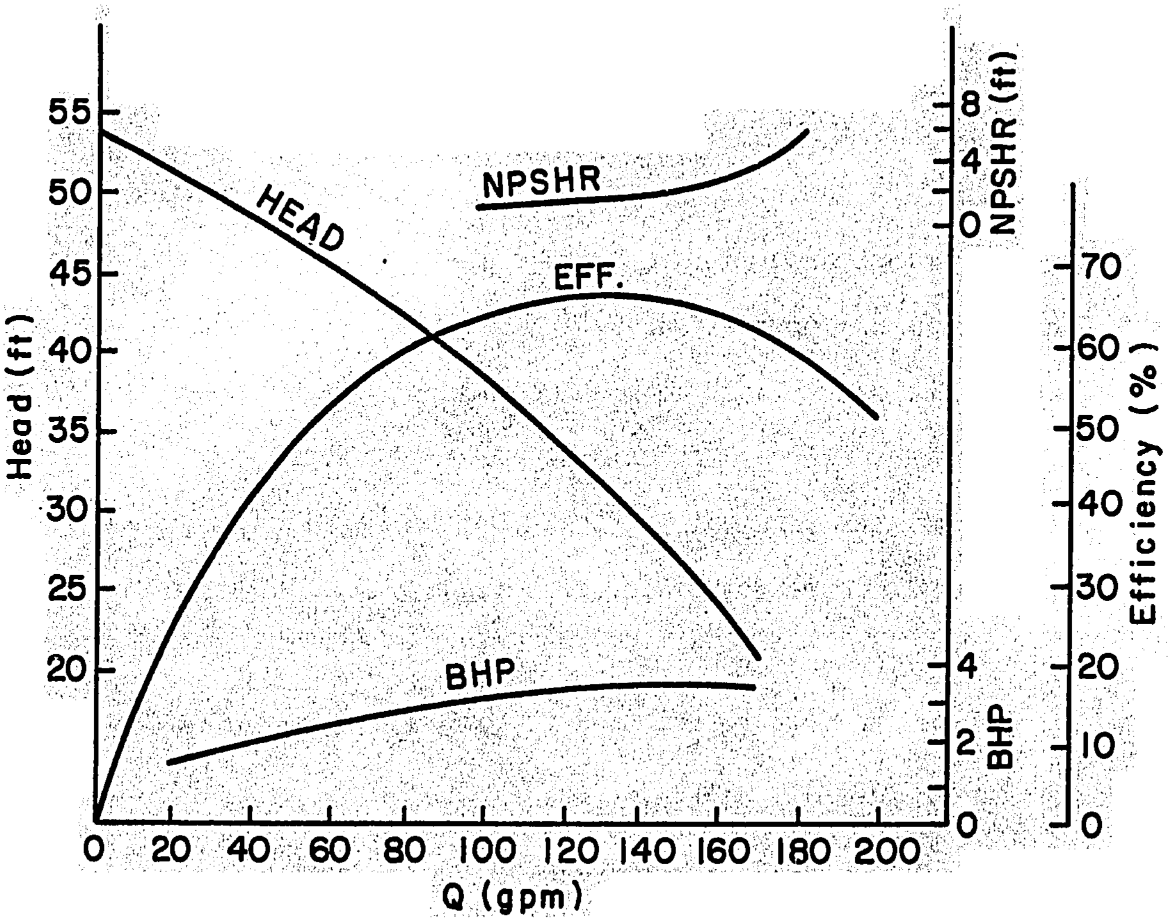

Figure 3.3. A typical performance curve.

There are several graphical variations of performance curves as shown in Figure 3.4. Generally these variations are composites of the curves shown in Figure 3.3. Many performance curve charts will present three or more head-discharge curves. Each curve is for a different size impeller, or a different operating rpm. Efficiency, the brake horsepower required, and the net positive suction head required will vary for different sized impellers and operating rpm..

Affinity Laws

Pump impellers can be cut smaller or rotated at varying speeds to produce performance characteristics slightly different than those indicated by the performance curves. A set of relationships called affinity laws have been developed to predict the pump characteristics with a different size impeller or rotational speed. However, these laws must be applied with care; not all affinity laws are applicable to all pumps and their use should be restricted to speed and impeller diameter variances of less than 10%. (3) (4)

If the speed of rotation is varied but all other aspects of the pump remain fixed:

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$$

$$\frac{H_1}{H_2} = \frac{N_1}{N_2}^2$$

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(3) Wood, pg. 49.

(4) Dorn, Thomas W. and Fischbach, Paul E., Deriving Pump Curves for Various Speeds and Impeller Trim Diameters, Agricultural Engineering Department, University of Nebraska, Lincoln.

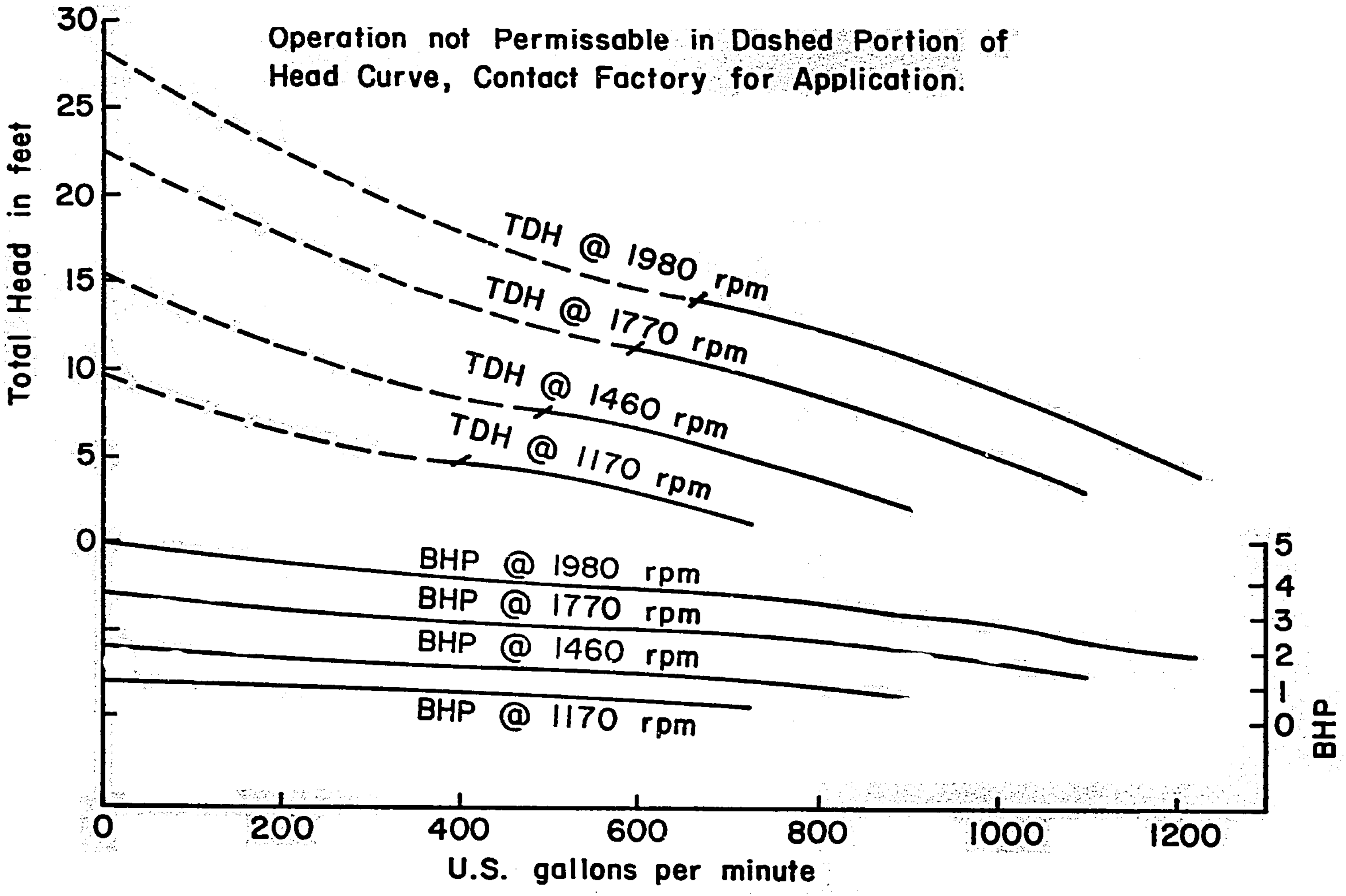

Figure 3.4. A performance curve for an axial flow pump operating at different speeds.

$$\frac{BHP_1}{BHP_2} = \frac{N_1}{N_2}^3$$

where N = pump speed in revolutions per unit time.

If the diameter of the impeller is varied but all other aspects of the pump remain fixed:

$$\frac{Q_1}{Q_2} = \frac{D_1}{D_2}$$

$$\frac{H_1}{H_2} = \frac{D_1}{D_2}^2$$

$$\frac{BHP_1}{BHP_2} = \frac{D_1}{D_2}^3$$

Both pumps and pumping applications can be described with the terms just discussed. A head-discharge curve can be developed through an examination of an individual's pumping needs. Such a curve is called a system head-discharge curve. Once such a curve has been developed a pump could be selected with an identical head-discharge curve and a high efficiency over the expected discharge operating range.

Chapter IV

THE PUMPING SYSTEM

A pumping system consists of three components:

1. The pump
2. The driver
3. The conveyance system which carries water to and away from the pump.

The Pump

Pumps are categorized as either positive displacement or kinetic. (1) Positive displacement methods range from bucket and rope to water wheels to modern direct acting pistons. Each of these methods have a common trait which is the displacement of the fluid from one head to another by a reciprocating motion. The only displacement pump that will be considered in this report is the traditional sakia which is a technically sophisticated water wheel.

Kinetic pumps are a much more recent development. It was not until the 19th century that the successful production of a kinetic pump occurred. Kinetic pumps have been subclassified as either rotodynamic or jet and within the rotodynamic classification further subclassifications exist between regenerative, centrifugal, mixed, and axial or propeller pumps.

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(1) A. D. Wood, J. F. Ruff, and E. V. Richardson, Pumps and Water Lifters for Rural Development, Colorado State University, Fort Collins, Colorado, June, 1977.

The choice of a particular kind of irrigation pump for a given situation is a function of the height which the fluid has to be lifted (head), the quantity of water which must be pumped (discharge), the driver which will power the pump, and the operating environment of the pump. The selection of a pump simply as a function of head and discharge is a fairly simple technical exercise. It is considerably more difficult to select a pump as a function of operating conditions such as dust, heavily sedimented water, poorly trained pump operators, and restricted spare part supplies. There is little quantitative data on the effect of the pumping environment upon the costs of pumping. This is a particularly important problem which will be discussed in greater depth in this paper.

The greatest pumping efficiencies occur with rotodynamic pumps. The three subclassifications of rotodynamic pumps, centrifugal, mixed flow, and axial flow pumps have different characteristics and therefore each type of pump operates most efficiently under different pumping requirements. An axial pump is significantly more efficient than the centrifugal and mixed flow pumps when a static head of approximately one meter and discharges ranging from 12.5 to 140 litres per second are required. These are the typical pumping requirements in Egypt.

The mixed flow pump's discharge increases as the head decreases until a head of approximately six meters is reached. At this point, any additional drop in head does not result in an increase in discharge and the efficiency of the pump begins to fall rapidly. The net result is that a mixed flow pump requires almost as much power to lift a given discharge two meters as it does to lift it six meters. The centrifugal pump's efficiency at low heads is even poorer than that of the mixed flow pump.

The axial flow pump on the other hand reaches maximum efficiency at heads varying between 1 and 6 meters. Furthermore, the axial flow pump has a flatter efficiency curve over its normal operating range which results in a fairly steady efficiency over a range of varying heads. Should the water level in the meska fall fourty centimeters, a properly sized axial flow pump will continue to operate at a high efficiency. The maximum efficiency of the pump extends over a broader range of heads than a mixed flow or centrifugal pump. (2) Figure 4.1 describes the Head discharge curves of a 6 inch centrifugal pump and a 6 inch axial flow pump.

An axial flow pump is usually less costly than other pumps. Because the pump casing of an axial flow pump is less complicated, lighter in weight, and smaller, several axial flow pumps including one designed by the International Rice Research Institute are significantly simpler to construct and maintain than centrifugal pumps presently being sold in Egypt.

On the other hand, an axial flow pump is more susceptible to abuse than other pumps. Because of it's high shut off head the required horsepower at the shut off head can be 250% greater than that required at the point of maximum efficiency. If the pump is operated near this shut off head, severe damage to the pump and it's motor will occur due to overloading. Secondly, it is more difficult to vary the discharge of an axial flow pump. In spite of these two serious limitations of the axial

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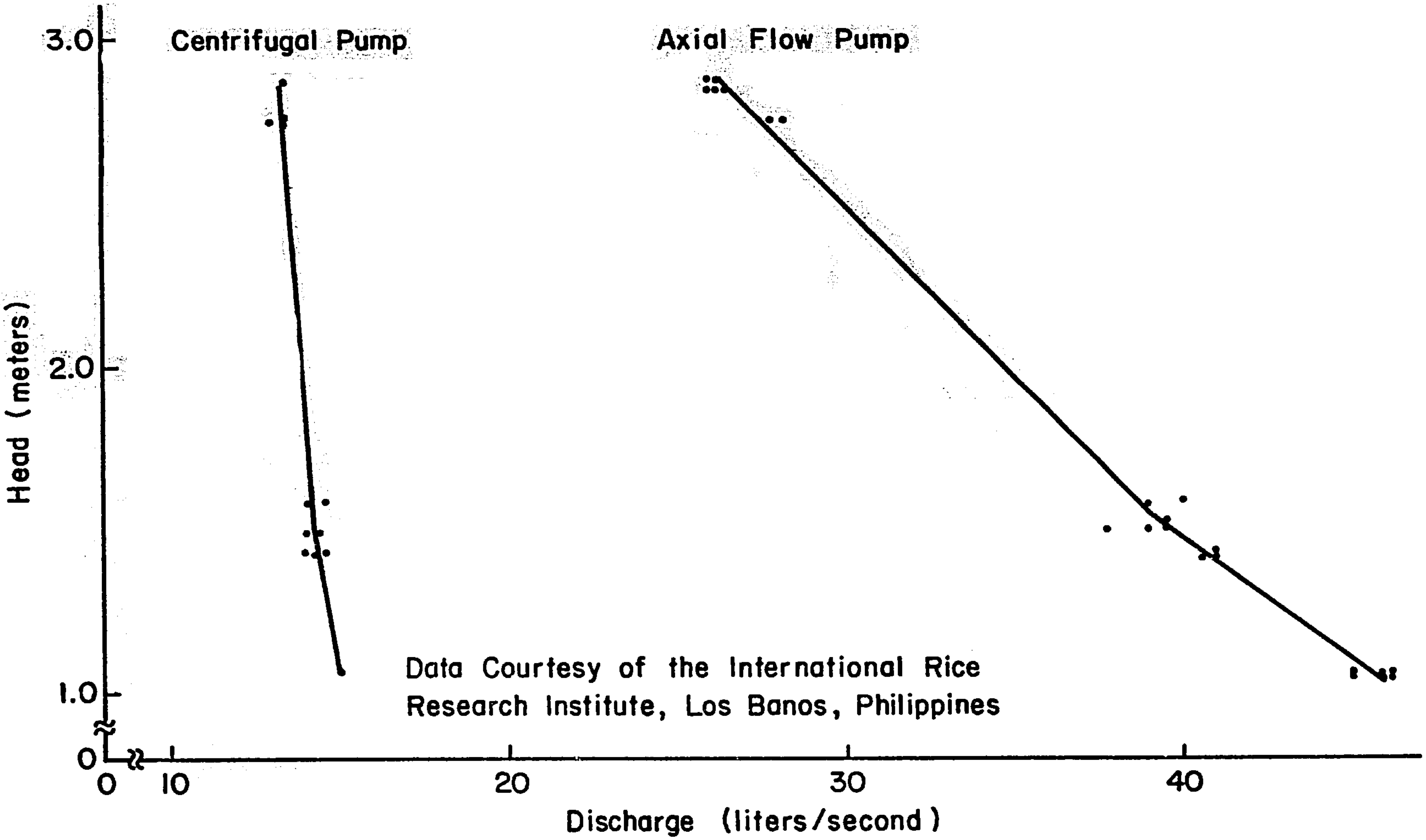
(2) Snodgrass, George F., Selection and Design of High-Volume, Low Head Pumps., ASAE Transactions #2723



Data Courtesy of the International Rice Research Institute, Los Banos, Philippines

Figure 4.1. Head discharge curves at a 6-inch centrifugal pump and an IRRI 6-inch axial flow pump.

flow pump, the significantly better efficiencies it provides at the low static heads found in Egypt suggests that this type of pump would be significantly more economical than the mixed flow or centrifugal pumps.

The Driver

The driver can be a human, an animal, an electric or fossil fuel fired engine, or a renewable energy source such as a solar engine. The choice of driver often will dictate the pump that will be used and vice versa. Recently, with the rising cost of energy, be it human or fossil fuel, the criteria for the selection of a driver has changed radically.

Today, the energy cost of pumping has become much more significant than in the past. Consequently, increased emphasis must be placed on the driver's ability to efficiently convert input energy intc usable output energy which powers the pump. This tends to increase the capital cost of the driver and in turn to increase the burden on capital constrained countries who are trying to convert to mechanized pumping.

The cost of energy plays a large part in determining the feasibility of a particular pumping scheme. However, projecting future energy costs is a risky affair. Therefore all of the pump schemes examined in this paper will be tested to determine their sensitivity to large fluctuations in the cost of energy.

The Conveyance System

The conveyance system is the physical plant which carries water to the pump intake and from the pump outlet to the fields. A conveyance system should be designed and maintained so that it can provide the required quantities of water when needed by the crops. The conveyance system in Egypt consists of open ditches (marwas) and canals (meskas). Any pumping system is totally dependent upon the conveyance system's ability to provide it with an adequate and timely supply of water. The best engineered pumping system is useless if the conveyance system can not provide adequate water to the pump intake, or carry the pump discharge to the fields. Egypt has an extensive conveyance system but in those areas where the system has deteriorated, a pumping system may exacerbate what is already a difficult problem. A mechanized pumping system is not a substitute for the renovation of conveyance systems. Rather its success is dependant upon the existence of a well designed and maintained water delivery system.

Pump Requirements in Egypt

The Required Lift

The Egyptian irrigation system was designed with the premise that if farmers had to lift water to their fields they would be sparing in their use of the water. Consequently, Egypt's most precious resource, water, would be conserved. The majority of the meskas in Egypt were built with a design water level 60 centimeters below the level of the land. Today a little over 80% (3) of the Egyptian Agricultural acreage is irrigated with water lifted a height of 75 to 100 centimeters, from the meskas to field ditches. In some parts of Egypt the static lift is as low as 50 cm. While in Middle and Upper Egypt the static lift may be 3.5 meters. Greater lifts are encountered in the land reclamation projects. For the purposes of this study the pump must be able to operate with a static lift ranging from 0.5 meters to 4 meters.

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(3) Era 2000, Further Mechanization of Egyptian Agriculture, United States Agency for International Development, March, 1979, pg. XII.2

The Required Discharge

The required discharge of the pump is a function of both the volume of water needed on an annual basis, the volume needed for the single largest irrigation, and the amount of time during which pumping can occur. An estimate of the average annual irrigation water requirement per feddan is 6800 cubic meters. The maximum water requirement per irrigation is approximately 425 cubic meters per feddan. These numbers were derived by the Egypt Water Use Project and are based upon country-wide crop patterns, evapotranspiration values, and application efficiencies. (4) Certainly some crops such as rice will require significantly more water and many others less. However, in the initial selection of pumps to be considered in this analysis the national average figures can be used as bench marks.

Ideally, on a six day on, six day off rotation, the farmers would have up to six days to pump the water they require. Under such ideal circumstances Table 4.1 lists the required discharges.

However, when factors such as multiple users of a single pump, irregular rotations, and low meska water levels due to upstream pumping are considered a minimum discharge of 50 cubic meters per hour is required. The discharge of the sakia, the most utilized pumping device in Egypt ranges from 50 to 110 cubic meters per hour depending on size.

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(4) Wahby, Hassan, Gene Quenemoen, and M. Helal, A Procedure for Evaluating the Cost of Lifting Water for Irrigation in Egypt, Project Technical Report No. 7, Egypt Water Use and Management Project, Colorado State University, 1982.

Table 4.1

Required Irrigation Pump Discharges

Total area irrigated with one lifting device	425 m^3/Fed* 10 hrs/day** 6 days on***	425 m^3/Fed 12 hrs/day 6 days on	425 m^3/Fed 14 hrs/day 6 days on
1 Feddan			
gpm	31.19	25.99	22.28
m^3/hr	7.08	5.90	5.06
5 Feddan			
gpm	155.94	129.95	111.39
m^3/hr	35.42	29.51	25.30
10 Feddan			
gpm	311.88	259.90	222.77
m^3/hr	70.83	59.03	50.60
15 Feddan			
gpm	467.82	389.85	334.16
m^3/hr	106.25	88.54	75.89
30 Feddan			
gpm	935.64	779.70	668.31
m^3/hr	212.50	177.08	151.79
60 Feddan			
gpm	1871.28	1559.40	1336.63
m^3/hr	425.00	354.17	303.57
75 Feddan			
gpm	2339.09	1949.24	1670.78
m^3/hr	531.25	442.71	379.46
100 Feddan			
gpm	3118.79	2599.00	2227.71
m^3/hr	708.33	590.28	505.95

*maximum required volume per irrigation
**hours of operation
***irrigation rotation

The Possible Drivers

The pumps selected will most probably be driven by animal power or by fossil fueled engines. The lack of a rural electric distribution grid eliminates electric motors as a near term possibility. However, the significant cost advantages of electric motors over fossil fueled engines would suggest that the electric drivers be considered as a long term possibility.

Egypt is presently an exporter of petroleum. Her refining capability is limited to low octane fuels. There are presently no catalytic cracking refineries in Egypt. Diesel, gasoline, or kerosine drivers can be used to power the pumps.

The Operating Environment

The pump and driver will be operated in an extremely dusty environment. Wind borne sand will be prevalent in many areas. Repair facilities will be limited in equipment and distant from the fields. Trained mechanics are scarce but often ingenious. Farmer maintenance must be limited to simple tasks such as oiling and greasing the pump and driver. Generally, the water will not be heavily sedimented.

Ideally, the pump would be small and portable. The small farm holdings, the divided nature of these holdings, and the difficulty of organizing such holdings into single irrigation units hinders the introduction of large fixed pumps. Preferably it would be a unit that could be manufactured in Egypt, or at the least spare parts could be produced in country. The cost of Egyptian labor and Egypt's desire to build an industrial base would facilitate the introduction of an in-country built pump. Repair and maintenance would also be cheaper and faster.

Pump Survey

Fifty irrigation pump manufacturers worldwide were contacted and asked if they had a pumping unit that would meet the above requirements. Most of the manufacturers responded, but their response was disappointing. Very few manufacturers build pumps that were designed for such low operating heads.

Generally, the efficienies of the pumps were very poor at such low heads. The few pumps that were efficient, were not portable, and were quite large. These large pumps were expensive, and would require that a large area be organized into a single irrigation unit. In Egypt this would have been a very difficult task.

A computerized literature search was run for information on pumps and pumping in developing countries. Little technical information with regard to pumps in developing countries was obtained. However, the existence of a small axial flow pump developed by the International Rice Research Institute in Los Banos, Philippines was discovered. Subsequently additional information on this pump was obtained from the International Rice Research Institute (IRRI). It became apparent that this pump was designed for lift, discharge, and operating conditions similar to those in Egypt.

The following section will describe the sakia and the IRRI 6 inch axial flow pump. These two pumps are the most unusual of the pumps considered in this analysis and the most suited for pumping in Egypt. The other pumps that are considered in this analysis are typical axial or mixed flow pumps. No centrifugal pumps were considered because of their extremely poor operating efficiencies at the low lifts encountered in Egypt.

Pump Data

The discharge head curve, efficiency, friction and form losses of most of the pumps analyzed were obtained from information supplied by the pump manufacturers. However, in the case of the IRRI pump and the sakia, this data was not readily available.

An analysis of the discharge versus head data, and the efficiency of the sakia and the IRRI axial flow pump is presented in the following sections. For further information on the sakia, the reader should also refer to the work by Slack on the subject. (5)

The Sakia

The sakia is a sophisticated water wheel which is used to lift water from a ditch to a farmers adjacent field. It is the most prevalant type of water lifting device in Egypt where 52% of the Egyptian farmers rent, share, or own one. (6)

The wheel of the sakia consists of several individual compartments which curve inwards towards the center of the wheel. Each compartment has a large inlet at the outer circumference of the wheel and an outlet at the hub of the wheel. These compartments are called kawadeis (kados), and the number and shape of the kawadeis will vary from one sakia to another.

As the sakia turns, a kados submerges and fills with water. Then as the wheel completes its rotation the filled kados is raised out of the water and the water trapped in it flows away from the inlet on the

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(5) Slack, Roger; The Volume Discharge and Mechanical Efficiency of the Field Sakia, M.S. Thesis, Department of Agricultural and Chemical Engineering, Colorado State University, 1981.

(6) Era 2000, pg. XII.2

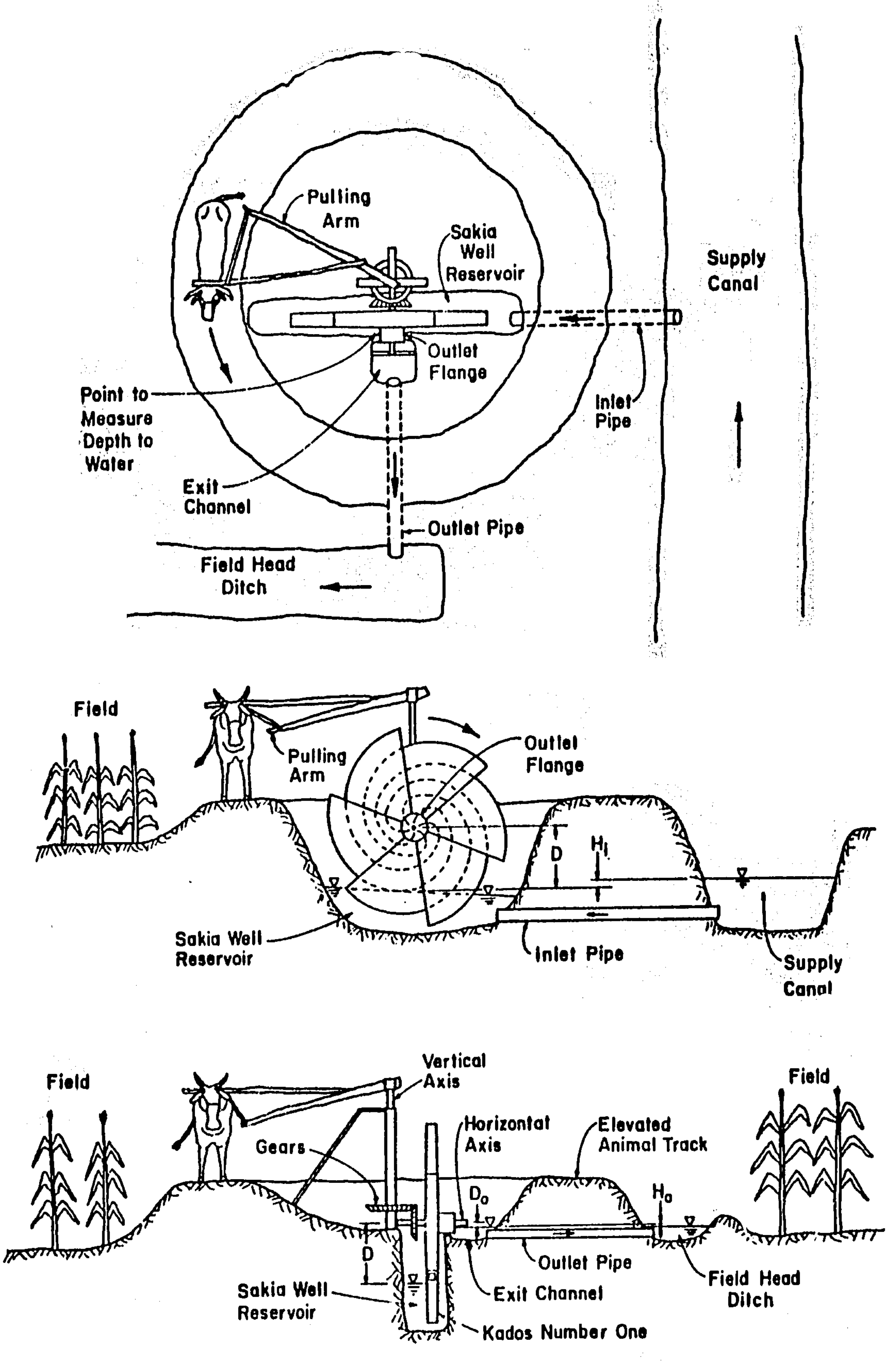

Figure 4.2. A typical sakia installation.

outer circumference of the wheel towards the center outlet which is now lower than the rest of the compartment. The water exits from the outlet at the hub of the wheel into a channel which will carry it to the fields.

Today, sakias are primarily made of galvanized steel, and generally have diameters of 2 to 3 meters and include 4 to 6 kawadeis. They are usually driven by cows or water buffalos but some farmers have replaced animal power with electric motors. Presently researchers at the University of California, Davis and the University of Alexandria are building a hot air engine with which they hope to drive a sakia. (7)

The sakia is an ancient machine which lifts water with a good deal of sophistication. It is the only water wheel type lifting device whose design does not require that the water be lifted significantly above the discharge elevation. Consequently the sakia has an efficiency of approximately 45%. (8) While this efficiency is low compared to most modern kinetic pumps, it is a significant improvement over all other water wheel type lifting machines.

Roger Slack in a M.S. thesis published in fall 1981 reported that the energy losses of the sakia are primarily caused by friction, backflow, and over lifting. Slack also noted that the discharge of the sakia can be significantly decreased by small drops in the water level of the ditch from which it is pumping. (9)

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(7) Kaminaka, M. S.; Garrett, R.E.; Majaja, B.A. Development of a Small Power Unit for Water Lifting Under Local Egyptian Conditions: Phase I. Department of Agricultural Engineering, University Of California, Davis. 1982

(8) Slack, Roger, "The Volume Discharge and Mechanical Efficiency of The Field Sakia," M.S. Thesis, Department of Agricultural and Chemical Engineering, Colorado State University, 1981. pgs. 61,62

These energy losses and the sensitivity to intake water levels put the sakia at a disadvantage when compared to some of the modern kinetic pumps. However, the ease and speed with which a sakia can be repaired in Egypt makes it, in the eyes of many Egyptian farmers, far less risky than a modern pump.

> We might imagine that it's (the sakia) days are numbered now that modern pumps can do the work faster and sometimes also more cheaply. The truth of the matter is, however, that the sakia and noria are increasing in number; they are old machines with which the peasant is completely familiar, while the motor pump is a tempermental piece of machinery that makes unprecedented demands on specialized knowledge or a well filled wallet. (10)

The sakia's discharge can vary widely as a function of its size, width, the static lift, the speed at which it revolves, and how well it is maintained. Both Slack in 1981 (11) and Molenar in 1956 (12) report however that the discharge of a 3 meter sakia lifting water approximately one meter is between 72 and 75 cubic meters an hour.

More specifically Slack reported that while there is considerable variance in individual sakia performances, on the average a 3 meter diameter sakia discharges 400 liters per revolution at a lift of 1 meter and 600 liters per revolution at a lift of 0.75 meters, (13) which is

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(9) Slack, Roger, pg. 29.

(10) Schioler, Thorkild. Roman and Islamic Water-Lifting Wheels. Odense University Press, 1973, pg. 171.

(11) Slack, Roger, The Volume Discharge and Mechanical Efficiency of The Field Sakia. M.S. Thesis, Department of Agricultural and Chemical Engineering, Colorado State University, 1981. pg. iii

(12) Molenar, A., Water Lifting Devices for Irrigation, FAO Agricultural Development Paper No. 60, 1956, Food and Agriculture Organization, Rome.

(13) Slack, Roger, pg. iii

equivalent to 72 cubic meters and 108 cubic meters per hour respectively; these discharge figures assume that the sakia revolves at approximately 3 rpm as Slack reported. (14)

$$(400 \text{ liters/rev.}) \times (3 \text{ rpm}) \times (60 \text{ min/hr}) = 72 \text{ meters}^3/\text{hr}$$

$$(600 \text{ liters/rev.}) \times (3 \text{ rpm}) \times (60 \text{ min/hr}) = 108 \text{ meters}^3/\text{hr}$$

It should be noted that sakia design tends to change from one region of Egypt to another. The majority of Slack's data is from the Kafr El Sheikh region. Consequently regional average sakia discharges may vary slightly from Slack's measurements.

The IRRI Pump

No head discharge curves were available for the IRRI 6 inch axial flow pump. Data from an in field pump test of the IRRI pump was available. (15) During this test 9 separate one hour runs of the pump at static heads ranging from 1.06 to 2.88 meters were conducted over a period of several weeks. The pump was powered by a 5 HP gasoline engine. Static head, discharge, and fuel consumption were measured during these trials. Using this data an equation for the static head - discharge relationship was derived and used to extrapolate discharges for a range of static heads from 0.5 meters to 2.5 meters.

Derived Discharge Equation

The equation is:

$$\text{Static Head} = 13.535 - 3.257 \ln (Q)$$

$$r^2 = 0.998$$

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(14) Slack, Roger, pgs. 15, 25

(15) International Rice Research Institute, Test Report, January 18, 1982

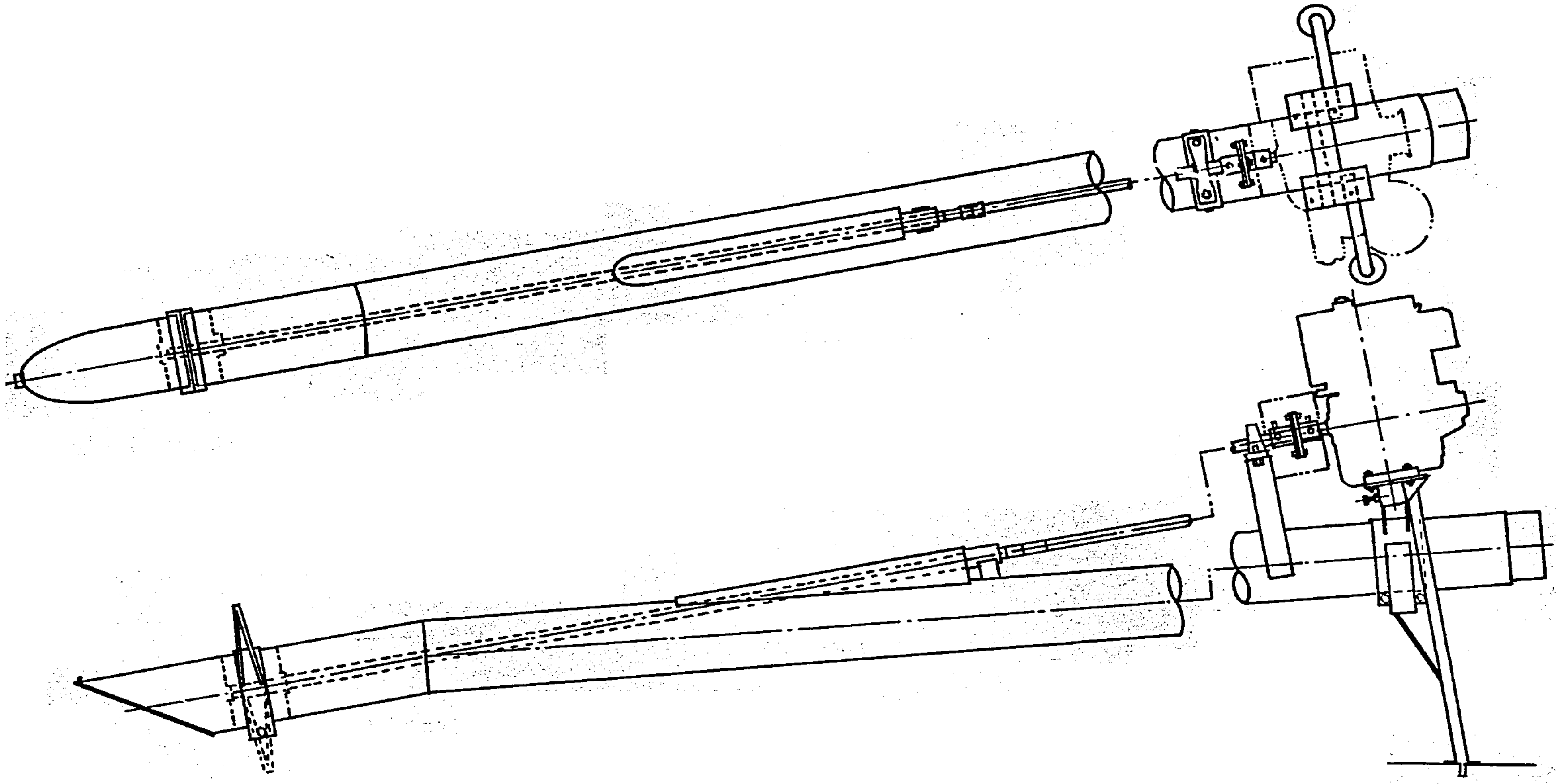

Figure 4.3. The IRRI axial flow pump.

where:

Static Head is in meters

Discharge is in litres/sec

Tables listing the data from the pump test and the values generated by the derived equation follow. The derived curve is superimposed over the actual data and presented in Figure 4.4.

The pump test data, and the derived curve do not provide total head versus discharge information but only static head versus discharge data. It should also be noted that 2 ft to 12 ft long 6 inch diamater PVC extension tubes and a 120° PVC discharge elbow were attached to the pump. The friction and form losses caused by the extension tube and elbow, while not considerable, would also affect the discharge of the pump.

Approximations of the friction and form losses were determined. The friction loses were approximated utilizing the Darcy Weisback friction formula, the dimensions of the pump, the discharges and a friction coefficient which is a function of the Reynolds number and the extension tube material. Likewise, the form loss for the elbow was approximated utilizing standardize form loss equations. In the worst case the form and friction losses amounted to 20 cm of head.

Given the difficult operating conditions the pumps will be subjected to, and the likelihood that in many applications extension tubes will be fitted to the pumps, head losses similar to these would be experienced in Egypt. Therefore, the derived equation based on the static head discharge data from IRRI will be used to determine the discharge of the IRRI pumps for the varying static lifts. The

Table 4.2

IRRI 6 INCH AXIAL FLOW PUMP TEST DATA

Run #	Average Q (Litres/Sec)	Static H (Meters)	WHP	Fuel Consumption Litres/Hr
1	40.9	1.43	0.76855	1.5
2	39.3	1.52	0.78497	1.19
3	39.8	1.59	0.83156	0.95
4	26.3	2.85	0.98495	1.5
5	27.8	2.76	1.008	1.4
6	26.3	2.88	0.995	1.5
7	46.0	1.06	0.64	1.6
8	46.2	1.07	0.6495	1.4
9	45.9	1.07	0.64537	1.4

Source: IRRI Test Report, January 1982, The International Rice Research Institute, Los Banos, Phillipines.

Table 4.3

IRRI 6 INCH AXIAL FLOW PUMP
DERIVED STATIC HEAD VERSUS DISCHARGE

Static Head Meters	Discharge Litres/Sec	Discharge Meters^3/hour	WHP
2.50	29.61	106.6	0.97
2.40	30.53	109.92	
2.30	31.49	113.35	
2.20	32.47	116.89	0.93
2.10	33.48	120.53	
2.00	34.52	124.29	0.91
1.90	35.60	128.16	
1.80	36.71	132.16	
1.70	37.86	136.28	0.85
1.60	39.04	140.53	
1.50	40.25	144.91	
1.40	41.51	149.43	
1.30	42.80	154.09	
1.20	44.14	158.89	
1.10	45.51	163.85	0.66
1.00	46.93	168.96	0.62
0.95	47.66	171.57	
0.90	48.40	174.22	
0.85	49.14	176.92	
0.80	49.90	179.66	0.52
0.75	50.68	182.43	0.50
0.70	51.46	185.26	
0.65	52.26	188.12	
0.60	53.06	191.03	
0.55	53.89	193.99	
0.50	54.72	196.99	0.36

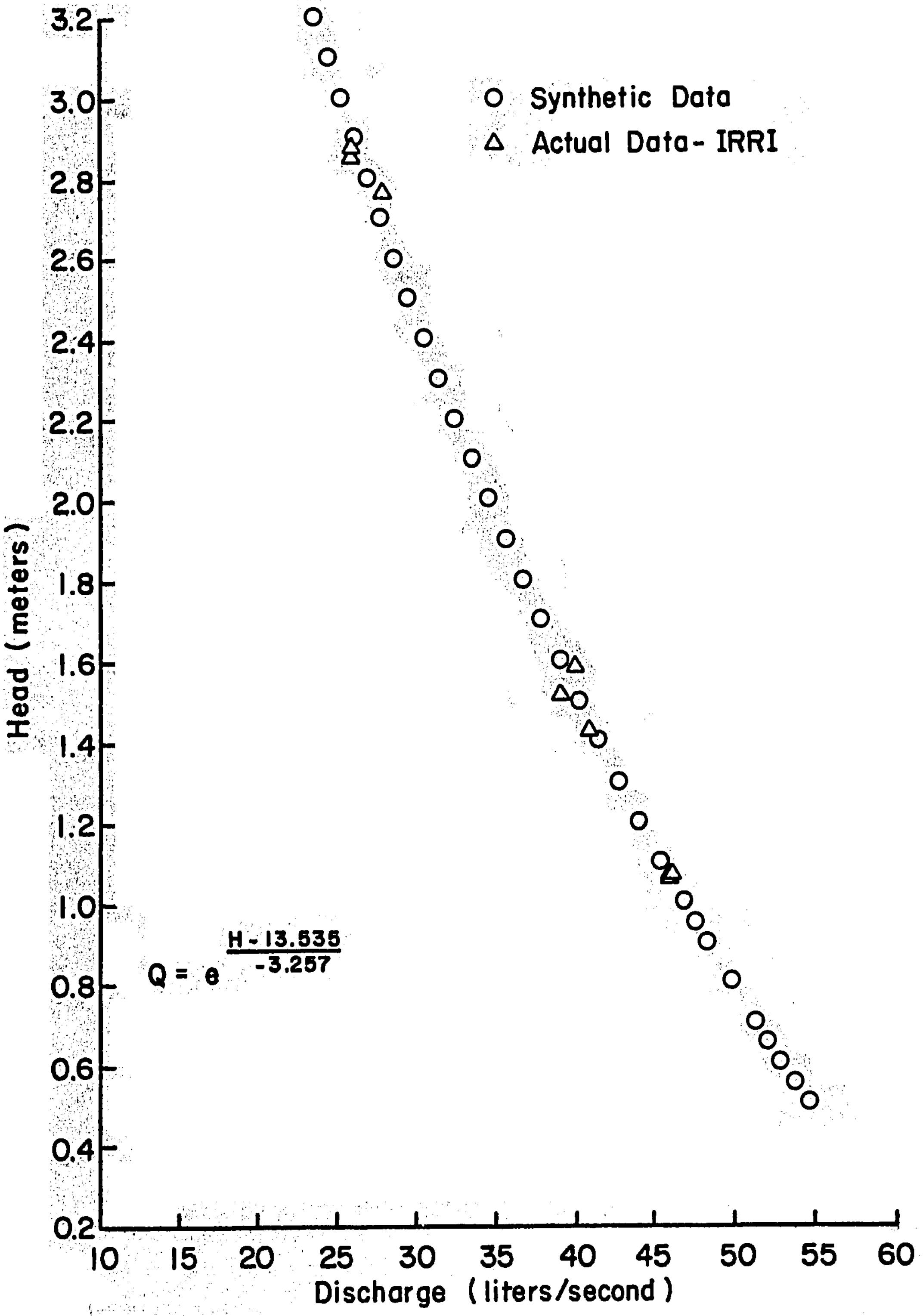

Figure 4.4. Derived head discharge curve for the IRRI 6-inch axial flow pump.

implication of this is that there is a built-in head loss adjustment in the static lift value of the pump.

IRRI Pump Efficiency

No data which would allow the calculation of efficiency is available on the IRRI 6 inch pump. Generally axial flow pumps tend to have lower maximum efficiencies than centrifugal pumps. However efficiencies in some axial flow pump are as high as 85% under optimum operating conditions.

The "overall efficiency" of an early developmental model of the IRRI pump was reported to be 40% in the IRRI 1978 Annual Report. (16) No definition of overall efficiency was given. It is suspected that this value includes all friction and form losses throughout the length of the discharge tube as well as the efficiency of the propeller. If this is so then this efficiency is the ratio between the input brake horsepower (BHP) and the output water horsepower (WHP) where all friction and form losses in the pump, intake, and discharge tube have already been included in the calculation of the water horsepower.

Recent reports on the IRRI pump suggests efficiencies of 70% are possible. (17) An efficiency of 50% was utilized in the computer model as a conservative compromise.

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(16) International Rice Research Institute, Annual Report for 1978, International Rice Research Institute, Los Banos, Philippines, 1979, pg. 426.

(17) Personal communication with Marvin Parker, Rice Research and Training Project, Ministry of Agriculture, Arab Republic of Egypt.

Chapter V

ECONOMIC BACKGROUND THEORY

Decision makers, be they farmers or cabinet ministers are always faced with a large number of pressing needs and limited resources with which to meet these needs. The decision maker must distinguish which of these needs are most important and which of the many solutions proposed will maximize the benefits of his limited resources.

Types of Costs and Benefits

When needs and solutions can be identified and quantified, economists have devised methods which aid the decision maker in determining the priority of needs and the effectiveness of alternative solutions. These methods require that the costs of the projects and their expected benefits be determined. Considerable care must be taken to identify all costs and benefits and to insure that all are counted but none are counted twice. Projects often impact people and institutions outside of the project. In many cases these benefits and costs, called externalities, must also be identified, quantified, and considered in the analysis.

It is highly convenient to quantify all needs and resources in monetary terms. However, the attempt to reduce needs and resources to monetary terms is at best difficult, and at worst grossly misleading. Those aspects of the problem which can not be quantified monetarily are called incommensurables, those that are unquantifiable, intangibles.

> Incommensurables would include lives lost, injuries and illnesses sustained, national defense, other public goods such as recreation facilities, and some externalities. Evidently, incommensurables may involve economic or noneconomic values. Their distinguishing characteristic is that they may be readily quantified, but not in money terms.
>
> Intangibles would include the effects of the project on such things as social justice, social harmony, personal freedom, democracy, or aesthetics. These all involve values beyond the economic and do not exhibit even likely dimensions for measurement, much less actual numerical values. (1)

It is the decision maker's responsibility to weigh the results of the economic analysis against the incommensurable and intangible aspects of the problem. If he does not perform this analysis his conclusion as to the worth of a project may be flawed. Economic analysis does not replace the function of the decision maker. It is only a tool which allows the decision maker to understand more clearly the economic aspects of the problems he is dealing with.

Time Value of Money

The majority of the economic methods utilized to examine intertemporal problems and their solutions are based upon the hypothesis of the time value of money. Simply stated, "a dollar now is worth more than the prospect of a dollar next year or at some later date." (2) This hypothesis does not address the question of inflation but the "return obtainable by the productive investment of capital." (3)

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(1) Sassone, Peter G.; Schaffer, William A., Cost-Benefit Analysis, Academic Press, New York, 1978, pg 166

(2) Grant, E. L.;Ireson, W. G.; Leavenworth, R. S., Principles of Engineering Economy, John Wiley and Sons, New York, 1982, pg. 30.

(3) ibid.

For example, in an economy with 12% inflation and an 18% nominal interest rate the return from the productive investment of capital, the real interest rate, would be 6%.

The moral validity of obtaining a return for the productive investment of capital is commonly accepted in many societies including Egypt. The Koran for example "does not question either the contribution capital can make to the production of new wealth, or the justification of people who own capital to benefit from its productive use." (4) What is often objected to is the idea of a fixed return on capital regardless of the success of the investment.

Discount Rate

In general, most methods of inter-temporal economic analysis assume that on the average a certain amount of benefit is gained from the productive use of capital and utilize that average benefit in their economic analysis of a problem. This factor, the discount rate, allows the time value of a resource (money) to be quantified. The discount rate does not imply a fixed rate of return on every investment, no matter what the consequences of the investment, but enables us to express future costs and benefits in terms of present values. Within the context of state investments:

> The correct discount rate, which we shall term the social discount rate, is that rate which, when applied to future costs and benefits, yields their actual social values. In other words, the proper rate is the rate at which society as a whole is willing to trade off present for future costs and benefits. (5)

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(4) EWUP Draft paper-Skold etc and personal communication with Muslim students at Colorado State University.

(5) Sassone, Peter G.; Schaffer, William A.,

However, in practice, translating this definition into a numerical value is often difficult and controversial. The problem is twofold: 1. Which of the many conceptually different methods accurately measures the social discount rate? 2. Each of the conceptually different methods usually generates a range of values.

The determination of a discount rate for private investment is only slightly less controversial. Some experts argue that the bond market rate is an appropriate private discount rate. Unfortunately, there is a multitude of different bond rates because the risk of default on a bond varies from one bond to another. Other experts would like to add a premium for taxes to the private discount rate. (Sassone and Schaffer provide a detailed analysis of the different discount rates.) (6)

The reason such controversy exists over the discount rate is because of <u>its critical role in the determination of which of several projects is economically preferable</u>. The ranking of the alternative projects in a cost-benefit study is a direct function of the discount rate chosen. Economic analyses identical in all respects except the discount rate, can arrive at different conclusions about the same project. A low discount rate will favor projects whose benefits will not begin until far in the future. A high discount rate will favor projects with more immediate benefits.

For example: Two projects, X and Y each initially cost $50 and have 5 year lives. Project X shows an annual net benefit beginning in the first year of $15, while project Y does not show a net benefit until the fifth and final year when it shows a net benefit of $80. If a

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(6) Sassone, Peter G.; Schaffer, William A., Chapter 6.

discount rate of 10% was chosen, the net present value of project X is $6.87 while that of project Y equals -$0.33. With this discount rate project X is superior to project Y. On the other hand if a discount rate of 2% was chosen then the net present value of project X would be $20.70 and that of project Y would equal $22.46. A decrease in the discount rate has caused project Y to become preferable to project X. The lower discount rate has favored the project whose benefits do not begin until the far future.

A review of the benefit cost analysis literature reveals that actually the choice of a particular social discount rate is usually avoided. Instead, either a sensitivity analysis of the impact of a range of values is performed or a rate is specified by the decision maker. In the later case, the rate specified may reflect influences other than a concern for an accurate measure of the true social discount rate. Gittinger faces this problem with a refreshing frankness.

> In practice the rate chosen is simply a rule of thumb: 12 percent seems to be a popular choice and almost all countries seem to think it lies somewhere between 8 percent and 15 percent. (7)

Economic Life

Economic analyses compute the benefits and costs of each problem and their respective solutions across their economic life. Often the economic life of a piece of equipment or a project is far shorter than it's wear out life due to technological advances. These advances can render solutions to recently adopted problems obsolete and excessively costly. However, water lifting tends to be "characterized by slow rates

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(7) Gittinger, J. P.; Economic Analysis of Agricultural Projects, The International Bank for Reconstruction and Development, John Hopkins University Press, Baltimore, 1972, pg 90.

of technological change." (8) As the pumping equipment that will be considered in this paper is presently state of the art it is highly unlikely that this equipment will be technically obsolete prior to when it wears out. Consequently, it is appropriate to assume that in the context of low lift pumping the economic life of a piece of pumping machinery will be its wear out life.

Unfortunately, little is actually known about the wear out life of pumping machinery in the harsh environments often encountered in development schemes.

> It is an unfortunate fact, however, that textbook estimates of useful life are often used in project analysis without regard for what is known of previous evidence about an investment's actual life, or for prevailing conditions which are likely to affect the length of life of the proposed investment.....the productivity of irrigation works has decreased fairly rapidly, and the useful life of many investments in this area has been far less than the standard values attributed to such investments in standard references. (9)

Wearout Life

The wear out life of low lift pumping equipment is a function of many things including, the quality of maintenance, the availability of spare parts, clean fuel supplies, low suspended sediment loads, the quality of the original equipment and, the nature of the tasks the equipment performs.

While performing a survey of pumpsets in Middle and Upper Egypt in 1980 this author and his wife discovered problems in all of the above

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(8) Wahby, Hassan, Gene Quenemoen, and M. Helal, A Procedure for Evaluating the Cost of Lifting Water for Irrigation in Egypt, Project Technical Report No. 7, Egypt Water Use and Management Project, Colorado State University, 1982, pg. 3.

(9) EWUP, Preliminary Draft, Feasibility Studies and Evaluation of Irrigation Projects, July 1981, pg. 19

mentioned areas. The Egyptian farmers and mechanics were resourceful enough to be able to repair most of the pumps. Fourty and fifty year old operating pumpsets were not uncommon. However we suspect that the efficiencies of most of these pumpsets were poor.

There are two fundamental problems in determining the wear out life of a pump. First, pumps are often evaluated in qualitative not quantifiable terms. The pump lifts water or it doesn't. Often, especially where energy costs are not representative of world energy prices, the question of how much energy it takes to raise the water is not asked. Pumps rarely breakdown, they simply consume increasing amounts of energy. Secondly, the consequence of this qualitative perspective is that a clear definition of the criteria for determining when a pump is worn out does not exist. One approach could be based upon economic conditions. A pump could be deemed worn out when the cost of pumping with it becomes higher than the cost of pumping utilizing a refurbished or alternative pump.

Economic Perspective

Equally important is the question of perspective, whose costs and benefits is the analysis concerned with? The economic impact of a development scheme is not equally felt by all. Different costs and benefits accrue to different individuals and entities. Consequently the perspective or point of view of an economic analysis will define the categories of costs and benefits. In many countries these costs and benefits can be distorted and a project evaluated from two different perspectives will generate contradictory conclusions.

Many countries subsidize a farmer's cost of energy products such as diesel fuel or electricity. Consequently the farmer could perceive his pumping costs to be low which would encourage him to increase his use of mechanized pumping. On the other hand, from a national perspective, the farmers pumping costs are perceived to be much higher because the actual and not the subsidized energy costs are considered. From a national perspective, mechanized pumping may not be economically justifiable yet the distortion of cost and benefits encourages the farmer to increase mechanized pumping. Contradictions such as this can paralyze planned economic development.

> The economic analysis of a project reflects the profitability of the project from the viewpoint of society as a whole: that is, whether the project makes the most efficient use of the nation's resources in producing national income. It is concerned with the flow of real resources, therefore transfer payments are excluded. Also in the analysis, resources are valued in terms of their opportunity costs, which may be different than their price in the market. (10)

Such studies assume that a course of action favorable to the economics of the country as a whole will in turn be favorable in the short term to the individuals within the country who will be expected to carry out the proposed program. Such an assumption as was just pointed out, can be false. A distinction must be drawn between the economic viability of a project from the perspective of the country or region as a whole, and the financial implications of the project on an individual basis.

A financial analysis of a project from an individuals perspective analyzes the profitability of that individuals actions which are impacted by the project on a year to year basis. Was the profitability or satisfaction of that person year by year increased or decreased by the project? A project with a sound economic return can fail if the

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(10) Brown, Maxwell L., <u>Farm Budgets</u>, The World Bank, The John Hopkins University Press, Baltimore 1979, pg. 8.

financial or quality of life benefits of the project on a yearly basis are not sufficient to induce the individual members of a state to aid in the implementation of the project.

Farmers Objectives

A further consideration which increases the complexity of the individual's incentive is that simple increases in an individual's profit may not be sufficient to guarantee his participation in the implementation of a project. Brown, suggests that "family satisfaction" is often the criterion by which farmers measure the benefits of a particular action and that an increase in farm family satisfaction is not always generated by an increase of the farm families' profit.

> Realizing a profit on the sale portion of the crop is important, but maximizing profit is not always the overriding consideration in allocating resources. Increased profits increase family satisfaction only to a certain degree. At some levels profit maximization might be secondary to family satisfaction, and enterprises and productive processes that allow the family greater security and satisfaction might take precedence over those that are more profitable. (11)

The question of family security and satisfaction is particularly appropriate in Egypt. Family ties, extended families, and the individual's responsibilities towards his/her family are a strong dominating force in Egypt. The individual is subservient to the family in Egypt. The individual who accepts risk is perceived to have imposed that risk upon his family and placed his welfare above that of his family. Naturally the willingness to accept risk is reduced, and as all innovations are to some degree a risk, the willingness to accept innovations is in turn somewhat decreased.

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(11) Brown, Maxwell L., pg. 10.

How one would evaluate family satisfaction and risk are questions beyond the scope of this paper. However, an attempt will be made to outline the family impacts that the development of mechanized pumping might initiate.

Setting aside the question of family satisfaction versus profit maximization the problem of the discrepancy between an economic and financial analysis of a project remains. Anytime price structures are implicitly or explicitly established by government, the possibilities of contradictions between the economic welfare of the state and that of the individual must be considered. This suggests that a financial analysis, as defined previously by Brown, is a necessary part of an economic analysis of mechanized pumping in Egypt.

Technically, financial analysis addresses a large number of questions with a sophistication unnecessary here. A brief discussion of the two kinds of financial incentives most important to most farmers follows.

> By far the most important (incentive) for most farmers is the farm family net benefit - the home consumed production plus the net cash income after repayment of interest and principle - which will be available to the farmer if he participates in the project.... A second kind of incentive to take part in a project is the return a participant can expect to realize on the capital he invests. For a small farmer of course this may be a relatively unimportant consideration since he may contribute very little or even no capital to the project. (12)

<u>Analysis Perspective</u>

This paper will examine the costs of low lift pumping in Egypt from two different perspectives. The first perspective will be that of the society as a whole. Without assuming who is going to pay for the pump-

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(12) Gittinger, J. P.; pg. 142.

ing this perspective is utilized to determine if the country is making "the most efficient use of the nation's resources in producing national income". The result of an analysis utilizing this perspective is often called the "economic cost."

From this perspective all costs must be calculated in terms of the international opportunity costs of equipment and energy. As an example, the cost of diesel fuel would be the price that Egypt would receive on the international market for that fuel. The purpose in choosing this perspective is to allow the decision maker to compare the economics of low lift pumping within an objective reference system which is theoretically not subject to the price distortions often found in any particular country.

The second perspective will be that of the farmer, how much does it cost him to pump water. Previously we have been concerned with analyzing whether a project would be beneficial from the perspective of the economy as a whole. We must be equally concerned with the incentives the project provides those individuals and entities which are expected to participate in the project. Are the incentives sufficient in size and design to elicit the kinds of actions that are necessary for the success of the project?

Finally, in this analysis, because all the alternative pumping devices are assumed to provide the same benefit, that device which costs the farmer the least to buy and operate will provide the most family benefit and return on investment.

Chapter VI

ANALYSIS METHODOLOGY

A methodology must be selected with which we can evaluate the economic and financial cost of the alternative pumping systems. The task is simplified somewhat because we are comparing mutually exclusive technologies "performing essentially the same function but which have different cost streams." (1)

Net Present Value

Generally the net present value (NPV) criteria is the most widely accepted method of analyzing the economic merits of a series of alternative projects.

> The net present value method reduces a stream of costs and benefits to a single number in which costs or benefits which are projected into the future are "discounted". (2)

The equation for the net present value of a project is:

$$NPV = \frac{B_0 - C_0}{(1 + d)^0} + \frac{B_1 - C_1}{(1 + d)^1} + \ldots + \frac{B_t - C_t}{(1 + d)^t} + \frac{B_n - C_n}{(1 + d)^n}$$

where:

C_t is the value of costs incurred at time t,

B_t is the value of benefits incurred at time t,

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(1) Gittinger, J. P.; Economic Analysis of Agricultural Projects, The International Bank for Reconstruction and Development, John Hopkins University Press, Baltimore, 1972, pg 123.

(2) Sassone, Peter G.; Schaffer, William A., Cost-Benefit Analysis, Academic Press, New York, 1978, pg 14.

d is the discount rate,

n is the life of the project

Annual Cost

To further simplify the analysis, the benefits accruing to each pumping system being compared will be considered to be equivalent. Consequently the net present value method can be modified by deleting the annual benefits that accrue. Only the annual costs of the different pumping alternatives need then be considered. Therefore the alternative with the lowest present cost will be the economically preferred solution. This method is known as the present cost method (PC). Its equation is:

$$PC = \frac{C_0}{(1 + d)^0} + \frac{C_1}{(1 + d)^1} + \ldots + \frac{C_t}{(1 + d)^t} + \frac{C_n}{(1 + d)^n}$$

where:

C_t is the value of costs incurred at time t

d is the discount rate

The present cost of a pumping system can also be represented as a uniform annual cost (AC) during the life of the pump system. Sassone and Schaffer argue that "this criterion is formally equivalent to the net present value method." (3)

The advantage of an annual cost method (AC) over the present cost method is that "generally speaking, people seem to understand annual costs better than they understand present worths." (4) The equation for the annual cost method is:

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(3) Sassone, Peter G.; Schaffer, William A., pg. 19.

(4) Grant, E. L.;Ireson, W. G.; Leavenworth, R. S., Principles of Engineering Economy, John Wiley and Sons, New York, 1982, pg. 105.

$$\sum_{t=0}^{n} \frac{A}{(1+d)^t} = PC \sum_{t=0}^{n} \frac{C_t}{(1+d)^t}$$

where:

A is the annual cost.

C_t is the value of costs incurred at time t

d is the discount rate

A problem with the annual cost and present cost approach is that they assume that the different pumping system alternatives have the same economic operating life. When they do not, the comparison of the present costs of the alternatives must be made over a period of years which is the least common multiple of the lives of the alternatives. However, if it is assumed that the "replacement assets will repeat the costs that have been forecast for the initial asset," (5) and present costs are transformed into uniform annual costs, then the least common multiple does not need to be found. As the replacement costs are assumed to be the same as the initial costs, then the uniform annual cost of an alternative in its initial cycle will not change during its subsequent life cycles.

This assumption is not as ridiculous as it might first seem. The operating lives of the pumps that will be analyzed in this study range from four to twenty years. At most five life cycles of one pump would occur during the life cycle of another pump. Because the technology and materials that are employed in these pump's design and fabrication changes very slowly, there is little reason to suspect that the replacement costs of the pumps, especially those with the shortest life cycles,

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(5) Grant, E. L.;Ireson, W. G.; Leavenworth, R. S., Principles of Engineering Economy, John Wiley and Sons, New York, 1982, pg. 83.

will change significantly. Furthermore, if for instance the replacement cost of a pump with a fifteen year operational life changed by thirty percent the net change in the uniform annual cost would be less than 4.5% assuming a discount rate of 12%.

The uniform annual cost methodology will be utilized in this analysis because uniform annual costs are generally more comprehensible to the general reader than other analytic methods.

Cost Identification Theory

Identifying the benefits and costs of a project requires a careful analysis of the impact of the project upon the project's intended beneficiaries. One aid in this process is to ask what the impact would be with and without the project.

> The difference is, in general, the net additional benefit arising from the project. You can then proceed to verify that the specific costs and benefits that you have identified do add up to the difference "with" and "without" and that none are missing. (6)

Another method of identifying benefits and costs is to search for goods, services, and people affected by the proposed project. (7) The task is not easy with either method. Care must be taken to ensure that benefits or costs are not counted more than once in the attempt to cover all objectives of the project. Additionally, not everything that might at first appear to be a cost or benefit should be considered in the analysis. Previously the difficulties of handling incommensurables and intangibles were discussed. In addition, the external and indirect

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(6) Gittinger,J. P.; pg. 15.

(7) Sassone, Peter G.; Schaffer, William A., pg. 165

effects of a project further complicate the task of identifying the costs and benefits of the project.

Direct and Indirect Effects

Direct effects are the intended impacts of the project on its intended recipients. As an example, a direct or primary effect of a mechanized irrigation project would be the cost of the fuel consumed by a diesel driven pump.

An indirect effect might be the increased income due to increased fuel sales, of the local diesel fuel merchant.

> "Secondary or indirect benefits `reflect the impact of the project upon the rest of the economy' (Eckstein, 1958, p. 154). The term is normally applied to `the increased incomes of various producers... that stem from ... projects' (McKean, 1958, p. 154) (8)

Gittinger identifies 3 types of economic effects which are often called secondary or indirect effects. They are;

1. Forward and backward linked "induced" effects.
2. Those due to scale economies.
3. Dynamic secondary effects.

The later two types of secondary effects are usually omitted from most economic analyses because of the extreme difficulties encountered when trying to evaluate them.

> While it may be true that in terms of the economic development aspects of public investment the scale effects and dynamic effects hold the greatest potential for large scale impacts on the economy, they are by nature so difficult to evaluate that few attempts have been made to deal with them empirically. (9)

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(8) Sassone, Peter G.; Schaffer, William A., pg. 36.

(9) Gittinger, J. P.; pg. 123.

In this analysis, only the forward and backward linked or "induced" effects will be considered. Throughout the discussion that follows the term secondary effects will refer only to these "induced" effects.

Generally secondary benefits or costs are additional employment or unemployment resulting from a project's economic impact upon the surrounding region. Often the distinction between primary and secondary effects is confused. An example of a secondary effect would be the income lost by the sakia maker when his sales fall due to a switch to some other kind of water lifter. His loss is his neighbor's gain who happens to sell the now more popular water lifter. On the other hand the increase in milk production of a cow when not required to drive a sakia is a direct effect which results in an increase in the farmer's income. Primary or direct effects tend to be things that relate to the efficient use of limited resources. Secondary effects tend to be things which indicate a change in the distribution of economic benefits and costs.

The argument for including secondary effects is based upon the concept that an increase in the income of a project's participant will result in increased consumption by that participant. To supply this increase in consumption additional material and labor must be employed. In turn, the consumption of this newly employed labor is increased and the cycle repeats itself. This is sometimes called the multiplier effect of a project investment.

Secondary benefits are popular because they can considerably enhance the attractiveness of projects which otherwise are economically infeasible. However, most of the writing by economists on the subject suggests that these secondary benefits should not be included in a project analysis unless the perspective of the analysis is regional instead of national.

If an ideal market economy exists where all prices accurately represent the marginal value of the product, all material and labor resources will be fully employed. An increase in the demand for a product would then be reflected by a change in the marginal value of the product and in turn a change in that product's price. If all resources are already fully employed the increase in the demand for a product would result in a transfer of resources away from another product. In the ideal market economy there has not been an increase in economic activity or goods, but a transfer from one area to another.

Generally, however, most developing nations do not approach free market economies with full employment of resources and prices which mirror the marginal cost of production. In such situations "project investments can lead to benefits not incorporated into an analysis based solely on market prices." (10) However, in such situations additional stipulation must be met before secondary benefits can be included; i.e., that the unemployment or underemployment must exist for the entire length of the project. Sassone and Schaffer argue that;

> The hazards and uncertainties associated with projecting long term resource unemployment are such that the measurement of secondary benefits in a national cost-benefit analysis is not warranted. (11)

There is a strong possibility that there is some underemployment of resources, particularly unskilled labor, during intervals in the crop

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(10) Gittinger,J. P.; pg. 26.

(11) Sassone, Peter G.; Schaffer, William A., Cost-Benefit Analysis, Academic Press, New York, 1978, pg 39.

seasons in rural Egypt. Consequently, the question of secondary benefits and costs is germane. Rather than employ considerable resources trying to quantify the nature of these benefits and costs, and risk the legitimacy of the remaining analysis by their inclusion in the formal summation of the costs of the various pumping alternatives, the secondary benefits will be identified and listed separately.

External and Internal Effects

Internal effects are those which affect the project and its participants. External effects affect people outside of the project. An internal effect of a drainage project would be the improved drainage of the project land or the reduction in the need for drains through better management of the irrigation water application. An external effect of the same project might be the additional drainage water which a farmer downstream on the drainage canal can now use for supplementary irrigation.

External benefits thus may be defined as benefits involuntarily received by others for which they pay nothing. External costs are similarly defined as costs imposed on others without compensation. Collectively, these external effects are often called externalities. They are neither deliberately produced nor deliberately consumed. (12)

Technological and Pecuniary Externalities

Externalities can be further categorized as technical or pecuniary. Technological externalities result in a real change in resource allocation. For example, a land reclamation project located above a river valley applies so much water to leach salts out of the top soil that the

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(12) Sassone, Peter G.; Schaffer, William A., Cost-Benefit Analysis, Academic Press, New York, 1978, pg 33.

fields in the valley are flooded with highly saline water. The quality of the soil and the crops planted in these valley fields are damaged by the salt and consequently the loss of income that those farmers will suffer because of this damage is a technological externality. Consumption or production opportunities outside of the project have been changed. Because real change in consumption or production opportunities outside of the project has occurred, technological externalities must be included in the summation of the benefits and costs of a project.

Pecuniary externalities however, are the financial effects of the market adjusting to a project's inputs and outputs. For instance, several farmers in the past have rented cows to drive the sakia from another farmer. Now these same farmers have bought a diesel driven pump and so do not need to rent the cows any longer. The farmer who owns the cows no longer receives the rent money. His income has been reduced, but his lost income should not be considered in an economic analysis of the farmer's pumping project. He still has his cows and he could employ them in some other task, such as producing more milk. Pecuniary externalities, because they do not represent real changes in resource allocation should not be included in an economic analysis.

Chapter VII

COST CATEGORIES

There are generally four kinds of direct or primary costs in agricultural projects. (1)

A. Goods and services

B. Labor

C. Land

D. Taxes and subsidies

Within these broad categories the costs of operating a low lift pump can be further detailed.

Under the general heading of goods and services the following costs have been identified.

1. The present replacement cost of the pump and driver in Egypt including installation.
2. The cost of energy.
3. The expected repair and maintenance costs.
4. The cost of oil and grease.
5. The wear out life and salvage value of the pump and driver.

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(1) Gittinger, J. P.; Economic Analysis of Agricultural Projects, The International Bank for Reconstruction and Development, John Hopkins University Press, Baltimore, 1972, pg. 15.

Replacement Cost of Pump and Driver

The present replacement cost of the pump and driver is often difficult to determine. Those pumps and drivers that are available in Egypt will be valued at their Egyptian present cost. However, several of the pumps and drivers that are considered in this analysis are presently unavailable in Egypt. These pumps, if they have been previously built in third world countries, will be valued at their present cost in the countries where they are currently being produced. Or, the costs of producing them in Egypt will be estimated. It is assumed that a pumpset built in any of the third world nations can also be built in Egypt at comparable costs. All other pumps and drivers unavailable in Egypt are valued at their United States quantity prices.

There is some speculation that certain of the pumps and drivers presently imported into Egypt are being sold at subsidized prices. It is asserted by some American pump manufacturers that the governments of certain countries, in order to build markets for their exports, subsidize the cost of their pumps and engines imported into Egypt. While this may seriously impact the American pump manufacturers ability to remain competitive, the apparently subsidized prices still remain an accurate measure of the cost of these pumps in the near future to the Egyptian economy.

Some pump setups will require initial construction such as pumping platforms, discharge bays, pumping houses, or electrical installation costs. Capital improvements will be included in the replacement costs when they are thought necessary for the sucessful operation of the pump. Electrically powered pumps will be charged indirectly for the cost of the rural electrification grid. This cost will be included in the shadow price of the cost of electricity.

Under the labor category the costs of the pump operators must be quantified. The cost of land on which the pump and any necessary structures stand must be determined. Finally, pump ownership taxes and the effect of subsidies must be analyzed. The costs that fall under each of these categories will be discussed and quantified in the following chapter.

Energy Costs

There are three types of energy utilized by the pumps under consideration in this study. They are:

(1) animal power, either cow or buffalo used to drive a sakia
(2) electrical
(3) petroleum based fuels

The Cost of Animal Power

There have been numerous studies on the cost of cow or buffalo power in Egypt. Table 7.1 lists the results of some of these studies. Five of the latest studies were analyzed and the results of those studies will be presented. Estimates of the cost of cow and buffalo power utilized to power a sakia varied widely. They ranged from LE. 3.17 to LE. 42.99 per feddan irrigated per year.

The wide range in cost estimates is attributable to several factors.

1. Different studies utilized different economic criteria to determine what animal costs were attributable to the use of the animal for pumping water.

Table 7.1

Estimates of the Opportunity Cost and Pumping Time Requirements of Animal Labor		
	Total Cost (piastres/hr.)	Hours per year to irrigate a feddan
FAO/World Bank - Estimate I		
-Average feed cost	9.8	143
FAO/World Bank- Estimate II		
-Meat/Milk loss	16.9	143
ERA 2000		
-Cattle meat/milk loss	6.6	198
-Buffalo meat/milk loss	6.8	198
Berger International		
-Meat/Milk loss plus extra feed	24.4	176
El Tambadawy		
-Work less than 4 hr./day	0.0	78
-Work more than 4 hr./day	3.6	78
ERA 2000		
-Market price for rental	19.0	198
Dyer - Farmer Survey - 1979		
-Market price for rental	33.0	87
Dyer		
-Cattle meat/milk loss plus extra feed		
Summer	10.8	
Winter	17.0	
-Buffalo meat/milk loss plus extra feed		
Summer	14.8	
Winter	32.8	
EWUP PTR #7 - Wahby		
-Market price for rental	30.0	100
EWUP SP #21 - Walters		
-Cattle meat/milk loss plus extra feed	3.28	100
-Buffalo meat/milk loss plus extra feed	12.99	100

*table derived from Dyer

Note: 1 Egyptian pound (L.E.) is equal to 100 piastres.

2. Most of the studies assumed different annual irrigation water requirements, different sakia discharges, or significantly different hours of animal labor required to irrigate one feddan annually. Four of the five studies calculated the the cost of animal power in terms of the cost of irrigating a feddan for a year. The fifth study computed the cost of animal power in terms of the cost per hour of animal power. All costs have been converted to both a cost per feddan irrigated per year and a cost per hour of animal power in this analysis.
3. Assumptions varied about decreases in milk yields and calving rates as a function of the use of a cow or buffalo to power a sakia.
4. Differing prices were used when valuing the milk and calf production.
5. Several studies did not differentiate between the power costs of cattle and those of buffalo.

Table 7.2 lists the differing cost estimates of the five studies analyzed and indicates the various components of those estimates.

Three fundamentally different economic methods have been utilized to determine the value of animal power. A brief discussion of these methods follows.

Incremental Opportunity Costs

Three separate studies utilized the incremental opportunity cost technique to determine the cost of animal power in Egypt.

Table 7.2

COST OF ANIMAL POWER

In LE per Feddan/Year

	EWUP #21 Buff.	EWUP #21 Cows	EWUP Proj. #7	ERA 2000	Louis Berger	Dyer + Buffalo	Dyer Cow
Milk Loss	12.50	2.60	0.0	10.08	19.80	11.794	5.699
Calving Loss	0.14	0.15	0.0	2.90	6.67	2.676	3.122
Extra Fodder	0.24	0.42	0.0	0.0	16.50	0.991	0.743
Depre-citation	0.0	0.0	0.0	0.0	8.21	0.0	0.0
Rental Rate*	0.0	0.0	20.43	0.0	0.0	0.0	0.0
TOTAL LE/FEDDAN	12.88	3.17	20.43	12.98	42.97	15.461	9.564

A discharge of 91.48 m^3/hour and an annual water duty of 6800 m^3 per year is assumed.

* Note: Rental rate is L.E. 0.30 per hour of labor.

\+ Dyer actually calculated a summer rate and a winter rate in L.E. per hour of labor. These rates were L.E. 0.148 and L.E. 0.328 respectively. It was assumed that 1/3 of the pumping is done in the winter, and 2/3 in the summer.

1. "Water Lifting by Sakia: The Incremental Cost of Cow Power", by Forrest Walters. Staff Paper No. 21, The Egyptian Water Use and Management Project.
2. "Further Mechanization of Egyptian Agriculture," Era 2000, USAID, March, 1979
3. "The Opportunity Cost of Animal Labor in Egyptian Agriculture", by Wayne Dyer. Economics Working Paper No. 3, The Agricultural Development Systems: Egypt Project, University of California, Davis.

These three studies utilized different data sets and fundamentally different approaches in determining the incremental opportunity cost of animal power. The derived opportunity costs varied considerably from LE 3.17 to LE 11.194 for cattle and LE 12.88 to LE 18.096 for buffalo per feddan irrigated per annum.

The incremental cost method is based upon the premise that the use of the cow to power the sakia is not the principal utility of the cow but rather a secondary one. The farmer would keep the cow for its milk and meat production regardless of whether he used it to power a sakia or not. Implicit in this argument is the additional supposition that the farmer would keep this "particular" type of cow even if it was not used for pumping but only for meat and milk production.

The incremental cost method does not charge the pumping operation any part of the annual fixed costs of the animal, nor the depreciation of the animal. This results in a low cost for animal power.

Walters argues that the incremental opportunity cost methodology is appropriate because;

> The major reason for keeping the cow is for meat and milk production and possibly for field power. Since a number of other

> means for lifting water (both mechanical and hand pumps) exist, the task of lifting water is an "added" task given the cow. As either the buffalo or baladi cow performs the task of pulling the sakia (1) milk production declines, (2) additional feed is required and (3) the calving rate declines.
>
> The decline in milk production and calving rates represents lost production -- a lost opportunity (opportunity cost) to produce. As a result, one of the costs of operating the sakia is the cost (opportunity cost) or value of lost production of milk and calves. The other cost is a direct add on cost of the additional feed required to supply the added energy needed for working the sakia. (2)

The authors of the ERA 2000 report suggest several additional reasons in support of the use of the incremental opportunity cost methodology. These include tractor and cattle growth trends and an analysis which indicates that utilizing the cow or gamousa solely for milk production is extremely profitable. (3) They report that over the past several years;

> The rapid expansion in tractorization of Egyptian farming undoubtedly has freed many cows from draft work. During that same period, however, cattle numbers have continued to increase at a rate of 1-2 percent per year. (4)

The ERA 2000 analysis of the profitability of raising and milking cattle which are not used as draft animals indicated that;

> A farmer would realize L.E. 27 per head per year from a non-working cow <u>even if</u> he valued the family labor spent taking care of the cow at the 1977 average boy-day wage rate <u>and</u> considered bank-rate interest a cost.

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(2) Walters, Forrest; <u>Water Lifting by Sakia: The Incremental Cost of Cow Power</u>. Staff Paper No. 21, The Egypt Water Use and Management Project, Colorado State University, 1980, pg. 4.

(3) Era 2000, <u>Further Mechanization of Egyptian Agriculture</u>, United States Agency for International Development, March, 1979, pg. VII.9.

(4) ibid.

> Under such circumstances few farmers are likely to sell their cows and buffalos when mechanization free them from farm draft work. (5)

These statistics, while not conclusive, suggest that the farmer is maintaining and even increasing his holdings of cattle for reasons other than their usefulness as draft animals. The use of cattle as draft animals appears to be a secondary use which supports the basic premise of the incremental opportunity cost methodology.

While the basic premise of the incremental cost methodology appears to be satisfied the question must be raised whether the choice of cattle breed is restricted by the draft requirements. It is argued that the demands pumping places upon the cow or buffalo prevent the adoption of livestock with improved meat and milk production characteristics. Therefore an added cost, the cost of this lost production should be charged to the use of the animal for powering a sakia.

Dr. Walters, in EWUP Staff Paper #68 published in the fall of 1981 suggests that the water lifting chores of the cows does impede the improvement of livestock in the Kafr El Sheikh area in the Egyptian delta.

> In the survey area it does appear possible that improved livestock could more easily be adopted if water lifting were not required. Also, specialization in livestock could be enhanced, since specific kinds of livestock would not be necessary for the related work activities -- e.g., cows are not required for the sakia. However the actual adoption of improved livestock appears to depend heavily on individual management initiative, and feed energy available from crop residues. For this reason it is probably not valid to use the "potential loss of opportunity of using improved livestock" in cost comparison calculations. (6)

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(5) Era 2000, pg. VII.11

(6) Walters, Forrest; <u>The Livestock Enterprise on Study Farms in</u>

Dr. Walters calculated that when it was appropriate to include an opportunity cost of using improved livestock that opportunity cost in the Kafr El Sheikh area of the Egyptian delta would be LE. 13.60 per feddan per year. If this cost is added to the previously calculated animal costs in EWUP Staff Paper #21 the cost on a per feddan basis of using buffalo power increases to LE. 26.48. Almost doubling Dr. Walters estimate of the cost of animal power in EWUP Staff Paper #21. All other cost estimates would be similarly affected.

The variation in the values of the opportunity cost of animal power in these three studies is a function of both differing data sets and different analytic approaches within a common methodology. Even the ERA 2000 study and the EWUP Report #21 whose values appear to be close, differ widely in the assumed farm gate prices for milk and the decrease in milk production of an animal being utilized to drive a pump.

Dr. Walters' analysis is based upon a comparison of the energy required to lift water (theoretically derived) and the energy required for the maintenance, and lactation of the animal. A combination of world averages and site specific values were utilized to determine the animal energy requirements.

The ERA 2000 report is based upon loss ratios with which the yields of nonworking cattle can be adjusted to approximate the yields of working cattle. The report does not elaborate upon how these loss ratios

Abu Raya, Kafr El Sheikh: Selected Indirect Effects of Water Distribution in Field Management. Staff Paper #68, The Egypt Water Use and Management Project, Colorado State University, 1981, pg. 1.

were determined, and utilizes the reported yields of the Ministry of Agriculture's research herds as their nonworking cattle standard.

Dyer, utilizes econometric techniques to derive an agricultural production function based upon a survey of 120 farmers from the Sharkia Governorate in 1977/78. This farmer survey was carried out by El Tambadawy as part of his masters thesis. (7)

The incremental opportunity cost methodology appears to be an appropriate tool for the evaluation of the cost of animal labor. However, the wide range of values and the question of the opportunity cost of herd improvement evidence the difficulty of utilizing this or any other cost methodology.

Incremental Opportunity Costs and Depreciation

A second method utilized to calculate animal labor costs is combining the incremental opportunity costs with the cost of depreciation of the animal.

A report prepared by the Egyptian Ministry Of Irrigation in conjunction with Louis Berger International Inc. suggests that the depreciation of the capital cost of the animal be added to the opportunity cost of the losses of milk and calf production when determining the cost of animal power. (8) However, this inclusion of depreciation in an incremental opportunity cost study contradicts the basic premise of the incremental cost method. Both milk and calf production losses caused by

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(7) El Tambadawy, Moustafa. "Economics of The Production and Marketing of Milk in The Sharkia Governorate." Unpublished Masters Thesis, Zagazig University, 1979 (in Arabic)

(8) Ministry of Irrigation, Mechanical and Electric Department, Arab Republic of Egypt; Louis Berger International Inc.: Technical and Economic Feasibility of Electrifying Tertiary Pumping Means in Middle and Upper Egypt, pg. 133

pumping and the entire depreciation of the animal are included in this study. The inclusion of both costs creates a fundamental contradiction within the analysis.

Technically, the depreciation of the animal can not be charged to the lifting of irrigation water, unless it is assumed that a primary reason for the farmer maintaining the animal is to provide pumping power. This contradicts the initial assumption of the incremental cost method which was that the use of the animal to drive a pump was a secondary use.

The probable intent of this analysis was to try to avoid the assertion that the farmer's decision to use an animal to power a pump does not influence the number or types of animals that the farmer chooses to own. Unfortunately, charging the entire depreciation of the animal to pumping distorts the costs of pumping and results in a cost of animal power that tends to be high. Additional factors which caused the Louis Berger estimate to be higher are significantly higher milk yield reductions and higher market values for the calves than are found in the other studies. Finally, the marginal feed costs are much higher than those of Walters or ERA 2000.

Rental Rate

The rental rate is another method that has been used to determine animal power costs.

A rental rate of LE 0.30 per hour was utilized by Wahby, et al. in EWUP Project Paper #7. The authors of this report state that this rate was based on farmer interviews. They acknowledge the wide range of values that are found in the literature, the implications of both high and low values upon the further mechanization and development of

Egyptian farms, and indicate that they hope to be able to provide additional data on this question in the future.

An appendix of EWUP Project Paper #7 sites another study of the cost of animal power by Abdel Hady Abdel Bary Nasser. (The cited study was not available when this paper was being researched). It is stated that Dr. Nasser concluded that the cost of animal power for driving a sakia was LE. 37.50 per feddan irrigated per year. This cost estimate is not close to the EWUP value.

Dyer also conducted a survey of rental rates. His survey indicated a mean rate of LE 0.33 per hour which is comparable to the EWUP value. Dyer questioned the validity of this number because of the large variance in reported rates and because the median rate of LE 0.50 was significantly higher than the mean.

There are several reasons why the rental rate may not be an appropriate measure of the cost of animal power for water lifting in Egypt. These include: (9)

1. The rental of cows and buffalos in general is an exception to to the normal practices of the Egyptian farmer. When animals are rented they are rented for specialized tasks such as plowing.
2. The rental often includes the driver and plow or other farm implement being pulled by the animal. The rental cost of the laborer and the farm implement would have to be deducted from the rental rate in order to determine the cost of the animal power.

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(9) see Era 2000, Further Mechanization of Egyptian Agriculture, US AID, March, 1979 pg. VII.7

3. The owner may consider renting an additional task above and beyond the animals' normal work load, leading to excessive losses of milk and calf production. Consequently, the owner would charge a rental rate that did not reflect normal use and cost of the animal power.
4. Owners would expect a return over their costs and so the rental rate would not represent the actual cost incurred by most farmers.
5. Some farmers rent their draft animals in return for fodder for the animal. (10)

Using a rental rate for an animal of LE 0.30 per hour and a sakia discharge of 100 cubic meters per hour the EWUP study calculated the cost of animal power on a feddan basis to be LE 20.43. This is considerably higher than Dr. Walters or the ERA 2000 report's estimate but lower than that of Dr. Nasser or the Ministry of Irrigation and Louis Berger.

Incremental Opportunity Cost Discrepancies

Previously the incremental opportunity cost method was shown to be the most appropriate method of determining animal power costs. The basic assumption of this methodology, that the use of a cow or buffalo to drive a pump is a secondary use, has been well supported in the literature. Furthermore, significant questions have been raised about the validity of the other two methods utilized in deriving animal power costs.

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(10) Dyer, Wayne. The Opportunity Cost of Animal Labor in Egyptian Agriculture, Economics Working Paper Series No. 3. Agricultural Development Systems: Egypt Project, University of California, Davis. June, 1980 pg. 5.

However, two unresolved problems remain with the values generated by the different incremental opportunity cost studies. The first is the large variation between the results of the different studies. The second is the problem of the opportunity costs associated with the inability to utilize breeds with improved milk and calving characteristics because of the use of these animals for draft power. From a practical standpoint, these questions would become moot if an economic analysis were to show that (utilizing the lowest of the values for the animal energy cost, and not including a lost opportunity cost) the cost of sakia pumping was still higher than that of using the cheapest diesel or gasoline pump. Unfortunately this is not the case and consequently these two issues must be addressed.

The discrepancies between the power cost estimates are due to differing assumptions as follows:

1. How many hours of pumping a year is required to irrigate one feddan.
2. How much meat and milk production is lost per hour worked.
3. The farm gate value of a unit of milk or meat.

Sakia Discharge Discrepancies

Most studies in the past made educated guesses about the number of hours a sakia would pump per feddan per year. In the last two years actual field data has become available. This data is in one of two forms. Either actual discharge measurements of sakias or records of the actual number of hours a year a sakia was used.

Roger Slack (11) surveyed a large number of sakias and concluded that though there were large variations, on the average a 3 meter diameter sakia (the size most typically powered by a buffalo) pumped 72 m^3/hr at a lift of 1 meter and 108 m^3/hr at a lift of 0.75 meters. The total time pumping per feddan per year would then range from 94.4 to 63.0 hours respectively, assuming an annual water duty of 6800 m^3 per feddan.

Further analysis of Slack's data indicates that the 2 meter diameter sakia has an average discharge of 52.5 m^3/hr at a lift of 3/4 meter. Again assuming an annual water duty of 6800 m^3 per feddan it would take 130 hours a year to irrigate one feddan with this sakia. No data were available for the 2 meter sakia at a lift of 1 meter.

Another excellent data source on farmer's sakia use are the annual Farm Record Summary and Analysis (12) (13) reports published by the economics team of the Egypt Water Use and Management Project. These reports are based upon biweekly farmer interviews and include data on the hours of sakia use. The data of the farms in the Abou Raia area indicates that in the 1979 - 1980 farm year the average annual sakia use was 58.83 hours per feddan irrigated. In the 1980 - 1981 farm year the average use was 64.64 hours per feddan irrigated. These two values

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(11) Slack, Roger. The Volume Discharge and Mechanical Efficiency of The Field Sakia. M.S. Thesis, Department of Agricultural and Chemical Engineering, Colorado State University, 1981.

(12) Abdel Al, Farouk and Melvin Skold, Farm Record Summary and Analysis for Study Cases at Abu Raya and Mansuriya Sites, 1978-1979. Project Technical Report No. 8, The Egypt Water Use and Management Project, Colorado State University, 1981.

(13) Abdel Al, Farouk and Melvin Skold, Farm Record Summary and Analysis for Study Cases at Abuyha, Mansuriya, and Abu Raya Sites, 1979-1980. Project Technical Report No. 23. The Egypt Water Use and Management Project, Colorado State University, 1982.

bracket the 63 hour estimate derived from Slack's data. At the EWUP pilot site near Minia, no sakias are used. All irrigation is by gravity or tambour. At the Mansuria pilot site, the wide use of diesel pumps distorts the sakia data.

In addition to these two data sources, surveys on the average annual sakia use per feddan were conducted by Dyer and Tambaday. Dyer's survey (14) indicated that average sakia use was 87 hours and Tambaday's survey indicated 78 hours of use. Neither of these authors indicated what size sakias were surveyed.

The distinction between the two meter and three meter diameter sakias is crucial to an understanding of two puzzling pieces of data. On the one hand all analyses of the cost of cow and buffalo power indicate that cow power is roughly 1/2 the cost of buffalo power. Consequently one would expect to see considerably more cows than buffalo powering sakias. This is not the case. All data indicates that cows and buffalos are used about equally. It is hypothesized that the difference between the strength and endurance of the cow and the buffalo is the cause of the apparent contradiction. Specifically the hypothesis is that the 2 meter diameter sakias with a maximum lift of 0.75 meter represent the maximum pumping load that a cow can power at 3 revolutions per minute over an extended period of time. When greater lifts or discharge are required, then a larger sakia, and a buffalo or two cows must be utilized.

(14) Dyer, Wayne. <u>The Opportunity Cost of Animal Labor in Egyptian Agriculture</u>, Economics Working Paper Series No. 3. Agricultural Development Systems: Egypt Project, University of California, Davis. June, 1980 pg. 5.

Slack measured the discharges of several 2 meter sakias. The average discharge was approximately 54 m^3 per hour. Interestingly, Slack could not find a two meter sakia with a lift greater than 0.75 meters.

The annual power cost per feddan irrigated is L.E. 16.24 for a two meter cow powered sakia with a 75 cm lift using Dyer's animal power costs, and Slack's discharge measurements. That cost for the 3 meter buffalo powered sakia is L.E. 13.10. The ratio of the annual cost of buffalo power per feddan irrigated to the annual cost of cow power per feddan irrigated is 0.81 given this hypothesis. The ratio of the cost of buffalo power per hour of labor to the cost of cow power per hour of labor is 1.61. The former ratio would indicate conditions under which it would be reasonable to expect cows and buffalos to be used equally to power sakias. Undoubtedly the hypotheses that cows can only power the smaller 2 meter sakias does not fully explain the wide discrepancy between the cost per hour of labor of the two animals, and their equal use to power sakias. It does however offer a partial explanation.

Additional considerations might be that Slack's discharge measurements for the smaller sakias are low, or Dyer's cost estimates of an hour of cow labor is high. In either case the ratio between the annual power cost of the two animals per feddan of land irrigated would approach unity.

This hypothesis was discussed with Slack, and Tom Ley, an EWUP engineer with considerable field experience in Egypt. Both felt that the hypothesis was reasonable, but neither had data to confirm it. Additionally, Ley stated that he had heard someone suggest that the buffalo completed fewer revolutions per minute of the sakia than the cow. If this were so, then further adjustments would have to be made in the relative discharges per hour. Regardless of the discrepancies that still exist, the hypothesis that a single cow can only power a two meter sakia combined with Slack's discharge data offers the most plausible explanation of cow and buffalo use for pumping in Egypt. Slack's discharge for both the two and three meter sakias will be used in this analysis. These discharge are:

1. 54 m^3/hour for a 2 meter sakia at a 0.75 meter lift.
2. 108 m^3/hour for a 3 meter sakia at a 0.75 meter lift.
3. 72 m^3/hour for a 3 meter sakia at a 1 meter lift.

Furthermore it will be assumed that the 3 meter sakia is powered only by buffalo, and that the two meter is powered only by cows. A sensitivity analysis will be performed to indicate the influence of varying discharges on the cost of pumping.

Animal Labor Production Functions

Three aspects of cattle and buffalo milk and meat losses are generally agreed upon.

1. Addition energy demands are imposed on the cow and buffalo by pumping.
2. The supplemental feeding, if any, given to these animals does not completely compensate these energy demands.
3. The net energy deficit results in a decrease in the calving rate and the quantity of milk produced.

The quantification of the decrease in the milk and calving rate has not been easy. Some studies used figures based upon limited surveys and estimates made by individuals in the field. Two studies, by Walters (15) and by Dyer (16) both written in the summer of 1981, analyzed the energy requirements of a lactating animal, the additional energy demands of driving a sakia, and the energy value of the feed of these animals.

Both authors then built production functions to describe the opportunity cost of the lost milk production and the decreased calving rate. The coefficients in Dyer's production function were based upon an analysis of El Tambadawy's data. Walter's functions were derived from theoretical considerations and data on cattle and buffalo in Europe and North America. Both authors' results indicate that the cattle opportunity cost is less than that of the buffalo and Walters opportunity cost for the buffalo is within 9% of Dyers summer buffalo opportunity cost. However, the opportunity costs of cattle are significantly different and Dyer found it necessary to built separate production functions for the summer and winter seasons. Table 7.3 lists the different components of these two production functions.

There is a major discrepancy between Dyer's and Walter's opportunity costs for cows. Walters placed the opportunity cost of cattle at 1/4 the cost of buffalo. Assuming Slack's discharge measurements to be reasonally accurate, Walters cost of cow power would result in a pumping cost for cattle that is half that for buffalo. In fact farmers tend to use buffalo slightly more more than cattle. Certainly, as the butterfat content and consequently the price of buffalo milk is higher than the milk of a cow's (with similar volume yields) one would expect the

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(15) Walters, Forrest; Water Lifting by Sakia: The Incremental Cost of Cow Power. Staff Paper #22, The Egypt Water Use and Management Project, Colorado State University, 1980.

(16) Dyer, Wayne; The Opportunity Cost of Animal Labor in Egyptian Agriculture, Economics Working Paper Series No. 3. Agricultural Development Systems: Egypt Project, University of California, Davis, June, 1980.

Table 7.3

The Cost of Meat and Milk Production Losses

	Milk Cost/hr of Labor	Additional Feed Cost/hr of Labor	Calving Cost/hr of Labor	Total Cost/hr of Labor
Walters - Buffalo	0.125	0.00237	0.002512*	0.1299
Dyer				
Summer - Buffalo	0.092	0.020	0.036	0.148
Winter - Buffalo	0.292	-0-	0.036	0.328
Walters - Cow	0.026	0.0042	0.002569*	0.0328
Dyer				
Summer - Cow	0.051	0.015	0.042	0.108
Winter - Cow	0.128	-0-	0.042	0.170

*Walters did not calculate the opportunity cost of a decreased calving rate on a per feddan or per hour basis. Rather he assumed that 3 cows would be used and no cow would work more than 3 hours per day. He then determined a fixed calving opportunity cost of L.E. 2.22 for cows and L.E. 2.17 for buffalo. This value was used regardless of the number of feddans irrigated. Walters also assumed that the annual water duty was 6800 m^2 per feddan, and that it required 100 hours to lift the total annual irrigation needs of 1 feddan.

With two additional assumptions a calving opportunity cost per hour of labor can be deduced. First, it is assumed that the maximum number of cubic meters needed per feddan per irrigation is 450 m^2. Secondly, that the meska has water flowing into it 6 consecutive days at a time. The first assumption is a standard EWUP assumption, the second overly generous.

Given these assumptions the maximum number of feddan that can be irrigated with three cows or buffalo is 8.16 feddans. Walters fixed opportunity cost of the decline in the calving rate is then divided by 8.16 feddans to arrive at a per feddan and in turn per hour rate.

opportunity costs of cattle to be lower than for buffalo. The opportunity costs in both studies reflect this. Consequently Dyer's value for the opportunity cost of cattle labor, which is lower than that of the buffalo but higher than Walter's appears to be more realistic. As shown in the previous section, Dyer's animal labor costs combined with Slack's discharge measurements suggest a level of usage of both cows and buffalo that is consistent with actual farmer practice.

Dyer, utilizing data collected in Egypt, analyzed the feed requirements and feed supply for animals in Egypt.

His analysis of the feed requirements and supply for these animals pinpointed the critical disparity between summer and winter feed levels.

> The most obvious pattern is the dichotomy between summer and winter seasons. Feed utilization, measured in total digestible nutrients (TDN) is concentrated in the winter, being more than double the summer level. The relative difference between summer and winter is even greater in digestible protein (DP) utilization because the winter feed consists almost entirely of the protein-rich berseem crop.
>
> The utilization of animal labor also involves a seasonal pattern. However the concentration is the opposite of seasonal feeding because the hours of animal labor required in summer are more than double those needed during the winter months. The animal is being fed to gain weight during the winter in order to survive the near starvation levels of feed during the summer. (17)

Due to the seasonal disparity in feed supplies Dyer established separate seasonal production functions. The extremely low level of summer feed supplies caused the opportunity cost of animal labor in the summer to decline even though the summer irrigation requirements are twice those in the winter. On first thought this is counter-intuitive. Dyer's reasoning is that milk yields are already significantly decreased

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(17) Dyer, 1980, pages 6, 7, 21

during the summer because of the low feed supply. The use of the animal to drive a sakia does not further reduce the already low summer milk yields as much as in the winter when milk yields of non pumping animals tend to be much higher.

Dyer was dissatisfied with his summer production function for buffalo but the close agreement between he and Walters lends additional support to the validity of his production function.

Dyer's values are high when compared to the values utilized by most of the other studies. It should also be noted that both Dyer's and El Tambadawy's data indicated that the number of hours per year to irrigate one feddan is significantly less than that reported in most of the previous studies.

While recognizing and emphasizing that no one has definitively defined the opportunity costs of animal labor in Egypt, Dyer has presented the most comprehensive and realistic estimate to date and these will be the primary values used in this analysis.

Breed Costs

The last aspect of animal power cost that must be examined is the opportunity cost that is incurred when high milk yielding breeds of cattle and buffalo cannot be used in Egypt because they lack the physical stamina needed to drive a sakia. This is to some degree a best of all possible worlds argument which hypothesizes that the best of all possible worlds is a certain reality if we would only make certain changes. In some respects it is a naive argument, but the assertion that the power requirements do hamper the introduction of other breeds is correct.

A change to a higher milk producing breed would require not only the elimination of the animal power requirement but would "depend heavily on individual management initiative, and feed energy from crop residues," (18)

What is at issue here is not whether there is an opportunity cost of production forgone, but how to measure that cost and properly apportion it to the various production inputs. These would include management, improved forage supplies, and the animal labor restraints.

From a practical standpoint apportioning these costs would be extremely difficult, and in the eyes of many might bias the entire analysis. Reason would suggest that a trial opportunity cost be examined as part of the sensitivity analysis, but otherwise that the question be put aside until more data is accumulated. The sensitivity analysis will use the opportunity cost of L.E. 13.60 suggest by Walters.

Fossil and Electrical Energy

Today Egypt is fully utilizing the energy production of the turbines at the Aswan dam. She has no new hydropower plants coming on line, nor potential hydropower sites in the near future.

The demand for electricity has increased rapidly in the last 5 years. In 1977 hydropower generated twice as much electricity as did thermal power plants. In 1981, hydropower accounted for only 51% of the electric supply. (19) The era of cheap energy is over for Egypt. In the next 10 to 15 years increased demand for electricity will be met

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(18) Walters, 1981

(19) Abu-Neima, El-Mousily, El Gazzar, and Ibrahim, Electricity Use in Egypt, The Ministry of Electricity and Energy, The Government of Egypt, April 1981.

primarily with crude oil fired generating plants. The operation of these plants is expensive. Additionally, as demand for electricity grows in the rural areas of the country, an electrical distribution system will have to be built. The costs of such a system are enormous.

All energy product prices are subsidized to some extent in Egypt. A recent study compared 1978 through Fiscal Year 1982 subsidized prices with international prices. The results of that study, modified to reflect the new exchange rate of L.E. 1.0 = $1.00 is presented in Table 7.4.

The 1982 International prices presented in this table will be used in the economic analysis for the diesel, kerosine, and gasoline fuel costs. The electric energy cost will be a modification of the cost presented in this table. That modification is discussed in the following section.

The 1982 subsidized egyptian prices will be used in the financial analysis for the diesel, kerosine, and electric costs. A cost of L.E. 0.15 per litre will be used for the cost of gasoline in the financial analysis. This was the cost of gasoline in Egypt in late 1982 and early 1983. (20)

The Cost of Electrical Power

Several studies have looked at these costs. One study by the Egyptian Ministry of Irrigation in conjunction with Louis Berger International (21) investigated the cost of installing an electrical tertiary

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(20) Correspondence with Farouk Abdel Al

(21) Ministry of Irrigation, Mechanical and Electric Department; Arab Republic of Egypt, Louis Berger International Inc.: Technical and Economic Feasibility of Electrifying Tertiary Pumping Means in Middle and Upper Egypt.

Table 7.4

ENERGY PRICES IN L.E.[1]

SOURCE	CY 1978	CY 1979	FY 1981	FY 1982
	EGYPTIAN SUBSIDIZED PRICES			
Butane Gas (12 1/2 Kg) Cylinder	0.65	0.65	0.65	0.65
Gasoline, Premium (liter)	0.08	0.11	0.13	0.127
Kerosene (liter)	0.025	0.025	0.03	0.029
Diesel Fuel (liter)	0.021	0.021	0.026	0.0245
Mazout (MT)	7.5	7.5	7.5	7.5
Natural Gas (MT)	7.5	8.7	10.35	11.00[3]
Electricity (KWH)	0.0093	0.0097	0.0106	0.0106[4]
	INTERNATIONAL PRICES			
Butane Gas (12 1/2 kg)	5.44	5.64	4.07	4.67
Gasoline (liter)	0.296	0.296	0.257	0.237
Kerosene (liter)	0.19	0.319	0.267	0.273
Diesel Fuel (liter)	0.227	0.291	0.257	0.239
Mazout (MT)	123.84	150.00	217.50	164.629
Natural Gas (MT)	123.84	150.00	217.50	164.629
Electricity[5] (KWH)	0.070	0.071	0.109	0.084

1. Exchange rate L.E. 1.0 = U. S. $1.00

2. Average electricity prices increase because residents and commercial users face upward block pricing structures so that rising consumption increases the average effective price.

3. Only 1979 and 1981 data were available. Other values are estimated.

4. Assumed to be the same as the previous year.

5. Estimated as the cost of production at the Ismalia Thermal Power Plant when mazout is priced at the International level.

CY - calendar year

FY - fiscal year

Table derived from United State Government Memorandum, Egypt - A Quantitative Standard for Programming Against Sector Wide Performance in Energy Pricing, June 7, 1982.

pumping system in Middle and Upper Egypt. This study envisaged replacing all existing low and high lift pumps including sakias and diesel powered pumps with new efficient electrical pumps. The project would have required that an extensive rural power grid be installed throughout Middle and Upper Egypt to bring electricity to the pump installations in the fields.

As part of this study an estimate was made of the cost of generating electricity with a fossil fuel generating plant. It was assumed that Egypt's hydroelectric generating capacity had been exhausted and that an oil fired generating station would have to be built to meet the power requirements of the project. The analysis used 1977 constant prices and the cost of fuel oil was assumed to be $64 a ton. The Louis Berger study estimated that the cost of electricity not including the distribution grid costs was L.E. 0.0199 per KWH.

With the doubling of crude oil prices between 1977 and 1980, this estimate of the cost of power generation became unrealistically low. The power grid costs must also have escalated along with the oil prices. How much these costs increased is not known, and no other estimation of power grid costs has been found.

An agency of the United States Government in June of 1982 issued a memorandum which compared fiscal year (FY) 1982 Egyptian energy prices with international prices (see preceeding section). Within this memorandum:

> The international shadow price for electricity is calculated by finding the expected average cost of producing electricity in the nearly completed Ismalia Thermal Power Units 1 and 2. The international price of mazcut is used in the calculation leading to an average cost of 58.8 milliems per KWH for 1982. (22)

With the stabilization of oil prices, the international market price assumptions made in this study are probably still valid. However this study assumed an exchange rate of L.E. 0.70 = \$1.00. Today the exchange rate has reached parity at approximately L.E. 1.0 = \$1.00. This represents a 43% decrease in the value of the Egyptian pound and consequently a 43% increase in the cost of electricity in pounds. The cost of generating power per kilowatt hour is then approximately:

L.E. 0.0588 x 1.43 = L.E. 0.0841

This cost does not include the cost of the distribution grid that would have had to be installed throughout the project area if electric motors were to be used to drive tertiary level irrigation pumps. In addition transmission losses of 10 to 15% would further increase costs.

As part of the Ministry of Irrigation/Berger study in 1977 the Rural Electrification Authority "designed the electric network to electrify all irrigation means in each district taking into consideration current and projected domestic loads." (23) The cost of the proposed power transmission grid was then estimated in 1977 prices to be L.E. 72,707,039. This estimate included all poles, high, medium, and low tension lines, all transformers, submarine cable, administrative, equipment, and transportation expenses. Assuming this grid had a 60 year

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(22) United States Government Memorandum, "Egypt - A Quantitative Standard for Programming Against Sector Wide Performance in Energy Pricing," United States Agency for International Development, Cairo, Egypt, June 7, 1982.

(23) Ministry of Irrigation, Mechanical and Electrical Department, Arab Republic of Egypt and Louis Berger International; Technical and Economic Feasibility of Electrifying Tertiary Pumping Means in Middle and Upper Egypt, pg. 7, Cairo.

life and the opportunity cost of capital in Egypt was 12% the authors of the Berger report concluded that the annual interest and depreciation would be L.E. 8,734,576. The grid was designed to carry 119,177,267 KWH annually throughout rural Middle and Upper Egypt. If the entire cost of the power grid were to be apportioned to pumping, the cost of a kilowatt hour would increase by L.E. 0.0733 (24) at the 1977 exchange rate or L,E. 0.1047 at the current exchange rates. It is questionable whether the entire grid costs should be assigned to electrical pumping. However this analysis will charge the entire grid costs to pumping for two reasons. First, the relative cost advantages of electrically driven pumps over other pumps are not significantly altered by assigning the entire grid costs to electrical pumping. Secondly, a conservative analysis of the pumping costs is desired.

The cost of the electrical distribution system apears to be very high when compared with the generation cost of that electricity. Engineers with a local rural electric utility company and a new power plant in Colorado were consulted. These engineers thought the distribution cost per KWH was very high. Yet, upon inspection, the estimated unit material costs of the system were reasonable, if not slightly low. One possible explanation for these discrepancies is that a denser power distribution system is required in Egypt due to the small size of farms. It is difficult to organize these farms into large blocks of land for various technical and social reasons. Consequently most irrigation units served by a single pump would be smaller than 60 feddans and most probably around 15 feddans.

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(24) ibid, pg. 136.

Each pump no matter how small would require a hookup to the system, and the number of distribution lines needed would be much higher than in the United States. The quantity of material per unit area required to build a power distribution system in Egypt would in turn be much greater than in the United States. Consequenlty, the costs would also be much higher.

Finally transmission losses of 10 to 15% (25) must be included. Assuming that such losses can be kept to 10%, the total cost of generation and distribution of electricity is L.E. 0.192 per KWH. Remembering that L.E. 1.00 = $1.00, this translates into approximately 19 cents per KWH, approximately 3 to 4 times what we pay in the United States.

The reason this cost is so high is two fold. First, a totally new power plant would have to be built, at 1981 prices, to meet the increased electrical demand if small electric pumps were to be used throughout rural Egypt. Secondly, the entire cost of a rural power grid was assigned only to irrigation pumping.

That there are inherent problems with this analysis of the cost of electricity must be acknowledged. To begin with, the entire cost of the distribution system is being charged only to the pumps. The distribution system was designed to serve the domestic, irrigation, and all other agricultural and industrial needs for electricity in rural Upper and Middle Egypt. If these other users were to bear a proportionate part of the distribution system costs the cost for irrigation pumping would be reduced. Secondly, the distribution system requirements in

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(25) United States Department of Energy. <u>Joint Egypt/United States Report on Egypt/United States Cooperative Energy Assessment</u>, Vol 1. April 1979, pg. 28

Upper and Middle Egypt are not necessarily those of the delta. However, this study will apply these regional costs on a nationwide basis. The significance of this distribution assumption will most probably not be known unless further detailed studies are conducted. Presently, these types of assumptions are unavoidable. In conclusion, the KWH cost that will be used in the economic analysis is L.E. 0.192.

Chapter VIII

THE COST OF GOODS AND SERVICES

Repair and Maintenance Costs

A considerable portion of the repair and maintenance costs of pump operation are a function of the kind of driver being used. The repair and maintenance costs of electric drivers are usually significantly lower than fossil fueled drivers. However, in the often severe environments found in developing countries it is difficult to divorce the subjects of repair and maintenance costs from those of replacement cost, wear out life, salvage value, and operator training. Although numerous references to the interdependency of these factors are found throughout the literature, (1) there is little work quantifying these relationships. Generally most reports on irrigation costs use textbook values for repair and maintenance costs or the best guess of someone with field experience in the locality being studied. None of these methods are satisfactory.

The only satisfactory method for determining repair and maintenance costs in developing countries is to use actual field data. Either test the pumps themselves in the actual operating environment, or use data collected on similar pumps in similar operating conditions.

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(1) Wahby, Hassan, Gene Quenemoen, and M. Helal, 1980

To test the pumps themselves requires a considerable amount of time and money. And again for reasons of time, money, and a lack of initiative, there is little available data on the repair and maintenance costs of pumps and drivers in developing countries.

Recently, the International Rice Research Institute conducted a study of the cost of irrigation in the Central Luzon region of the Philippines. (2) Data on the irrigation costs of gravity, low lift, and deep well projects were collected. Maintenance, repair, labor, and energy costs were itemized for four low lift pumping projects. Three of these projects were relatively large areas served by electrically powered central pumping systems run by the National Irrigation Administration. The fourth project was actually a random selection of 20 small diesel driven centrifugal pumps owned and operated by individual farmers within central Luzon.

An analysis of the data from the IRRI survey indicated that repair and maintenance costs for the small diesel powered pumps was approximately $7.15 per cropped acre. The repair and maintenance costs of operating the larger electric powered low lifts pumps averaged $2.15 per cropped acre.

The group of small farmer owned diesel pumps, incurred maintenance costs that were 3 1/3 times the average of the electric pump projects. This difference is a reflection of four specific characteristics of small, farmer operated, diesel low lift pumpsets.

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(2) Cost Of Different Types Of Irrigation Systems In Central Luzon, Moya,P.F., Small,L.E., Bhuiyan, S.I., Department Of Agricultural Economics, International Rice Research Institute, June 1980.

1. Fossil fueled engines characteristically require more maintenance than electric motors.
2. The maintenance and repair of fossil fueled engines requires skilled operators and mechanics with access to tools often unavailable in some developing areas.
3. Generally, the farmers operate their own pumps instead of hiring a trained operator. This results in a significant decrease in a farmers labor costs, but can increase the maintenance costs.
4. Small pumps owned by individual farmers are usually not operated for as many hours a year as larger, cooperative or government owned systems. Consequently, the cost of the maintenance that is required annually regardless of use is a greater proportion of the annual cost of irrigation.

The high maintenance costs for the small farmer owned pumps appear to be reasonable in light of the above considerations. Especially when considering the labor savings of a farmer operated pump.

These figures from the Phillipines can serve as benchmarks for checking derived repair and maintenance costs for pumps and drivers in Egypt. They cannot be used directly because neither the length of the irrigation season, nor the annual discharges of the pumps are known. Additionally, the data appears to be pre 1978, prior to the 1979-1980 rise in oil prices.

Utilizing these Philippines prices as benchmarks, pump and pump driver manufacturers', salesmen and engineers were consulted. In most cases these individuals were familiar with the operating environment of developing countries. Additionally, construction companies and equipment rental companies were consulted. Finally, EWUP project engineers with considerable field experience in Egypt reviewed the cost estimates.

The repair and maintenance cost calculations are presented in Appendix C.

The calculated repair costs on a per feddan basis are listed in table 8.1. The diesel powered IRRI pump repair and maintenance costs are extremely close to the costs reported in the Philippine studies. The gasoline and kerosine maintenance costs are predictably higher. The costs of the electric driven pumps is however considerably lower than in the study of the pumping systems of the central Luzon in the Philippines.

Implicit in the determination of repair and maintenance costs is an estimate of the wearout life of the pump and driver. When determining these costs the question that must be answered is - at what point do you buy a new piece of equipment instead of repairing an old one? The computer model developed does not allow for a pump with a different wearout life than that of the driver. The diesel driver for the IRRI pumps has a wearout life of 7500 hours, or approximately 5 years of expected use. This is short when compared to other studies where a life of 15 years is often assumed. It is also significantly less than the expected life of the IRRI pumps. In an attempt to compensate for the shortened life of the pump, no pump repair cost are included in diesel powered IRRI pump analysis. The same is true of the gasoline and kerosine driven IRRI pumps. However, in the case of

Table 8.1

Annual Pump Repair and Maintenance Costs Per Feddan Irrigated

Pump & Driver	Annual Repair & Maintenance Cost per Feddan L.E.
Sakia	0.787
Diesel powered IRRI pump	7.40
Gasoline powered IRRI pump	8.594
Electric powered IRRI pump	1.50
Electric powered Cascade pump	0.80

the electric pumps, where a 15000 hour wearout life is assumed, the pump repair and maintenance costs are included.

Because of the difficulty of ascertaining these repair costs, a sensitivity analysis will be performed. The repair costs will be varied ± 25% to determine the effect of a change in repair costs on the solution.

Oil and Grease Costs

The oil and grease consumption rates are those specified by the manufacturer of the pumps. In certain cases where consumption rates were not specified by the manufacturer, estimates were made based upon the consumption rates of similar pumps. Oil and grease consumption estimates are included in Appendix C.

Wear Out Life & Salvage Value

The wear out life and salvage value of a pump and its driver is a function of many variables including the initial quality of the units, the quality of the maintenance and repair the units receive, the operating environment, and the skill of the pump operators (See the previous section on repair costs).

Setting these considerations aside for a moment, a comment on how pumps are actually operated in many developing countries is appropriate. Most pumps are utilized for far longer periods of time than ever envisaged by their designers. These pumps may be operating at efficiencies far below their designed efficiencies, but capital constraints, cheap labor, considerable ingenuity, and subsidized energy costs usually promotes the continued use of outdated, highly inefficient pumps and drivers. For example, some of the Ministry of Irrigation pumping plants in Middle Egypt were installed in the early 1930's. These plants are still operating, but at unknown efficiencies. Many of the privately owned pumps I observed in Middle and Upper Egypt in 1979 were apparently even older.

There are several reasons why pumps and drivers are operated in Egypt far past their manufacturer specified wearout life. The artificially low subsidized prices of energy often hides the true cost of operating a pumpset past its wearout life. Furthermore, the inability of the farmer to obtain the necessary cash or credit to finance a new pumpset denies him the opportunity to select the most economic alternative and forces him to continue to use a worn out pumpset. The low cost of labor and the ingenuity of the Egyptian repairman ease the cost of utilizing these non-optimal economic alternatives.

The economic analysis of pump sets assumes that the designed efficiency of the pump is maintained throughout its economic life. Furthermore, as was discussed previously the economic life and the wearout life of the pump sets were assumed to be the same. The wearout life of a pump set under "normal operating conditions" is specified by most manufacturers of the pumps and drivers. While it is not explicitly stated by the manufacturers, it is usually understood that with proper repair and maintenance, efficiencies close to the design efficiencies can be maintained during the specified wearout life of the pump.

The "real" repair and maintenance costs of operating a pump beyond its wearout life are generally prohibitive. From a national perspective, it would be better to replace than to continue to operate these worn out and inefficient pumpsets.

Determining the life of a particular pump and driver, operating in a developing nation, without the advantage of hindsight, is more art than science. Consequently, engineers and other individuals with extensive experience with small motors, engines and pumps were consulted. It is their estimates that will be used in this analysis.

These estimates assume that the units would be operated in extremely dusty environments, and exposed to the elements. Minimal maintenance would be assumed. As a rule, the quality of the maintenance an electric motor received was assumed to be better than that received by a combustion engine. This bias is the result of personal experience and the inspection of a series of large electric pumping stations which continue to operate 50 years after their installation in Middle and Upper Egypt.

Most probably some double counting will occur between conservative wear out lives and high maintenance and repair costs. Conservative estimates are preferrable to overly optimistic estimates.

A listing of the wearout lives for the sakia and IRRI pumps are provided in Table 8.2. The wearout lives of all pumps considered in this analysis is presented in Appendix C.

Labor Costs

The next cost category is labor. The only component of labor that must be considered in this analysis is the operator of the pump, or the person who insures that the animal driving the sakia continues to work. Different economic studies of the Egyptian agriculture and/or irrigation have valued the labor component in significantly different ways. This diversity of methods and numbers is perhaps the results of a lack of confidence in the available demographic data on Egypt. However, there

Table 8.2

Estimated Sakia and IRRI Pump/Driver Wearout Lives

Pump & Driver	Wearout Life	
	Hours	Years of Expected Use
Sakia Buffalo Powered	15000	19.8
Diesel driven IRRI Pump	7500	4.9
Gasoline driven IRRI Pump	2000	1.3
Kerosine driven IRRI Pump	2000	1.3
Electric driven IRRI Pump	15000	9.9

also appears to be theoretical distinctions between some of the methodologies utilized to determine labor costs.

A brief explanation of some of the alternative methods of valuing the cost of labor follows.

Often the difficulty of determining the cost of labor in developing countries lies in the fact that the addition or subtraction of an additional agricultural worker does not increase or diminish the total product.

> We may say that the marginal value product of such labor - the amount it adds to the gross domestic product - is zero...If an agricultural laborer was adding nothing to the production in his community, then we lose nothing by transferring him to productive labor elsewhere. This being the case we need not consider that this labor has any cost attached to it. The true wage is zero because that is what it could otherwise produce. Following this line of argument, the proper price to charge in the economic (not financial) analysis of projects would be zero. (3)

The implication of this reasoning is often not fully understood. Essentially Gittinger is arguing that if a surplus of agricultural labor exists, the wage rate of that surplus labor, no matter if employed in the fields, or in a factory, is zero.

Sakia Operator Cost

An argument that runs counter to Gittenger's was suggested in EWUP Staff Paper #7.

> The amount L.E. 0.05 per hour for a sakia (operator) seems consistent with other studies and is perhaps adequate unless one considers the cost of the children driving animals turning sakias in terms of their foregone opportunity of going to school. (4)

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(3) Gittinger,J. P.; Economic Analysis of Agricultural Projects, The International Bank for Reconstruction and Development, John Hopkins University Press, Baltimore, 1972, pg 41.

(4) Wahby, Hassan; Appendix A, pg. 3.

Whether or not there is surplus agricultural labor in Egypt is a subject of considerable debate. Landowners and many government ministers will argue strongly that there is actually a shortage of agricultural labor.

A recent EWUP report by Elewa and Darwish supports this contention. (5) These authors document the change in the cotton harvest practices in Egypt. Over the last several years many farmers have abandoned the previous custom of a third picking of the cotton crop. This change in long standing agricultural practise can be demonstrated to be a function of increasing rural wages.

An Era 2000 study of agricultural mechanization in Egypt further documents the increasing rural wage rate because of rural labor shortages. Utilizing census data, the results of a farm survey, and reports of Egyptian and international institutions, a farm labor balance was built. This balance compared on a weekly basis the farm labor requirements with the available farm labor force. The authors of this study concluded that during 12 weeks of the year there was a shortage of farm family labor and that consequently there were;

> opportunities for farm operators and/or members of their families to be employed on other farms as hired workers. Thus from that perspective the opportunity cost of family labor is the prevailing hired labor rate. (6)

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(5) Elewa, Sabhi and Darwish, Ragy; A Comparison of the Cost of Picking Cotton to the Value of Cotton. Draft Working Paper #112, The Egypt Water Use and Management Project, Colorado State University, January, 1983.

(6) Era 2000, Further Mechanization of Egyptian Agriculture, US AID, March, 1979 pg. VII.19

The Era 2000 study indicates that in 1977 the prevailing national average wage rate per man was LE. 0.76 and for a boy was approximately one half of that at LE. 0.355 per day. No figures for a woman's wage rate were given. In the author's travels throughout Middle and Upper Egypt far more young girls than boys were seen supervising the animals driving sakias. Characteristically, one might suppose that in Egypt their wage rate would be less than that for a boy. Assuming that a girl's wage rate is no higher than a boy's, the Era 2000 report would indicate that the unskilled labor cost of operating a sakia throughout the year should be less than or equal to LE. 25.56.

Assuming the sakia irrigated 12 feddans, Slack's discharge data for a 3 meter sakia and an annual water budget of 6800 m^3 per feddan, this amounts to a cost of L.E. 0.034 per hour. With the revaluation of the pound and the increase in labor scarcity since 1977 the figure of L.E. 0.05 per hour is conservative. This figure will be used as the operator cost of the sakia in this analysis. The sensitivity of the sakia costs to the cost of the sakia operator will also be examined.

Mechanized Pump Operator Costs

There is little data on the cost of skilled pump operators. EWUP Staff Paper #5 uses a cost of LE 0.30 per hour for a mechanized pump operator. "Given the work habits of rural laborers LE. 0.30 per hour for overseeing mechanical pumps seems realistic and consistent with information obtained by farmer interviews" (7) This rate, assuming an 8 hour day would correspond to the monthly salary of a young college

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(7) Wahby, Hassan; Appendix A, pg. 3.

trained engineer in Egypt. This seems therefore to be an unusually high labor cost.

Data collected by the University of Menoufia and presented in the EWUP report suggested even higher hourly labor costs of L.E. 0.794 for a diesel driven pump and LE. 0.318 for an electric pump. No explanation of how these figures were derived is presented. Within the context of small low lift pumps this cost seems extremely high.

The Era 2000 study used the Egyptian 1977 average man-day wage rate of LE. 0.76 as the daily cost of a skilled mechanized pump operator. This is considerably lower than the rate utilized by EWUP, and is probably to low.

The relationship between labor and maintenance costs were discussed in the previous section on maintenance and repair costs. It was suggested that in the case of farmer owned small pumps, the farmer would be his own operator. Technically, the time the farmers spends operating his pump should then be charged to the pump as a cost. However, trying to separate the task of irrigating his fields, from the limited time he spends starting and regulating the pump would be difficult. Therefore this study will assume that there is no labor cost for farmer owned and operated pumps.

For the purposes of this study the EWUP skilled labor cost of LE. 0.30 per hour will be used for those pumps requiring operators. This cost, while seemingly high, lies between the ERA 2000 and the Menoufia data. A cost of LE. 0.05 per hour will be used for the sakia attendent wage. The sensitivity of the pumping costs to these labor costs will be examined in the sensitivity analysis.

The Cost of Land

The third general cost category is land. As Brown points out,

> Land serves two basic functions. It provides the space for production to take place, and it is the repository of the physical, chemical, and biological properties of nature. (8)

The land a pump and its related structures sit upon provides the space for the pumping operation. A use which prevents the farmer from utilizing the lands natural properties. The farmer is unable to grow crops on the same ground that the pump is situated and the value of this forgone production is an accurate measure of the economic value of the land. Ideally, "If there were a perfect market such that economic considerations were the sole determinants of land values (and no land market anywhere fits that description)," (9) the value of the forgone production and the rental value would be equivalent. There is general agreement however in the literature that in most imperfect markets "in the absence of precise data, the annual rent for similar land may be taken as a reasonable estimate." (10)

The rental value of most Egyptian agricultural land is determined by the Ministry of Agriculture and varies as a function of the type of crop grown and the productivity of the soil in each district. Until

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(8) Brown, Maxwell L.; Farm Budgets, (World Bank Staff Occasional Papers; no. 29) The International Bank for Reconstruction and Development, John Hopkins University Press, Baltimore, 1979 pg 46.

(9) Gittinger, J. P.; Economic Analysis of Agricultural Projects, The International Bank for Reconstruction and Development, John Hopkins University Press, Baltimore, 1972, pg 16.

(10) Brown, Maxwell L.; 1979, pg. 50.

1979, a 1946 soil productivity survey was the primary data source for the soil productivity determinations. For example the rent per feddan in 1976 in the governorates of Sohag for land cropped with cotton was LE. 30.00; with maize, LE. 15.00; and with beans, LE. 20.00.

There are some lands which are not subject to government fixed rents. Lands used for horticulture, bee keeping, or livestock and poultry raising are not subject to government rent control and in 1976 these lands were reported to have been rented for over LE. 100.00 per feddan. The black market rental rate was similarly reported to be over LE. 100.00. (11) Certainly this discrepancy in the rental rates indicates that the government fixed rates underestimate the economic value of the land. Cuddihy states that,

> During the 25 years this system has been in operation, many changes have occurred in the physical and financial relationships of production, yet rental values have not been adjusted to reflect these movements. (12)

Consequently, this study will utilize the approximation of the black market rate of L.E. 100.00 per feddan as the rental rate of land and in turn the cost of forgone production. The cost of land for the sakia would then be approximately L.E. 1.60 annually. This assumes that the operation of a sakia requires approximately 64 meters^2 of land.

Taxes

Taxes are transfer payments from the individual to the state. They do not represent a real cost to the production process when

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(11) Cuddihy, W.; 1980, pg. 76

(12) ibid.

evaluated from the perspective of the state. From the farmers financial perspective taxes are a production cost.

Whether there is a government regulated tax on pumps was never definitively determined. During a survey of the Irrigation Systems of Middle and Upper Egypt in 1980 I was lead to believe by some pump owners that they paid a tax to the Ministry of Irrigation. Engineers with the Ministry of Irrigation disputed this claim at that time.

Subsidies

The fourth general cost category is subsidies. Subsidies are, in effect, transfer payments to the project and/or farmers in the project. "In economic analysis terms we must adjust market prices to reflect the amount of the subsidy." (13)

Subsidies are the way of life in Egypt. In the past a subsidy would be enacted by the Government of Egypt in response to a particular problem. Unfortunately, what often happened is that the subsidy remains in effect today, long after the problem that occasioned the subsidy had changed. The result is a tangle of subsidies which are often difficult if not impossible to sort out. For example, it is probable that some of the materials used in the construction of a sakia are subsidized and so the price of a sakia should be adjusted to reflect those subsidies. In practice, a tremendous amount of analysis would be required to pinpoint the value of those subsidies, and consequently the subsidies are ignored.

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(13) Gittinger, J. P.; Economic Analysis of Agricultural Projects, The International Bank for Reconstruction and Development, John Hopkins University Press, Baltimore, 1972, pg 123.

All items such as diesel fuel which are traded internationally will be priced at world market levels. Such a pricing policy effectively sidesteps the problem of directly determining the subsidies. Those items which cannot be priced at international market prices, will be valued at their Egyptian market value. The subsidies that are implicit in these values will hopefully not distort the analysis signficantly.

Identifying Financial Costs

For all pumps but the sakia the following rules were used in determining the financial costs.

1. Egyptian subsidized fuel costs were used.
2. The replacement costs were increased by 30% over the figures used in the economic analysis. The 30% markup represents the typical retail markup for imported machinery and includes typical taxes and license fees.

(14)

3. The repair costs were increased 30% over the values used in the economic analysis.
4. The interest costs remained unchanged in the base case but were varied from 3 to 32 % in the sensitivity analysis.

It should be noted that increased custom duties on the importation of small gasoline and diesel engines are being proposed by some Egyptian manufacturing companies. If increased duties were imposed it could significantly affect the outcome of the financial analysis.

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(14) Personal communication with Briggs & Stratton Middle East Sales Representative

The Sakia - Financial Versus Economic Analysis

The costs of operating the sakia are the same in the financial and the economic analysis. The distincition between a financial and economic analysis is the distinction between costs and benefits accruing to the state and those accruing to the individual. All input to the sakia and its output (water lifted) are produced and or consumed in Egypt. The costs represent real costs to both the economy of the country and the farmer. There is no market outside of Egypt for the products of the animals powering the sakia. Also the Egyptian market for meat and milk products is generally unregulated. Consequently, the cost of animal power, when calculated in terms of decreases in milk and meat yields represents the real costs to the economy and the farmer. For these reasons no distinction between the financial and economic costs of operating the sakia will be made.

Chapter IX

THE COMPUTER MODEL

A computer program was developed which models the economic and financial cost characteristics of a pumping system. This program, based upon a model developed by the authors of EWUP Staff Paper #5 is written in Hewlett Packard Programming Language (HPL). The program was developed for use on small desk top computers with very limited core memory such as the Hewlett Packard 9825.

The program aids in the selection of a low lift irrigation pump given certain irrigation and hydraulic parameters, and will perform a financial and/or economic assessment of a particular pumping system. A data file for each system analyzed is created and a permanent copy can be loaded onto a casette tape. Data can be loaded into the program from a keyboard, or a cassette tape. Additionally, a plotting routine built into the model allows graphical comparisons of the financial and economic aspects of alternative pumps. The various tasks this program performs can be accessed individually or in any combination by the user.

The program consists of a driver and 10 subroutines. All but one of the subroutines are called when needed by the driver. The subroutine "Net Present Value" is called by the subroutine "Initiate Annual Cost Calculations."

The driver and subroutines are stored on disc and all data files are stored on cassette tape. All tape and disc transfers are controlled by the driver. At any one time only the driver, one or two subroutines, and one data file are loaded in memory. This minimizes the memory size needed to execute the program.

Pumpfit

Pumpfit is a subroutine which aids in the selection of an appropriate low lift pump for a given set of pumping conditions. The subroutine asks for 6 parameters.

1. The maximum number of cubic meters of water required per feddan per irrigation.
2. The maximum number of feddans irrigated with one pump per irrigation rotation.
3. The maximum hours per day that the pump will be operated.
4. The minimum number of days that water is available during an irrigation rotation.
5. The number of meters that the water must be lifted. (The static lift required.)
6. An estimate of the expected head loss in meters.

The Pumpfit subroutine then calculates and displays the required discharge (Q) in litres per second, the required total dynamic head (H_t) in meters, and the water horsepower (WHP) required. With this information and a set of pump performance charts the user can quickly determine which pump best meets his needs.

The subroutine will then ask for the pump model number, the manufacturer, impeller size, cost, and installation cost. This and all other information input in this subroutine is automatically stored in a data file. A permanent copy of this file can be later stored on a tape cassette. The subroutine will also ask for the efficiency of the pump at the design discharge and will then calculate and display the brake horsepower required to power the pump. With this information the user can select a properly sized pump driver and any drive linkages required.

The Pumpfit subroutine will then ask for the pump driver make and model, cost, and efficiency. The subroutine terminates at this point and program control returns to the computer program driver.

Old Data

If a pump and pump driver has already been selected, the Pumpfit subroutine can be skipped and the subroutine Old Data called. This subroutine assumes that pump and driver requirements are known to the user and asks him for those requirements and the names, makes, efficiencies, and costs of the pump and driver selected. As with Pumpfit, this information is stored in the data file.

General Variables

This subroutine, called by the driver, enters additional pumping system parameters into the data file. It will ask the user for the annual water duty in cubic meters per feddan, the wearout life (hours), salvage value, and fuel consumption of the pump and driver. The pumping system wearout life is assumed to be the shorter of either the pump or driver pump wearout life. Additional cost information including the cost of fuel, operator, taxes and licenses and, grease and oil is asked for. Finally, this subroutine will ask the user for an annual energy cost escalation factor. This variable allows projected energy cost increases to be included in the analysis. If energy cost escalation is not desired the user must enter 0.

Print

This subroutine, called by the program driver calculates fixed costs, and annual energy, depreciation, and labor costs. If desired, this subroutine then begins a printout of the cost of the pumping system.

Header

This subroutine called by the program driver prints the headings for the cost printout.

Initiate Annual Cost Calculations

This subroutine called by the driver calculates the annual financial costs of a pumping system and if desired produces a printout of these costs.

Net Present Value

This subroutine, called by the Initiate Annual Cost Calculations subroutine calculates the net present value of the pumping system and loads this information into an array.

Tail

This subroutine called by the driver completes the annual cost printout.

Format and Print of Present Cost

This subroutine produces a printout of the present cost of the pumping system.

Use Plot

This subroutine produces plots of user selected cost parameters of the pumping system. The abscissa dimension is feddans while the ordinate dimension is Egyptian pounds.

The ordinate variable, selected by the user, can be:

1. Annual cost per feddan.
2. Cost per horsepower hour.
3. Energy cost.
4. Operator cost.
5. Repair cost.
6. Depreciation

Line and data point format is user specified. Additionally, plots of different parameters can be superimposed upon the same graph.

Chapter X

ANALYSIS RESULTS

Over 170 computer runs were performed utilizing different pump driver combinations and cost assumptions. The results of these runs will be presented in the following chapters. First the results of the economic and then the financial analysis of the base case models will be presented. These base case models were constructed from what appeared to be the most realistic technical and cost assumptions about low lift pumping in Egypt. The sensitivty of the base case results to variances of the base case assumptions will be discussed in Chapter 11. A review of the different cost and technical assumptions was presented in Chapters 7 and 8.

Economic Results

This section will examine the economic costs of low lift pumping. These costs will vary for any pump driver combination as a function of the number of feddans irrigated. This analysis will examine for comparative purposes:

a. First, the economic costs of each pump driver combination operating at its maximum possible utilization per irrigation rotation.

b. Then, the economic operating costs will be examined at a level of utilization more consistent with actual farmer practices.

Static Lift of 0.75 Meters

The results of the economic analysis indicate that the most cost effective method of pumping at a static lift of 0.75 meters is a portable electric IRRI 6 inch axial flow pump. The annual pumping cost per feddan with this pump was L.E. 11.88. The next cheapest pumping system is the Buffalo powered sakias which at L.E. 21.65 is almost twice as expensive. The cost of lifting with a cow powered sakia is 7% more expensive than with the buffalo powered sakia (See Table 10.1).

Aside from the electrically driven 6 inch IRRI axial flow pump, all other mechanized pumping systems considered were more expensive than pumping by sakia. The cost of these other mechanized pumps on an annual per feddan basis ranged from L.E. 24.10 to L.E. 100.97.

The electrically powered 6 inch IRRI axial flow pump is significantly cheaper than all other non sakia pumps because of the inherent advantages of an electric driver over other fossil fueled driver. An electric motor is cheaper to build, and maintain, has a longer wearout life, and is much more efficient. However, the electrically powered pump is not at present an effective means of pumping in Egypt because of the lack of an extensive rural power transmission network grid. Only with such a grid could electric power be distributed to electric pumps in the fields.

The construction of such a grid requires years of planning, construction, and scarce capital resources. It is highly improbable that such a grid will be constructed throughout the fields of rural Egypt in the next 5 to 10 years. Significant efforts are being made to electrify all the villages in rural Egypt. However to extend that distribution

Table 10.1

Economic Analysis - Static Lift = 0.75 meters

Pump Type	Sakia	Sakia	IRRI	IRRI	IRRI	IRRI	Crissafulli	Crissafulli	Crissafulli	Crissafulli	Crissafulli	Cascade
Pump Size	3 meter	2 meter	6 inch	6 inch	6 inch	6 inch	2 inch	2 1/2 inch	4 inch	6 inch	8 inch	10 inch
Driver	Buffalo	Cow	Diesel	Gasoline	Kerosine	Electric	Gas	Electric	Electric	Electric	Electric	Electric
Driver Size	-	-	5 HP	5 HP	5 HP	3 HP	7 HP	5 HP	20 HP	10 HP	15 HP	3 HP
Portable or Fixed	Fixed	Fixed	Portable	Portable	Portable	Portable	Portable	Portable	Portable	Portable	Portable	Fixed
Operator Required	yes	yes	no	no	no	no	no	no	yes	yes	yes	yes
Static Lift - meters	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Annual number of hours pumping per feddan	63	126	37	37	37	37	161	82	27	19	15	20
Annual cost per feddan per total # of feddans irrigated												
5 feddans	27.49	26.40	33.21	30.99	33.80	16.91	103.06	54.50				
10 feddans	23.42	22.33	27.77	29.06	31.47	13.91	97.85	48.74	82.48	60.45	61.41	48.28
15 feddans	22.06		25.96	28.10	30.69	12.91		46.82	72.69	51.99	52.00	38.58
30 feddans			24.15	27.38	29.92	11.91			62.90	43.53	42.59	28.88
45 feddans									59.64	40.71	39.45	25.65
60 Feddans										39.30	37.88	24.03
Max # of feddans irrigated per rotation per pumping unit	18	9	31	31	31	31	7	14	42	61	77	58
Annual pumping cost per feddan	21.65	23.14	24.10	27.36	29.90	11.88	100.97	47.20	60.13	39.24	36.85	24.21
Probable # of feddans irrigated annually per pumping unit	12	6	41	41	41	41	9	19	56	81	103	39
Annual pumping cost per feddan	22.87	25.04	23.67	27.19	29.71	11.64	98.43	46.05	58.36	38.21	35.91	26.25

network to the fields would be extremely expensive, and perhaps more importantly extremely time consuming.

The next most attractive alternative to pumping with a sakia is the diesel powered IRRI 6 inch axial flow pump. This pump at L.E. 24.10 costs L.E. 2.45 more per feddan per year to operate than a buffalo powered sakia. This is assuming that both pumps are being operated at their maximum capacity during the irrigation rotation.

The sakia irrigating 18 feddans is slightly cheaper than the IRRI diesel pump irrigating 31 feddans. However the IRRI pump requires only 37 hours of operation to supply the annual water requirements of 6800 m^3 per feddan while the buffalo powered sakia requires 63 hours. Where rural labor is plentiful, this time savings may be of little significance. Moreover, the introduction of labor saving devices can be devasting to the socio economic fabric of a region with plentiful rural labor. This however is not the case in Egypt.

If it is assumed that there is an opportunity cost of the farmer's labor, then this difference in operating time becomes significant. If the opportunity cost of the farmer's labor is L.E. 0.0943 per hour, and the time the farmer spends irrigating is included in the pumping costs of both systems, the operating costs of both systems woud be equal. Today, it is difficult to hire farm labor in Egypt at L.E. 1.50 for an 8 hour working day. This would suggest that the opportunity cost of a farmers labor is L.E. 0.1875 per hour. As the opportunity cost of a farmers labor increases above L.E. 0.0943 per hour the diesel powered IRRI 6 inch axial flow pump will become an increasingly superior economic investment over the buffalo powered 3 meter sakia. At an

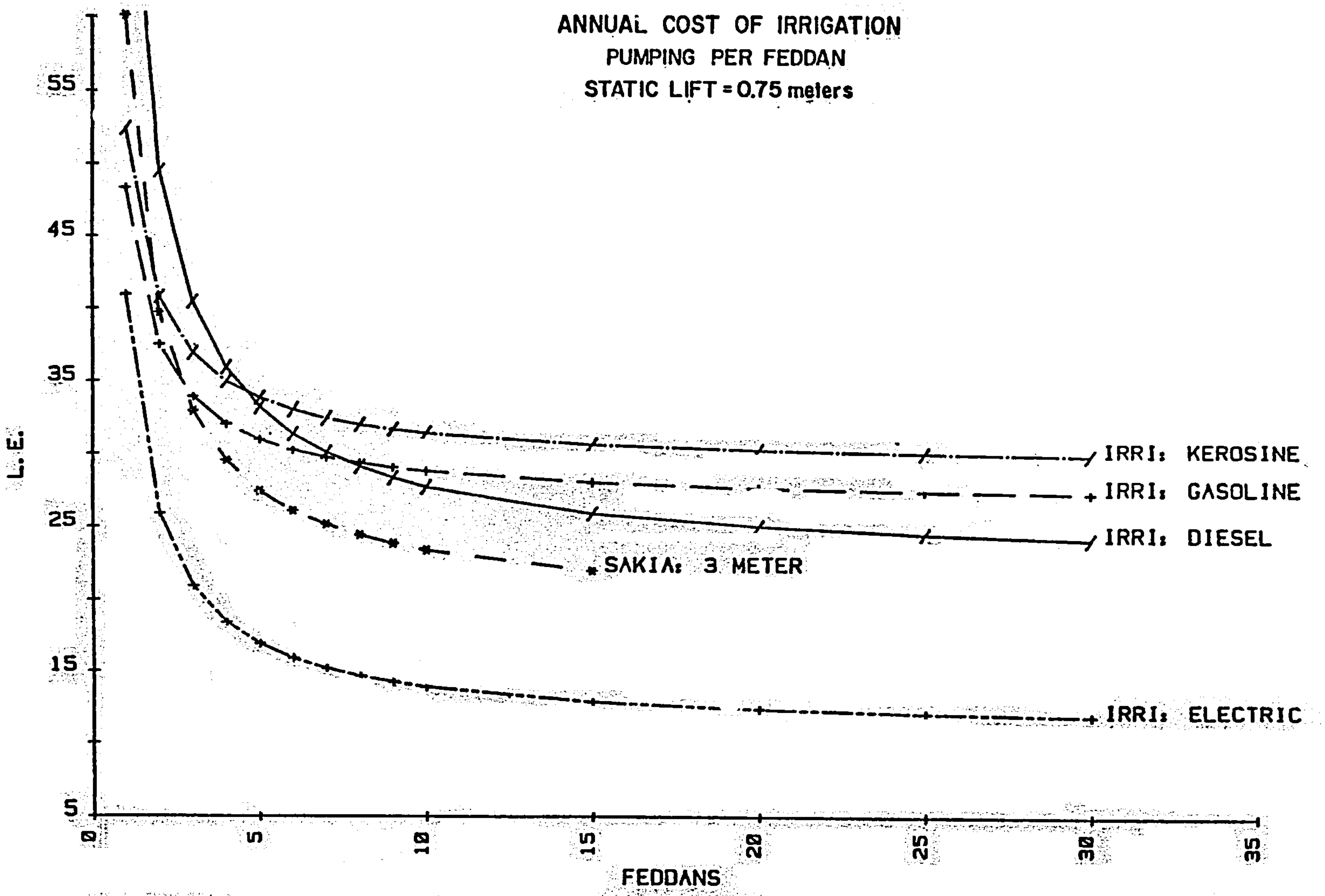

Figure 10.1. Annual economic cost of irrigation pumping for the IRRI axial flow pump and the sakia.

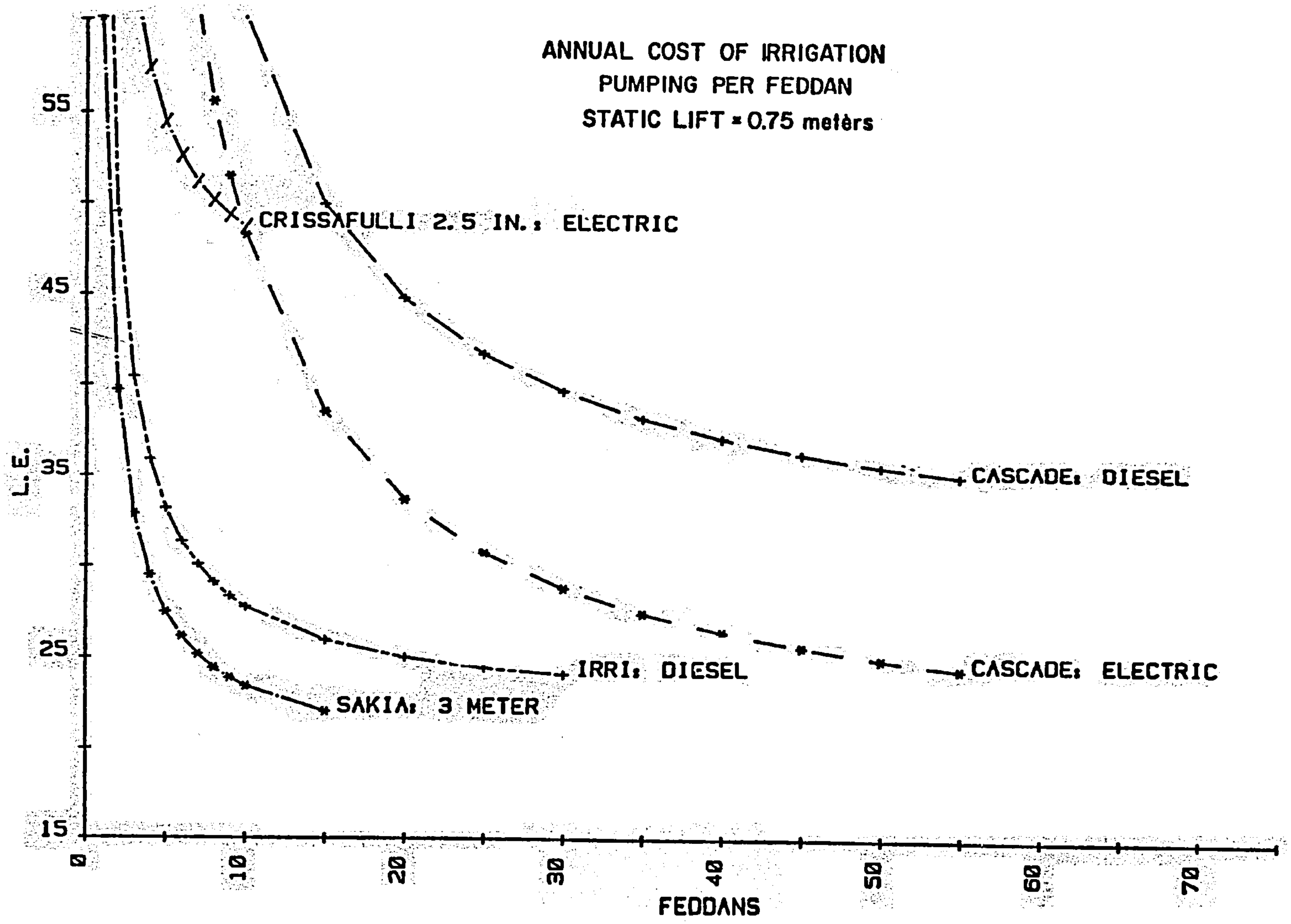

Figure 10.2. Annual economic cost of irrigation pumping for the Crissafulli and Cascade pumps.

opportunity cost of L.E. 0.1875 the IRRI diesel pump is annually L.E. 2.43 per feddan less expensive to operate than the sakia.

The irrigation time savings that a farmer can obtain by using an IRRI pump have not only economic but social implications. This is time that could be utilized in family or recreational activities. More importantly perhaps, a separate individual who tends the animals powering the sakia is not required when axial flow pumps are being used. This person is usually a child who could be in school if he were not required to tend the animals powering the sakia.

The economic desirability of the sakia over the IRRI diesel powered pump hinges on the opportunity cost of the farmers labor. Fluctuations in the demand for Egyptian labor in other Middle Eastern countries will affect the opportunity cost of rural labor, and are difficult to predict. However, the continued migration of rural Egyptians to the cities and other Arab countries suggests that the scarcity of rural labor will be a continuing trend.

Again, when comparing the economic costs of pumping with a buffalo powered sakia versus a gasoline powered or a kerosine powered IRRI 6 inch axial flow pump, the buffalo driven sakia is cheaper unless the opportunity cost of the farmers labor is considered. If the opportunity cost of the farmer labor is to be considered, then when that opportunity cost equals L.E. 0.2196 per hour the cost of pumping with a gasoline powered pump equals the cost of the sakia. The kerosine pump requires a farmer's opportunity cost of L.E. 0.3180 per hour to break even with the buffalo powered sakia.

The level of opportunity cost of the farmer's labor at which the IRRI pumping costs equal the cow powered sakia costs is much lower. The breakeven labor opportunity costs for the diesel, gasoline, and kerosine powered IRRI pumps are respectively L.E. 0.0108, L.E. 0.0474 and L.E. 0.0759.

Excluding the IRRI pumps, the only other pump whose economic operating cost approached that of the sakia is the 10 inch Cascade Electric axial flow pump. Because it is electric it has the same advantages and disadvantages as the electrically driven IRRI pump discussed above.

Static Lift 1 Meter

An increase of only 25 centimeters of static lift significantly reverses the cost advantages of the sakia over the IRRI axial flow pump. At a static lift of one meter the buffalo powered sakia is more costly to operate than any of the IRRI 6 inch axial flow pumps. The IRRI 6 inch electric driven pump costs L.E. 14.95 to operate per year per feddan irrigated. This is followed by the diesel powered pump which costs L.E. 25.94, the gasoline driven pump, 29.43 and the kerosine powered pump, L.E. 32.19 per feddan irrigated. The buffalo powered sakia costs LE. 35.54 per annum per feddan irrigated. The significant change in sakia pumping costs between a static lift of 0.75 meters and 1 meter is a reflection of the relatively steep head discharge curve of the sakia. By comparison the head discharge curve of the IRRI axial flow pumps is relatively flat.

As the head increases the IRRI axial flow pump remains the economically preferred pump up to a head of 3 to 4 meters. Beyond this point a large Crissafulli type portable pump or a fixed pump similar to the axial flow Cascade pump becomes more efficient.

Table 10.2

Economic Analysis - Static Lift = 1 meter

Pump Type	Sakia	IRRI	IRRI	IRRI	IRRI
Pump Size	3 meter	6 inch	6 inch	6 inch	6 inch
Driver	Buffalo	Diesel	Gasoline	Kerosine	Electric
Driver Size	-	5 HP	5 HP	5 HP	3 HP
Portable or Fixed	Fixed	Portable	Portable	Portable	Portable
Operator Required	yes	no	no	no	no
Static Lift - meters	1	1	1	1	1
Annual number of hours pumping per feddan					
Annual cost per feddan per total # of feddans irrigated					
5 feddans	37.16	34.93	33.04	36.04	19.92
10 feddans	33.09	29.49	30.87	33.71	16.92
15 feddans	31.73	27.69	30.15	32.94	15.92
30 feddans		25.87	29.43	32.16	14.92
45 feddans					
60 feddans					
Max # of feddans irrigated per rotation per pumping unit	12.00	29.00	29.00	29.00	29.00
Annual pumping cost per feddan	32.54	25.94	29.46	32.19	14.95
Probable # of feddans irrigated annually per pumping unit	8	39	39	39	39
Annual pumping cost per feddan	34.10	25.46	29.27	31.98	14.69

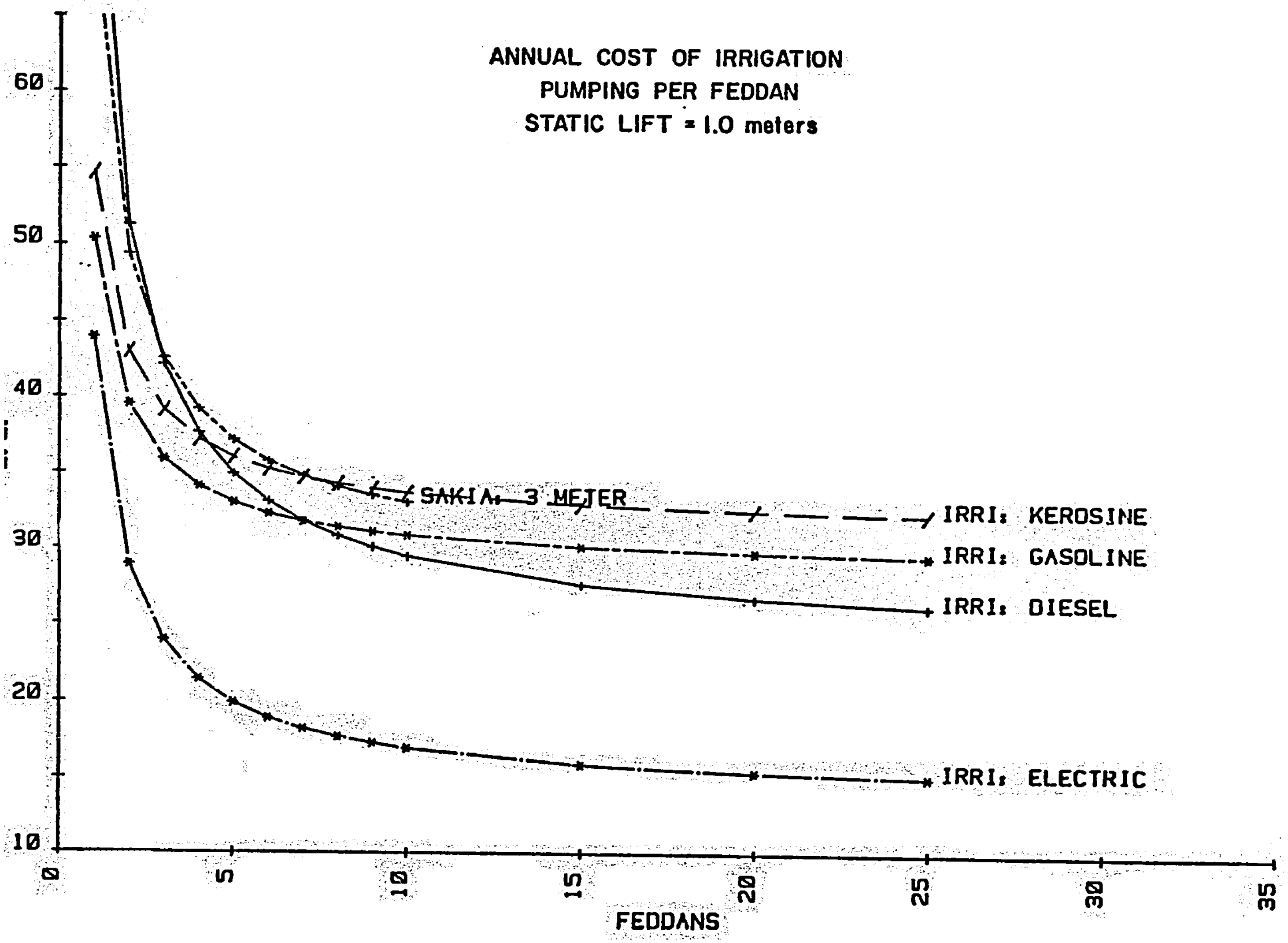

Figure 10.3. Annual economic cost of irrigation pumping for a static lift of 1 meter.

Actual Farmer Pump Utilization

The economic characteristics of the IRRI pumps improve if the comparison of the different types of low lift pumps is not based upon maximum possible utilization within one rotation but upon a pump utilization consistent with actual farmer use.

As utilization of a pumping system increases the fixed annual costs of that system per feddan irrigated decrease significantly. It is also possible that other economies of size occur as a systems utilization increases.

The IRRI 6 inch pumps are portable while the sakia is not. The IRRI pump can be moved from one meska or branch canal to another. Consequently when one watercourse's rotation is over, the pump can be utilized at another watercourse thus increasing the number of feddans irrigated with one pump. The sakia cannot be moved and is unusable during the off rotation. Furthermore, when a meska rotation is on, a sakia at the tail end of the meska remains unused until water reaches it. Upstream farmer's water use sometimes delays the arrival of water to the tail till evening. Again throughout the day the sakia remains unused. The portability of the IRRI pump allows it to be used at any point on a meska.

The IRRI pumps can be easily shared by large groups of farmers because of their extreme portability and relatively high discharges. The sharing of these pumps would promote the most efficient use of the pumps and decrease significantly each farmer's capital investment in water lifting devices.

Egyptian farmers tend to irrigate 6 to 8 hours a day. If an average of 8 hours of irrigation per day during the on rotation is assumed then the utilization of the pumping systems is 66% of the maximum possible utilization per rotation. This would mean that a buffalo powered 3 meter sakia would irrigate 12 feddans per annum which corresponds closely with reported observations. Further it will be assumed that the portable pumps are moved from one watercourse to another following the irrigation rotation pattern. Where diesel pumps are used in Egypt this is a common practice. The IRRI pump would probably irrigate approximately 41 feddans annually. This figure assumes a 6 day on, 6 day off rotation and 8 hour pumping days.

Under these conditions the difference between the cost of pumping with a buffalo powered sakia and the cost of any of the portable mechanized pumping units decreases. Of particular significance is that the cost of operating the diesel powered 6 inch IRRI axial flow pump decreases to L.E. 23.67 per feddan per annum at a static life of 0.75 meters. This is only L.E. 0.80 more than the cost of the buffalo powered sakia. If the opportunity cost of the farmers labor is more than L.E. 0.031 per hour and included in the pumping cost the diesel powered pump becomes a cheaper lifting device than the sakia.

The gasoline powered IRRI pump is the cheapest of the fossil fueled pumps when one to seven feddans are irrigated annually. However, after 8 feddans the diesel powered IRRI pump becomes cheaper to operate. The far superior wearout life and the decreased repair costs of the diesel driven pump offset its high initial cost when eight or more feddans are irrigated annually.

Summary - Economic Results

From the perspective of the economic interests of Egypt, the small low lift IRRI axial flow pumps appear to be the preferred alternative to lifting irrigation water by sakia. The scarcity of rural labor and consequently the opportunity cost of the farmers labor combined with the portability of the IRRI pump results in a lower pumping cost than with the sakia. As the required static lift increases from 0.75 meters to 3 to 4 meters, the economic advantages of the IRRI pumps become overwhelming.

At present the preferred driver for the IRRI pump is the diesel 5 horsepower engine. However, if an extensive rural electrical distribution network were ever to be built, the cost of pumping could be halved utilizing an IRRI 6 inch pump driven by a 3 horsepower electric motor.

Financial or On Farm Results

The on farm financial analysis indicates that pumping with any of the electrically driven, portable pumps is less expensive than pumping with a sakia. The IRRI electrically driven pump was the cheapest by a factor of 3, followed by the Crissafulli 2 1/2 inch electric pump. In the economic analysis none of the Crissafulli pumps were competitive. This difference between the economic and financial results is due to the extremely low, subsidized electric power rates in Egypt. These low rates have effectively down graded the importance of a pump's efficiency and increased the relative importance of the capital and repair costs of the pump in the financial analysis.

Financially, pumping with the diesel and kerosine IRRI 6 inch pump is also cheaper than pumping with a sakia. Again, this is a reflection of the subsidized energy costs. The difference between the economic and financial costs of pumping with the diesel powered IRRI pump was L.E. 6.77 per feddan annually at a static lift of 0.75 meters. This is a 30% decrease over the economic costs which is remarkable considering the

Table 10.3

Financial Analysis - Static Lift = 0.75 meters

Pump Type Pump Size Driver Driver Size Portable of Fixed Operator Required Static Lift - meters	Sakia 3 meter Buffalo - Fixed yes 0.75	Sakia 2 meter Cow - Fixed yes 0.75	IRRI 6 inch Diesel 5 HP Portable no 0.75	IRRI 6 inch Gas 5 HP Portable no 0.75	IRRI 6 inch Kerosine 5 HP Portable no 0.75	IRRI 6 inch Electric 3 HP Portable no 0.75	Crissafulli 2 1/2 inch Electric 5 HP Portable no 0.75	Crissafulli 8 inch Electric 15 HP Portable yes 0.75	Cascade 10 inch Electric 3 HP Fixed yes 0.75
Annual number of hours pumping per feddan	63	126	37	37	37	37	82	15	
Annual cost per feddan per total # of feddans irrigated									
5 feddans	27.49	26.40	28.96	30.60	24.87	11.18	25.98		
10 feddans	23.42	22.33	22.10	27.98	22.03	7.45	18.69	48.59	52.07
15 feddans	22.06		19.81	27.10	21.08	6.21	16.26	36.60	39.71
30 feddans			17.52	26.23	20.13	4.97		24.62	27.34
45 feddans								20.62	23.22
60 feddans								18.62	21.16
Max # of feddans irrigated per rotation per pumping unit	18	9	31	31	31	31	14	77	58
Annual pumping cost per feddan	21.65	23.14	17.45	26.20	20.11	4.93	16.75	17.30	21.38
Probable # of feddans irrigated annually per pumping unit	12	6	41	41	41	41	19	103	39
Annual pumping cost per feddan gated per pumping unit	22.87	25.04	16.90	25.99	19.88	4.64	15.29	16.11	25.93

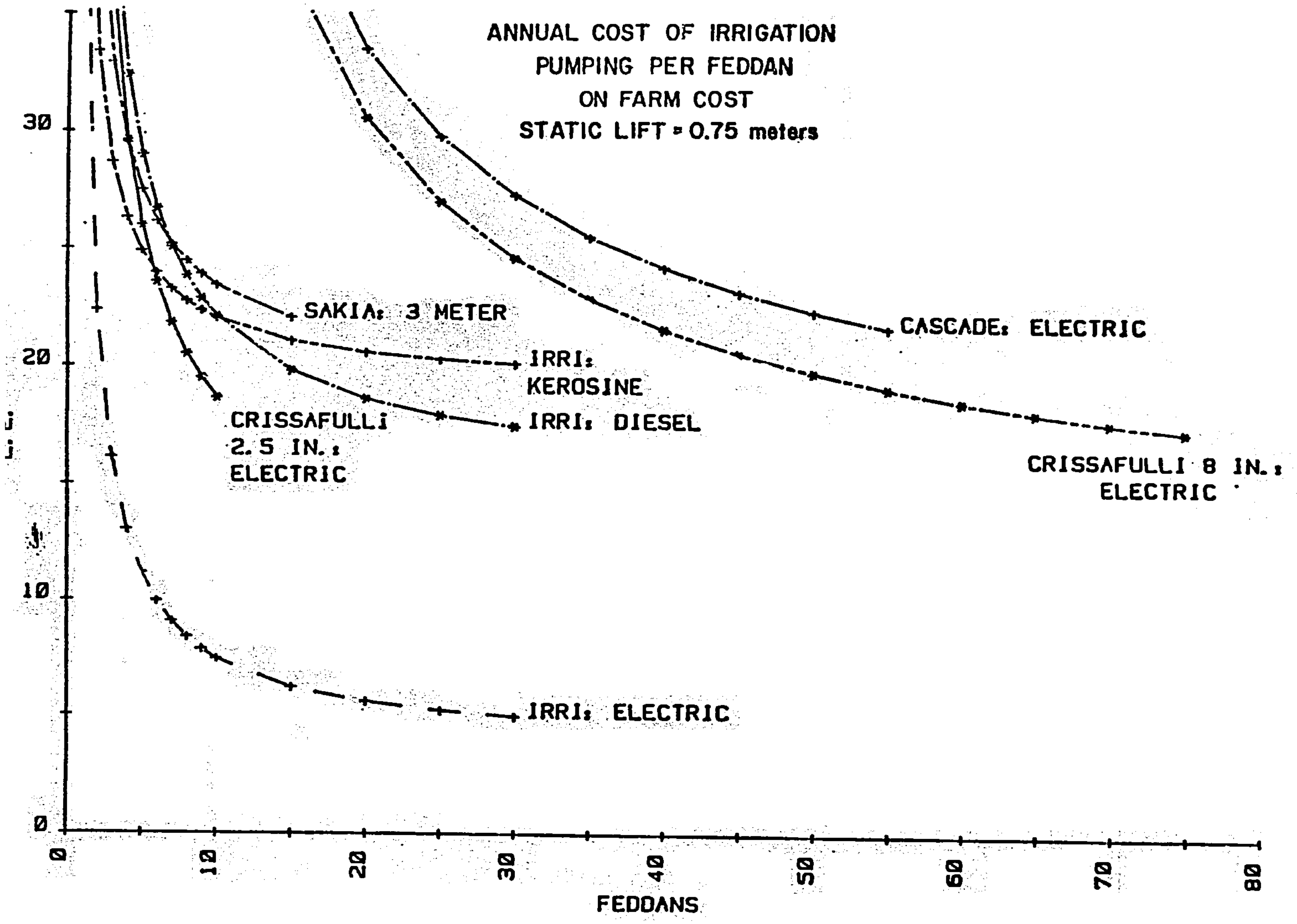

Figure 10.4. Annual on-farm cost of irrigation pumping.

decrease over the economic costs which is remarkable considering the replacement and repair costs in the financial analysis are 30% higher than in the economic analysis.

The pumping cost distortions caused by the subsidized fuel prices are not proportional for all pumps. The gasoline driven IRRI pump cost only L.E. 1.20 less to operate in the financial analysis than in the economic analysis. On the other hand the Crissafulli 2 1/2 inch electric pump operating cost fell L.E. 30.76. These differences reflect significantly different levels of energy subsidies for different fuels by the Egyptian government.

Clearly, the energy subsidies distort the costs of low lift pumping. The financial cost of all mechanized pumping is less than the economic costs. Generally, it appears that the introduction of mechanized pumping should be enhanced by such distortions. However, these distortions also encourage the utilization of the economically inferior, less efficient mechanized pumps over more efficient mechanized pumps. A further consideration is that the artifically low energy prices encourage current pump owners to continue to operate their worn out pumps instead of replacing them.

If a market were to develop in Egypt for the IRRI pumps, it would most probably be limited to those farmers whose present pumping device was no longer operable.

If electric pumps are excluded from consideration because of the lack of an extensive rural power grid, the diesel powered IRRI pump still remains a financially viable alternative to pumping with a sakia. At the maximum utilization rate per rotation the diesel IRRI pump is L.E. 4.20 cheaper per feddan than the 3 meter buffalo powered sakia.

sidered, the financial advantages of the diesel pump are overwhelming.

As in the economic analysis, when the pumping costs are analyzed assuming a pump usage consistent with actual farmer practices or with static lifts greater than 0.75 meter, the cost advantages of the IRRI pumps improve considerably.

The combination of highly subsidized energy prices, a dwindling rural labor supply, and the technical efficiency of the IRRI pumps result in their considerable financial cost advantage over the sakia. Only extreme changes in some of the basic cost assumptions could overturn this advantage.

Chapter XI

SENSITIVITY ANALYSIS

The sensitivity analysis will be divided into two subsections. The sensitivity of the economic results to changes in cost and performance assumptions will first be discussed. Then the sensitivity of the financial results will be examined.

Economic Sensitivity Analysis

Cost of Animal Power

The cost of operating a 3 meter buffalo powered sakia varies from L.E. 16.74 to L.E. 27.44 per feddan as a function of the animal power costs assumed. (These figures and all others in this section unless specifically stated are based upon the maximum utilization of the sakias.)

The average value was L.E. 21.43, the high value of L.E. 27.44 was based upon a buffalo power cost of L.E. 0.30/hour, and the low value of L.E. 16.74 was based upon a buffalo power cost of L.E. 0.130. The high value power cost of L.E. 0.30 is the mean value of a survey of rental rates by EWUP. The low value power cost was determined by Dr. Forrest Walters, utilizing estimated animal meat and milk production losses caused by the animal labor. See chapter 7 for a discussion of the various power costs.

The base case buffalo power cost was L.E. 0.208 per hour and was derived by Dyer. This translates into a pumping cost of L.E. 21.65. This is surprisingly close to the average of the different animal power

Table 11.1

Economic Impact of Varying Animal Power Costs

Pump Type	Sakia	Sakia	Sakia	Sakia	Sakia	Sakia
Pump Size	3 meter	3 meter	3 meter	3 meter	3 meter	3 meter
Driver	Buffalo	Buffalo	Buffalo	Buffalo	Buffalo	Buffalo
Driver Size	-	-	-	-	-	-
Static Lift	0.75	0.75	0.75	0.75	0.75	0.75
Base Case	-	Base Case	-	-	-	-
Parameter	Rental Rate - EWUP #7	Rate from Dyer	Rate from Walter EWUP #21	Walters updated with 1982 prices	Walters*	Dyer x 1.15
Value of Parameter	0.30/Hour	0.208/Hour	.130/Hour	.180/Hour	.363/Hour	0.239/Hour
Max # of feddans irrigated per rotation	18	18	18	18	18	18
Pumping cost per feddan at max # of feddan irrigated per rotation	27.44	21.65	16.74	19.88	31.41	23.60
Probable # of feddans irrigated annually per pumping unit	12	12	12	12	12	12
Pumping cost per feddan at probable # of feddans irrigated per pumping unit	28.66	22.87	17.96	21.10	32.63	24.82

*Walters updated with 1982 prices and the opportunity cost of breed restrictions due to animal power requirements.

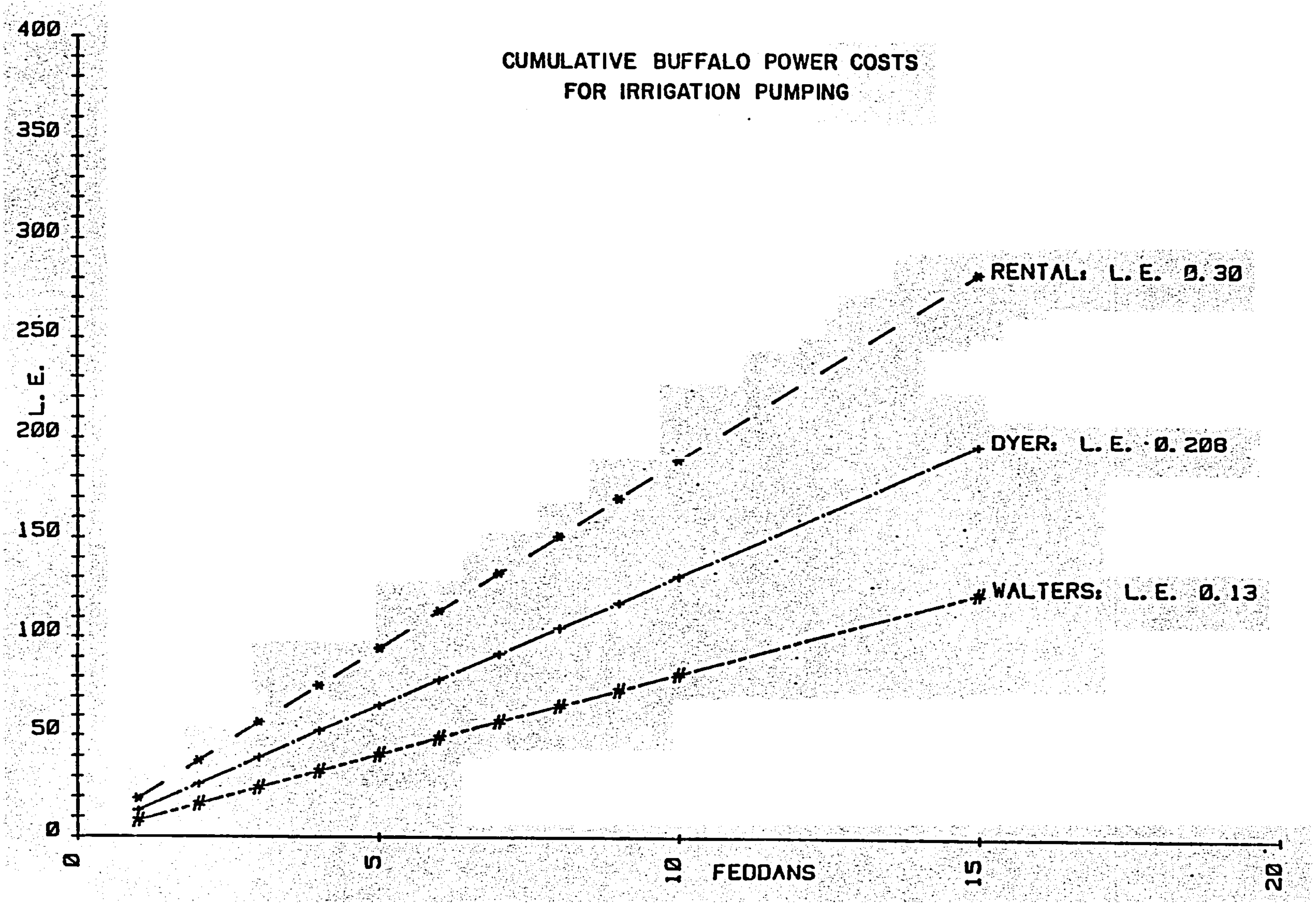

Figure 11.1. Cumulative buffalo power costs.

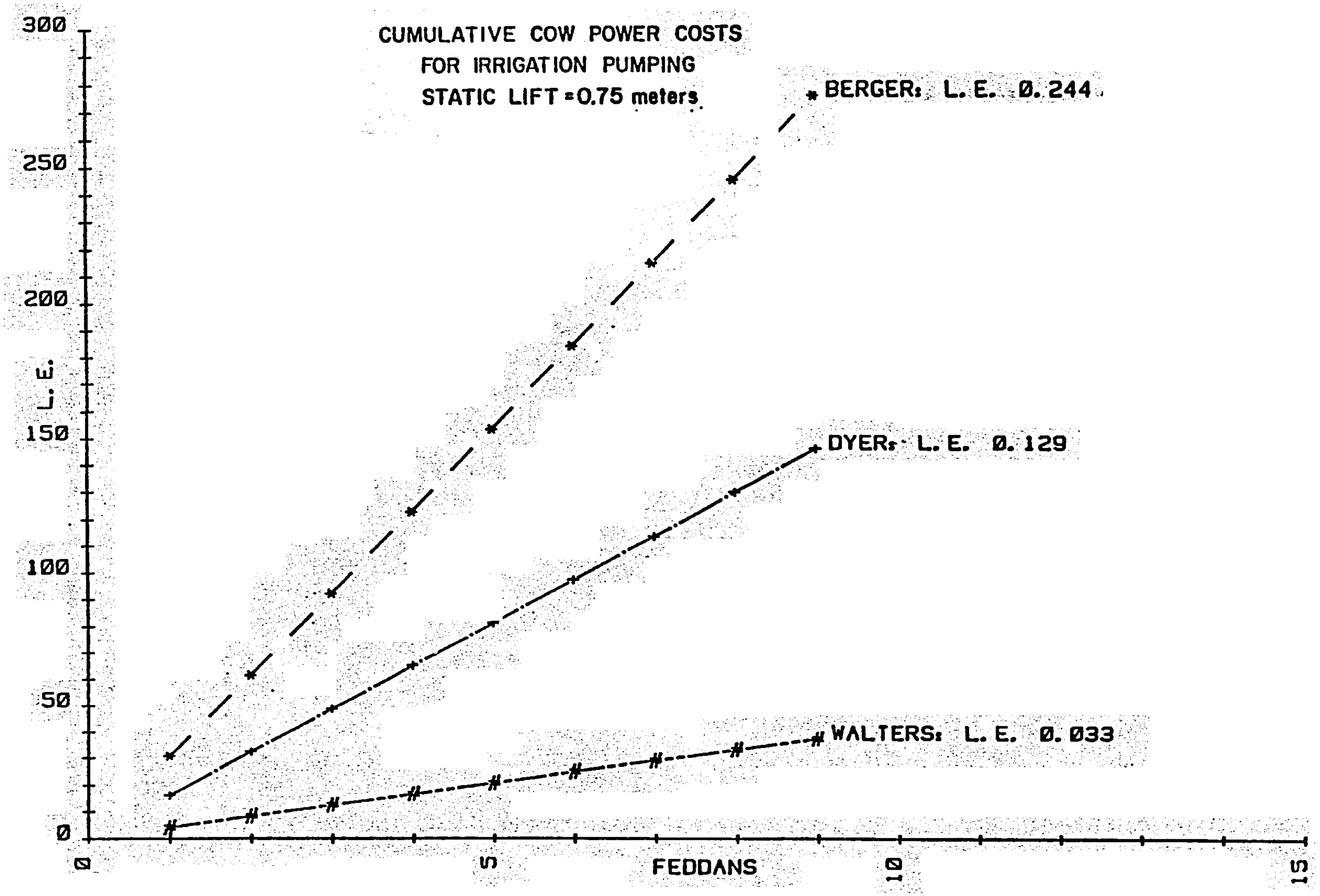

Figure 11.2. Cumulative cow power costs.

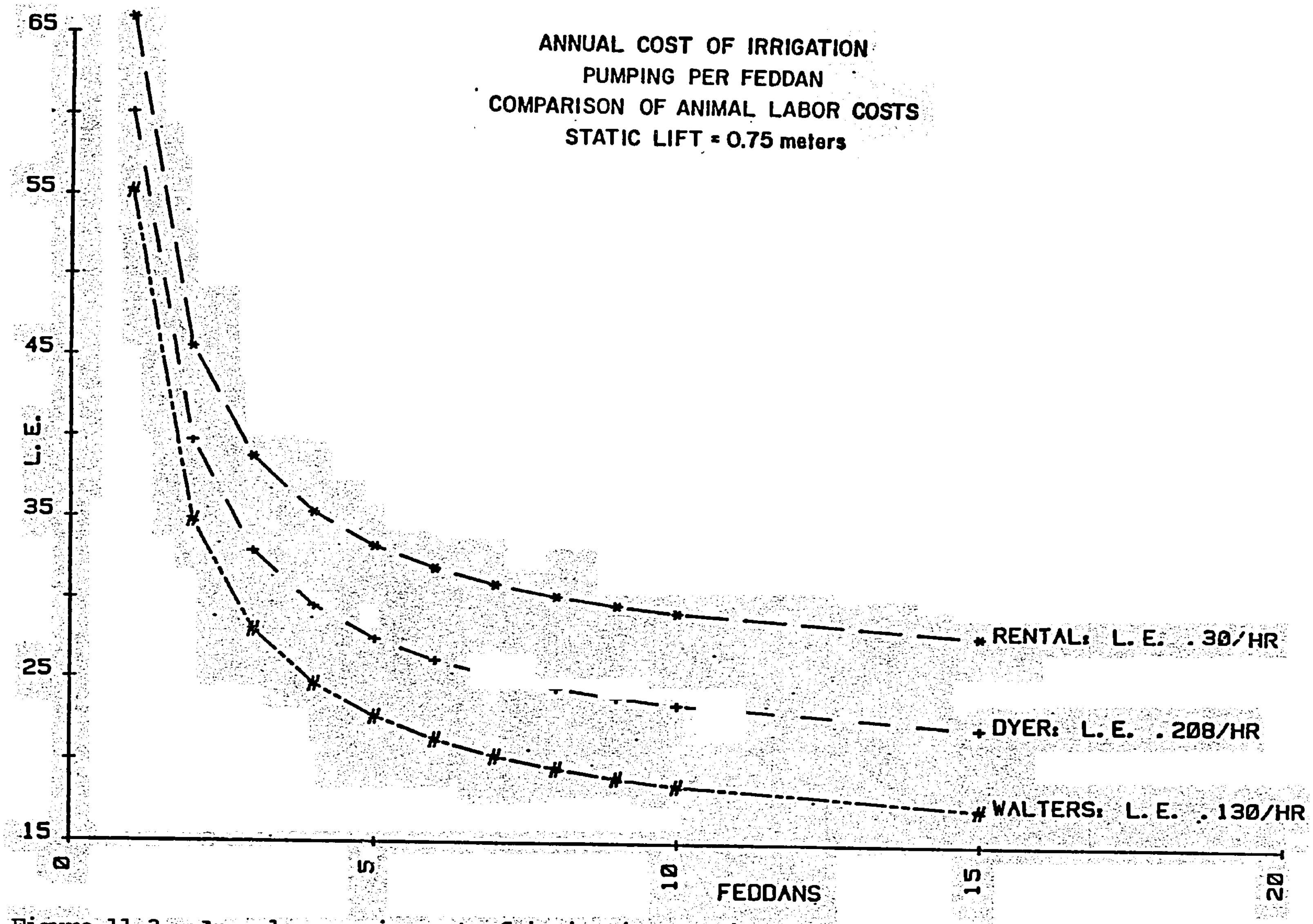

Figure 11.3. Annual economic cost of irrigation pumping for varying animal labor costs.

cost assumptions. When Walter's buffalo power cost is revised to reflect 1982 milk and meat prices, then it increases from L.E. 0.130 to L.E. 0.160. This results in a pumping cost of L.E. 19.88 and would suggest that the base case animal power cost lies on the lower end of the animal cost estimates.

If the base case animal power costs are low, then the IRRI 6 inch axial flow pumps may be more advantageous than indicated by the base case analysis. For example, if the buffalo power cost was increased 15% the annual pumping costs of irrigating one feddan would increase to L.E. 23.60. This is only L.E. 0.50 less than the cost of irrigating with a diesel powered IRRI 6 inch pump and at a utilization level more consistent with farmer pumping patterns, irrigating with the sakia would then cost L.E. 1.16 more than with the IRRI diesel pump.

Cost of Fuel

When all the base case fuel costs including animal labor costs are increased by 15% the difference between the pumping costs using fossil fuel driven IRRI pumps and the sakia costs decrease. The sakia is then only L.E. 0.527 less expensive per feddan on an annual basis than the diesel powered IRRI pump. This is a clear example of the increasing importance of pump efficiency as energy prices rise.

Interest Rates

Surprisingly, as the interest or discount rate is varied for all pumps from 9 to 17%, the IRRI pumps become more attractive. While some of these pumps require larger initial capital investments than the sakia, because the IRRI pump can irrigate a significantly larger

Table 11.2

Economic Impact of Varying Fuel Costs

Pump Type	Sakia	IRRI	IRRI	IRRI	IRRI	Crissafulli	Cascade
Pump Size	3 meter	6 inch	6 inch	6 inch	6 inch	8 inch	10 inch
Driver	Buffalo	Diesel	Gasoline	Kerosine	Electric	Electric	Electric
Driver Size	-	5 HP	5 HP	5 HP	3 HP	15 HP	3 HP
Static Lift	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Parameter	Dyer x 1.15	International x 1.15	International x 1.15	International x 1.15	Modified Berger x 1.15	Modified Berger x 1.15	Modified Berger x 1.15
Value of Parameter	0.239/Hour	0.275/Litre	0.273/Litre	0.314/Litre	0.221/KWH	0.221/KWH	0.221/KWH
Max # of feddans irrigated per rotation	18	31	31	31	31	77	58
Pumping cost per feddan at max # of feddan irrigated per rotation	23.60	25.82	29.38	32.19	13.16	40.43	25.20
Probable # of feddans irrigated annually per pumping unit	12	41	41	41	41	103	39
Pumping cost per feddan at probable # of feddans irrigated per pumping unit	24.82	25.35	29.21	32.01	12.92	39.64	27.65

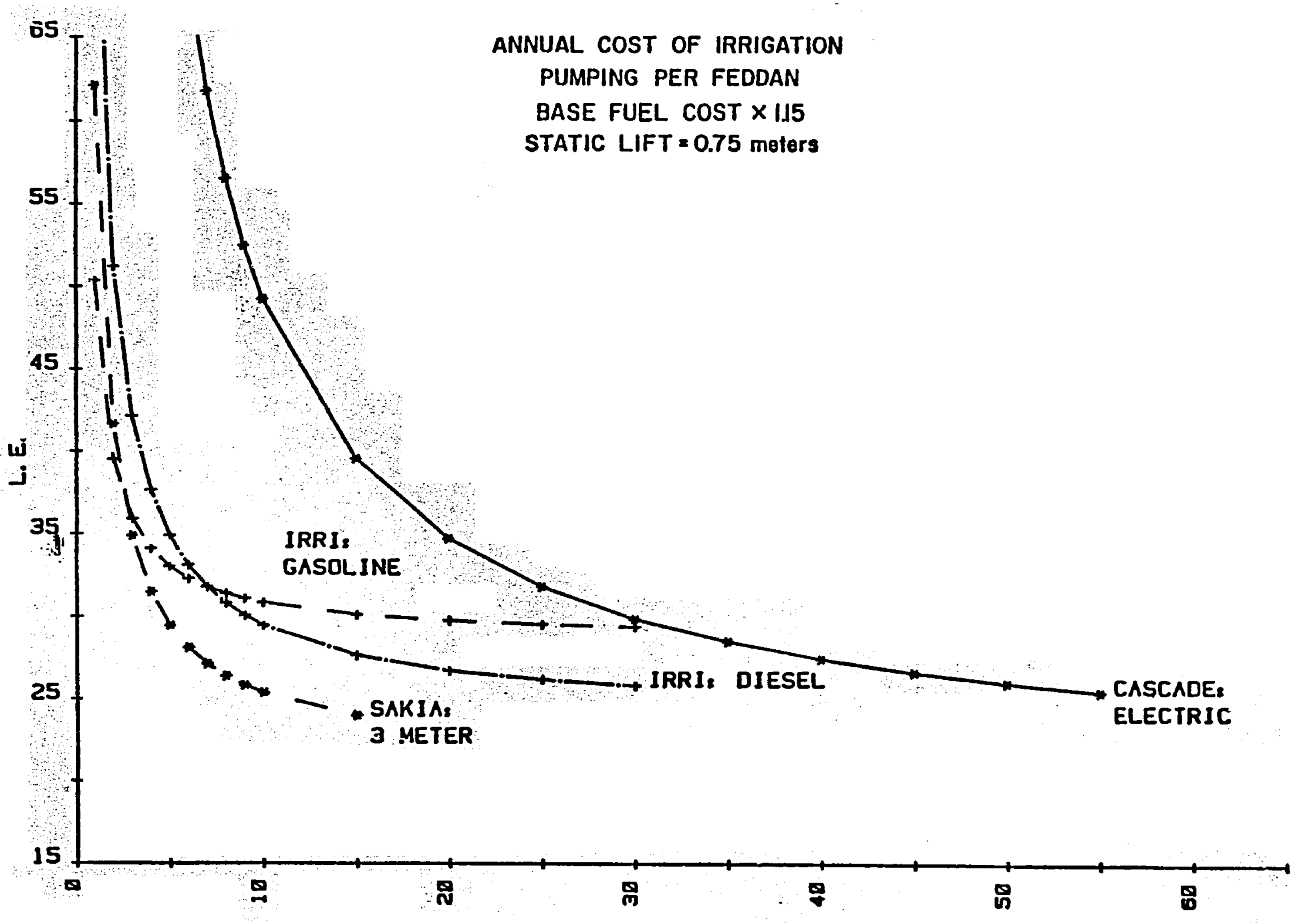

Figure 11.4. Annual economic cost of irrigation pumping for increased fuel costs.

Table 11.3

Economic Impact of Varying Interest Rates - 9%

Pump Type	Sakia	IRRI	IRRI	IRRI	IRRI	Crissafulli	Cascade
Pump Size	3 meter	6 inch	6 inch	6 inch	6 inch	8 inch	10 inch
Driver	Buffalo	Diesel	Gasoline	Kerosine	Electric	Electric	Electric
Driver Size	-	5 HP	5 HP	5 HP	3 HP	15 HP	3 HP
Static Lift	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Parameter	Interest Rate	Interest Rate	Interest Rate	Interest Rate	Interest Rate	Interest Rate	Interest Rate
Value of Parameter	9%	9%	9%	9%	9%	9%	9%
Max # of feddans irrigated per rotation	18	31	31	31	31	77	58
Pumping cost per feddan at max # of feddan irrigated per rotation	21.03	23.61	27.19	29.71	11.63	35.74	22.69
Probable # of feddans irrigated annually per pumping unit	12	41	41	41	41	103	39
Pumping cost per feddan at probable # of feddans irrigated per pumping unit	21.92	23.30	27.06	29.57	11.46	35.09	24.40

Table 11.4

Economic Impact of Varying Interest Rates - 17%

Pump Type	Sakia	IRRI	IRRI	IRRI	IRRI	Crissafulli	Cascade
Pump Size	3 meter	6 inch	6 inch	6 inch	6 inch	8 inch	10 inch
Driver	Buffalo	Diesel	Gasoline	Kerosine	Electric	Electric	Electric
Driver Size	-	5 HP	5 HP	5 HP	3 HP	15 HP	3 HP
Static Lift	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Parameter	Interest Rate	Interest Rate	Interest Rate	Interest Rate	Interest Rate	Interest Rate	Interest Rate
Value of Parameter	17%	17%	17%	17%	17%	17%	17%
Max # of feddans irrigated per rotation	18	31	31	31	31	77	58
Pumping cost per feddan at max # of feddan irrigated per rotation	22.27	24.59	27.53	30.08	12.13	37.96	25.73
Probable # of feddans irrigated annually per pumping unit	12	41	41	41	41	103	39
Pumping cost per feddan at probable # feddans irrigated per pumping unit	23.83	24.04	27.31	29.85	11.83	36.74	28.93

area than the sakia, the increase in cost per feddan due to increasing interest rates is smaller for the IRRI pump than for the sakia.

Operator Costs

The base case assumed that all IRRI pumps would be farmer operated. If this is not the case, and an operator needs to be hired EWUP surveys indicate that L.E. 0.30 per hour is a good estimate of the prevailing wage for trained pump operators.

The inclusion of an operator cost significantly increases the cost of pumping with the IRRI pump. The buffalo powered sakia is then L.E. 10.01 cheaper than the IRRI diesel powered pump at a static lift of 0.75 meters.

Wearout Life

The wearout life of the buffalo powered sakia and the IRRI pumps was varied ± 33% from the base case values. All the pumps analyzed showed far greater sensitivity to the decrease in wearout life than to an increase in wearout life. As the wearout life of the sakia and IRRI pumps was increased, the cost of pumping with an IRRI pump approached the cost of pumping with the sakia.

The decrease in wearout life by 33% resulted in a new annual sakia pumping cost of L.E. 22.80 and the diesel driven IRRI pump cost changed to L.E. 25.99 per feddan. The difference between these pumping costs, L.E. 3.19 is 1.3 times the difference between the base case costs. When the wearout life is increased for the sakia and IRRI pump to 133% of the base case value, the difference between the sakia pumping costs and that of the IRRI diesel driven pump drops to L.E.

Table 11.5

Economic Impact of Operator Costs

Pump Type	IRRI	IRRI	IRRI	IRRI
Pump Size	6 inch	6 inch	6 inch	6 inch
Driver	Diesel	Gasoline	Kerosine	Electric
Driver Size	5 HP	5 HP	5 HP	5 HP
Static Lift	0.75	0.75	0.75	0.75
Parameter	Operator cost	Operator cost	Operator cost	Operator cost
Value of Parameter	.30	.30	.30	.30
Max # of feddans irrigated per rotation	31	31	31	31
Pumping cost per feddan at max # of feddan irrigated per rotation	36.31	38.57	41.11	23.09
Probable # of feddans irrigated annually per pumping unit	41	41	41	41
Pumping cost per feddan at probable # of feddans irrigated per pumping unit	34.88	38.40	40.92	22.85

Table 11.6

Economic Impact of Varying Wearout Life - Base Case Wearout Life x 1.33

Pump Type Pump Size Driver Driver Size Static Lift	Sakia 3 meter Buffalo - 0.75	IRRI 6 inch Diesel 5 HP 0.75	IRRI 6 inch Gasoline 5 HP 0.75	IRRI 6 inch Kerosine 5 HP 0.75
Parameter	Base case wearout life x 1.33	Base case wearout life x 1.33	Base case wearout life x 1.33	Base case wearout life x 1.33
Value of Parameter	20,000	10,000	2666	2666
Max # of feddans irrigated per rotation	18	31	31	31
Pumping cost per feddan at max # of feddan irrigated per rotation	21.07	23.16	26.16	28.58
Probable # of feddans irrigated annually per pumping unit	12	41	41	41
Pumping cost per feddan at probable # of feddans irrigated per pumping unit	22.29	22.72	25.99	28.40

Table 11.7

Economic Impact of Varying Wearout Life - Base Case Wearout Life x 0.66

Pump Type	Sakia	IRRI	IRRI	IRRI
Pump Size	3 meter	6 inch	6 inch	6 inch
Driver	Buffalo	Diesel	Gasoline	Kerosine
Driver Size	-	5 HP	5 HP	5 HP
Static Lift	0.75	0.75	0.75	0.75
Parameter	Base case wearout life x 0.66	Base case wearout life x 0.66	Base case wearout life x 0.66	Base case wearout life x 0.66
Value of Parameter	10000	5000	1333	1333
Max # of feddans irrigated per rotation	18	31	31	31
Pumping cost per feddan at max # of feddan irrigated per rotation	22.80	25.99	29.75	32.52
Probable # of feddans irrigated annually per pumping unit	12	41	41	41
Pumping cost per feddan at probable # of feddans irrigated per pumping unit	24.03	25.56	29.58	32.34

2.09 at the maximum number of feddans irrigated per rotation level and L.E. 0.43 at the probable number of feddans irrigated annually.

The gasoline and kerosine pumps showed the greatest change in pumping costs as a function of a change in wearout life. This is to be expected as annual depreciation is a larger percentage of their annual cost of pumping than with the diesel powered pump.

Repair Cost

The repair costs of the sakia and the IRRI pumps with different driver configurations were varied ± 25% from the base case. An increase of 25% in the repair costs of the IRRI pumps significantly affected the cost of operating the IRRI pumps. The annual cost of pumping with the sakia increased to L.E. 23.03, an increase of L.E. 0.16 from the base case. The IRRI diesel driven pump operating cost increased L.E. 1.57 to L.E. 25.24. This is a 7% increase. The gasoline and kerosine pumps were as sensitive to the increase of repair costs.

The decrease in repair costs by 25% resulted in a 7% reduction in the cost of pumping with the diesel driven IRRI pump. When the repair costs are 25% less than the rate used in the base case, the annual cost of pumping is L.E. 0.61 less per feddan with the IRRI diesel pump than with the buffalo powered sakia.

Financial or On-Farm Sensitivity Analysis

The purpose of the financial analysis is to determine if the most economical low lift pumps are also attractive to the farmer financially. Therefore, in the interest of simplicity the analysis of the sensitivity of the financial results will be limited to those pumps that are the more economical choices. Those are the sakia and the IRRI axial flow pumps. The question to be answered by the sensitivity analysis is

Table 11.8

Economic Impact of Varying Repair Costs - Base Case Repair Costs x 1.25

Pump Type	Sakia	IRRI	IRRI	IRRI
Pump Size	3 meter	6 inch	6 inch	6 inch
Driver	Buffalo	Diesel	Gasoline	Kerosine
Driver Size	-	5 HP	5 HP	5 HP
Static Lift	0.75	0.75	0.75	0.75
Parameter	Base case repair cost x 1.25	Base case repair cost x 1.25	Base case repair cost x 1.25	Base case repair cost x 1.25
Value of Par	.0125	0.209		
Max # of feddans irrigated per rotation	18	31		
Pumping cost per feddan at max # of feddan irrigated per rotation	21.81	25.67	29.23	32.76
Probable # of feddans irrigated annually per pumping unit	12	41	41	41
Pumping cost per feddan at probable # of feddans irrigated per pumping unit	23.03	25.24	29.06	31.58

Table 11.9

Economic Impact of Varying Repair Costs - Base Case Repair Costs x 0.75

Pump Type	Sakia	IRRI	IRRI	IRRI
Pump Size	3 meter	6 inch	6 inch	6 inch
Driver	Buffalo	Diesel	Gasoline	Kerosine
Driver Size	-	5 HP	5 HP	5 HP
Static Lift	0.75	0.75	0.75	0.75
Parameter	Base case repair cost x 0.75	Base case repair cost x 0.75	Base case repair cost x 0.75	Base case repair cost x 0.75
Value of Parameter	.008	0.125		0.150
Max # of feddans irrigated per rotation	18	31		31
Pumping cost per feddan at max # of feddan irrigated per rotation	21.49	22.53		27.98
Probable # of feddans irrigated annually per pumping unit	12	41		41
Pumping cost per feddan at probable # of feddans irrigated per pumping unit	22.71	22.10		27.84

whether reasonable variations in any of the cost or technical parameters will significantly change the financial costs of the more economical pumping units.

The impact of changing fuel, and operator costs, and wide variations in interest rates will be discussed in the following section.

Fuel Costs

The subsidized prices of the fossil fuels and electricity were doubled in order to analyze the financial impact of changing government subsidies. While the costs of operating the pumps increased, only the increase in the cost of operating the gasoline driven IRRI pump was significant. The operating costs of the other IRRI pumps remained less than that of the 3 meter sakia.

The substantial increase in the cost of operating the gasoline powered IRRI pumps is a reflection of the relatively small government subsidy of gasoline prices in Egypt.

Operator Costs

When an operator cost of L.E. 0.30 was included in the operating cost of the IRRI pumps all but the electrically driven pump were more expensive to operate than the sakia. The costs of running the diesel, gasoline and kerosine IRRI pumps respectively was L.E. 28.66, L.E. 37.41, and L.E. 31.31. In the case of the diesel pump this is a 64% increase in operating costs. The gasoline pump operating cost increased by 43%, the kerosine pump costs increased by 56%. The electric IRRI pump's operating cost increased to L.E. 16.14.

Table 11.10

Financial Impact of Doubling the Subsidized Fuel Costs

Pump Type	Sakia	IRRI	IRRI	IRRI	IRRI
Pump Size	3 meter	6 inch	6 inch	6 inch	6 inch
Driver	Buffalo	Diesel	Gasoline	Kerosine	Electric
Driver Size	-	5 HP	5 HP	5 HP	3 HP
Static Lift	0.75	0.75	0.75	0.75	0.75
Parameter	Buffalo Labor Cost Dyer	Egyptian Cost x 2	Egyptian Cost x 2	Egyptian Cost x 2	Egyptian Cost x 2
Value of Parameter	0.208	0.049	0.30	0.058	0.030
Max # of feddans irrigated per rotation	18	31	31	31	31
Pumping cost per feddan at max # of feddan irrigated per rotation	21.65	18.59	34.61	21.73	5.59
Probable # of feddans irrigated annually per pumping unit	12	41	41	41	41
Pumping cost per feddan at probable # of feddans irrigated per pumping unit	22.87	18.05	34.40	21.51	5.30

Table 11.11

Financial Impact of Operator Costs

Pump Type	Sakia	Sakia	IRRI	IRRI	IRRI	IRRI
Pump Size	3 meter	3 meter	6 inch	6 inch	6 inch	6 inch
Driver	Buffalo	Buffalo	Diesel	Gasoline	Kerosine	Electric
Driver Size	-	-	5 HP	5 HP	5 HP	3 HP
Static Lift	0.75	0.75	0.75	0.75	0.75	0.75
Parameter	Operator Cost	Operator Cost	Operator Cost	Operator Cost	Operator Cost	Operator Cost
Value of Parameter	0.05	0.10	0.30	0.30	0.30	0.30
Max # feddans irrigated per rotation	18	18	31	31	31	31
Pumping cost per feddan at max # of feddan irrigated per rotation	21.65	26.02	28.66	37.41	31.31	16.14
Probable # of feddans irrigated annually per pumping unit	12	12	41	41	41	41
Pumping cost per feddan at probable # of feddans irrigated per pumping unit	22.87	24.08	28.11	37.20	31.09	15.85

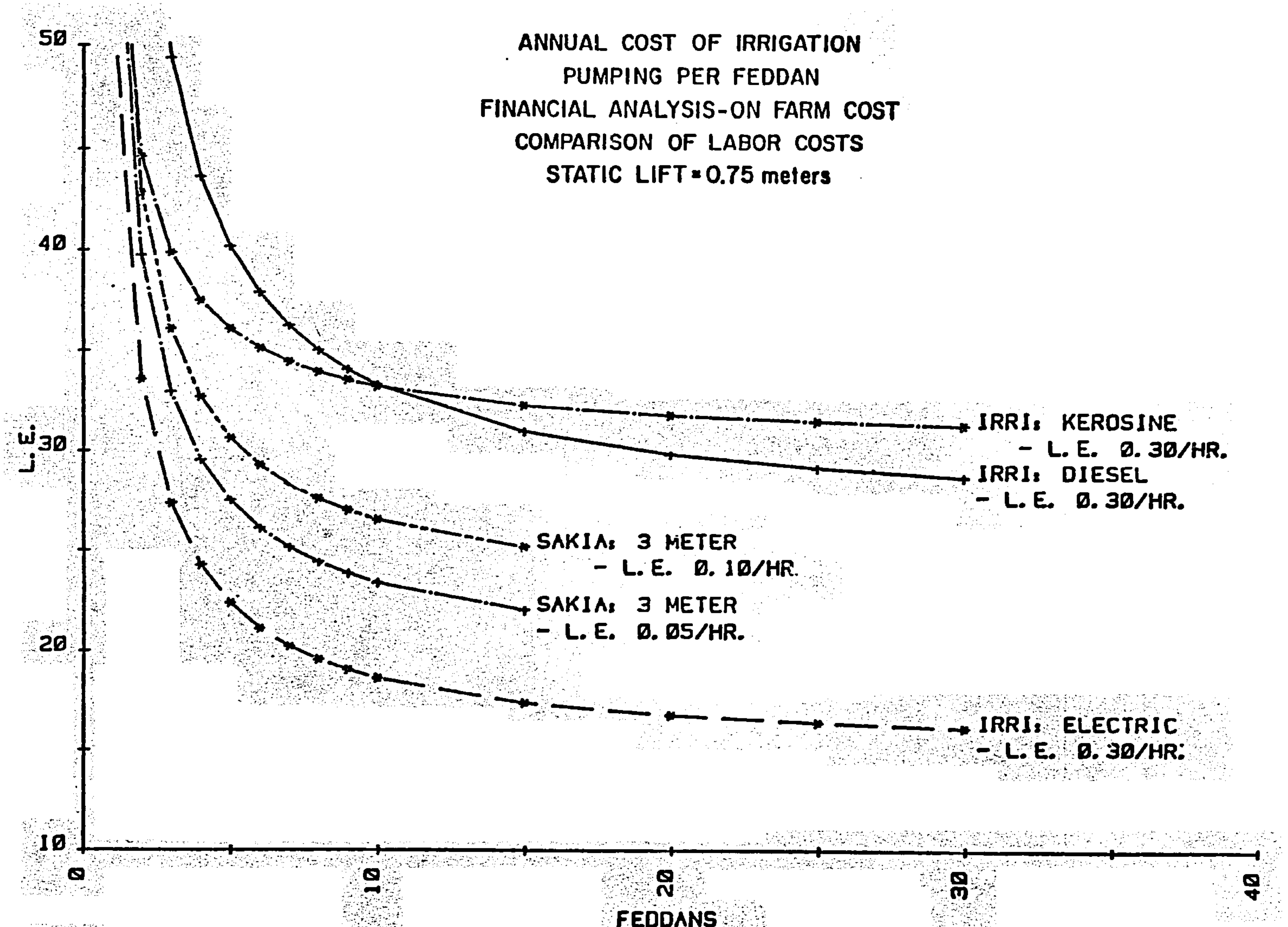

Figure 11.5. Annual on-farm cost of irrigation pumping for varying operator costs.

If however the time the farmer spent irrigating was also included as a cost, and that time was valued from L.E. 0.20 to L.E. 0.30 an hour, the IRRI diesel pump operating costs would approach the sakia costs. The sakia pumping costs are also sensitive to the operator labor cost. When the sakia operator cost was changed from L.E. 0.05 to L.E. 0.10 per hour the pumping cost of the sakia at its maximum utilization rate increased by 20%. However, with an operator cost of L.E. 0.10/hour the sakia is still financially cheaper to operate than any of the fossil fueled IRRI pumps with labor costs of L.E. 0.30/hour.

Interest Rate

Two interest rates were selected for the financial sensitivity analysis. A 3% rate was selected because many of the agricultural credit loan programs use similar rates. The second rate selected was 32%. The World Bank suggests that this rate is an average of rural interest rates worldwide. (1)

The IRRI diesel, kerosine, and electrically driven pumps had lower operating costs than the sakia at both the 3% and 32% rate. The gasoline powered pump was always the most expensive pump to operate. As the interest rates rose, the operating cost advantages of the diesel, kerosine, and electric IRRI pumps improved. This is due to the much larger number of feddans these pumps can irrigate. This characteristic offsets the higher replacement costs of the IRRI pumps.

(1) World Bank, Agricultural Credit: Sector Policy Paper, Washington, D.C., World Bank, 1975.

Table 11.12

Financial Impact of a 3% Interest Rate

Pump Type	Sakia	IRRI	IRRI	IRRI	IRRI
Pump Size	3 meter	6 inch	6 inch	6 inch	6 inch
Driver	Buffalo	Diesel	Gasoline	Kerosine	Electric
Driver Size	-	5 HP	5 HP	5 HP	3 HP
Static Lift	0.75	0.75	0.75	0.75	0.75
Parameter	Interest Rate	Interest Rate	Interest Rate	Interest Rate	Interest Rate
Value of Parameter	3%	3%	3%	3%	3%
Max # feddans irrigated per rotation	18	31	31	31	31
Pumping cost per feddan at max # of feddan irrigated per rotation	20.09	15.86	25.67	19.52	4.13
Probable # of feddans irrigated annually per pumping unit	12	41	41	41	41
Pumping cost per feddan at probable # of feddans irrigated per pumping unit	20.49	15.70	25.59	19.44	4.03

Table 11.13

Financial Impact of a 32% Interest Rate

Pump Type	Sakia	IRRI	IRRI	IRRI	IRRI
Pump Size					
Driver		Diesel	Gasoline	Kerosine	Electric
Driver Size					
Static Lift					
Parameter	Interest Rate	Interest Rate	Interest Rate	Interest Rate	Interest Rate
Value of Parameter	32%	32%	32%	32%	32%
Max # feddans irrigated per rotation	18	31	31	31	31
Pumping cost per feddan at max # of feddan irrigated per rotation	24.61	20.47	27.21	21.21	6.46
Probable # of feddans irrigated annually per pumping unit	12	41	41	41	41
Pumping cost per feddan at probable # of feddans irrigated per pumping unit	27.40	19.18	26.75	20.72	5.79

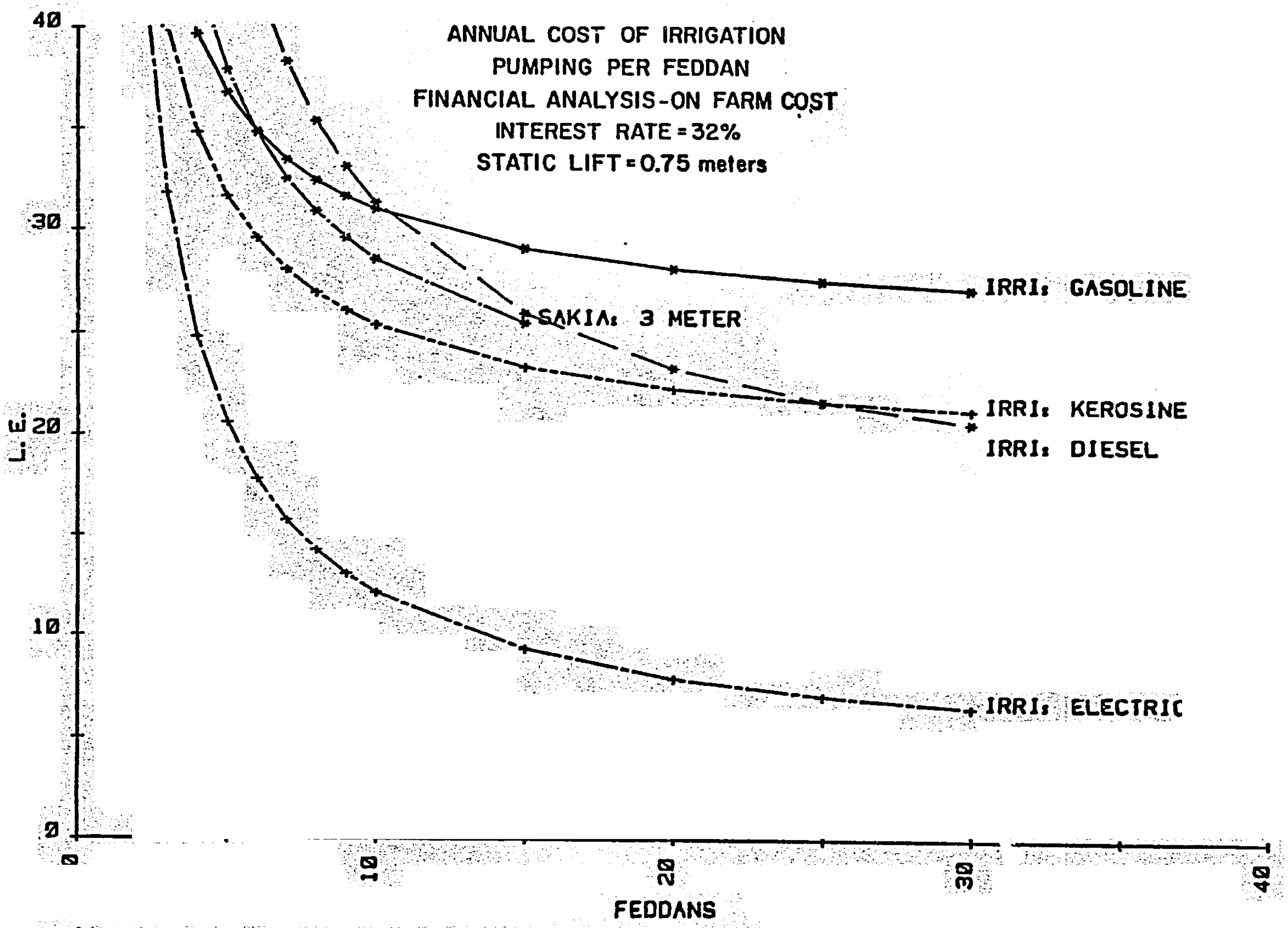

Figure 11.6. Annual on-farm cost of irrigation pumping assuming a 32% interest rate.

Chapter XII

SUMMARY

The national costs of lifting water with the sakia were determined. A buffalo driven sakia irrigating 12 feddans cost LE 22.87 per feddan to operate on an annual basis. This cost was compared with the operating costs of other low lift pumping devices.

The least expensive pump to operate was an axial flow pump designed by the International Rice Research Institute (IRRI) in Los Banos, Philippines. This pump can be constructed in almost any developing country because of its simple design. Furthermore it is light enough that it can be hand carried by two men. The electrical powered version of this pump cost LE 13.51 annually per feddan to operate assuming 12 feddans were irrigated and the cost of electrical energy was LE 0.192 per KWH. It would be feasible to irrigate 41 feddans with this pump because of its high discharge. If 41 feddans were to be irrigated the annual pumping costs of this pump would drop to LE 11.64 per feddan annually.

The lack of an extensive electrical grid in Egypt limits the immediate applicability and portability of an electrically driven pump. The same IRRI pump with a diesel driver is consequently more practical than the electrical version. The diesel driven pump cost LE 27.05 per feddan to operate assuming 12 feddans are irrigated and the cost of diesel fuel was LE 0.239 per litre. The portability of this pump and its high discharge suggest that 41 feddans could easily be irrigated with one pump. The annual operating costs of the pump would then drop to LE 23.67 per feddan.

This cost is still slightly higher than the operating cost of the sakia. The sakia however must operate 63 hours to provide the annual mean irrigation requirement per feddan. The IRRI pump can lift the same quantity of water in 37 hours. The IRRI pump is 60% faster and consequently the farmer need spend 40% less time irrigating than with the sakia. If the opportunity cost of the farmer's labor is considered the IRRI diesel pump becomes more economical than the sakia. For instance, if an opportunity cost of LE 0.03 per hour was assigned to the farmers labor the cost of operating the two pumps becomes equivalent. A more realistic estimate of the opportunity cost of the farmer's labor is LE 0.18 three times higher than the break even opportunity cost. The IRRI diesel powered axial flow pump is consequently the preferred irrigation water lifting device from the Egyptian national economic perspective.

The on farm or farmer costs of pumping with the mechanized pumps are significantly cheaper than with the animal powered sakias. This difference is primarily due to the enormously subsidized fossil fuel prices in Egypt. While some mechanized pumps such as the IRRI axial flow pumps were shown to be economically superior to the sakia, other pumps which are highly inefficient and consequently much more expensive than the sakia in the economic analysis are significantly cheaper than the sakia in the on farm cost analysis. In fact, there is at present a surge in the use of highly inefficient centrifugal diesel powered pumps by Egyptian farmers. There is a correlation between the relatively low farmer pumping costs for inefficient diesel pumps predicted by the computer model used in this analysis and the low operating costs implied by the surge in the use of these pumps by Egyptian farmers. This correlation tends to validate the accuracy of the computer model.

In the long run this analysis demonstrates that present farmer demand for mechanized pumping can be expected to continue as long as a subgrade delivery system is utilized and energy prices are subsidized. Unfortunately, the farmer has no incentive to utilize the most efficient of the mechanized pump models. Consequently, the choices the farmer is presently making are not in the long term national economic interests of Egypt.

Whether low lift pumping is preferable to an above grade gravity feed system or some combination of the two systems can not presently be determined. An economic and technical analysis of the costs of constructing and operating a new above grade system versus the costs of a sub grade system with lifting would have to be determined. Additionally the issues of a centralized versus a decentralized delivery system administrative structure and the introduction of free market forces in lieu of centralized planning will influence the selection of a delivery system. However, whatever the objectives of the policy makers, the implementation of those objectives in an efficient manner will be significantly aided by a scientific analysis of the irrigated agricultural system.

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Appendix A

Computer Model
User's Manual

WLDRV1 - The Driver

This is the program drive or conductor. This routine, depending upon user input, chooses the appropriate subroutines and their order of execution and then initiates the subroutine call. This routine can be broken up into 4 sections.

Section 1. Handle data input.

Section 2. Commands the computational processes and the printing of the annual cost calculations.

Section 3. Contains the data check procedure

Section 4. Commands the printing of the present cost calculations and the plotting routine.

It should be noted that the actual computation of the present cost values is done when the annual cost values are being computed in section 2.

Pumpfit

This subroutine called by the program driver calculates the required discharge (Q), total head (H), and the required water and break horsepower. This subroutine also performs all the data input function of subroutine OLD DATA.

Old Data

If a pump and pump driver has already been selected the Pumpfit subroutine can be skipped and the subroutine OLD DATA called. This subroutine assumes that pump and driver requirements are known to the user and asks him for those requirements and the names, makes, efficiencies, and costs of the pump and driver selected. As with PUMPFIT, this information is stored in the data file.

General Variables

This subroutine, called by the program driver, enter additional pumping system parameters into the data file. It will ask the user for the annual water duty in cubic meters per feddan and, the wearout life (hours), salvage value, and fuel consumption of the pump and pump driver. The pumping system wearout life is assumed to be the shorter of either the pump or driver wearout life. Additional cost information including the cost of fuel, operator, taxes and licenses and, grease and oil is asked for. Finally, this subroutine will ask the user for an annual energy cost escalation factor. This variable allows projected energy cost increases to be included in the analysis. If energy cost escalation is not desired the user must enter 0.

Print

This subroutine, called by the driver, calculates fixed costs, and annual energy, depreciation, and labor costs. If desired, this subroutine then begins a printout of the financial cost of the pumping system.

Header

This subroutine called by the driver prints the headings for the financial cost printout.

Initiate Annual Cost Calculations

This subroutine called by the driver calculates the annual financial costs of a pumping system and if desired produces a printout of these costs.

Net Present Value

This subroutine, called by the INITIATE ANNUAL COST CALCULATIONS subroutine calculates the net present value of the pumping system and loads this information into an array.

Tail

This subroutine called by the driver completes the annual financial cost printout.

Format and Print of Present Cost

This subroutine produces a printout of the present cost of the pumping system. It asks the user if a present cost printout is desired. Upon an affirmative answer the subroutine prints the present cost table. Command then returns to the driver.

Use Plot

This subroutine produces plots of user selected cost parameters of the pumping system. The abscissa dimension is feddans while the ordinate dimension is Egyptian pounds. The ordinate variable, selected by the user, can be:

1. Annual cost per feddan.
2. Present cost per feddan.
3. Cost per horsepower hour.
4. Energy cost
5. Operator cost
6. Repair cost

7. Depreciation

Line and data point format is user specified. Additionally, plots of different parameters can be superimposed upon the same graph.

Sample Computer Run

The following is a sample run of Program WLDRV1

Console on

Disc Drive on

Printer on - on line

1. Insert Disc
2. Type CAT and then press the RUN key
3. Type GET "WLDRV1" - the name of the file on the disc
4. Press the RUN key

   WLDRV1 the driver of a program which determines the present value and annual costs of pumping system

5. WATER LIFTING COST

   NEW DATA 1, OLD DATA 2

   Enter 1 or 2

   Example 1 press CONTINUE key

6. TRACK #

   Enter 1 or 2

   Example 1 press CONTINUE key

7. FILE #

   Enter the file number

   Example 4 press CONTINUE key

   Note: the tape must have already been formatted before data can be loaded onto it. See 9825 operating manual for tape formatting instructions.

8. DATA PREPARING DATE

DDMMYY

Enter the day - two digits

Enter the month - two digits

Enter the year - two digits

Example	22	02	83
	the 22 day	February	1983

Press CONTINUE

9. DATA PREPARED BY

Enter your name

Example Henry Ridgely Horsey

Press CONTINUE

CALL PUMPFIT - YES 1 (a subroutine which aids in the selection of a pump)

If you want to use this subroutine type 1 and press CONTINUE, otherwise do not type anything and press CONTINUE.

Instructions on the use of subroutine PUMPFIT and all other subroutines called by WLDRV1 follow these instructions.

Example 1 press CONTINUE

If you call PUMPFIT, upon the completion of PUMPFIT the command will return to WLDRV1 but the next subroutine OLD DATA will be omitted.

If you do not use the PUMPFIT subroutine OLD DATA is called. The operating instruction for subroutine OLD DATA follow the instructions for PUMPFIT.

Upon the completion of subroutine PUMPFIT or OLD DATA, subroutine GENERAL VARIABLES is automatically called. The operating instructions for subroutine GENERAL VARIABLES follow the instruction for OLD DATA.

Upon the completion of subroutine OLD DATA or, upon indicating that you will not be entering new data, WLDRV1 calls subroutine PRINT. Operating instructions for subroutine PRINT follow OLD DATA instructions.

Upon the completion of subroutine PRINT or if a printout is not wanted control returns to WLDRV1. At that point one of two sequences occurs.

Sequence I If a printout is not wanted subroutine INITIATE ANNUAL COST CALC. is called and once completed command returns to WLDRV1 and the DATA CHECK section of WLDRV1 begins, no user input is required during the INITIATE ANNUAL COST CALC. subroutine.

Sequence II If a printout is desired subroutines HEADER, INITIATE ANNUAL COST CALC., and TAIL are called. The annual cost table is printed and command returns to WLDRV1. No user input is required during this sequence.

DATA CORRECT Y YES; N NO

Enter Y if the data is correct or N if not. If Y is typed the following sequence occurs, if N is typed the program jumps down to WANT TO CHANGE DATA? Example Y press CONTINUE

MAKE COPY? YES - 1

Enter 1 if another annual cost table is desired, 0 if not. If 1 is entered the print sequence described above is repeated.

Example 0 press CONTINUE

WANT DATA LOADED ON TAPE? NO - N

Enter N if you do not want the data loaded. Enter nothing if you do want the data loaded. This data will be loaded on the track and in the file initially specified at the beginning of WLDRV1.

Example press CONTINUE

Note: Nothing was entered

WANT TO CHANGE DATA? YES - 1

Enter 1 if data is to be changed, 0 if it is not. If 1 is entered the program enables the keyboard and waits while the user changes the data. Pressing CONTINUE will reactivate the program and offer the options of a new printout or the loading of the corrected data into a new tape file.

Example 0 press CONTINUE

At this point subroutine FORMAT AND PRINT OF PRESENT COST is called. Command transfers to the subroutine. Operation instructions for subroutine FORMAT AND PRINT OF PRESENT COST will be found after the instruction for subroutine PRINT. Upon transfer of command back to WLDRV1 from FORMAT AND PRINT OF AND PRESENT COST the subroutine PLOT is called. Operating instructions for subroutine PLOT follow the instructions for FORMAT AND PRINT OF PRESENT COST.

Upon the completion of subroutine PLOT command again transfers back to WLDRV1.

Another Run? - Yes = 3

If another run is desired command is transferred back to the beginning of WLDRV1 and the entire procedure is repeated. Otherwise, the program terminates at this point

Example 2 press CONTINUE

If the program is terminated the display will go blank.

PUMPFIT
A subroutine called
by user in Program WLDRVI

MAX WATER/FED/IRR - M. CUBED

Enter the maximum cubic meters of water needed for one irrigation of one feddan.

Example 425 press CONTINUE

MAX FED IRRG WITH 1 PUMP

Enter the maximum number of feddans that would be irrigated with one pump

Example 15 press CONTINUE

MAX HOURS IRRG/DAY

Enter the maximum number of hours per day that the pump would be operated

Example 12 press CONTINUE

MIN # DAYS IRRG ROTATION ON

Enter the minimum number of consecutive days that water will be available in the meska (farm supply ditch)

Example 6 press CONTINUE

STATIC LIFT - METERS Enter the number of meters that the water must be lifted measured from the average water surface in the meska to the outlet of the pump.

Example 0.5 press CONTINUE

HEAD LOSSES - METERS

Enter the number of meters of head loss expected. Head loss is caused by pipe friction, entrance and exit losses, and clogged strainers

Example 0.25 press CONTINUE

PUMP SELECTION is then displayed

The required

Q - xx.xx	discharge in cubic meters per hour
HEAD - xx.xx	the required head in meters
WHP - xx.xx	the required water horsepower

Are printed and displayed. With this information the user can then select a pump which best meets these criteria.

To continue press CONTINUE

Example Q - 88.54 Head - 0.75 WHP - 0.24

PUMP MANUFACTURER

Enter the name of the pump manufacturers. The name must be less than 15 characters long

Example IRRI press CONTINUE key

PUMP MODEL

Enter the name or model number of the pump

Example LOW LIFT/PROPELLER press CONTINUE key

IMPELLER SIZE

Enter the size of the impeller and the units it is measured in

Example 6 INCHES press CONTINUE key

EFF AT DESIGN Q - 0.1 to 1.0

Enter the pump efficiency at the normal operating discharge rate

Example 0.65 press CONTINUE key

PUMP RPM AT DESIGN Q

Enter the pump RPM at the normal operating discharge

Example 2300 press CONTINUE key

PUMP LIST COST

Enter the pump list cost in L.E.

Example 480 press CONTINUE key

INSTALLATION COSTS

Enter the costs incurred to install the pump, including stilling basins if need. Do not include costs that will also be included in the driver installation costs.

Example 40 press CONTINUE key

SELECT DRIVER

MAX BPH REQ - X.XX AT XXXX RPM

The required continous brake horsepower input to the pump is determined. With this determined the user can select the proper driver or driver and transmission combination for the pump.

Example MAX BHP REQ - 0.37 AT 2300 RPM

To continue press CONTINUE

DRIVER - ANIM., DIES, ELEC.?

Enter the type of driver to be used. Don't forget to put a period after the driver name. The name must be capitalized. If the driver is a gas or kerosene engine type "DIES."

Example DIES. press CONTINUE

DID YOU PUT A "." AT END? NO-1

Enter 1 if the period at the end of the name was forgotten. It is entered the program will jump back two steps and ask again for the correct name. Then when the program again asks if the period was forgotten, enter 0.

Otherwise enter 0 if period was placed after name

Example 0 press CONTINUE

MOTOR MANUFACTURER

If a motor or engine is the driver enter the name of the motor manufacturer

Example THAI press CONTINUE

MODEL

Enter the model type

Example GAS press CONTINUE

SIZE

Enter the size of the driver

Example 5BHP press CONTINUE

LIST COST

Enter the cost of the driver in L.E.

Example 150.0 (5HP Briggs & Stratton from Granger)

press CONTINUE

INSTALL COST INCL POWER HOOKUP

Enter the cost in L.E. of installing the driver on the pump, the cost of a pump house if needed, and in the case of an electric motor, the cost of hooking this motor up to the rural electric system.

Example 50 press CONTINUE

EFF OF ELEC MOTORS - 0.1 TO 1.0

Enter the efficiency of the electric motor.

Example 0.9 press CONTINUE

At this point PUMPFIT ends. Command transfers back to WLDRV1 and subroutine is called.

OLD DATA
A subroutine called by Program WLDRV1

Note: This subroutine is called only if subroutine PUMPFIT is not called. If subroutine PUMPFIT is called, subroutine OLD DATA will not be called.

MAKE

Enter the name of the manufacturer of the pump

Example IPRI press CONTINUE

MODEL

Enter the name or model number of the pump

Example LOW LIFT/PROPELLER press CONTINUE

SIZE

Enter the impeller size and the units it is measured in

Example 6 INCHES press CONTINUE

POWER SOURCE ANIM. DIES. ELEC.

Enter the type of driver to be used. Don't forget to put a period '.' after the driver name. The name must be capitalized. If the driver is a gas or kerosene engine type "DIES." If these formatting instructions are not precisely followed the program will terminate later.

Example DIES. press CONTINUE

PRES REPLACEMENT PRICE IN EGYPT

Enter the present replacement price of the <u>pump driver and installation costs</u>, installation costs should include the cost of a pump house, stilling basins and driver and pump mounting, if needed. If the driver is an electric motor the cost of hooking the driver up to a rural electrical grid must also be included.

Example 720 press CONTINUE

ELECTRIC ENERGY REQUIRED, KW HR

If the driver is electric enter the kilowatt hour demand, if the driver is not electric enter nothing

Example press CONTINUE

Note: nothing entered

DISCHARGE OF PUMP CUBIC M/HR

Enter the pump discharge in cubic meters per hour

Example 166 press CONTINUE

OVERALL EFFICIENCY, .01 TO 1.0

Enter the efficiency of pump and driver combined

Example .078 press CONTINUE

ENGINE EFFICIENCY 0.1 TO 1.0

Enter the efficiency of the engine

Example 0.12 press CONTINUE

STATIC HEAD, METERS

Enter the number of meters that the water must be lifted measured from the average water surface in the meska to the outlet of the pump.

Example 0.5 press CONTINUE

DYNAMIC HEAD, METERS

Enter the total dynamic head required. This should be the static head and all pump losses and the velocity head loss (if significant).

Example 0.75 press CONTINUE

MAXIMUM HOURS/DAY

Enter the maximum number of hours per day that the pump would be operated.

Example 12 press CONTINUE

MINIMUM IRRIGATION INTERVAL, DAY

Enter the minimum number of consecutive days that water will be available in the meska (farm supply ditch).

Example 6 press CONTINUE

MAX WATER REQ./IRRIG. CUB. M/FED

Enter the maximum cubic meters of water needed for one irrigation of one feddan.

Example 425 press CONTINUE

At this point OLD DATA ends. Command transfers back to WLDRV1 and subroutine GENERAL VARIABLES is called.

GENERAL VARIABLES
A subroutine called by
program WLDRV1

WEAROUT LIFE IN HOURS

Enter the expected wearout life of the pump and driver. This program assumes that both the pump and engine have the same wear out life and no salvage value.

Example 1000 press CONTINUE

EXPECTED AVERAGE REPAIR COSTS L.E./HR

Enter the expected average repair costs over the life of the driver and/or pump.

Example 0.065 press CONTINUE

FUEL CONSUMPTION, LITER/HR

Enter the average fuel consumption per hour.

FUEL COST L.E./L

Enter the fuel costs in L.E. per litre if not applicable enter 0

Example 0.264 press CONTINUE

OIL COST, L.E./100 HOURS

Enter the lubricating oil costs in L.E. per hundred hours of operation. If not applicable enter 0.

Example 2.779 press CONTINUE

GREASE COST, L.E./100 HOURS

Enter the grease costs per hundred hours of operation. If not applicable enter 0

Example 0 press CONTINUE

ELECTRICITY COST, L.E./KW HR

Enter the electricity costs in L.E. per kilowatt hour. If not applicable enter 0.

ANN. ENERGY INCREASE FACTOR - 0?

Enter the average rate at which the costs of energy products are expected to increase annually over the life of the pump and driver. Note: This is not an inflation factor. DO NOT input an increase factor which includes an inflation component. The value input here should be the "real" increase in energy as a function of increased demand or diminishing supplies.

Example 0 press CONTINUE

ENTER SALVAGE VALUE AT END OF LIFE L.E.

Enter the expected salvage value of the pump and driver at the time that the first of the two fails and/or is replaced.

Example 0 press CONTINUE

TAXES, LICENSE, PERMITS, RENT, L.E./YR

Enter the annual sum of the above.

Example 5 press CONTINUE

INTEREST RATE, PERCENT

Enter the interest rate which represents the real opportunity cost of money. Note, enter it as a percent.

Example 12 press CONTINUE

OPERATOR OR LABOR COST, L.E./HR

Enter the cost of the labor if any which must attend to the water lifting device during its normal operation.

Example 0.8 press CONTINUE

ANIMAL ENERGY COST/HR L.E.

Enter the cost of animal energy per hour of use. If no animal energy is used enter 0.

Example 0 press CONTINUE

WATER DUTY PER YEAR, CUBIC M./FEDDAN

Enter the average total amount of water applied per feddan in one year.

Example 6800 press CONTINUE

This is the end of the subroutine GENERAL VARIABLE. Command now shifts back to WLDRV1.

Print
A subroutine called by WLDRV1

WANT ANN. COST PRINT OUT? NO-1

Enter 1 if annual cost printout is not wanted. Enter 0 if an annual cost printout is wanted.

Example 0 press CONTINUE

If a printout is not wanted control immediately returns to WLDRV1. Otherwise the annual cost printout will then be printed. Note: printer must be turned on and on line.

PRINT is terminated at this point and command returns to WLDRV1.

FORMAT AND PRINT OF PRESENT COST

A subroutine called by WLDRV1

WANT PRESENT COST OUTPUT? NO-2

Enter 2 if you do not want the calculation and printout of the present cost. Otherwise enter 0.

If 2 is entered command returns to WLDRV1 immediately. Otherwise the present cost table is printed and then command returns to WLDRV1.

Appendix B

Computer Code and Sample Output

File - WLDRV1

```
0: "WATER LIFTING COST---DRIVER(1) & SUBROUTINES":
1: sfg 14
2: dim A[50],A$[7,30],T[100],F[100]
3: dim C[20],D[20],B$[7,20]
4: dim S$[2],E$[2],Z[40],P[40],B[40]
5: dim C$[1],E[40],G[40],H[40],I[40],J[40],K[40],L[28,175]
6: 0→O
7: dsp "WATEK LIFTING COST";wait 1500
8: ent "NEW DATA 1, OLD DATA 2",B
9: ent "TRACK#",M;ent "FILE #",N
10: if B=2;trk M;rew;ldf N,A[*],A$,T[*],F[*]
11: if B=2;gto "PRINT-DRIVER"
12: ent "Data preparing date DDMMYY",A$[6]
13: ent "DATA PREPARED BY",A$[7]
14: ent "CALL PUMPFIT? YES-1",E;if E=1;chain "PMPFIT",75,15
15: if E=1;gsb "PUMPFIT"
16: if E=1;jmp 3
17: chain "ODATA",75,18
18: gsb "OLD DATA"
19: chain "GVARI",75,20
20: gsb "GENERAL VARIABLES"
21: "----------------------------------":
22: "PRINT-DRIVER":
23: "----------------------------------":
24: chain "WPRINT",75,25
25: gsb "PRINT"
26: if L=1;jmp 3
27: chain "HEADER",75,28
28: gsb "HEADER"
29: chain "INCALC",75,30
30: chain "PRSCST",98,31
31: gsb "INITIATE ANNUAL COST CALC."
32: if L=1;jmp 3
33: chain "WTAIL",75,34
34: gsb "TAIL"
35: "----------------------------------":
36: "DATA CHECK":
37: "----------------------------------":
38: ent "DATA CORRECT? y yes, n no",E$
39: if E$="y";ent "MAKE COPY? YES-1",T;if T=1;gto "PRINT-DRIVER"
40: if E$="y";if B=1;ent "WANT DATA LOADED ON TAPE? NO-n",E$
41: if E$="y";if B=1;trk M;rew;rcf N,A[*],A$,T[*],F[*]
42: if E$="y";if B=1;dsp "DATA LOADED TRACK-",M," FILE-",N;wait 3000
43: ent "WANT TO CHANGE DATA? YES-1",G
44: if G=1;dsp "GTO LIVE KEYBOARD TO CHANGE DATA";wait 3000
45: if G=1;dsp "PRESS CONT. KEY ONCE DATA CHANGE";wait 2000;stp
46: if G=1;ent "WANT NEW PRINTOUT? YES-2",G
47: if G=2;gto "PRINT-DRIVER"
48: if G=1;ent "NEW DATA LOADED ON TAPE? YES-3",G
49: if G=3;ent "TRACK #?",M,"FILE #?",N
50: if G=3;trk M;rew;rcf N,A[*],A$,T[*],F[*]
51: if G=3;dsp "DATA LOADED TRK-",M," FILE-",N;wait 2000
52: "----------------------------------":
53: chain "F+PCST",75,54
54: gsb "FORMAT AND PRINT OF PRESENT COST"
55: chain "USPLOT",75,56
56: gsb "USE PLOT"
```

File - WLDRV1 (continued)

```
57: ent "ANOTHER RUN?-YES=3",B;if B=3;gto 6
58: end
59: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX":
60: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX":
61: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX":
62: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX":
63: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX":
64: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX":
65: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX":
66: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX":
67: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX":
68: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX":
69: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX":
70: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX":
71: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX":
72: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX":
73: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX":
74: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX":
75: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX":
*722
```

File - WTAIL

```
0: "-----------------------------------":
1: "TAIL":
2: "-----------------------------------":
3: fmt "MAX. SYSTEM CAPACITY     =",f10.3," FED./YEAR";wrt 701,F[100]
4: fmt "REQUIRED POWER INPUT TO PUMP AT MAX DISCHARGE = ",z
5: wrt 701
6: fmt f10.3," BRAKE HORSPOWER"
7: A[14]A[19]/273.4A[16]→A[40];wrt 701,A[40
8: fmt "HOURS PUMPING PER FEDDAN = ",f10.3,
9: wrt 701,A[23]/A[14]
10: fmt "  MAX HOURS PER IRRIG. →→→→→ ",z
11: wrt 701
12: fmt f10.3," Hrs/YEAR";wrt 701,A[24]
13: fmt "ENERGY INPUT TO DRIVER AT MAX DISCHARGE",z
14: wrt 701
15: fmt " = ",f10.3," HP Hrs/YEAR →→→  ",f10.3," KW Hrs/YEAR"
16: wrt 701,A[40]/A[17],.746A[40]/A[17]
17: ret
18: end
19: "-----------------------------------":
20: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX":
*8819
```

File - PMPFIT

```
0: "-----------------------------------";
1: "PUMPFIT":
2: "-----------------------------------";
3: "BEGINNING":
4: "-----------------------------------";
5: ent "MAX WATER/FED/IRR-M.CUBED",A[23]
6: ent "MAX FED IRRG WITH 1 PUMP",C[1]
7: ent "MAX HOURS IRRG/DAY",A[21]
8: ent "MIN # DAYS  IRRG ROTATION ON?",A[22]
9: ent "STATIC LIFT - METERS",A[18]
10: ent "HEAD LOSSES - METERS",C[2]
11: if A[18]=0;1→A[18]
12: if C[2]=0;.83→C[2]
13: A[18]+C[2]→A[19]
14: A[23]×C[1]/(A[21]×A[22])→A[14]→D[1]
15: A[19]×(D[1]/60)/4.5683→D[2]
16: dsp "PUMP SELECTION";wait 2000
17: prt "Q-",D[1],"HEAD-",A[19],"WHP-",D[2]
18: dsp "Q-",D[1],"HEAD-",A[19],"WHP-",D[2];stp
19: ent "PUMP MANUFACTURER",A$[2]
20: ent "ACTUAL PUMP Q-M.cub./HR",A[14]
21: ent "PUMP MODEL",A$[3]
22: ent "IMPELLER SIZE",A$[4]
23: ent "EFF AT DESIGN Q- .01 TO 1.0",A[16]
24: ent "RPM AT DESIGN Q",B$[1]
25: ent "PUMP LIST COST",C[3]
26: ent "INSTALLATION COSTS ",C[4]
27: D[2]/A[16]→C[5]
28: dsp "SELECT DRIVER";wait 2000
29: prt "MAX BHP REQ-",C[5],"AT ",B$[1],"RPM"
30: dsp "MAX BHP REQ-",C[5]," AT ",B$[1],"RPM";stp
31: ent "DRIVER - ANIM.,DIES.,ELEC.?",A$[5]
32: ent "DID YOU PUT A "".""  AT END? NO-1",r1
33: if r1=1;jmp -2
34: len(A$[2])→r2;"/"→A$[2,r2+1]
35: ent "MOTOR MANUFACTURER",A$[2,r2+2]
36: len(A$[3])→r3;"/"→A$[3,r3+1]
37: ent "MODEL",A$[3,r3+2]
38: len(A$[4])→r4;"/"→A$[4,r4+1]
39: ent "SIZE",A$[4,r4+2]
40: ent "LIST COST",C[6]
41: ent "INSTALL COST INCL POWER HOOKUP",C[7]
42: ent "EFF OF ELEC MOTOR- .01 TO 1.0",A[17]
43: C[5]*.746/A[17]→A[8]
44: 99999→r20
45: C[3]+C[4]+C[6]+C[7]→A[1]
46: ret
47: end
48: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX";
*29602
```

File - ODATA

```
0: "---------------------------------";
1: "OLD DATA";
2: "---------------------------------";
3: ent "make",A$[2]
4: ent "model",A$[3]
5: ent "size",A$[4]
6: ent "POWER SOURCE ANIM. DIES. ELEC.",A$[5]
7: ent "prsnt replacement price in EGYPT",A[1]
8: ent "electric energy required, Kw Hr",A[8]
9: ent "Discharge of pump, cubic m./hr",A[14]
10: ent "PUMP EFFICIENCY:.01 to 1.0",A[16]
11: ent "Engine efficiency .01 to 1.0",A[17]
12: ent "Static head, meters",A[18]
13: ent "Dynamic head, meters",A[19]
14: ent "Maximum hours/day",A[21]
15: ent "Min. irrigation interval, days",A[22]
16: ent "Max. Water Req./irrig. cub.m/fed",A[23]
17: ret
18: end
19: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX";
*909
```

File - WPRINT

```
0: "-----------------------------------------";
1: "PRINT":
2: "-----------------------------------------";
3: O+1→O
4: A[20]/A[14]→A[24];0→R
5: A[12](A[1]+A[10])/200→R
6: R+A[11]→A[30]
7: A[4]A[5]→A[27]
8: if A$[5]="ELEC.";A[9]A[8]→A[27]
9: if A$[5]="ANIM.";A[15]→A[27]
10: A[27]A[24]→A[50]
11: A[24](A[1]-A[10])/A[2]→A[48]
12: .01A[24](A[6]+A[7])→A[49]
13: A[13]A[24]→A[26]
14: A[3]A[24]→A[28]
15: ent "WANT ANN. COST PRINTOUT? NO-1",L;if L=1;ret
16: wtb 701,27,110
17: fmt 3,/,/;wrt 701.3
18: fmt 3,/,/;wrt 701.3
19: conv 124,27
20: wrt 701,"|n|&k1S"
21: fmt 2,10x,"TABLE(   ) WATER LIFTING COST";wrt 701.2
22: wrt 701,"|n|&k0S"
23: if A[13]=0;fmt 5,20x,"not including cost of machine operator";wrt 701.5
24: fmt 7,5x,"DATA PREPARED BY",c20;wrt 701.7,A$[7]
25: fmt 7,5x,"Tape 3 ; Track",f2.0," ; File",f3.0;wrt 701.7,M,N
26: fmt 3,/;wrt 701.3
27: fmt 7,"NAME OF MACHINE:",2x,c20;wrt 701.7,A$[1]
28: fmt 3,/;wrt 701
29: fmt 7,"MAKE: ",c20,2x,"MODEL: ",c20,2x,"SIZE: ",c20
30: wrt 701.7,A$[2],A$[3],A$[4]
31: fmt 7,"POWER SOURCE",5x,c10;wrt 701.7,A$[5]
32: fmt 3,/;wrt 701
33: fmt 4,"DATE                    ",15x,c6
34: wrt 701.4,A$[6]
35: fmt 7,"PRESENT REPLACEMENT COST IN EGYPT, LE",8x,f10.3;wrt 701.7,A[1]
36: fmt 7,"WEAR OUT LIFE IN HOURS",23x,f10.3;wrt 701.7,A[2]
37: fmt 7,"EXPECTED AVERAGE REPAIR COST LE /HOUR   ",5x,f10.3;wrt 701.7,A[3]
38: if A[4]=0;jmp 3
39: fmt 7,"FUEL CONSUMPTION LITERS PER HOUR",13x,f10.3;wrt 701.7,A[4]
40: fmt 7,"FUEL COST LE/LITER     ",23x,f10.3;wrt 701.7,A[5]
41: fmt 7,"OIL COST LE/ 100 HOURS   ",20x,f10.3;wrt 701.7,A[6]
42: fmt 7,"GREASE COST LE /100 HOURS    ",17x,f10.3;wrt 701.7,A[7]
43: if A[8]=0;jmp 3
44: fmt 7,"ELECTRIC POWER REQUIRED ,Kw hour    ",10x,f10.3;wrt 701.7,A[8]
45: fmt 7,"ELECTRICITY COST LE /Kw.hour",17x,f10.3;wrt 701.7,A[9]
46: fmt 7,"SALVAGE VALUE AT END OF WEAR OUT LIFE:LE",5x,f10.3;wrt 701.7,A[10]
47: fmt 7,"ANNUAL TAXES,LICENSE,PERMIT,RENT,etc.:LE",5x,f10.3;wrt 701.7,A[11]
48: fmt 7,"INTEREST RATE,PERCENT  ",22x,f10.3,2x,"%";wrt 701.7,A[12]
49: if A[13]#0;fmt 7,"OPERATOR COST LE/hr      ",21x,f10.3;wrt 701.7,A[13]
50: fmt 7,"Hrs PER FEDDAN PER YEAR",22x,f10.3;wrt 701.7,A[24]
51: fmt 7,"DISCHARGE OF PUMP,cubic mt./hr",15x,f10.3;wrt 701.7,A[14]
52: if A$[5]#"ANIM.";jmp 2
53: fmt 7,"ANIMAL POWER COST LE/hr",22x,f10.3;wrt 701.7,A[15]
54: if A[16]>0;fmt ,"EFFICIENCY OF PUMP",27x,f10.3;wrt 701,A[16]
55: fmt "EFFICIENCY OF DRIVER",25x,f10.3;wrt 701,A[17]
56: fmt ,"STATIC HEAD (METERS)",25x,f10.3;wrt 701,A[18]
```

File - WPRINT (continued)

```
57: fmt "DYNAMIC HEAD (METERS)",24x,f10.3;wrt 701,A[19]
58: fmt 7,"WATER DUTY PER YEAR,cubic mt/fd",14x,f10.3;wrt 701.7,A[20]
59: fmt 7,"MAX. TIME SYSTEM WILL RUN PER DAY,hours",6x,f10.3;wrt 701.7,A[21]
60: fmt 7,"MIN. TIME BETWEEN IRRIGATION,days",12x,f10.3;wrt 701.7,A[22]
61: fmt ,"MAX. WATER REQUIRED PER IRRIG.,cubic mt/fd",3x,f10.3;wrt 701,A[23]
62: wrt 701.3
63: ret
64: end
65: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX";
*20096
```

File - GVARI

```
0: "-------------------------------------";
1: "GENERAL VARIABLES";
2: "-------------------------------------";
3: ent "Wearout life, hours",A[2]
4: ent "Expected av. repair costs,LE/hr",A[3]
5: ent "Fuel consumption, liter/hr",A[4]
6: ent "Fuel cost LE/Liter",A[5]
7: ent "oil cost, LE/100 hours",A[6]
8: ent "grease cost, LE/100 hours",A[7]
9: ent "electricity cost, LE/Kw Hr",A[9]
10: ent "ANN. ENERGY INCREASE FACTOR-0.?",A[31]
11: ent "salvage value at end of life:LE",A[10]
12: ent "Taxes,License,permits,rent,LE/yr",A[11]
13: ent "interest rate, percent",A[12]
14: ent "Operator or Labor cost, LE/hour",A[13]
15: ent "Animal energy cost/hr. L.E.",A[15]
16: ent "Water duty/year, Cubic m./feddan",A[20]
17: 0→I
18: I+1→I
19: if B=1;if I=1;1→F[1];jmp -1
20: if B=1;if F[I-1]<10;F[I-1]+1→F[I];jmp -2
21: if B=1;F[I-1]+5→F[I];if F[I]<100;jmp -3
22: if B=1;-12→F[I+1]
23: ret
24: end
25: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX";
*9077
```

File - PRSCST

```
0: "PRSCST":
1: "------------------------------------";
2: "NET PRESENT VALUE":
3: "------------------------------------";
4: "INITALIZE VARIABLES":
5: "------------------------------------";
6: O+1→O
7: 0→C→F→K
8: "------------------------------------";
9: "YEARS OF LIFE":
10: "------------------------------------";
11: A[2]/A[24]/F[I]→C
12: "------------------------------------";
13: "CALCULATE ANNUAL DISCOUNTED COSTS":
14: "------------------------------------";
15: F+1→F
16: if F>170;1→A;gto "SET POINTER"
17: if F>C;gto "SET POINTER"
18: (A[47]+A[44]+A[43]+A[11]+(1+F*A[31])*A[42])/(1+A[12]/100)↑F→L[0,F]
19: if F=1;L[0,F]+A[1]→L[0,F]
20: jmp -5
21: "------------------------------------";
22: "SET POINTER":
23: "------------------------------------";
24: -.987654→L[0,F]
25: F-1→F
26: "------------------------------------";
27: "SUMMATION":
28: "------------------------------------";
29: if F=0;gto "ENTER NPV INTO ARRAY"
30: K+L[0,F]→K
31: F-1→F
32: jmp -3
33: "------------------------------------";
34: "ENTER NPV INTO ARRAY":
35: "------------------------------------";
36: if A=1;K→L[0,172];jmp 2
37: K→L[0,int(C+2)]
38: ret
39: "------------------------------------";
40: end
*30135
```

File - F+PCST

```
0: get "F+PCST"
1: "FORMAT AND PRINT OF PRESENT COST":
2: "-----------------------------------":
3: ent "WANT PRESENT COST OUTPUT? NO-2",L;if L=2;ret
4: "--------------------------------":
5: "PRESENT COST FORMAT":
6: "------------------------------------":
7: wtb 701,27,110
8: wtb 701,27,51
9: fmt 1,60x,z;wrt 701.1
10: wtb 701,27,49
11: wtb 701,27,38,108,54,118,54,68
12: wtb 701,27,38,107,49,83
13: wtb 701,27,38,100,68
14: fmt 2,17x,"NET PRESENT VALUE CO   TATIONS",18x;wrt 701.2
15: fmt 3,/,/,/;wrt 701.3
16: fmt 9,c
17: wrt 701.9,A$[1]
18: wtb 701,27,38,100,65
19: wtb 701,27,38,107,48,83
20: fmt 4,/,/,"DATA PREPARED BY:",3x,c,z;wrt 701.4,A$[7]
21: wtb 701,9
22: fmt 1,"DATE:  ",c;wrt 701.1,A$[6]
23: fmt 3,"TRACK #:  ",f1.0,z;wrt 701.3,M
24: wtb 701,9
25: fmt 4,"FILE #:  ",f1.0;wrt 701.4,N
26: fmt 2,"MAKE:    ",c,z;wrt 701.2,A$[2]
27: wtb 701,9
28: fmt 3,"MODEL:   ",c;wrt 701.3,A$[3]
29: fmt 4,"SIZE:    ",c,z;wrt 701.4,A$[4]
30: wtb 701,9
31: fmt 5,"POWER SOURCE:   ",c;wrt 701.5,A$[5]
32: fmt 6,"****DISCOUNT RATE %:   ",f5.2,z;wrt 701.6,A[12]
33: wtb 701,9
34: fmt 7,"****ANNUAL ENERGY COST INCREASE FACTOR:   ",f8.6;wrt 701.7,A[31]
35: fmt 1,/;wrt 701.1
36: wtb 701,27,38,100,68
37: fmt 1,130x;wrt 701.1
38: wtb 701,27,51
39: wtb 701,27,38,100,65
40: fmt 1,35x,z;wrt 701.1
41: wtb 701,27,49
42: fmt 2,40x,z;wrt 701.2
43: wtb 701,27,49
44: fmt 3,35x,z;wrt 701.3
45: wtb 701,27,49
46: wtb 701,13,10
47: wtb 701," FEDDANS",9,"NET PRESENT",9,"NET PRESENT",9,"OPERATING"
48: wtb 701,13,10,"IRRIGATED",9,"  COST OF",9,"  COST OF",9,"   LIFE"
49: wtb 701,10,13,9,"IRRIGATION",9," IRR./FED.",9," -YEARS-",13,10
50: wtb 701 27,38,100,68
51: fmt 1,130x;wrt 701.1
52: wtb 701,27,38,100,65
53: wtb 701,10,10,13
54: "-----------------------------------":
55: "PRINT PRESENT COST":
56: "-----------------------------------":
```

File - F+PCST

```
57: 1→I
58: "LOOP":
59: 0→F
60: F+1→F
61: if L[I,F]=-.987654;gto "TTL COST VALUE"
62: jmp -2
63: "TTL COST VALUE":
64: fmt 1,f3.0,z;wrt 701.1,F[I]
65: wtb 701,9
66: fmt 2,f8.2,z;wrt 701.2,L[I,F+1]
67: wtb 701,9
68: fmt 3,f7.2,z;wrt 701.3,L[I,F+1]/F[I]
69: wtb 701,9
70: fmt 4,f6.2;wrt 701.4,A[2]/A[24]/F[I]
71: if F[I]>F[100];gto "MAX FED STATM"
72: I+1→I
73: if F[I]<0;ret
74: gto "LOOP"
75: end
76: "------------------------------------";
77: "MAX FED STATM":
78: "------------------------------------";
79: wtb 701,10,10,13,/,"MAX. POSSIBLE FED. IRRIG. WITH THIS PUMP = "
80: fmt 1,f6.2;wrt 701.1,F[100]
81: ret
82: end
*11994
```

File HEADER

```
0: "------------------------------------";
1: "HEADER":
2: "------------------------------------";
3: fmt ,z,1x;wrt 701
4: wtb 701,"FEDD.           ANNUAL      DEPRECIA.      REPAIRS      ENERGY
5: wtb 701,"      GREASE   OPERATOR   TOTAL ANNUAL     ANNUAL    "
6: wtb 701,"       OUTPT       COST    "
7: wtb 701,13,10
8: wtb 701,"              FIXED COST
9: wtb 701,"COST         &OIL      COST           COST"
10: wtb 701,"         COST/fd    HP Hrs.    HP HOUR"
11: wtb 701,13,10
12: ret
13: end
14: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX":
*3447
```

File - USPLOT

```
0: "-----------------------------------";
1: "USE PLOT":
2: "-----------------------------------";
3: ent "USE PLOT. yes y, no n",S$
4: if S$#"y";ret
5: if J=5;gto "PLOT"
6: ent "X AXIS FROM",r1,"TO",r2,"TIC",r3,"STEP",r4,"Yintercept",r5
7: ent "Y AXIS FROM",r6,"TO",r7,"TIC",r8,"STEP",r9,"Xintercept",r0
8: "-----------------------------------";
9: "PLOT AXIS":
10: "-----------------------------------";
11: pen# 4
12: scl r1,r2,r6,r7
13: line
14: fxd 0;xax r5,r3,r1,r2,r4
15: cplt -(r1+r2)/1.35,-2.5;lbl "FEDDANS"
16: fxd 2;yax r0,r8,r6,r7,r9
17: csiz 1.65,2,1,0
18: plt .5(r2+r1)-3,r7-(r6+r7)/2/10,0
19: lbl "FIGURE (    )"
20: cplt -16,-1.3
21: lbl "WATER LIFTING COSTS"
22: ent "WANT MODEL LABEL? YES-1",r25;if r25#1;jmp 4
23: lbl A$[2]
24: cplt -12,-1
25: lbl A$[3]
26: csiz 1.65,2,1,90
27: "-----------------------------------";
28: "Y AXIS VARIABLE":
29: "-----------------------------------";
30: prt "SELECT Y AXIS VARIABLE"
31: prt "ANN COST/FED-1","COST/HP HOUR-2","TL ANN COST-3"
32: prt "ENERGY COST-4","OPERATOR COST-5","REPAIR COST-6"
33: enp "DEPREC - 7",A
34: plt -(r1+r2)/2/6,r6+(r7-r6)/3,0;dsp "LABEL PLOT";ptyp
35: "-----------------------------------";
36: "PLOT":
37: "-----------------------------------";
38: 0→I
39: 1+I→I;if I)36;jmp 9
40: if A=1;Z[I]→K[I]
41: if A=2;B[I]→K[I]
42: if A=3;E[I]→K[I]
43: if A=4;I[I]→K[I]
44: if A=5;J[I]→K[I]
45: if A=6;H[I]→K[I]
46: if A=7;G[I]→K[I]
47: jmp -8
48: ent "SELECT LINE TYPE 0→6",r11
49: ent "SELECT DATA POINT TYPE-1 CHARAC.",C$
50: line r11
51: pen
52: scl r1,r2,r6,r7
53: pen# 3;csiz 1.65,2,1,0
54: plt F[1],K[1]
55: 0→I
56: csiz 1.65,2,1,0
```

File - USPLOT (continued)

```
0: "INCALC":
1: "-----------------------------------":
2: "INITIATE ANNUAL COST CALC.":
3: "-----------------------------------":
4: 0→O
5: 0→I
6: "---------------------------------":
7: "CALC.":
8: "------------------------------------":
9: 1+I→I;if F[I]<0;ret
10: A[30]+F[I](A[48]+A[28]+A[50]+A[49]+A[26])→A[45]→E[I]
11: A[45]/F[I]→Z[I];A[48]F[I]→A[41]→G[I]
12: A[28]F[I]→A[47]→H[I];A[50]F[I]→A[42]→I[I]
13: A[49]F[I]→A[43];A[26]F[I]→A[44]→J[I]
14: A[22]A[21]A[14]/A[23]→F[100]
15: A[14]A[18]A[20]F[I]/273.4A[14]+P[I];A[45]/P[I]→B[I]
16: gsb "NET PRESENT VALUE"
17: if L=1;jmp 3
18: fmt 1,f6.2,f13.3,f14.3,f14.3,f12.3,f10.3,f10.3,f16.3,f12.3,f12.3,f11.4
19: wrt 701.1,F[I],A[30],A[41],A[47],A[42],A[43],A[44],A[45],Z[I],P[I],B[I]
20: gto "CALC."
21: end
22: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX":
*8306
```

File - INCALC

```
57: 1+I→I;if F[I]>F[100];pen;gto "GRAPH SUPERPOSITION"
58: plt F[I],K[I],2;pen
59: cplt -.33,-.25;lbl C$;cplt -.67,.25
60: jmp -3
61: "-----------------------------------":
62: "GRAPH SUPERPOSITION":
63: "-----------------------------------":
64: ent "ANOTHER GRAPH SUPERIMPOSED 5 YES",J
65: if J=5;ent "USE SAME DATA? YES-1",H
66: if H=1;gto "DATA CHECK"
67: if J=5;ent "NEW DATA ON TAPE? NO-2",H
68: if H=2;1→B;gto "OLD DATA"
69: if J=5;ent "TRACK #",M;ent "FILE #",N;2→B;gto "OLD DATA"
70: if J#5;end
71: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX":
*19696
```

Table B.1. Sample Output - The Cost of Pumping with a Diesel Driven IRRI Pump

```
                    not including cost of machine operator
    DATA PREPARED BY                      HRH
    Tape 3 ; Track 0 ; File  2


NAME OF MACHINE:

MAKE:      IRRI AXIAL FLOW  MODEL:       5 HP PETTER DS.  SIZE:                6 INCH
POWER SOURCE          DIES.

DATE                                 263383
PRESENT REPLACEMENT COST IN EGYPT, LE           759.000
WEAR OUT LIFE IN HOURS                         7500.000
EXPECTED AVERAGE REPAIR COST LE /HOUR             0.167
FUEL CONSUMPTION LITERS PER HOUR                  1.250
FUEL COST LE/LITER                                0.239
OIL COST LE/ 100 HOURS                            2.100
GREASE COST LE /100 HOURS                         1.000
SALVAGE VALUE AT END OF WEAR OUT LIFE:LE          0.000
ANNUAL TAXES,LICENSE,PERMIT,RENT,etc.:LE          5.000
INTEREST RATE,PERCENT                            13.000  %
Hrs PER FEDDAN PER YEAR                          37.363
DISCHARGE OF PUMP,cubic mt./hr                  102.000
EFFICIENCY OF PUMP                                0.400
EFFICIENCY OF DRIVER                              0.120
STATIC HEAD (METERS)                              0.750
DYNAMIC HEAD (METERS)                             0.750
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      DEPRECIA.      REPAIRS      ENERGY    GREASE   OPERATOR   TOTAL ANNUAL    ANNUAL     OUTPT      COST
          FIXED COST                                 COST     &OIL     COST          COST        COST/fd    HP Hrs.   HP HOUR
   1.00     54.335        3.781          6.240      11.162     1.158    0.000         76.676     76.676     18.654    4.1104
   2.00     54.335        7.562         12.479      22.324     2.316    0.000         99.017     49.508     37.308    2.6540
   3.00     54.335       11.343         18.719      33.486     3.475    0.000        121.358     40.453     55.962    2.1686
   4.00     54.335       15.124         24.950      44.640     4.633    0.000        143.699     35.925     74.616    1.9258
   5.00     54.335       10.905         31.198      55.810     5.791    0.000        166.040     33.208     93.270    1.7802
   6.00     54.335       22.687         37.437      66.973     6.949    0.000        188.381     31.397    111.924    1.6831
   7.00     54.335       26.468         43.677      78.135     8.108    0.000        210.722     30.103    130.578    1.6138
   8.00     54.335       30.249         49.916      89.297     9.266    0.000        233.063     29.133    149.232    1.5618
   9.00     54.335       34.030         56.156     100.459    10.424    0.000        255.404     28.378    167.886    1.5213
  10.00     54.335       37.811         62.396     111.621    11.582    0.000        277.745     27.774    186.540    1.4889
  15.00     54.335       56.716         93.593     167.431    17.374    0.000        389.450     25.963    279.810    1.3918
  20.00     54.335       75.622        124.791     223.242    23.165    0.000        501.155     25.058    373.080    1.3433
  25.00     54.335       94.527        155.989     279.052    28.956    0.000        612.860     24.514    466.350    1.3142
  30.00     54.335      113.433        187.187     334.863    34.747    0.000        724.565     24.152    559.620    1.2947
  35.00     54.335      132.338        218.385     390.673    40.538    0.000        836.270     23.893    652.890    1.2809
  40.00     54.335      151.244        249.582     446.484    46.330    0.000        947.975     23.699    746.159    1.2705
  45.00     54.335      170.149        280.780     502.294    52.121    0.000       1059.680     23.548    839.429    1.2624
  50.00     54.335      189.055        311.978     558.104    57.912    0.000       1171.384     23.420    932.699    1.2559
  55.00     54.335      207.960        343.176     613.915    63.703    0.000       1283.089     23.329   1025.969    1.2506
  60.00     54.335      226.866        374.374     669.725    69.495    0.000       1394.794     23.247   1119.239    1.2462
  65.00     54.335      245.771        405.571     725.536    75.286    0.000       1506.499     23.177   1212.509    1.2425
  70.00     54.335      264.677        436.769     781.346    81.077    0.000       1618.204     23.117   1305.779    1.2393
  75.00     54.335      283.582        467.967     837.157    86.868    0.000       1729.909     23.065   1399.049    1.2365
  80.00     54.335      302.488        499.165     892.967    92.659    0.000       1841.614     23.020   1492.319    1.2341
  85.00     54.335      321.393        530.363     948.777    98.451    0.000       1953.319     22.980   1585.589    1.2319
  90.00     54.335      340.299        561.560    1004.588   104.242    0.000       2065.024     22.945   1678.859    1.2300
  95.00     54.335      359.204        592.758    1060.398   110.033    0.000       2176.729     22.913   1772.129    1.2283
 100.00     54.335      378.110        623.956    1116.209   115.824    0.000       2288.434     22.884   1865.399    1.2268
MAX. SYSTEM CAPACITY      =    30.833 FED./YEAR
REQUIRED POWER INPUT TO PUMP AT MAX DISCHARGE =     1.248 BRAKE HORSPOWER
HOURS PUMPING PER FEDDAN =      2.335  MAX HOURS PER IRRIG. +++++      37.363 Hrs/YEAR
ENERGY INPUT TO DRIVER AT MAX DISCHARGE =     10.401 HP Hrs/YEAR +++       7.759 KW Hrs/YEAR
```

Table B.2. Sample Output - The Cost of Pumping with a Sakia

```
    DATA PREPARED BY                        HRH
    Tape 3 ; Track 1 ; File  2


NAME OF MACHINE:

MAKE:                SAKIA  MODEL:                       SIZE:
POWER SOURCE          ANIM.

DATE                                   130383
PRESENT REPLACEMENT COST IN EGYPT, LE                550.000
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                              0.250
SALVAGE VALUE AT END OF WEAR OUT LIFE:LE               0.000
ANNUAL TAXES,LICENSE,PERMIT,RENT,etc.:LE               5.000
INTEREST RATE,PERCENT                                 13.000  %
OPERATOR COST LE/hr                                    0.050
Hrs PER FEDDAN PER YEAR                               62.963
DISCHARGE OF PUMP,cubic mt./hr                       108.000
ANIMAL POWER COST LE/hr                                0.208
EFFICIENCY OF PUMP                                     0.450
EFFICIENCY OF DRIVER                                   1.000
STATIC HEAD (METERS)                                   0.750
DYNAMIC HEAD (METERS)                                  0.850
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      DEPRECIA.     REPAIRS     ENERGY    GREASE   OPERATOR  TOTAL ANNUAL   ANNUAL     OUTPT      COST
          FIXED COST                                COST    &OIL     COST          COST      COST/fd    HP Hrs.   HP HOUR
   1.00     40.750        2.309        0.630      13.096    0.157     3.148        60.090     60.090     18.654    3.2213
   2.00     40.750        4.617        1.259      26.193    0.315     6.296        79.430     39.715     37.308    2.1290
   3.00     40.750        6.926        1.889      39.289    0.472     9.444        98.770     32.923     55.962    1.7650
   4.00     40.750        9.235        2.519      52.385    0.630    12.593       118.110     29.528     74.616    1.5829
   5.00     40.750       11.543        3.148      65.481    0.787    15.741       137.451     27.490     93.270    1.4737
   6.00     40.750       13.852        3.778      78.578    0.944    18.989       156.791     26.132    111.924    1.4009
   7.00     40.750       16.160        4.407      91.674    1.102    22.037       176.131     25.162    130.578    1.3489
   8.00     40.750       18.469        5.037     104.770    1.259    25.185       195.471     24.434    149.232    1.3098
   9.00     40.750       20.778        5.667     117.867    1.417    28.333       214.811     23.868    167.886    1.2795
  10.00     40.750       23.086        6.296     130.963    1.574    31.481       234.151     23.415    186.540    1.2552
  15.00     40.750       34.630        9.444     196.444    2.361    47.222       330.852     22.057    279.810    1.1824
  20.00     40.750       46.173       12.593     261.926    3.148    62.963       427.552     21.378    373.080    1.1460
  25.00     40.750       57.716       15.741     327.407    3.935    78.704       524.253     20.970    466.350    1.1242
  30.00     40.750       69.259       18.889     392.889    4.722    94.444       620.954     20.698    559.620    1.1096
  35.00     40.750       80.802       22.037     458.370    5.509   110.185       717.654     20.504    652.890    1.0992
  40.00     40.750       92.346       25.185     523.852    6.296   125.926       814.355     20.359    746.159    1.0914
  45.00     40.750      103.889       28.333     589.333    7.083   141.667       911.056     20.246    839.429    1.0853
  50.00     40.750      115.432       31.481     654.815    7.870   157.407      1007.756     20.155    932.699    1.0805
  55.00     40.750      126.975       34.630     720.296    8.657   173.148      1104.457     20.081   1025.969    1.0765
  60.00     40.750      138.519       37.778     785.778    9.444   188.889      1201.157     20.019   1119.239    1.0732
  65.00     40.750      150.062       40.926     851.259   10.231   204.630      1297.858     19.967   1212.509    1.0704
  70.00     40.750      161.605       44.074     916.741   11.019   220.370      1394.559     19.922   1305.779    1.0680
  75.00     40.750      173.148       47.222     982.222   11.806   236.111      1491.259     19.883   1399.049    1.0659
  80.00     40.750      184.691       50.370    1047.704   12.593   251.852      1587.960     19.849   1492.319    1.0641
  85.00     40.750      196.235       53.519    1113.185   13.380   267.593      1684.660     19.820   1585.589    1.0625
  90.00     40.750      207.778       56.667    1178.667   14.167   283.333      1781.361     19.793   1678.859    1.0611
  95.00     40.750      219.321       59.015    1244.148   14.954   299.074      1878.062     19.769   1772.129    1.0598
 100.00     40.750      230.864       62.963    1309.630   15.741   314.815      1974.762     19.748   1865.399    1.0586
MAX. SYSTEM CAPACITY      =     18.296 FED./YEAR
REQUIRED POWER INPUT TO PUMP AT MAX DISCHARGE =      0.746 BRAKE HORSPOWER
HOURS PUMPING PER FEDDAN =      3.935  MAX HOURS PER IRRIG. +++++      62.963 Hrs/YEAR
ENERGY INPUT TO DRIVER AT MAX DISCHARGE =      0.746 HP Hrs/YEAR +++        0.557 KW Hrs/YEAR
```

Table B.3. The Cost of Pumping with an Electrically Driven IRRI Pump

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                  not including cost of machine operat--
     DATA PREPARED BY                    HRH        .
     Tape 3 ; Track 0 ; File 36


NAME OF MACHINE:

MAKE:       IRRI AXIAL FLOW  MODEL:          3 HP  ELEC.  SIZE:               6 INCH
POWER SOURCE            ELEC.

DATE                                      100483
PRESENT REPLACEMENT COST IN EGYPT, LE                385.000
WEAR OUT LIFE IN HOURS                             15000.000
EXPECTED AVERAGE REPAIR COST LE /HOUR                  0.030
OIL COST LE/ 100 HOURS                                 0.000
GREASE COST LE /100 HOURS                              1.000
ELECTRIC POWER REQUIRED ,Kw hour                       1.179
ELECTRICITY COST LE /Kw.hour                           0.192
SALVAGE VALUE AT END OF WEAR OUT LIFE:LE               0.000
ANNUAL TAXES,LICENSE,PERMIT,RENT,etc.:LE               5.000
INTEREST RATE,PERCENT                                 13.000  %
Hrs PER FEDDAN PER YEAR                               37.363
DISCHARGE OF PUMP,cubic mt./hr                       182.000
EFFICIENCY OF PUMP                                     0.400
EFFICIENCY OF DRIVER                                   0.790
STATIC HEAD (METERS)                                   0.750
DYNAMIC HEAD (METERS)                                  0.750
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     DEPRECIA.     REPAIRS     ENERGY    GREASE   OPERATOR  TOTAL ANNUAL   ANNUAL     OUTPT       COST
          FIXED COST                              COST     &OIL     COST          COST      COST/fd    HP Hrs.    HP HOUR
  1.00     30.025        0.959         1.121      8.455    0.374    0.000        40.934     40.934      18.654    2.1944
  2.00     30.025        1.918         2.242     16.910    0.747    0.000        51.842     25.921      37.308    1.3896
  3.00     30.025        2.877         3.363     25.366    1.121    0.000        62.751     20.917      55.962    1.1213
  4.00     30.025        3.836         4.484     33.821    1.495    0.000        73.660     18.415      74.616    0.9872
  5.00     30.025        4.795         5.604     42.276    1.868    0.000        84.568     16.914      93.270    0.9067
  6.00     30.025        5.754         6.725     50.731    2.242    0.000        95.477     15.913     111.924    0.8531
  7.00     30.025        6.713         7.846     59.187    2.615    0.000       106.386     15.198     130.578    0.8147
  8.00     30.025        7.672         8.967     67.642    2.989    0.000       117.295     14.662     149.232    0.7860
  9.00     30.025        8.631        10.088     76.097    3.363    0.000       128.203     14.245     167.886    0.7636
 10.00     30.025        9.590        11.209     84.552    3.736    0.000       139.112     13.911     186.540    0.7457
 15.00     30.025       14.385        16.813    126.828    5.604    0.000       193.655     12.910     279.810    0.6921
 20.00     30.025       19.179        22.418    169.104    7.473    0.000       248.199     12.410     373.080    0.6653
 25.00     30.025       23.974        28.022    211.380    9.341    0.000       302.742     12.110     466.350    0.6492
 30.00     30.025       28.769        33.626    253.656   11.209    0.000       357.286     11.910     559.620    0.6384
 35.00     30.025       33.564        39.231    295.933   13.077    0.000       411.829     11.767     652.890    0.6308
 40.00     30.025       38.359        44.835    338.209   14.945    0.000       466.373     11.659     746.159    0.6250
 45.00     30.025       43.154        50.440    380.485   16.813    0.000       520.916     11.576     839.429    0.6206
 50.00     30.025       47.949        56.044    422.761   18.681    0.000       575.460     11.509     932.699    0.6170
 55.00     30.025       52.744        61.648    465.037   20.549    0.000       630.003     11.455    1025.969    0.6141
 60.00     30.025       57.538        67.253    507.313   22.416    0.000       684.547     11.409    1119.239    0.6116
 65.00     30.025       62.333        72.857    549.589   24.286    0.000       739.090     11.371    1212.509    0.6096
 70.00     30.025       67.128        78.462    591.865   26.154    0.000       793.634     11.338    1305.779    0.6078
 75.00     30.025       71.923        84.066    634.141   28.022    0.000       848.177     11.309    1399.049    0.5063
 80.00     30.025       76.718        89.670    676.417   29.890    0.000       902.721     11.284    1492.319    0.6049
 85.00     30.025       81.513        95.275    718.693   31.758    0.000       957.264     11.262    1585.509    0.6037
 90.00     30.025       86.308       100.879    760.969   33.626    0.000      1011.808     11.242    1678.859    0.6027
 95.00     30.025       91.103       106.484    803.245   35.495    0.090      1066.351     11.225    1772.129    0.6017
100.00     30.025       95.897       112.088    845.521   37.363    0.000      1120.894     11.209    1865.399    0.6009
MAX. SYSTEM CAPACITY      =    30.833 FED./YEAR
REQUIRED POWER INPUT TO PUMP AT MAX DISCHARGE =      1.248 BRAKE HORSPOWER
HOURS PUMPING PER FEDDAN =      2.335  MAX HOURS PER IRRIG. +++++      37.363 Hrs/YEAR
ENERGY INPUT TO DRIVER AT MAX DISCHARGE =      1.580 HP Hrs/YEAR +++        1.179 KW Hrs/YEAR
```

Appendix C

Cost Data

IRRI AXIAL FLOW PUMP COSTS

Material Costs (U.S. Prices)	
8' - 6" ID 18 gauge galvanized spiral wound pipe @$2.63/ft	21.04
70" - 5/18 cold rolled shaft $0.63/ft	3.68
20' - 1/8 x 1 1/2 x 1 1/2 angle iron @$0.16/ft	3.20
1 ft^2 1/4" plate @ $2.77/$ft^2$	2.77
3 5/8" bushings @$1.73	5.19
1 5/8" flex coupling @$10.00	10.00
1 forged propeller	29.00
Subtotal - materials	74.88
Labor Costs (Egyptian)	
32 hours x $1.50/hr	48.00
Total Cost	122.88

A cost of $123 was used in the analysis.

The IRRI axial flow pump design must be changed when electric motors are used as the driver. The electric motor cannot be coupled directly to the pump shaft because 2300 rpm electric motors are not commonly available. They can be built on a custom order basis but the cost would be prohibitive unless extremely large quantities were ordered.

A belt drive mechanism must then be built to gear a higher rpm electric motor down to 2300 rpm. Additional support for the pump shaft will also be required. It is estimated that these modifications will add $25 to the cost of the pumps. The cost then for an electrically driven IRRI pump is $148.00.

Repair Costs

No repair costs were assigned to the IRRI pump when coupled to drivers with wearout lives of 7500 hours or less. Certainly repair costs will be incurred, however it is expected that the life of the pump will exceed 7500 hours, while the analysis methodology assumes that the pump will be replaced every time the driver is replaced. To compensate for this discrepancy the value of the pump is assumed to equal the pump repair costs. Field data suggests that these pumps are exceptionally sturdy, and their repair costs are minimal.

Those IRRI pumps which are coupled to drivers with wearout lives in excess of 7500 hours were charged $0.03 per hour for repair costs.

SAKIA COSTS

Replacement Costs

Wahby et al reported the replacement cost of a sakia to be LE 500 in 1979. Assuming 10% inflation since 1979 a replacement cost of LE 550 was used in this analysis.

Repair Costs

In the above mentioned report a repair cost of LE 0.008 per hour of operation was estimated. This analysis will use a repair cost of LE 0.01 per hour of operation.

Maintenance Costs - Grease & Oil

A maintenance cost of LE 0.25 per 100 hours of operation will be used in this analysis. The value used by Wahby et al was LE 0.10. This value was multiplied by 2.5 to compensate for inflation and the subsidized prices of petroleum based products.

Wearout Life

The wearout life of the sakia was assumed to be 15000 hours. This figure is the same as that used by Wahby et al but smaller than that used in other studies. Some experts suggest that while this may be a reasonable estimate of sakia wearout life in Middle and Upper Egypt, the wearout life in the delta is probably significantly shorter. (1)

5 HP GAS AND KEROSINE ENGINE COSTS

Source - Briggs and Stratton

1. For application in Egypt. Quantity purchase (120 units) is approximately 46% of list retail price.
2. The power of a kerosene engine at 3600 rpm is approximately 20% less than on similar gas engines. The power loss increases as the rpms decrease.
3. Maintenance and repair cost of kerosene engine similar to gas engines.

Shipping Costs

60 engines	Ocean	$662
2160 lbs	Inland U.S.	$220
109 ft^2	Handling Charges	$160
	Insurance	$ 18
	Total	$1060

Shipping Cost Per Engine = $18.00 approximately.

---

(1) Personal correspondence with E. V. Richardson

Replacement Cost

	List Price	Approx. Quantity Price
5 - HP Kerosene - IC	$305	$140
5 - HP Gas - IC	$248	$115

Repair Costs

Source - Briggs & Stratton

For Egyptian Field Applications - 5 HP Gas IC Engine

Every 300 hours - major overhaul

Labor cost $25

Parts $35.65 (Author's estimate)

Parts costs could range ($5 - $100)

Value guides, values, seats - cleaned and reground and rings replaced.

Problems - gas is low octane which results in carbon deposits

Major Overhaul Parts

Source -- Bath Power & Equipment

Seals	3.50
Rings	9.00
Tune up kit	9.15
Gasket set	7.00
Carb kit	5.00
Air filter	2.00
Subtotal	35.65

Labor	$25.00
Parts	$35.65
Total	$60.65

$\frac{\$60.65}{300 \text{ hours}} \simeq \$0.20/\text{Hr}$

A repair cost of $0.20 per hour of operation will be used in this analysis.

Maintenance Costs

Source - Pacific Power Equipment Company

Every 25 hours clean air filter with soap and water, change oil, 1 pint. (Authors Estimate)

Oil Cost $\frac{\$0.50}{25} = \$0.02/\text{Hr}$

Fuel Consumption

There is a limited amount of fuel consumption data on a "relatively new" 5 hp Briggs and Stratton gasoline engine that powered a 6 inch IRRI axial flow pump. A comparison of fuel consumption with the pump water horsepower output showed significant scatter. See Table 4.2.

No information on pump efficiency, nor of the efficiency of the drive system connecting the pump with the motor was given. No data on the power output of the Briggs & Stratton engine while pumping was given. Consequently, it would be difficult to estimate the fuel consumption utilizing theoretical considerations. The available IRRI data indicates that fuel consumption varied between .95 and 1.6 litres per hour. The mode was 1.5 litres per hour which occurred under a wide range of discharges. For this study the fuel consumption of a gasoline driver of this pump will be assumed to be 1.5 litres per hour under all discharge conditions.

5 HP DIESEL ENGINE COSTS

Source - Petter Diesel

Replacement Costs

Large Lot Prices

Petters AB-I 5.5 Horsepower	$560.00
Cyclonic Air Filter	$ 19.00
Fuel Filter	$ 17.31
Shipping & Insurance (estimate)	$ 20.00
	$616.31

Maintenance

Overhaul Parts - crank, cylinder, barrel, piston, rings, etc.	$400.00
Labor - 12 hours x $1.50	18.00
	$418.00

Major overhaul every 2500 hours	
Maintenance cost per operating hour	$ 0.167

Wearout life - 7500 hours

Note: the cyclonic air filter will substantially increase the wearout life of this engine. This filter is specifically designed to be used in high dust areas. Intake of dust into a small engine is the primary cause of early engine failure.

Oil Consumption - 0.042 pints/hour

Consumption per 100 hours ≃ 2.1 quarts

Fuel Consumption - 1.25 litres/hour

FARYMAN DIESEL COSTS

Replacement Cost

Faryman 4.8 HP	$600.00
Shipping & Insurance (estimated)	$ 20.00
	620.00

Maintenance

Overhaul	
Parts - 1/2 purchase price	$300.00
Labor 12 hours x $1.50	$ 18.00
	$318.00

Major overhaul every 2000 hours

Maintenance cost per operating hour = $ 0.159

Wearout life 6000 hours

ELECTRIC MOTOR COSTS

Source: G. E.

1. Small Motors -

    15000 hours wearout life

    repair cost - none

    maintenance costs - none

Note: All bearings are sealed. No lube or grease for the motor is necessary.

2. 3 HP Motor - TEFC, 3450 rpm

    wholesale price - $222

3. The efficiency of the electric motor was assumed to be 79%

CRISSAFULLI PORTABLE PUMP COSTS

Replacement Costs

The Crissafulli pumps were priced as a package which included a driver provided by the Crissafulli company. The replacement costs used in this analysis are 60% of the list rates. This discount represents the usual discount for large orders.

Pump Type	List Price	Replacement Cost	Shipping Cost
2 inch gasoline/7HP	$1175	$705	$20
2 inch electric/3HP	$1270	$762	$20
2 1/2 inch electric/3HP	$1300	$780	$30
4 inch electric/10HP	$5800	$3480	$300
6 inch electric/10HP	$5880	$3528	$300
8 inch electric/15HP	$6660	$3966	$300

Note: The prices for the 4 inch pumps and larger are for the knockdown model and in the case of the 6 and 8 inch pumps represent pump/driver configurations that must be special ordered. Crissafulli diesel power units for the pumps ran from a list of $13,382 to $16,326.

Repair Costs

The repair costs for the 2 and 2 1/2 inch electric pumps were estimated to be $0.02 per hour. The repair cost for the 2 inch gasoline pump was estimated to be $0.20 per hour. These costs are comparable to the repair costs of the IRRI pump.

The repair cost for the 4, 6 and 8 inch electric pumps were estimated to be $0.03, $0.03 and $0.035 respectively per hour of pumping. These relatively low repair costs are a reflection of a simple and sturdy pump design and the inherent advantages of totally enclosed fan cooled electric motors. Additionally, labor and material charges in Egypt are extremely low.

Maintenance Costs

The only maintenance costs associated with the electrically driven pumps was grease for the pumps. $1.00 per 100 hours of operation was the estimated cost of the grease required. The gasoline powered pump was estimated to use $1.00 of grease and $2.00 of oil per 100 hours of operation.

Wearout Life

The wearout life of the electric pumps was assumed to be 15000 hours. The wearout life of the gasoline pump was assumed to be 2000 hours.

8 INCH FIXED AXIAL FLOW PUMP COSTS

Source - Peabody Flowway

. 8" F & F axial flow

1779 rpm

950 gpm

Static lift 2.5 ft

Losses 0.5 ft

2 HP input required

Pump Price	$3540	
3 HP Motor	$ 660	Efficiency 79%
Right Angle Drive	$ 250	Armarillo gear - #20 (Stub Lavender)
Total	$4450	

Pump Weight	700 lbs	3' x 3' x 6'
Motor Weight	79 lbs	2' x 2' x 2'
Drive Weight	145 lbs	22" x 15" x 20"

10 INCH FIXED AXIAL FLOW PUMP COSTS

Replacement Costs - Large Lot Prices

1. Diesel Powered Unit

Petter 5 HP Diesel	$ 616
Amarillo Right Angle Drive	$ 250
Cascade Pump	$3140
Total	$4006
Shipping	$ 350
Site Preparation	$ 300

2. Electric Powered Unit

Cascade pump with a 3 HP electric motor	$3800
Shipping	$ 300
Site Preparation	$ 300

Repair Costs

Repair costs of $0.03 and $0.167 were assumed for the electric and diesel powered pumps respectively.

Maintenance Costs

Grease costs of $1.00 per 100 operating hours were assumed. The oil cost for the 5 horsepower diesel was estimated to be $2.10 per 100 operating hours.

Wearout Life

A wearout life of 7500 hours was assumed for the diesel powered pump while a wearout life of 15000 hours was assumed for the electric powered pump.

Fuel Consumption

The diesel engine was assumed to consume 1.5 litres per hour. The electric motor efficiency is 79%.

Table C.1. A Summary of the Pump Data Utilized in the Economic Analysis

Pump	Sakia	Sakia	Sakia	IRRI	IRRI	IRRI
Driver	Buffalo	Cow	Buffalo	5 HP	5 HP	5 HP
Pump Price (LE)	550	550	550	123	123	123
Driver Price (LE)	-	-	-	115	140	616
Shipping Costs (LE)	-	-	-	18	18	20
Installation Costs (LE)	-	-	-	-	-	-
Wearout Life (hours)	15000	15000	15000	2000	2000	7500
Engine Efficiency (%)	-	-	-	12	12	12
Fuel Type	-	-	-	gas	kerosine	diesel
Fuel Consumption (Litres/Hr)	-	-	-	1.5	1.5	1.25
Fuel Cost (LE/Litre or LE/kwH)	-	-	-	0.237	0.273	0.239
Animal Energy Cost (LE/Hr)	0.208	0.129	0.129	-	-	-
Repair Cost (LE/Hr)	0.01	0.01	0.01	0.20	0.20	0.167
Oil Cost (LE/100 Hr)	-	-	2.0	2.0	2.10	
Grease Cost (LE/100 Hr)	0.25	0.25	0.25	1.0	1.0	1.0
Taxes, rent, permits (LE)	5.0	5.0	5.0	5.0	5.0	5.0
Interest (%)	13	13	13	13	13	13
Operator Cost	0.05	0.05	0.05	-	-	-
Discharge (m^3/Hr)	108	54	72	182	182	182
Pump Efficiency (%)	45	45	45	50	50	50
Static Head (meters)	0.75	0.75	1.00	0.75	0.75	0.75
Dynamic Head (meters)	0.85	0.85	1.15	0.75	0.75	0.75

Table C.1. Continued.

IRRI 3 HP	Crissafulli 2 inch/3 HP	Crissafulli 2 inch/7 HP	Crissafulli 2.5 inch/3 HP	Crissafulli 4 inch/10 HP
148	762	705	780	3480
222	-	-	-	-
15	20	20	30	300
15000	15000	2000	15000	15000
79	79	12	79	79
electric	electric	gas	electric	electric
-	-	1.0	-	-
0.03	0.02	0.20	0.02	0.03
0	0	2.0	0	0
5	5	5	5	5
13	13	13	13	13
-	-	-	-	0.30
182	42	42	83	205
40	10	10	10	10
075	0.75	0.75	0.75	0.75
0.75	0.80	0.80	0.80	0.80

Table C.1. Continued.

Crissafulli 4 inch/20 HP	Crissafulli 6 inch/10 HP	Crissafulli 8 inch/15 HP	Cascade 10 inch/3 HP	Cascade 10 inch/5 HP
4142	3528	3966	3800	3140
-	-	-	-	866
300	300	300	300	350
-	-	-	300	300
15000	15000	15000	15000	7500
79	79	79	79	12
electric	electric	electric	diesel	electric
-	-	-	-	1.5
0.192	0.192	0.192	0.192	0.239
-	-	-	-	-
0.03	0.03	0.035	0.030	0.167
0	0	0	0	2.10
1.0	1.0	1.0	1.0	1.0
5.0	5.0	5.0	5.0	5.0
13	13	13	13	13
0.30	0.30	0.30	0.30	0.30
247	358	454	340.5	340.5
10	15	17	69	69
0.75	0.75	0.75	0.75	0.75
0.80	0.80	0.80	1.00	1.00

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 x 10^4	247.105	238.048	100.000
1 sq. mile	259 x 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
= drain (vb.), or drainage. See also masraf, (n.)

EGYPT WATER USE AND MANAGEMENT PROJECT

PROJECT TECHNICAL REPORTS

NO.	TITLE	AUTHOR
PTR#1	Problem Identification Report for Mansuriya Study Area, 10/77 to 10/78.	By: Egyptian and American Field Teams.
PTR#2	Preliminary Soil Survey Report for the Beni Magdul and El-Hammami Areas.	By: A. D. Dotzenko, M. Zanati, A. A. Abdel Wahed, & A. M. Keleg.
PTR#3	Preliminary Evaluation of Mansuriya Canal System, Giza Governorate, Egypt.	By: American and Egyptian Field Teams.
PTR#5	Economic Costs of Water Shortage Along Branch Canals.	By: A. El Shinnawi M. Skold & M. Nasr
PTR#6	Problem Identification Report For Kafr El-Sheikh Study Area.	Egyptian and American Field Teams.
PTR#7	A Procedure for Evaluating the Cost of Lifting Water for Irrigation in Egypt.	By: H. Wahby, M. Quenemoen, and M. Helal.
PTR#9	Irrigation & Production of Rice in Abu Raya, Kafr El-Sheikh Governorate.	Compiled By: R. Tinsley.
PTR#10	Soil Fertility Survey in Kafr El-Sheikh, El Mansuriya and El-Minya Pilot Projects.	By: Zanati, Soltanpour, Mostafa, & Keleg.
PTR#11	Kafr El-Sheikh Farm Management Survey Crop Enterprise Budgets and Profitability Analysis.	By: M. Haider & F. Abdel Al.
PTR#12	Use of Feasibility Studies in the Selection and Evaluation of Pilot Studies for Alternative Methods of Water Distribution in Egypt.	By: R. McConnen, F. Abdel Al, M. Skold, and G. Ayad.
PTR#13	The Role of Rural Sociologists in an Interdisciplinary, Action-Oriented Project: An Egyptian Case Study.	By: J. Layton and M. Sallam.

AUTHOR	NO.	TITLE
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