Mid Project Report
Volume IV

Appendix C
Technical Articles

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Definitions

<u>Meska</u> - Generally speaking a "meska" is a privately owned tertiary canal serving 30 to more than 200 feddans.

<u>Marwa</u> - In traditional irrigation systems a "marwa" is a farmers constructed field ditch serving a number of small (say 6 meters x 6 meters) basins.

<u>Sakia</u> - A water wheel, generally powered by animals for lifting water from meskas to fields.

<u>Tambour</u> - A water lifting device usually powered by human labor, also called "archemedian screw."

CONVERSION FACTORS[1/]

Area		Sq. meter		Acre		Feddan		Hectare
1 feddan (fed)	=	4,200.8335	=	1.03805	=	1	=	0.42008
1 acre	=	4,046,856	=	1	=	0.96335	=	0.40469
1 hectare (ha)	=	10,000	=	2.47105	=	2.38048	=	1
1 sq kilometer	=	100×10^4	=	247.105	=	238.048	=	100
1 sq mile	=	259×10^6	=	640	=	616.4	=	259

Water Use:

1 billion m^3	= 810,710 acre-feet
1,000 m^3	= 0.81071 acre-foot = 9.72852 acre-inch
1,000 m^3/feddan	= 0.781 acre-foot/acre = 9.372 acre-inch/acre
	= 238 mm of rainfall

Commodity Measurements

	Egyptian Unit	Weight in kg	Weight in lbs
Cotton (unginned)	Metric kantar	157.5	346.92
Cotton (lint or ginned)	Metric kantar	50.0	110.13
Sugar, onion, flax straw	Kantar	45.0	99.12
Rice (rough or unmilled)	Dariba	945.0	2081.50
Lentils	Ardeb	160.0	352.42
Clover	Ardeb	157.0	345.81
Broadbeans, fenugreek	Ardeb	155.0	341.41
Wheat, chickpeas, lupine	Ardeb	150.0	330.40
Maize, Sorghum	Ardeb	140.0	308.37
Linseed	Ardeb	122.0	268.72
Barley, cottonseed, sesame	Ardeb	120.0	264.32
Groundnuts (in shells)	Ardeb	75.0	165.20

Other

1 ardeb	=	198 liters = 5.62 bushels (U.S.)
1 ardeb/feddan	=	5.41 bushels/acre
1 kg/feddan	=	2.12 lb/acre

[1/] From Contemporary Egyptian Agriculture, by H. A. Tobgy.

FARM SYSTEMS MANAGEMENT

BY

Dr. Hassan Wahby - Aly*

(for the workshop to be held in New Mexico)

August 11-23, 1980

As irrigation water plays a major role in agricultural production, attention must be given to its management. There are many conflicting ideas regarding its management and effect, upon crop yield. Excessive use of irrigation water does not necessarily mean high production, although it has been proven, farmers generally do not agree with stated evidences. As a matter of fact, high crop yield can only be met if one manages efficiently all resources and elements involved in the system. Soil and water conservation are the main elements in the system, and must be fully utilized before achieving optimum production. Farmers' attitudes seem to be a major constraint to agricultural production concerning this point. This is due to their culture, traditions, experience, and behavior differences from one place to another, even in the same country. Management concepts cannot be imposed upon farmers unless they do believe in it, and this represents the most difficult aspect of implementing water management programs. Sometimes, farmers respond to the extension services offered to them by competent governments, authorities, and international

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agencies for development if they can see and try different practices as put forth by the goals of such projects. However, the objectives of such projects cannot be accomplished unless a very good farming system is adopted to maintain the soil and control water application to farms. Such a system will best meet the requirements of the plants over their various growing stages. It is important to design a farming system that can be operated efficiently with least cost. At the same time, it should be flexible in order to give marginal opportunities to decision makers to adopt policies and make modifications for implementation according to the constraints that may occur. A pay-off system is not necessarily of a modern type. The system adopted will depend to great extent on the available resources of manpower and energy along the costs of operation and maintenance. In order to implement such a system with success, it should be designed to provide quick service on highly technical grounds to ensure efficient operation. This needs mutual cooperation and trust among the scientific people working in this field with farmers. In other words, an interdisciplinary group of engineers, agronomists, sociologists and economists should be established to work closely with farmers in order to avoid bias and to make appropriate decisions.

Since farm management systems are very complex and challenging, it must attract those competent persons concerned with food production. As population in the world increases rapidly, the demand for food increases. In the last two decades, some countries which have run short of water resources have faced shortage of food and/or suffered from famine and starvation. Such incidents come to attention of the United Nations and interantional agencies to take major role in solving these problems which might threaten mankind. Different approaches, options, and alternatives have been exercised in order to identify problems and look for their solutions. Through experience, it has been found that a highly skilled level of management must be established to lay out the principles and methods of soil and water management on farms in very efficient and economic ways.

In order to upgrade the farm operation for a better crop yield, and in order to design a farming system that pays off in the short and long run, one has to consider the following points:

I From the Engineering Point of View

a. Water Management

In order to satisfy the needs of plants for water over their growing stages, without subjecting them to stresses of any kind, either from shortage of irrigation water or from high water table an irrigation system should be designed to provide them with the proper amount of water before reaching the wilting point. This is in order not to subject plants to stresses, or deficiencies under any circumstances.

The rise of water table from leaching and over-irrigation may adversely affect the farm land leading to a serious loss of crop yield from salinity or poor aeration in the root zone un improved through proper irrigation and drainage practices. Generally, the effect of a rising water table has been to alter cropping patterns and reduce yields rather than to cause the land to be abandoned. Therefore control of the water table is essential so as not to permit the water table to be maintained in the root zone of plants. Under conditions of excellent water quality and the absence of soil salinity, high water tables may be tolerated to provide water for plants provided aeration requirements are satisfied.

In practice, a thorough knowledge and experience in knowing the impact of each of the following items on the system, and how they are interrelated to each other are needed:

a.1. Availability of irrigation water in quantity and quality.

a.2. Type and characteristics of water courses with respect of conveyance and distribution from main canals to the small ditches.

a.3. Conveyance losses in the network of water courses.

a.4. Type and cost of methods of irrigation.

a.5. Condition of water table and its fluctuation with time.

a.6. Conditions and kind of aquatic weeds if they exist in watercourses.

a.7. Stability of the open channels.

a.8. Type of field irrigation, basin, border, short or long furrows.

a.9. Field irrigation efficiency.

a.10. Practice, attitude, behavior, and cooperation of farmers.

Proper management plays a significant role in designing drainage systems. Under conditions of the absence of soil salinity and high quality irrigation water, the need for drainage systems may be diferred or costs greatly reduced for such systems. This is a good investment and saves a lot of the capital amount which is to be spent to meet drainage requirements.

When the water table is controlled; aeration can be maintained for plant roots, which results in an increase in the rooting zone permitting the plant to flourish, thus creating the potential for high yields. However, particular attention should be given to the rise of water table, when the soil water contains a moderate to a high degree of salts which in turn may be detrimental to the crop yields. Therefore, proper application of water in appropriate amounts combined with other good management practices provides a reasonable and economical drainage depth.

II From the Agronomy Viewpoint:

An objective of improved irrigation water management is to increase crop yields not only through engineering practices, but also in combination with good agronomy practices, that must be taken into consideration and jointly implemented. These agronomic practices include proper plant stand density and selecting good varieties of seed, maintaining proper soil fertility, using proper mechanization and controlling pests.

Pest Control:

The control of major field crop insects and pests during the plant growing stages is of paramount importance to optimum yields. In fact, there are many plants, such as cotton, corn, rice, wheat barley and sugarcane if not put under pest and insect control, during their growing stages, their yeilds will be considerably decreased. There are many countries where the economy depends entirely on agricultral production. Attention should be given to control of these insects at the proper time. Wherein the national economy is saved from serious loss.

Insect and Pest Control Measures:

Insects and pests control measures differ according to the kind and variety of crop grown. As regards cotton, for example, early plowing of fields is essential in order to expose the soil to the sun heat for the reasonable time to become dry before sowing. The use of chemicals as insecticides and pesticides has proved to be effective as a relevant control measure applied in infested fields through spraying. However, field observations have shown that the application of some kinds of chemicals year after year produces an immunity with certain insects and pests. Therefore, laboratory and field experiments should be made from time to time to ensure the effectiveness of chemical insecticides and pesticides and their suitability for usage.

Weed Control:

Farm and watercourse weed consume considerable quantities of water and creates problems that hamper high crop yield. In farms, weed cause a false plant density and consumes much of the plant nutritive elements and water in the soil. Furthermore the existence of weeds on farms and watercourses increases the application time of irrigation and creates a rough boundary for water distribution on fields. Proper weed control well permit good water management and an efficient water distribution system.

Fertilizer application:

The impact of fertilizers on crop yield is well recognized. However, water and fertilizers used in proper amounts and at the proper time will bring about economic utilization of resources

Through the application of excessive irrigation water some lands may have their soil fertility reduced due to excessive leaching and percolation to the water table. For example, low soil fertility occurrs in Upper Egypt, where formerly the basin irrigation system was to be practiced. Farmers are accustomed to excessive applications of water and do not recognize the advantages of the new perennial system they are now using. On the other hand, soil alkalinity has increased on some lands due to poor irrigation practices. As a result of this, some lands have become alkaline. Consequently, this needs soil amelioration for reclamation, and this really represents a loss of capital, money and time.

Land classification surveys are essential for providing reconnaissance soil information for cultivated areas and detailed soil and land information on the specific areas selected or proposed for development.

Very valuable information regarding soil conservation always furnishes a basis for estimating the length of time required for land reclamation in the proposed area.

To build the soil fertility, more attention should be given to nutrient balance and micronutrient requirements, and the addition of organic manures.

Agricultural Mechanization:

Mechanization is an important means for raising the productivity of the agricultural resources already available and reducing production costs in so far as due regard is paid to the socio-economic conditions of the country as well as the availability of energy and labor charges for the operation of machinery. There is no doubt that the introduction of mechanization in farming system, simply increases the efficiency of operation and maintains fields levelled for better management and production. It has been found that the use of surface irrigation on uneven land leads to low germination levels. Thus utilization of farm machinery in preparation and harvesting always pays off praticularly when labor charges are high.

The success of mechanization depends on the availability of the requisite number of well trained and skilled personnel to operate, maintain and repair the machinery.

The Generalization of Agricultural Mechanization:

The generalization of agricultural mechanization is, in fact, the role of the State in making mechanized services available to the growers, especially to those who are not able to possess such equipment, to achieve this end, the following measures may be recommended:

1. Encouraging individual growers through extension to make more use of machinery.

2. Supplying machinery to existing agricultural cooperatives at reasonable prices and encouraging the formation of others while giving them the necessary guidance in selecting the apropriate type of machinery.

3. Encouraging the companies to provide mechanized services for the growers, especialy where cooperatives do not exist.

However, it should be noted that labor charges have raised as a result of the development of civilization. This is besides, fuel prices which reached a climax on a world scale. All this acts as a constraint for the generalization of agricultural mechanization, though it pays off and provides a full automation system characterized mostly by quick performance, accuracy, easy and good farm management; thus contributes largely to raising the production yield to a maximum.

Soil and Land Improvement:

A suitable soil is one of the basic elements upon which rests crop production, as it provides the requisite environment for germination, growth and fruition. Increased attention should be directed to studying soil chemical and physical properties as well as problems of its improvement, in order to provide the appropriate environment for the plants.

The successive cultivation of field crops in certain areas has led to decreasing soil nutrient contents and consequently to affecting the mineral balance. In the meantime, the misuse of irrigation water has led to the rise of the ground water table and the increase of soil salinity, and alkalinity; thus creating many problems.

Industrialization of Farm Production on Site:

The main problem confronting any developed country arises from the excessive pressure of population on the land. There are but two alternative solutions to this problem: either to make available more land, which unfortunately naturally limited, or to provide other means of employment in order to absorb the surplus population. Here, industrialization becomes a necessity, as agricultural development cannot alone solve the problem of overpopulation, not to mention the necessity of diversifying the economy.

Industrial and agricultual developments are quite often viewed as competing with each other. The contrary is in fact true, for they are both complementary to each other. This complementary role should be taken into consideration for those countries embarking on economic development to attain sustained and broad-scale results. A developing agriculture with a population enjoying a better standard of living will provide an expanded market for industrial products, whether they are consumer goods or agricultural requisites. Moreover, it will be able to provide raw materials for developing industry as well as food for the growing industrial population. On the other hand, a progressing industry gives a tremendous impetus to the development of agriculture because of the increased demand on the various agricultural products.

Nevertheless, the contribution of various industries to the development of agriculture is not one and the same. Some types of industries assist agricultural development, while others do not. Examples of the first type are the processing, manufacturing and power industries. Processing industries improve the value of raw materials prior to their export. These may create new markets for various agricultural products, provided that the processed product meets the standard of quality requisite for its being competitively marketable abroad. An opposite type is the the extracting industires. These do not benefit agriculture in the same way as the first group since they are producers of raw materials, and consequently they do not consume agricultural products in the same sense.

Therefore, it will be more benefitable to the country if manufacturing and processing industries that depend on agricultural raw materials take place on farm sites, because this saves time as well as transport expenses of such materials to factories established in cities. In the meantime, industrialization of farm products on site encourages settlement in fields and avoid immigration to cities, particularly the capitals which are suffering from overpopulation. Moreover, this will be for the interest and welfare of farmers themselves, as it will increase their income resources and offer them industrial training besides their knowledge of agriculture. The industrialization of farm products on site may include cotton spinning and weaving, wool and other fibres, pulp, paper, wood, leather training, sugar manufacturing, fruit and vegetable processing, fats, oils and dairy indsturies. This is besides development rural industries and handicrafts. These industries engage full and prat-time rural wokers. However, they are now handicapped by the inefficiency of the implements and tools in use, the lack of technical knowledge, the non-availability of suitable raw materials and the lack of both financing and marketing facilities. Poultry and honey-bees breeding are also profitable for the farmres.

Specialized units should be established for the preparation of local raw materials needed by the various industries and the training of the largest possilbe number of workers in order to increase their productivity. These units should be located in the rural areas and include wool spinning for carpets and rugs, flax spinning as well as for dyeing and preparation of cloth. This is besides molasses production, straw work and perfume manufacture. A special organization should be established to look after the promotion of these industries, including the provision of technical advice, credit and other necessary facilities and services.

Water Management and Farming Systems From the Ecological Point of View:

Perhaps the most effective factor, which is of paramount importance and should be given priority in the evaluation and development of water management and farming systems, is the environmental conditions pervailing in a region or country.

It is scientifically known that the age of any praticular form of life is the age of that particular environment in which it lives; and as environment changes throughout the age, so do the different forms of organic life which live in its midst. To attempt to live unadapted to environment is to perish, and much has perished. Adaptation is evolution, and where adaptation refuses to function, evolution stops. This principle is almost certainly responsible for the change and development of all modes of life on earth. Nature is constantly adapting organisms to environment; but perfect adaptation can never be attained. It is nature which supplies variation. Environment, under the guise of natural selection is the sole agent which dominates and determines variation, sometimes discarding, sometimes perpetuating.

In our modern age, man is trying to modify and develop all methods of his life, including those which he practices in irrigation and farming without due attention to environment. A certain developed method or system of irrigation, or farming used in one country or region could not be or difficult to be applied in other places. The reason for this is the differences of environments in which the users or growers live. They are subject to their traditional methods which they are accustomed to use during the elapse of times.

Therefore, it is difficult to change such traditional and conventional methods, unless through complete convincement on their part, though this will be for their mere interest and welfare, as it will increase their yields of agricultural production. Because farmers,users and growers live in rural places, i.e. with nature, their conception of variation in their traditional practices of irrigation and farming may be subject to external direction or directed from within. Therefore, the change of the actual practices of irrigation and farming should continue smoothly in stages along a course of progressive evolution and development. Certain methods may fail and discarded; others may show their success and continue to evolve.

In the meantime, soil and weather conditions as well as water resources differ from one place to another. What could be applied in a certain place may not be applicable in others due to the difference of these elements. Moreover, the socio-economical conditions, education and culture of famers and growers and their ability to adhere to the extension services to be offered to them by the government and concerned agencies are of great significance to planners and design-makers of relevant development projects, as these elements are the bases of the successful programs to be scheduled.

CONCLUSION

From the foregoing, it is evident that the development of farming systems has now become of vital importance to the survival and welfare of humanity and is the keystone to ensure food security in the coming years for the whole populations on earth. In the menatime, it is profitable to farmers and national economics, as it raises their standard of living and increases the government's revenues. It is therefore hoped that all the interrelated and complicated factors and elements mentioned above be well evaluated and appriased before the implementation of any irrigation or farming development project, due to their significant role and value in attaining successful results and realizing the goals intended therefrom.

Owing to food shortage expected to take place in the whole world in the coming years, due to the excessive increase of population, it has now become imperative to develop farming management systems and water management projects on a large scale to increase agriclutral production to a maximum to avoid serious famine and starvation in future and to accomplish benefits which pay off with reasonalbe internal rate of return for the welfare of farmers and nations as well.

Social Dimensions of Egyptian Irrigation Patterns[1/]

Edward Knop, Mohamed S. Sallam, Sheila Knop and Mona El-Kady[2/]

ABSTRACT

The paper begins with an overview of Egyptian irrigated agriculture patterns, including irrigation system operations and farm-level water management practices. A brief comparison is then made between what observed irrigation management patterns are and what, ideally, they should be from the perspective of irrigation technical experts familiar with Egyptian conditions. A sampling of those patterns identified as problematic are then subject to empirical examination for social dimensions which help to explain them and constitute factors in their solution. The examination is based largely on primary data collected from 75 case study farmers in three field areas representative of Egypt's differing agricultural and sociocultural conditions. Major analytic emphasis is given to correlations between a broad range of sociological variables and various specific farmer irrigation practices. A summary of implications for improving Egyptian irrigation patterns concludes the paper.

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[2/] Paper presented at the 5th World Congress for Rural Sociology, Mexico City, August 1980.

SOCIAL DIMENSIONS OF EGYPTIAN IRRIGATION PATTERNS

Edward Knop, Mohamed S. Sallam, Sheila Knop and Mona El-Kady

This paper deals with sociocultural factors influencing farmer's irrigation practices in three representative "old lands" agricultural areas of Egypt's Nile Valley. In a sampling of instances where there is variation among farmers in how "ideal" their present irrigation practices are, sociocultural and situational factors are considered for explanations of the "more ideal" and "less ideal" farmer practices. The purpose of such an analysis as this is to identify sociocultural factors that can be modified by experimental programs and government policies in support of more ideal irrigated agricultural practices in Egypt and other arid areas to which the generalizations might apply.

This paper is a short summary of some social background and situational factors relevant to an irrigated agriculture development project underway in Egypt. The report is based on: 1) personal insights of project field staff, 2) secondary data and reports, and 3) interviews of 75 case study farmers representative of those living in the three areas of project field work. The larger project is an interdisciplinary effort to improve farm level irrigation and agronomic practices through problem identification/solution applied research to be followed by rural neighborhood level extension/demonstration pilot programs in several target areas of Egypt.

THE EGYPTIAN CONTEXT

Almost all agriculture in Egypt is irrigated farming. About half of the nation's 40 million population are engaged in agriculture in the narrow, fertile Nile Valley, where improvements in agricultural practices have been underway for many years. Egyptian farmers are not traditional peasant farmers for the most part, but rather small-scale commercial farm operators extensively influenced by an elaborate national program of agricultural production and development.[2] Presently, they have reached a very high level of agricultural production by world standards.[3] But rapid population growth, relatively little "choice land" and limited supplies of other agricultural production inputs, including water, calls into question whether future consumptive needs in the nation can be met domestically. Additionally, there is evidence that unenlightened management of presently ample water resources is leading to the loss of some of the best Nile Valley agricultural land to water-logging and salinization, placing the nation's agricultural sufficiency in double jeopardy.[4]

In a nation where "food is life" in both physical and socioemotional senses, something must be done while there is still lead time. The Egypt Water Use Project, jointly sponsored by the Government of Egypt and U. S. AID, operates from within the Egyptian government to enlighten and influence farmers toward practices that are more ideal in the eyes of irrigated agriculture experts. It is noteworthy, here, that tough "farmer control" approaches as well as elaborate "high technology" approaches are being perceptively resisted in favor of the gentler, simpler "grass roots" development approaches emphasizing improved basic technology and farmer practices. There is awareness, as well, that improvement in/of institutional services supporting irrigated agriculture development must accompany self-help development efforts.

Much of the sociological literature on irrigated agriculture development has focused on the structure and functioning of support institutions.[5] Most attention here will be given the intermediate analytic level of farmers' more-or-less ideal irrigated agriculture practices, but with explanatory insights coming from the higher level of social system's operation, and from the lower level of farmer's cognitions, attitudes and values. Sample issues of farmer's practices to be analyzed have been chosen as representative of different facets of relevant farm operation.

DESCRIPTIVE OVERVIEW OF IRRIGATED AGRICULTURE PATTERNS

The typical Egyptian farmer operates small plots of land (average size: two to three acres, in several separate pieces), all or much of which he or his family owns. Cropping is normally continuous, allowing two or three harvests per year. Major summer crops include cotton, rice, corn and sugar cane; major winter crops include wheat, flax, vegetables, beans, citrus and clover. Summer crops, considered the more important ones, are largely subject to assignment and control by local-level councils implementing national production and policy guidelines of the Egyptian Agriculture Ministry.

The irrigation system in Egypt regulates the delivery of Nile water (stored in Lake Nasser, behind the Aswan High Dam) through a physical conveyance system, a system of water law, and an administrative system. Since the later 1960's, most old agricultural land has been under perennial irrigation, with water delivery being "rotated" in on/off cycles which vary in length (i.e., 4/4, 7/7, 5/10 days) between locations and times of the year according to soil texture, crop patterns and climatic conditions. In most areas, water must be lifted a short distance from the conveyance channel to the field level, consistent with government provisions to discourage excessive water application and control water table levels. Traditionally, the Irrigation Ministry's jurisdiction extends from Lake Nasser storage to the end of public canals, and includes responsibility for system design, construction, management, maintenance and enforcement of irrigation law (in conjunction with other civil authorities). Water, under Islamic tradition, is a free commodity to be shared fairly and equitably by all with an established use right and needs which provides the principle underlying government water codes.

Because area and local farmer circumstances, as well as traditions, differ somewhat throughout Egypt, the effort to develop and manage a fair, universal body of law regulating irrigation practices is difficult, and often results in common extralegal or illegal irrigation practices at the local level. A well-developed national research program defines many technically ideal water management practices which are incorporated into periodic revisions of the water law, but only extension education programs can eventually ensure general understanding and acceptance of these ideals at the village level.

Other's experience and past research on farmer irrigation practices in Egypt suggest:[6]

1. Farmers often apply greater amounts of water to fields than is optimal for crop yields and good soil management, in part because a) they do not understand non-visible soil-plant-water relationships occuring beneath the earth's surface, b) water is available and they do not want to chance stressing crops by under-irrigation, c) they do not appreciate the idea of timing irrigations as well as they might, and d) they are reluctant to deviate from the traditional practice of maximally intensive field flooding, as was practiced during the annual Nile flood before perennial irrigation was possible.

2. Farmer's frequently do not understand or follow appropriate drainage practices, which, in combination with application of excess water, contributes to the accumulation of salinity in topsoil.

3. Farmer's concerns about getting adequate water to crops are prompted by problematic maintenance of public and/or private delivery ditches, often limiting equitable access to water; this absence or improper maintenance of drains is commonly considered the unavoidable cause of water-logging and salinity problems.

4. Farmers generally do not demonstrate much voluntary cooperation in scheduling irrigations along a delivery system, or in maintaining the private portions of the delivery and drainage system, government support of such cooperation has largely taken the form of official coercion when particular situations become quite problematic.

5. Otherwise hard-working farmers often favor "least effort" irrigation and related practices because sufficient water permits them (e.g., avoiding night irrigations and leveling land well, having young children supervise animal-powered irrigations, etc.). In response, the government approaches conservation of water and land productivity by forcing farmers to work harder (i.e., having to lift water, etc.).

SUMMARY OF OBSERVED IRRIGATION PATTERNS

Data from our interviews with 75 case study farmers in three representative regions of Egypt (Minya Governate in Upper Egypt, Giza Governate in Middle Egypt, and Kafr El Sheikh Governate in the central Delta area) show:

1. Farmers often irrigate more frequently than necessary, and often apply more water per irrigation than is ideal. Average numbers and intervals of irrigations per major category of spring/summer crops, and corresponding recommended figures are shown in Table 1.

Table 1. Average number of total irrigation and average intervals per major crop category by farmer's anticipated/actual practice* and expert recommendations

	Farmer's Practice		Expert Recommendations	
	$\bar{X}$ Total Irrigations	$\bar{X}$ Interval (in days)	$\bar{X}$ Total Irrigations	$\bar{X}$ Interval (in days)
Cotton (n = 25)	10.0	16.8	7-9**	14-21**
Wheat, flax (n = 8)	8.4	15.0	3-6**	15-30***
Corn (n = 8)	8.6	12.7	5-7**	12-14**
Sugar Cane (n = 7)	16.0	15.7	10-14**	12-18**
Vegetables melons (n = 9)[1]	18.4	12.1	7-10**	7-15***
Clover (n = 12)[2]	11.6	14.3	4-6**	15-30***
Citrus (n = 1)	6.0	15.0[3]	Variable	10-20***[3]
Rice (n = 11)	unsure[4]	1.5	Flooded	Continuously

*Farmer-reported data.

[1] Includes several multi-season crops like artichokes.

[2] Only full-season berseem included.

[3] During flowering and fruit-development period.

[4] Rice is puddled and kept under constant irrigation, with sufficient water being added recurrently to maintain immersion.

**EWUP Agronomy Staff estimates for single-season crops under normal conditions in study areas.

***C.L.M. Bentvelsen and G.O. Vittenbagaard, "Crop Water Requirements and Irrigation Schedules," Alexandria, ARE: UNDP/FAO, Working Paper No. 3, p. 12 (Table 6, most comparable North Tahrir data).

2. Farmers note reliance on the following criteria for when to begin an irrigation: 67% indicated interval since last irrigation (related to supply rotation cycle) was a consideration: 43% indicated when topsoil appeared dry or developing cracks and another 13% said when topsoil resisted crushing in their hands (both of which, in typcially heavy Nile Valley soils, occurs considerably before the middle and lower root zones are deficient of moisture). Only one farmer of the 75 indicated use of even a simple sub-soil moisture inspection procedure, though this is the most ideal. Sixty-four percent of the farmers noted that plant appearance (e.g., dry looking, limp or yellowing) was a criterion they used, although all of these visual cues usually mean something other than drought-stress. When these cues do happen to indicate under-irrigation, eventual yield is diminished as it is too late to remedy the situation, the plant having been visibly stressed before water was applied.

3. Interviews revealed farmers end an irrigation according to the following criteria: 67% indicated when all the field is covered with water, while the remaining 33% said they stopped when the water reached a point of the field from which it could be drained onto the remainder of the field (the more desirable practice both for water conservation and water-logging/salinity control). Just over one-third also indicated they considered the depth of water on the border of their basins or furrows, most of these (75%) stopping at about five centimeter minimum average depth, although the remaining quarter said about 10 cm. depth was one of their criteria. Usually, given the application intervals and basin irrigation practices followed, less than five centimeters would be ample for heavy soils. No other criteria (length

of time water had been applied, personal convenience, percolation evidence, etc.) were noted. Often the loss of flow in the channel prompts the interruption of an irrigation for part of a day, or even several days.

4. Unlevel fields require the application of excessive water to lower portions so that an appropriate amount can reach higher parts. Rather primitive, but effective leveling techniques are known to all farmers, but require considerable tedious labor. Thirty-three percent of the case study farmers did note some form of land-leveling operation, and 47% indicated irrigating their fields during seed bed preparation to adjust water flows before planting. Most farmers growing row crops furrowed their fields (80%), which often facilitates the even distribution and conservation of water.

5. Ideally, farmers should apply just the amount of water the root-zone will accept, making field drainage unnecessary. If excess water is applied, it should be removed to prevent both super-saturation, causing root rot and evaporation, concentrating salts in the topsoil. Of the case study farmers, 28% indicated they had serious drainage problems and/or inadequate drainage opportunities, and another 14% said they occasionally had drainage problems. Nineteen percent said they did not drain their fields because they applied not excess water. (Most of these were among those who stopped irrigations before water reached the end of the field). Forty-seven percent indicated they drain extra water into collector drains when it is necessary, 30% drain back into the supply channel, and 5% let the excess water evaporate off (impressions are that a much higher percentage do this to a limited extent).

6. Farmers do not have a clear understanding of the concept "water table," even in its popular form, and tend to over-estimate its depth below their fields. The average measured water table in project field areas fluxuates from approximately 60-130 cms, while farmers estimate the water table beneath their land to average approximately 280 cms. Related, and perhaps more important, almost none (1%) of the farmers had a reasonable idea of root-zone water-plant relationships, and very few had an adequate understanding of the causes of water-logging (19%) and salinization (7%).

7. The farmers noted that, of the 75 specific land plots focused on in this research, 12% had problems with water-logging (of which 4% were thought minor or occasional problems) and 22% had salinity problems (12% thought minor or occasional).

8. Most of the farmers believed that they normally received adequate amounts of water (71%), and that the timing of delivery was generally satisfactory (79%). Only 13% indicated they usually got inadequate amounts (7% generally inadequate timing) and another 16% indicated deficient supply during the summer season only (15% inadequate timing). Those on the tail half of minor conveyance channels believed they generally received inadequate amounts of water far more often than others (22% tail to 5% head), although those at the head half more often felt a summer shortage (23% head to 8% tail). There is no head-tail difference concerning timing of delivery.

9. The "inadequate amounts" noted above generally refer to daytime delivery, as water is usually available at night. The Egyptian water delivery system, with its long major canals, is designed for equitable day-night supply; some night irrigation is a design feature of the system,

making infrequent night irrigations a violation of the ideal. Approximately half (51%) of the case study farmers sometimes irrigate at night. The mean relative frequency of night-to-day irrigation among those who sometimes do is 37% of their irrigations (a 19% relative frequency for the entire sample). The predominant condition under which night irrigation is, or would be, practiced is in sufficient day delivery (52%). Other reasons include being busy during the day (9%), the belief that night irrigation is better for their particular crops (19%)[7], a shortage of day labor (4%), etc.

10. Another occasional response to inadequate delivery system supply of water is irrigating with water from drains, an illegal practice which assumes drain water is considerably more saline. Only 3% of the case study farmers indicated using drain water often for irrigation (probably truthful, given the candor of responses to many more sensitive questions in the interviews).

11. One major factor contributing to unsatisfactory supplies of day water is competition among farmers for what is available. Ideally, they are assumed to work out some form of informal arrangement among themselves for equitable access to water along each minor watercourse, but it often does not happen that way. The common rule in Egypt is whoever comes first gets the water as long as it is available at that point of the channel, and others wait their turn. This practice may promote beneficial socializing among farmers, but it imposes particular hardships and inefficiencies on those further down water courses. Equitable voluntary scheduling of turns to water, ensuring a good delivery volume for faster application, is the official ideal, and there are statuatory provisions for forcing equitable access to water.

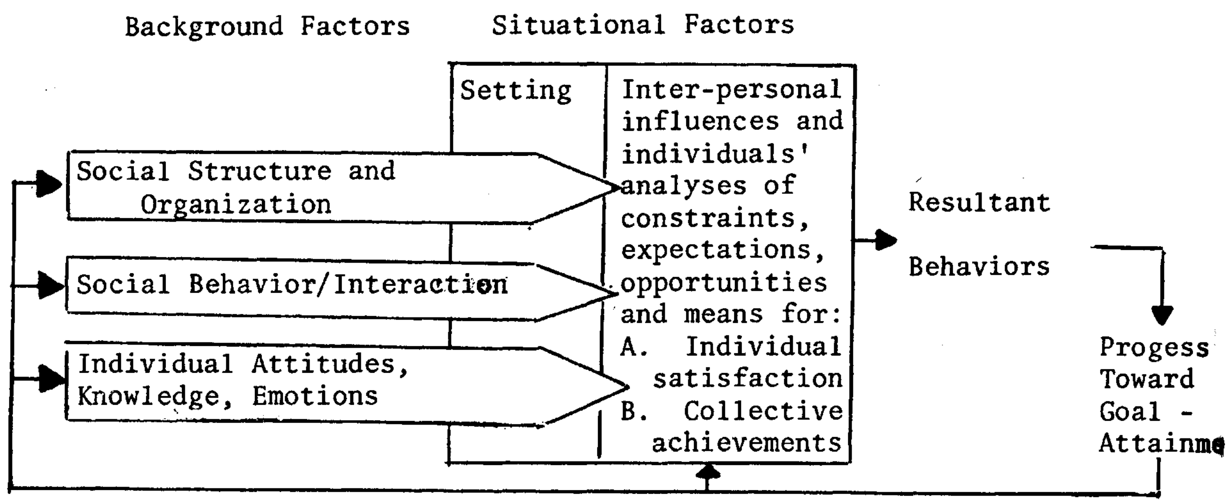
When farmers were asked if they would prefer a farmer-coordinated scheduling of turns or the present "who comes first" system, about half (47%) said they prefer the present system. The most common explanation was that it would be too difficult, or impossible, to reach agreement on a schedule with 50-100 farmers involved, and that trying to enforce the schedule would strain some delicate interpersonal relationships. As well, there are various "understandings" about turns among farmers now: 29% are involved in informal agreements with near neighbors or those sharing ownership of a water lifting wheel and 27% indicated there were informal norms on their ditch to let "busy people" and other "special cases" go first. Two private ditches (5% of the sample) are presently on a loose form of voluntary scheduling.

12. Maintenance problems with supply and drainage channels is another issue involving cooperation among farmers which interferes substantially with water availability and drainage practices. Approximately half (53%) of the farmers indicated they were dissatisfied with the maintenance of public canals and drains, which is a government responsibility, but even more (65%) were dissatisfied with the maintenance of the private ditches and drains serving them, which is their own collective responsibility. Thirty-nine percent specifically acknowledged problems with their neighbors' throwing trash and dirt in the ditches and drains (primarily the larger government ones), and with their taking dirt from the soil embankments of the public and private ditches, causing them to leak water and ruin roadways as well as to inundate crops. The Irrigation and Agriculture Ministries promote voluntary cooperation in channel cleaning and maintenance as an ideal, but also use coercive powers when this is not forthcoming.

Conceptual Model

The "human factor" operating in most topics of interest is difficult to understand and manage primarily because it involves a variety of causal dimensions working in interactive and feedback fashion. One way to view this is summarized in Figure 1.

Figure 1. Basic Social Dynamics Model



Each of the "boxed-in" sections of Figure 1 respresent a major category causal components for behavior. Background factors are "patterned," or persistent across situations and more-or-less integrated within a "level" of social reality as well as between them. These levels of social reality include: (1) the "extrapersonal" level of social structure and organization (i.e., groups, rules, authority, pattern, division of labor, communication provisions, etc., which are characteristics of collectives of people rather than individuals); (2) the "interperonsal" level of mutual influence between people, and individual behaviors that take other people into account; and (3) the "intra-personal" level of attitudes, knowledge, emotions and all such considerations that contained within our individual selves.

The need for this "levels" distinction is two-fold. First, we know that the three levels do not correspond well: often, for instance, rules and actual behaviors do not correspond, or personal attitudes and behaviors do not correspond on a give topic. Therefore the explanation of given behaviors may come more from one level than another and may even involve contradictory guidance from other social levels. Second, when we understand the causes of given behaviors and wish to change them, we realize that different approaches to change are most appropriate for each level. Specifically, (A) structural and organizational change is usually accomplished by enactment of authorities and/or collective decision making and enforcement procedures, whereas (B) social behavior and interactional change is best achieved by informal interpersonal influence in the situation of concern, and (C) change of attitudes, knowledge, etc. is most appropriately pursued by long-term educational approaches that use trusted guidance together with learning experiences in (or duplicating) real-world circumstances.

Background factors provide the "general" explanations for behavior. In addition, the situational component may heavily influence resulting behaviors in a "particularistic" way. For instance, our "normal" behaviors may become altered in particular situations due to constraints, expectations or opportunities of that situation. In times of rapid change, situational factors may be the major ones accounting for our behaviors. Part of the situation involves characteristics of the physical and social setting, including the intrusion of background factors. The rest of the situation is made up of people influencing one another while analyzing what they should and can accomplish in that situation. Background factors like rules, habits, feelings, etc., play an important, and maybe the predominant part in the process, of course.

The individual and collective behaviors that emerge in the situation have results both in terms of progress toward goal attainment and in terms of their "feedback" on the situation and the relevanat background factors. For instance, people seeking to get continuous delivery of irrigation water for their area may in time be successful, but in the process also effect changes in government inspection provisions, their own cooperative irrigation practices, and their knowledge and attitudes about plant-soil-water relationships.

The relative importance of each category of causal component (structural, interactional, attitudinal, situation) varies in time and among topics, requiring exploratory work be done when dealing with a new topic or setting of social inquiry. The theory resulting from related past research is an important guide in such exploratory study, of course, but the deductive approach more typical of social science research is most reliable only after more-inductive exploratory research is completed. This study represents an exploration into social background and situational dimensions of irrigation practices in Egypt. Based on findings, we can relate the Egyptian case to conclusions of studies done elsewhere, giving implications for effective program action among Egyptian farmers.

Background and Situational Factors to Irrigation Patterns

In a specific context like irrigation practices and preferences, the major background factors have been summarized in the two preceeding sections. Consistent with the general conceptualization summarized in this section, we now turn attention to some specific variables of potential relevance for understanding farmers irrigation behaviors and attitudes. There are many conventioned ways to "divide up" causal factors for analysis, as long as variables from all social levels are included. Here emphasis is given to obtaining a broad sampling of background and situational factors thought potentially relevant to improving our understanding of farmer's irrigation patterns. As indicated in the paper's introduction, we concentrate here on variables related to farmers structured backgrounds, behaviors, beliefs, and situations rather than on characteristics of the irrigation system. The rationalle for grouping these variables into the following categories includes considerations of both: (1) conceptual, commonality which they share in helping to explain observed irrigation behaviors and attitudes, and (2) programic commodity they have for later attempts to manage these variables by alternative intervention approaches.

Specifically, we first consider: (I) physical situation factors, like whether the case study plot is located nearer the head or tail of the water delivery channel, and whether the farmers are bothered by problems soils salinity or unlevel fields. These both share characteristics of being physical conditions of the setting and are factors mostly available to technical solution as supplemented by social organization and education.

It should be noted here that a variety of additional physical situation variables were identified for preliminary analysis of the kind reported here (e.g. perceived water-logging, assess to irrigate water supplemental to that provided through the public delivery system, etc.). The variables included in this report are either: (1) those showing the strongest or most consistent empirical relationships with dependent (outcome) variables chosen, and/or (2) those best representing the broad range of types of causal factors we or others thought potentially relevant. The rationalle, then, was to obtain a relatively short listing of differing factors contributing to an explanation of observed irrigation patterns so that these could be more easily compared for their relative contribution and implications for program attention. This practice of initially examining many variables, then reducing them to a short representative list, was followed for all of the following categories of variables.

It should also be noted that we are dealing here with farmers' subjective perceptions of their circumstances rather than our own objective determination of these. Accordingly, a man's fields may rather level or salt-free, but he thinks they should be more-so, whereas another man may be satisfied with objectively less-favorable field conditions. While in general we may assume that greater concern over one's conditions means they are worse than the average conditions he knows, in individual cases that is not necessarily so. More importantly, the farmers' subjective perceptions tell us something about himself as well as his land, which is as important to know when planning intervention strategy as is only the objective characteristics of the setting and situation (which is also being collected).

The second category of variables we examine for their causal contributions are intervening <u>social situation structural factors</u> (II). Included here are such matters as the number of local families the case study farmer or his wife are related to, how many children they have at home, and whether he is a full-time or part-time farmer. In an intervention program, the role of such social structure factors should be understood, but they are obviously not usually matters for experimental manipulation.

Next (III), a variety of individual socio-economic and demographic structured factors are considered. These include the farmer's age and schooling, his present or past status as an official (indicating local respect and influence) and the size of his farming operation and cattle herd (indicating his socio-economic status).

Then (IV), the farmer's integration into information patterns/ and networks is considered. Included here are such structural and interactional variables as whether he gets government extension publications in his home, whether he gets information on periodic canal closures directly from irrigation/agriculture department personnel, the number of others he often turns to for advise on irrigation problems or practices, and how many of these are officials working in a capacity where they should be more expert in this regard.

Because one's intrapersonal satisfaction with, and beliefs about, his local structural and interactional community is a major factor affecting personal moralle and long-term committment reflected in most that is done within that setting, several items examine farmer's evaluations of their community (V). One of these concerns beliefs about the quality of local leadership now as compared with 10 years ago, one concerns beliefs about how integrated or independent local people are, and a third concerns whether the case study farmers are sufficiently dissatisfied and uncommitted to their community that they would like to leave it. Evaluations of one's self (VI) are similar to those community both in terms of confidence and satisfactor with one's performance and the likelihood of extending this to influencing other's circumstances. Items used here include whether the farmer believes he ordinarily avoids behaviors and decisions that in time prove to be mistakes, and

and whether he wishes he had more influence/leadership in local affairs than he now has.

Relevant to both understanding farmers' present practices and the prospects for changing these is their receptiveness to innovations and change (VII). Here several specific matters are included for analysis: the farmer's fatalism (or belief that life's events are controlled by others having the power to do so, making attempts to change one's circumstances futile); whether the farmer believes changes which have occurred are more to his benefit than detriment; whether he is following the increasingly common new practice of paying relatives for their labor; and whether he is engaging in some mechanization of his farming operation.

Finally, we consider a series of farmers' perceptions on appropriate, effective general approaches to improving local living conditions (VIII). Included here are: (A) farmer beliefs about the importance of national policy and programs for realizing actual local development and whether the government's passing new rules requiring behavioral changes actually helps much in the process; (B) whether such educational processes as special demonstrations by experts or expanding and strengthening the effectiveness of formal educational programs operating at the village level are important in the villagers' eyes; (C) farmers' beliefs about the importance of established community processes like informal local leadership, public meetings to influence decision-making processes and good information on events of probable local consequences for local improvements; (D) their views on the potential of self-help organizations and processes, including whether these approaches are valued as useful in rural development and whether they believe more can be accomplished by a coordinated collective approach to local problem solving; and finally,

(E) what role the farmer sees in strengthening tradition values of the Egyptian village, as having increased caring about one another's needs and welfare, and having greater respect and privilege for those who show greatest initiative and effort for community-wide benefits.

Irrigation Dependent Variables

From the range of specific irrigation practices on which interview data have been collected, several have been chosen as dependent (outcome) variables for this analysis.[8] The variables were selected to represent a broad range of irrigation concerns in Egypt, and are ones which show acceptable variation in practice within each geographical area sampled.[9] Each has been chosen to also represent variation in how ideal the farmer's practices are under the prevailing circumstances. When the independent (causal) variables discussed above are related to this range or irrigation topics, it is possible to determine social background and situational factors which provide more general explanations of ideal practices, and those which apply only to a more limited type of desirable irrigation pattern. Knowing this enables us to examine the identified causal factors for ease and priority of experimental program management in the Egyptian setting.

The specific irrigation patterns being analyzed include: (A) whether land leveling practices, however basic, were used in seedbed preparation (subsequently called "field leveling"); (B) if the practice of stopping the application before it reached the end of the field, with excess water being spread to the remainder of the field, was followed during irrigations ("limited irrigation")[10]; (C) the relative frequency of night irrigations practiced ("R.F. night irrigation"); (D) whether the farmer was concerned about neighbors' taking soil from conveyance channel embankments, causing their deterioration ("ditch maintenance concern"); and (E) whether the farmer favored voluntary scheduling of irrigations among neighboring farmers ("scheduling turns").

The interrelationships between these variables are shown in Table 2A and B. The first contains simple bivariate correlations; the second, Verimax rotated factor loadings as an indicator of causal commonality. These findings tell us that there is an underlying common dimension in the empirical working of some variables (leveling and limited irrigations; leveling and the relative frequency of night irrigation), but that other variables operate as relatively distinct, independent phenomenon (concern for ditch maintenance; preference for scheduling turns). Accordingly, we may expect several sets of causal patterns to emerge, suggesting the need for differing specific approaches to their improvement, or a very broad general approach if they are to be addressed together by a single irrigation improvement program. Fuller attention will be given applied implications as sets of empirical relationships are explored.

Analysis of Social Background and Situational Causal Factors

Table 3 summarizes bivariate relationships between the constant set of independent variables and the irrigation patterns being explained. Note that the dependent variables have been arranged with the most strictly technical phenomenon on the left, gradually phasing to the most strictly social phenomenon on the right. Independent variables have been grouped to facilitate interpretation and reference during the following commentary.

Before turning attention to the explanation of specific irrigation practices, several general observations on characteristics of relationships in the data matrix may be made.

Table 2(A): Correlation matrix of dependent variables

	Field Leveling	Limited Irrigation	R.F. Night Irrigation	Ditch Maintenance Concern	Scheduling Turns
Field Leveling	1.00				
Limited Irrigation	-.44*	1.00			
R.F. Night Irrigation	.36*	.15	1.00		
Ditch Maintenance Concern	.40*	.18*	.28*	1.00	
Scheduling Turns	-.13	-.09	-.05	.05	1.00

*significant at or beyond .05 level; n=75.

Table 2(B): Verimax factor loadings for dependent variables

	Factor 1	Factor 2	Factor 3	Factor 4
Field Leveling	-.44*	-.44*	-.05	-.27
Limited Irrigation	-.43*	-.08	.00	-.14
R.F. Night Irrigation	-.16	-.60*	.07	.01
Ditch Maintenance Concern	-.04	-.22	.14	-.58*
Scheduling Turns	.17	.10	.72*	.10

*beyond .40 cutting point.

Table 3: Correlation matrix of selected ideal irrigation patterns with explanatory variables

	Field Leveling[1]	Limited Irrigation[2]	R.F. Night Irrigation[3]	Ditch Maintenance Concern[4]	Scheduling Turns[5]
I. PHYSICAL SITUATION FACTORS					
Head/tail location	-.23*	-.16	.12	-.02	.09
Perceived salinity	.24*	.42*	.21*	.29*	.23*
Perceived adequacy of field levelness	-.41*	.01	-.08	-.23*	.05
II. SOCIAL SITUATION FACTORS					
Number of related families	.13	.04	.07	-.37*	-.09
Number of children at home	.01	.00	.27*	.03	.01
Full-time/part-time farmer	.00	-.10	-.13	-.28*	-.32*
III. SOCIOECONOMIC & DEMOGRAPHIC CHARACTERISTICS					
Age	-.25*	-.23*	.00	-.10	.03
Schooling	-.29*	-.29*	-.22*	-.27*	-.08
Present government/council official	-.33*	-.27*	.01	-.18	.04
Past government/council official	-.27*	-.13	.09	-.10	.08
Total area (feddans) farmed	.02	-.02	.12	.14	-.04
Number of cattle owned	.35*	.19*	.17	.18	-.02
IV. INFORMATION PATTERNS					
Get extension materials for home	-.15	-.06	-.27*	-.21*	-.03
Get closure information from irrig. officials	-.32*	-.31*	-.02	-.13	.19
Number turned to for irrigation advice	.25*	.26*	.16	.27*	-.09
Number ag. officials asked for irrig. advice	-.49*	-.34*	-.29*	-.17	.20*
V. EVALUATION OF COMMUNITY					
(belief) local leadership weaker now	.30*	.13	.01	.29*	-.09
(b.) local people too much go own ways	-.06	-.06	-.38*	-.23*	.05
Would like to move elsewhere	-.37*	-.11	-.42*	-.25*	.10
VI. PERSONAL EVALUATION					
Seldom makes mistakes	-.12	-.28*	-.05	-.18	.13
Wishes more leadership	-.25*	-.23*	-.18	-.21*	.12
VII. RECEPTIVENESS TO CHANGE					
(b.) life controlled by powerful; efforts futile	.39*	.16	-.02	.18	-.27*
(b.) most local changes to his benefit	-.24*	.08	-.04	-.28*	.03
Pays relatives for services they give	.32*	.26*	.15	-.02	.01
Gross index of irrig. ag. mechanization	-.38*	-.35*	-.14	-.22*	.01
VIII. BELIEFS ABOUT APPROACHES TO RURAL DEVELOPMENT					
A. GOVERNMENT RESPONSIBILITY & POWER					
Natl. policy/progs. import. for loc. devel.	.11	.09	-.20*	-.09	-.38*
Government rules forcing change helps	-.39*	.19*	.04	-.20*	.02
B. EDUCATIONAL PROCESSES					
Demonstrations by experts useful	-.22*	-.06	-.22*	-.18	-.02
Better adult & youth education useful	-.30*	-.35*	-.21*	-.09	.10
C. ESTABLISHED COMMUNITY PROCESSES					
Informal local leaders importance	-.37*	-.36*	-.10	-.29*	.27*
Public mtgs. to influence official decisions	-.49*	-.43*	-.14	-.04	.27*
Getting better information in village import.	-.42*	-.36*	-.19*	-.04	.24*
D. ORGANIZATION FOR SELF-HELP					
Making organized local efforts valued	-.24*	-.26*	.18	-.13	.03
More accomplished by collective efforts	.36*	.36*	.27*	.08	.00
E. REINFORCEMENT OF TRADITIONAL VALUES					
More caring about each others'needs valued	.17	.19*	.03	.35*	-.08
More respect/privilege for altruism needed	-.32*	-.31*	-.25*	-.01	.00

*Significant at or beyond the .05 level; n=75.
Note: signs on relationships reflect variable coding practices, not necessarily intuitive causal direction.
[1]Multiple regression coefficient with these variables=.87 (76% of variance explained).
[2]Multiple regression coefficient with these variables=.79 (62% of variance explained).
[3]Multiple regression coefficient with these variables=.82 (67% of variance explained).
[4]Multiple regression coefficient with these variables=.88 (78% of variance explained).
[5]Multiple regression coefficient with these variables=.81 (66% of variance explained).

1. Overall, judging by the number of significant relationships observed in each column, the more strictly technical the phenomenon is, the more thoroughly it is explained by these predominately social variables. It must be noted, however, that these variables, as with most that are collected by interview method, concentrate on individual's characteristics and perceptions rather than on objective structural characteristics of the social setting. Presumably, individual characteristics are most useful in explaining those individual's practices, whereas system characteristics are most useful in explaining collective features of life.

This has two immediate implications. Inferences from personal experience in the setting will be required to a greater extent in explaining the variables which are more social in character. As well, their greater degree of system-level causation implies a greater degree of system-level facilitation in changing them, making this a slower, more complex process. For instance, education, or incentives, or reward-punishment reinforcement, or coercion strategies would probably be more effective in promoting the more technical and individual of ideal practices, but the realization of accomplishments which are more social in character presupposes both the modification of the institutional structure itself and the use of individually-oriented strategies with the subject population as well as within the changing institutional support structure. And since the social context provides better opportunities for effective "backlash," the slower, more "gentle" of individually-oriented strategies are ordinarily required to avoid counter-productive consequences.

2. Note also in Table 3 that few independent variables show significant relationships in most columns. Since these irrigation

practices represent relatively independent phenomenon (note Table 2 and discussion), we would expect different causal variables to explain each, and different approaches to be appropriate for targeted change of each. The closest we come to an exception is in the category of "established community processes." Farmers' belief in the values of informal leadership, getting many people tegether with officials to influence decisions, and getting good information on what is happening locally provides the broadest single basis for explaining ideal irrigation practices. Commitment to developing and reinforcing established community processes repeatedly appears in other analysis of these data to be a particularly significant causal dimension in a broad range of specific topics.

In turning attention to explanations of specific irrigation patterns, Table 3 shows:

<u>Land Leveling</u>

The ideal practice of trying to level one's field during seedbed preparation is associated with: (A) being located nearer the head of a ditch (perhaps because more people pass by there, affecting the cherished "good farmer" image of hard labor and fine-looking crops); (B) thinking one has salinity problems; (C) believing one has adequately level land for good irrigation; (D) being younger; (E) having less schooling (probably fewer other interests and commitments than farming); (F) not being a present or past official; (G) having more cattle; (H) being less likely to get information directly from irrigation officials; (I) being more likely to turn to other farmers for irrigation advice, but less likely to turn to agriculture or irrigation officials for advice; (J) being more likely to think local informal leadership is weaker now than it was 10 years ago; (K) being less desirous of moving from the community; (L) wishing he had more an informal leadership status than he does; (M) being less likely to take the fatalistic position that life is controlled by those with more power than him, so why try changing it; (N) believing that most changes in the village work to his benefit; (O) being more likely to have adopted the newer practice of paying relatives for the use of their animals or labor; (P) having a more mechanized farm operation; (Q) being less likely to value the government's making rules to force changes; (R) seeing the importance of demonstrations of improved techniques and improved education in general; (S) believing effective informal leadership is essential to local development, along with public meetings for speaking one's mind to officials and getting good information on whatever impositions might affect him, (T) believing it important that local people get together to try to solve their problems in their own ways; (U) believing that more can generally be accomplished by collective approaches than by individual efforts; and (V) that more respect and privilege are due those people who work hard for community benefits.

The overall pattern that begins to emerge here is that farmers who bother to attempt leveling their fields for improved water distribution are more proud, independent, conscientious and satisfied farmers who are concerned about the local area's present potentials for collectively resolving their own problems, but committed to this path in preference to collective or personal reliance on government, save for educational benefits. Accordingly, they favor a grass-roots level extension education and organization approach to local irrigated agriculture development. Conversely, those who do not attempt leveling their land show less evidence of these characteristics.

Thus several strategy dilemmas are introduced. Should alternative approaches, such as incentives or government regulations and inspections, be relied upon for those who deviate from the ideal, or should a long-term program be undertaken to first transform the farmers following the less ideal practice into more proud, independent, conscientious farmers so that they will then take more care in their farming operations and be more responsive to extension approaches? If those farmers who now follow the more ideal practice believe less in government assistance and regulation, what would the consequences of such a strategy be on their conscientious farming practices, and why are not those more receptive to government guidance now trying the advisable practice of land leveling? The examination of causal relationships with other irrigation patterns sheds light on the strategy matter.

Limited Irrigations

When considering the practice of stopping an irrigation before water reaches the end of the field, the same basic explanatory theme of the previous practice applies. The most noteworthy differences include: (A) perceptions of how level his land is make no difference; (B) judgements about changes in quality of local leadership and propensity to out-migrate are inconsequential; (C) he is more likely self-confident with his correctness in independent decisions; (D) he is less convinced most local changes are to his benefit; and (E) he is not as likely to value expert's demonstrations of new techniques, but does value general education.

The only real shift in patterning here from the previous irrigation pattern seems to be a greater commitment to self-reliance in farm operations among those who stop irrigations prior to the flooding of entire field. Otherwise, previously discussed patterns generally hold true here also.

Night Irrigation

3. Those who most frequently practice night irrigations are more likely to have these characteristics: (A) some perceived salinity problems; (B) more children at home (it is unclear whether he sends the children to irrigate, or leaves the house to avoid them or having more of them); (C) he is both less likely to receive agriculture extension materials in his home and to turn to agricultural officials for irrigation advice; (D) he is more likely to believe the community is made up of independent people who go their own separate ways; (E) he would not like to leave the community; (F) he does not sense that national level government has as great of value in promoting local development as does lower levels of governments; (G) he does value expert's demonstrations and general education; (H) he desires good information on things having local consequences; (I) his lective efforts are more effective than individual ones; and (J) he feels people who make efforts on behalf of the community do not get the respect or privileges they deserve.

It is noteworthy that location on a supply ditch does not appear related to the relative frequency of night irrigations, although data reviewed earlier showed location was related to whether farmers did or did not sometimes practice night irrigation. The data in this section suggest that those practicing frequent night irrigations are more independent people who do so for their own personal reasons, whereas those who practice infrequent night irrigation are prompted by day water shortages--for which they publicly show resentment. Other relationships noted here also show a tendency toward particularistic causation, where in situational factors play a major role. The self-reliance and independent themes appear again, for instance, but together with emphasis on getting export advise, planning information and local cooperation (all of which he now thinks deficient).

An implication of the more particularistic and situational causal pattern noted here, and to a lesser degree in the two previous irrigation patterns, is that any standardized (university-applied, common-element) plan for improved irrigation practices will be less effective than one which appeals specifically to the particular needs and circumstances of individual farmers, requiring it be more flexible, with multiple alternative dimensions.

Ditch Maintenance Concern

4. Concerns about villagers taking dirt from ditch embankments are associated with these situational and personal characteristics: (A) being more likely to think one has salinity problems; (B) believing one has inadequately level land; (C) having fewer relatives in the community than most; (D) being a full-time rather than part-time farmer; (E) being less likely to received agriculture extension materials; (F) turning to more other farmers for irrigation advice; (G) believing local leaderships has deteriorated and (H) that local people go their own separate, selfish ways; (I) all the same, being less likely to want to leave the community; (J) wanting to be more a leader than he is now; (K) believing most local changes are to his benefit, and (L) being more mechanized in his farm operations; (M) more likely to believe change should not be pursued through laws forcing change; (N) placing of high

value on informal leader's role in local development, and (O) more likely to emphasize people caring more about one another's needs.

As attention turns here to a more-clearly "social" matter of irrigation relevance, we find a response pattern that is sometimes popularly called the "solid citizen" phenemenon. Those adhering to the ideal of not altering ditch embankments, and withing others also would not, appear to be particularly conscientious both regarding their farming and their community. They are rather satisfied with their lot in one sense, their personal circumstances, but less satisfied with how their community is realizing its potentials. They value the role of local leadership, of which they wish they were more a part, and believe local people should care more about their neighbor's welfare. No one would argue with these aspirations. How they can be realized, however, is a more difficult matter, to which attention shall be turned shortly.

Scheduling Turns

5. Those favoring the voluntary scheduling of irrigation turns on minor supply channels have these characteristics: (A) more often think they have salinity problems; (B) are more likely full-time farmers; (C) more often turn to agricultural officials for advice; (D) are more likely to be fatalistic, feeling that life is controlled by people with more power than themselves; (E) less likely value national government's contributions to local development as highly as those of lower governmental levels; and (F) do not consider established community processes effective.

Since this item dealt with preferences rather than actual practices, it demonstrates an important mind-set found in Egypt which wishes for better practices, but shows little initiative to pursue them. Nothing--not even government force for change--holds promise to such people.

Given the importance of grass-roots cooperation and coordination in support of improved irrigated agriculture, the dynamics of this situation deserve brief attention.

Many aspects of ideal irrigated agriculture would be facilitated by greater cooperation and coordination among neighboring farmers, which they seem to recognize. But recognition, while a necessary condition, is not sufficient to get the job done. Other attitudes and social sensitivities often interfere with the realization of cooperative efforts to ease irrigation tasks. The most common pattern is that those most directly and adversely affected (perhaps operating land near the end of a conveyance channel, or on water-logged or saline land), will attempt to solve their problem by themselves--informally first, then more officially if necessary--involving as few others as practical (more often relatives than non-relatives).

Interview data show very little voluntary organization among these case study farmers (only 22% participate in even one voluntary organization arrangement), although there is strong commitment to the idea in principle. Eighty-three percent indicated that the most important things to want come only through cooperation, and nine percent said it was more enjoyable to work on something with others. Data and impressions suggest a deficiency of informal, voluntary leadership initiative is a major factor, as is not wanting to risk antagonizing or offending others sharing the crowded, sensitive village environment. Given a relatively low level of farmer coordination, it is not surprising that there is both reliance on government authorities for solving individual's problems, and reluctance to use this official resource. As well, given the national tendency toward personal independence in such social contexts, there also is sometimes evidence of local resentment toward authorities and the power resources they possess. What sometimes appears, then, as a "least effort" (or laziness) tendency among farmers on matters like scheduling irrigations or coordinating to clean ditches, is more correctly a "least social risk" tendency.

In the majority of farm-operation tasks, the farmer shows much independent initiative, making him a good farmer by world standards, but the irrigation context is one in which many of his practices both directly affect, and are affected by, those of his neighbors, and so are more officially regulated. Such regulation comprises his ability to act in his accustomed informal and independent fashion. In such a "social bind," it is normal to act less and worry more (which, perhaps, causes him to exaggerate signs of potential crop stress, apply more water than needed, be reluctant to drain off excess water when others have been waiting for their turn, etc.).

In neutral contexts, like factual information exchange, the relationships among farmers and with irrigation department officials are good. Recall most said they got good advanced information on periodic canal closures, for instance. In a less-neutral context, however, like being forced to irrigate at night because of inadequate water supply during the day, both neighbors and the government are blamed and resented, undermining cooperative potentials by encouraging social avoidance and fatalism.

Let us briefly consider one other example of difficult social dynamics. Although the first four irrigation patterns examined showed variation in specific causal contributions, a very general pattern seemed to emerge: those farmers most closely adhering to ideal practices were more conscientious persons, oriented toward their community's welfare. They were more knowledgeable, observant and serious about their farming, and interested in learning more about successful practices. They seemed quite realistic and pragmatic about their own and their neighbors' situations, not putting much faith in grandiose or coercive development tactics. Such personal attributes, of course, are "background" ones that cannot be easily, quickly or simply developed in others to make them practice ideal patterns of irrigation or anything else.

What can be done to transform those pressed into a defensive, fatalistic, "low social risk" posture without risking reinforcing these problematic tendencies? Clearly, forcing behavioral compliance with ideals in the hope that these eventually will become habit is not realistic. The most probably result of such an approach is making the target people more alienated, thus more a burden than a benefit to their social and economic systems.

The best alternative is to seduce and/or prod them out of their captivating mind-set into a more hopeful, understanding one. Such only occurs gradually as they are helped to develop new or stronger ideals, and are given confidence that they can contribute to the achievement of those ideals through successful experience and social support. Unfortunately, national government cannot do much directly in this process except help set the stage by structural changes and patiently, persistently support the long-term self-help development process rooted in their places of residence and work.

As matters of supportive policy or approach, appropriate indirect actions might include: (A) promoting education aimed at increasing basic understandings in the target population; (B) ensuring that reasonable incentives accompany invitations to risk, and that some rewards (including social ones) be given for effort and increased understanding, not exclusively for success; (C) developing the social cohesiveness and informal communications patterns within the community and work environments, and then encouraging social pressure as the major prod; (D) assisting and facilitating the development of new local leadership potential, initiative and skill by establishing opportunities and incentives (again, largely social) for new leaders to enter an expanded version of leadership structure; (E) ensuring that institutional support features and regulations undergo regular review and adjustment to keep them consistent with understandings and behavioral patterns developing at the grass roots level. The structural change process normally requires both departures from universal standards and provisions for genuine input/participation from persons throughout grass roots levels (so they may learn the process, experience the sense of personal significance, feel identity with the outcome, and add the benefit of their practical insights to the process).

Obviously, this is a highly complex and extensive undertaking which works in support of various rural development objectives in addition to ideal irrigation practices. It is not necessarily expensive in terms of money required, but is in terms of human skill and commitment. It should be pursued by degrees within local settings, of course, and focused on a realistically feasible number of people, so that they and their gradual success can serve as the best teacher for others. Other narrower approaches to irrigated agriculture development should parallel the institutionalization or expansion of this basic development process, to insure that actions tailored to specific explanatory patterns are forthcoming and that social system continuity is preserved.

For longer-run effectiveness, however, there seems no better option for Egypt than to invest well in the cultivation of the "basic" rural development seeds now being planted around the country by an enlightened national leadership.

Endnotes

1. Edward Knop is Associate Professor of Sociology at Colorado State University, Fort Collins, and former Consortium for International Development Senior Sociologist in Egypt; Mohamed S. Sallam is Senior Sociologist and Training Director of the Egypt Water Use Project, and former Director of the Egyptian Rural Development and Research Institute; Sheila Knop is an Adult and Extension Education Specialist with the Colorado Commission on Higher Education and former consultant with the Egypt Water Use Project in Egypt; Mona El Kady is a Civil Engineer and an Egypt Water Use Project Field Team Leader.

2. Richard Critchfield, Egypt's Fellahin (Parts I, II), Hanover, N.H.: American Universities Field Staff Reports, North African Series Vol. XXI, No. 7, 1976; The Egyptian U.S. Agricultural Sector Assessment Team, EGYPT: Major Constraints to Increasing Agricultural Productivity, Washington: U.S.D.A. Foreign Agricultural Economic Report No. 120, 1976; Michael Field, "Developing the Nile," World Corps 25(1), 1973; James B. Mayfield, Local Government in Egypt, Washington: USAID Report, 1976

3. The Egyptian U.S. Agricultural Sector Assessment Team, op.cit.

4. John Waterbury, "Egyptian Agriculture," Common Ground IV(3), 1978 and John Waterbury, Hydropolitics of the Nile Valley, 1979.

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6. Particular reliance here is on the Egyptian U.S. Agricultural Sector Assessment Team, op.cit. and Mona El Kady, On-Farm Water Management in Egypt, (Ph.D. Thesis), Cairo, ARE, Ain Shams University, 1979.

7. There is a contrasting belief that some crops, particularly vegetables, should not be irrigated at night to minimize the risk of accidental drowning. Approximately 40 distinct irrigation variables are being examined by the sociology team; response distributions for them are contained in a forthcoming EWUP report, "Regional Variations in Egyptian Irrigation Patterns."

8. Many variables on which data have been collected do not show sufficient variation within given geographical areas to permit their use in the sort of statistical analysis being done here.

9. From a strictly technical viewpoint, this practice is not necessarily most ideal, as it does not consider such matters as infiltration rates. In a practical sense, however, it does show more informed, careful water management effort on the farmer's part under prevailing field circumstances in our areas of sampling.

Bureaucracy and Development: Insights from Egypt[1/]

Edward C. Knop and Sheila A. Knop[2/]

Abstract

Development processes can be hindered or helped by bureaucracy. Most often, bureaucracy serves to promote technological development, but impedes other more "basic" development processes. When this situation prevails, reform of major bureaucracies' basic development strategies is appropriate so that they may effectively function in support of balances societal development. Egypt provides an ideal case to examine the relationship between development and bureaucracy. Historically, there is not a positive relationships between the two there. Contemporary survey data show officials and villagers alike feel the need for departure from bureaucratic dominance, and advocate basic development strategies together with other development approaches. Not coincidently, President Sadat has embarked on a unique and promising "corrective revolution" which combines basic development strategies with a program of national bureaucratic reform. This ambitious social experiment may well provide a model for others to follow-certainly to learn from.

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Bureaucracy and Development: Insights from Egypt

The nations and peoples of the world are engaged in an unprecedented survival challenge in which bureaucracy and development are central matters. The responsibility for managing world order as well as basic satisfaction of personal needs is increasingly being taken on by bureaucracies and multinational consortia who, in turn, point to "development" as the major means or condition for realizing international order and personal well-being. But their success in pursuit of both has been disappointing to them and their constituients, despite the investment of extensive resources. Development professionals, both within and outside these bureaucracies, regularly confide that bureaucratic structuring and functioning represent the most immediate and conspicuous impediment to realizing real development in the national contexts of their experience, whether East or West, capitalist or socialist, "developed" or "developing" nation. Yet, they wonder, is there any good alternative to reliance on bureaucracy?

Unquestionably, commonly-encountered features of bureaucracies do often impose severe limitations on the effectiveness of development processes, and yet major bureaucracies control most processes and resources upon which societal development depends. The relationship between bureaucracy, development and human conditions of justice, peace and prosperity are complex but critical to understand in order that aspirations for a better life for all can be pursued rationally and effectively. It is argued here that reform of bureaucracies, in ways that support their ultimate and universal human service responsibilities, is essential in this time of survival challenge. Further, it is argued that this reform is best accomplished when bureaucracies recognize, honor and incorporate "basic" development processes in their internal operations as well as in their service efforts. These matters are first assessed conceptually, and then empirically in the well-suited case of Egypt.

Conceptual Assessment

Bureaucracy

Bureaucracy, Max Weber argued in his pioneering explorations of the concept, is the ultimately rational means of structuring large, complex goal-seeking efforts (Weber, 1947). The reasons were simple: bureaucracy, as an "ideal type" of organized responsibilities and rights, was to avoid irrelevant and counter-productive common features of other organizational forms. Historical and contemporary evidence abounded in support of Weber's contention that highly ambitious, sustained undertakings are facilitated or enabled by bureaucratic organizational provisions.

Yet Weber and many subsequent students of bureaucracy have been bothered by features in the functioning of real-world bureaucracies which compromise the rationality and effectiveness of the organizational form (Ritzer, 1975; Goodman and Pennings, 1977). Five of these problematic features of special relevance to bureaucratic support of development processes include:

1. Bureaucratic emphasis upon impersonal, impartial rationality and universalistic treatment runs counter to the frequent need for strong infusions of affective and particularistic considerations, especially relevant in matters of human service and institutional reform--and, many would add, basic organizational effectiveness (Bennis, 1973; Thompson, 1975, Goodman and Pennings, 1977). What is needed, especially in developing contexts, is "bureaucracy with heart."

2. In major bureaucracies, there is a tendency to pursue many diverse, imprecise, unprioritized, often inconsistent goals, frequently expanding the bureaucratic jurisdiction beyond what is comprehensible and managable. What results is a non-thematic "mixed agenda" situation that is always confusing and sometimes paralyzing (Elgin and Bushnell, 1977). When longer-range human service is the objective, as with development, clarity of programmatic goals is often so lacking that the development of coherent means for pursuing them

is unattainable. The absence of a concensual value-framework and diverse vested-interests are major factors impeding idealistic and realistic goal-definition, which are particularly problematic in developing contexts.

3. Rational means for pursuing goals presumably rest on knowledge of normal causal relationships resulting from research and experience (Blau, 1974). Yet such knowledge is often limited, and the specialization characteristic of bureaucracies plus vested-interests promote differences of expert opinion about appropriate means to pursue given goals, particularly the broader and more innovative ones characteristic of development processes.

4. Under conditions of uncertainty about appropriate goals or means, role performance promotes what we have come to call "bureaucratic behavior." While at variance with the bureaucratic "ideal," conservative, non-communicative, defensive role performance frequently emerges, as does contagious distrust of other's competence and motives. When pressure from above, below or outside is added, the authoritarian pattern of preoccupation with controlling peers, subordinates or constituents becomes common, as does its counterpart "retreatist" reaction (Kaufman, 1977; Merton, 1957). Both organizational effectiveness and service to development processes presupposes these patterns can be avoided or effectively reversed when apparent.

5. Many students of social organization argue that existing bureaucracies operate primarily in support of the established societal order of which they are an integral part, and, even more-so, they operate in support of their own bureaucratic self-interest (Ferns, 1978; Coleman, 1974). This "maintenance preoccupation" obviously does not prepare them well to be major instruments of developmental changes in societies (Grindle, 1977; Prasad, 1974; O'Donnell, 1978). Some organizational scholars (Buckley, 1967; Ingalls, 1976) go even further, claiming bureaucracies do not even effectively promote their own maintenance, but instead tend to take themselves and their society toward stagnation

(technically "entrophy," or the loss of **effective creative vigor**). The counterpoint (Parsons and Shills, 1957) is that bureaucracies serve a societal integrative function, keeping different sorts of developments "in balance," even if slowed (e.g., the catch-up workings of "culture lag").

These general limitations in the functioning of many bureaucracies to support development processes set the context for later assessment of appropriate bureaucratic reform. Brief attention must first be given what "development" is.

Development

Most generally, development is increasing collective and personal capabilities to reasonably establish and effectively pursue commonly-held social ideals. As such, it is both the process and the products of conceptualizing, mobilizing and institutionalizing idealistic goal-seeking and problem-solving efforts (Warren, 1977; Meadows, 1971; Nisbet, 1969). More specifically, however, the term development is used to mean several rather different things.

1. The popular conception of development focuses on a nation's having acquired a relatively advanced technology which enables greater consumptive benefits with less productive labor (Chodak, 1973). Perhaps "industrialization" would be a preferable term for this process. It reflects the bias of the Western world's historic experience (which is probably inappropriate for most of the contemporary world); is keyed to production economics of one or another form (which is an unduly narrow perspective on process means); depends upon the resourcefulness of a relatively small, exclusive category of experts as well as surplus resources (thus depreciating the role of those who become surplus labor, while capitalizing upon the people and resources in scarcest supply in "less developed" settings); etc.

2. A broader and more basic conception of development gives emphasis to "institution building" and intermediate-level institutional accomplishments

which become the means for self-directed "modernization" (Thomas, et al., 1973). Examples include raising literacy rates, increasing per capita GNP, improving medical conditions, slowing population growth, etc. Unquestionably, these are critical ingredients of societal development, and they do give reasonable attention to approaches beyond national production economics. But they still tend to direct developmental processes toward modernization in a Western sense, and rely upon methods, expertise and innovations that require mainly patience (vs. participation) from the masses. Capitalizing upon personal interest and initiative yields the major development resource in any setting, and minimizes the problems of alienation which often accompanies disrupted cultural continuity.

3. Increasingly, a third conception, "basic development," is being emphasized within the circle of development-process professionals (Wilner, 1975; Biddle and Biddle, 1965; Arensberg and Niehoff, 1971). This conception is rooted in the belief that a people's acquiring insight and experience with self-guided development processes keyed to their existing resources and values is the basic means and end of their development. Various terms summarize aspects of this approach: "grass-roots initiative;" "appropriate technology;" "meaningful participation;" learning by doing;" etc. Major outcomes include some quick, tangible accomplishments that lie within easier reach, direct satisfaction with popular participation in the development process, and strengthening the personal and institutional bases for further incremental development. This conception of development is believed to best insure efficient use of limited development resources, favor a broad distribution of development benefits within the population, minimize cultural disruptions which often accompany change processes, and avoid the "strings" of international dependency with which most nations in time will have trouble living.

While these several understandings of development can presumably be mutually supportive, they tend to be competitive in field application. Usually, priority in official circles is given to pursuit of "short cut" technical acquistions, costing the more broad and gradual "basic" development processes the attention and resources they deserve. It would seem logical that development efforts begin with, or at least include, a "basic" development emphasis. On the other hand, it is not surprising that the complex dynamics of development commonly begin "backward," whereby initial attempts at development find governments and other bureaucracies borrowing technology in a quest for pay-offs of modernization, in time being forced to realize that ever more-basic development approaches are required to support initial development aspirations that have proved overly-simplistic.

In fact, there are no short-cuts to effective, balanced development, but probably only the more experienced, most-developed people can appreciate this. When the deeper level of "basic" development begins to be realized, these more broad and subtle developmental processes feed back upon the bureaucratic infrastructures which precipitated the development process, pushing them toward reform. Where there is bureaucratic responsiveness, the process goes full cycle, and complete, perpetual development processes are institutionalized.

Conceptual Interrelationships and Implications

Bureaucracy ostensibly is highly rational established social structure for organizing purposive activities. Development, regardless of interpretation, is innovative rational processes and products of idealistic goal-seeking or problem-solving. Accordingly, bureaucracy and development should ideally operate in a complementary fashion, with bureaucracy playing a central role in support of development processes, and with these, in turn, keeping bureaucracy more adaptive and effective in a changing social context. Unfortunately, however, this complementary functioning is seldom fully realized. Too often, the social- and self-maintenance concerns of bureaucracies run counter to the aspirations of development proponents, especially those favoring more "basic" forms of development.

Specifically, bureaucracies, as integral parts of an established social order, usually support developments that extend the capabilities of that order, or increase its efficiency. Such developments are typically of the technological form characteristic by the first interpretation of development introduced above. The more "basic" forms of development, on the other hand, tend to take the established order as nothing more than a starting point from which something considerably different and better might eventuallv emerge. Additionally, "basic" development proponents value and seek to strengthen non-bureaucratic forms of social organization such as community, voluntary associations, social movements, etc. Not only does this threaten to diminish bureaucracies' relative importance in society, at least for awhile; it also seems to challenge the role of specialized expertise resulting from previous development which is institutionalized in them. Thus it is not surprising that there is often antagonism between the custodians of bureaucracy and basic development advocates.

The underlying points of contention are important to consider. First, is the long-term drift toward giving bureaucracies more responsibility for doing things for us really development (i.e., are we now more able to effectively and efficiently realize our human ideals)? Second, is the drift toward increasingly-collectivized responsibility for societal and personal welfare ultimately doomed to a self-destructive collapse (i.e., are we setting the conditions for undermining individual responsibility, commitment, competence and creativity upon which bureaucratic effectiveness rests)? Third, are the heightened tensions of the present indicative that a collapse is nearing as we load more responsibility for critical but illusive development on a source incapable of satisfactorily delivering our desires?

Such complex issues cannot be briefly assessed, let alone resolved. Some insights central to the themes of this paper, however, follow. First, bureaucracies have enabled some forms of development that are of considerable realized or potential benefit, largely of materialistic nature. But these are gained at the cost of some previous benefits like having a sense of community, feeling of personal worth and social significance, etc. Importantly, these new benefits and losses, if well-understood together, can precipitate further development of a "basic" nature that in time yields a generally complete and satisfying balance of benefits (Caplow, 1975; Zurcher, 1977; Cornuelle, 1975; Brown, 1977). These should be expected to vary between societies and most often not take the form of conventional "industrialization" or even "modernization."

Second, the drift toward bureaucratic dependence does probably contain the seeds of self-destruction if dominant bureaucracies refuse timely reformation (Roy, 1975; O'Donnell, 1973; Berkley, 1971). Pragmatic and ideological pressures on them, and from within them, will doubtless yield the needed reform of many major bureaucracies, while the reluctance of others will cost them their dominance. We might expect the overall result to be a diverse blend of communal and bureaucratic organizational characteristics based in new conceptions of goals and rational means (Thayer, 1973; Herbst, 1976).

Third, present domestic and international tensions probably signal both the faltering of overloaded bureaucracies and a potential approach of an historic pivot point from which we can tip ourselves into a new developmental era of profound accomplishment and satisfaction (Bennis, 1973). How those inside and outside bureaucracies respond to the challenge is decisive. If pressures come in a form that encourage official responsiveness (vs. that promote bureaucratic destruction) and bureaucracies are more open, flexible and perceptive, they will probably adjust to maintain or increase their service effectiveness (Goodman, Pennings, et al., 1977). But times of bureaucratic faltering are not the times we might expect them to be most responsive or prepared for substantial reform (Taub, 1969; Greenberg, 1970).

One key to a favorable outcome is bureaucracies' willingness and preparedness to voluntarily undertake their own "basic" development during the "easy times" before great pressure for their reform mounts. In the absence of such pressure, they can experiment in a non-defensive mood, free of preoccupation with their organizational maintenance and without having to yield to antagonists whose adversarial position would be strengthened by concessions. Another key to successful reform is firm commitment to the service of some idealistic societal goals which transcend their own bureaucratic welfare (always the legitimizing dimension for a societal subsystem).

Concerning the means of societal and bureaucratic development, both the organizational effectiveness literature (Dyer, 1976; Goodman and Pennings, 1977) and the basic development literature (Biddle and Biddle, 1965; Arensberg and Niehoff, 1971) emphasize the following to be pursued in approximately this order:

1. capitalizing upon, and developing further, person's <u>interest</u> in aspirations and procedures for achieving them;

2. assuring adequate <u>incentives</u> (including non-monetary ones) to justify effort;

3. providing opportunity and encouragement for increased <u>involvement</u> in goal-seeking processes;

4. building <u>insight</u> (especially a sense of the "bigger picture" and what contributes to its future realization);

5. recognizing and promoting <u>innovativeness</u>;

6. capitalizing upon and facilitating personal <u>initiative</u>;

7. <u>institutionalizing</u> (incorporating into the bureaucracy as normal operational procedures) the procedures and products of this process;

8. integrating the structure of the whole to maintain internal consistency of approach and actions.

It is important to note that in the bureaucratic context, the use of authority in the promotion of development processes is sometimes necessary, but more often counter-productive. The matter is a complex one, but generally involves the following considerations. First, the forcing of compliance with developmental processes does little to promote understanding of them, but, rather, promotes "backlash." As well, it represents a precedent contrary to the spirit of basic development processes. Accordingly, authoritarianism should be avoided as a major tactic for most persons involved in the process--particularly those in the client population. It is generally inappropriate to assume people will "get used to" and "learn to like" changes they are unwilling to accept voluntarily.

But when time pressures for responsiveness are coupled with a scarcity of development resources, it is often necessary to use authoritarian tactics with special categories of people--especially functionaries in the process--who would otherwise substantially impede development progress. In this tricky matter, the best rule of thumb seems to be: with functionaries, first cajole, then, if essential, force them into the service of basic development processes (if they react negatively to the exercise of authority, it pushes them toward sympathy with the spirit of basic development; if they "withdraw," at least they are less an impediment). And with dissident constituent minorities and opportunists, they sometimes must be neutralized when they favor totalitarian or unduly devisive approaches (inconsistent with the "basic" development approach), so that relative social order and democratic processes prevail.

Finally, the integrative function of bureaucracy in development needs consideration. Major bureaucracies, like governments, control the means for extension and institutionalization of developmental processes throughout a society, and they hold the responsibility for keeping their society integrated and in balanced linkage with other societies. The tools of public policy, fiscal allocations, education programs, etc.are important for maximizing the diffusion of the development ethos, approach and accomplishments. Further, determined governments can best ensure an equitable distribution of development's benefits throughout the population. As well, insightful officials can use their coordinative responsibilities to ensure that the imbalances of more rapid change in some sectors of life (e.g., technology adoption, creeping materialism, etc.) be slowed and compensated for by compensating changes in other sectors of life (education, social cohesion, morality, etc.).

The Egyptian Context

All of the foregoing has roots in the social science literature, but represents ideas that took on new meaning and formulation during the authors' prolonged residence in Egypt. Because both bureaucracy and development are predominant in that nation's situation, and because this case is superbly illustrative of problems and options in the interface of the two, we now examine several dimensions of the Egyptian case. One dimension is the historic context of bureaucratic and national development there; another is consideration of selected data from surveys of Egyptian farmers and officials regarding national development processes; and a third is review of a bold and unique social experiment underway in Egypt to overhaul the national bureaucracy in support of development processes.

Historical Highlights

It is sometimes heard in Egypt that the "pharoahs' revenge" was, actually, the creation of bureaucracy, and that the curse of many centuries of foreign rule was bureaucratization to its problematic ultimate. There can be no doubt that the development of rudimentary ancient bureaucracies enabled amazing tangible accomplishments by the pharoahs, and that the ensuing years were made difficult by the bureaucratic control of outsiders and Egyptians. As well, there is ample evidence that Egypt's contemporary development aspirations are sometimes compromised or frustrated by her dominant bureaucracies, and that these are in other ways enabled and facilitated by them.

The "bureaucracies" of the pharoahs, it should be noted, were probably effective primarily because they recognized and honored specialized personal competencies (particularly for creativity), and because they had surplus resources to invest on aspirations which went far beyond survival needs. Much of the critical competence was used to coordinate human efforts situationally in pursuit of technical aspirations. As for those bureaucracies' other management characteristics, they presumably were clumsy, often counter-productive, and ultimately dependent on incentives, reward and punishment and interpersonal respect to make them work (Gardiner, 1962). In short, they were an embryonic form of heirarchial social organization, authoritarian control (a conceptually separate matter) and communal patterns (another separate matter).

During the majority of recent millenia, Egypt has been under the bureaucratic control of alien parties. Yet this state of subjugation by changing parties with differing traditions and aspirations apparently did not significantly alter her culture. The strongest of the alien regimes were hated and rather passively endured while life went on as usual. (To this day, countless cultural patterns can be traced to their early pharaonic precedents.) In contrast, several external influences that were accompanied by minimum-to-modest bureaucratic rule had substantially more impact.

The Greeks (332-20 BC) had massive influence (even to the extent of contributing common philosophical orientations and much of the colloquial language), yet their relationship with Egypt was one of mutually-agreeable union rather than domination and operated politically via the Greek pattern of democratic village confederations. In contrast, the Roman period (30 BC- 642 AD) emphasized various technical accomplishments implemented through the rather forceful form of Roman bureaucracy. The lasting influences are negligible; what remain are only such technological antiquities as aquaducts, monuments and administrative buildings. The first Christians filtered in (c: 45 AD) without the resources to dominate, and began successfully converting the country to their religion without bureaucratic mandate. In fact, the eventual bureaucratization and politicization of Christianity became a major factor in its Egyptian decline, though its philosophic influence is evident today throughout the Egyptian population (on the entire period, Bell, 1948).

The Arabs arrived in the latter part of the first millenium (640), possessing the power to militarily subjugate Egypt. But they chose to use this power sparingly, attempting instead an ideological victory within the country. Using incentives, persuasion and relatively few men, they managed an enduring transformation of Egypt which allowed for maintaining traditional patterns in sysnthesis with the new (Lone-Poole, 1969). The Islamic faith they brought, when subtly blended with early Christian and Pharaonic beliefs, is the cultural mainstay of the majority of Egyptians today.

By authority of first the Arabs and then the Ottomans, the Mameluke slave-sultans (c: 1260-1798) served as an imported ruling class, manning power positions in the bureaucracy. Under them, bureaucratic dominance in Egypt reached its ultimate, bringing to a standstill development of her peoples and the nation. Opportunities for initiative and innovation were practically non-existent. Punitive methods of ruling and controlling, largely in the interest of bureaucratic self-service, were the order of the day. The 500 year period of Mameluke rule has come to be thought of as the Egyptian Dark Ages. It is interesting to note that even with her strong development precedent, Egypt's development was at its lowest ebb during this period--the most bureaucratic of her history (Moorehead, 1962).

Napoleon came and quickly left (1798-1800), using his armies primarily to "liberate" the land from the Mameluke bureaucracy, but not to dominate Egyptians. His presence was felt primarily through influence and diplomacy. In the few years the French were there, the "high culture" influence took hold, precipitated a move toward education and general enlightenment, created domestic as well as foreign appreciation for Egypt's ancient civilization, and today remains a conspicuous force in the gentility and diplomacy of the country (Moorehead, 1962).

The last ruling dynasty was quasi-Turkish in origin, initiated by the strong man, Muhammed Ali, and reverted to much of the prvious bureaucratic tradition of earlier rulers. Ali broke with Turkey to establish an Egyptian oyal form of the same tradition, with one important added dimension. He saw need for technological development and invited foreign influence and assistance--most noteably British. Thus, development of a planned, technological sort took hold and has pervaded Egypt up to present times (Marlowe, 1965, 1975).

Upon reviewing the history of bureaucracy in the land of its origin, one is left seriously questioning just how important it is, relative to other organizational and operational forms, in the routines of the country or in their development. Similarly, one wonders about the extent and nature of influence that gradual social and cultural development have on bureaucracies in such a country. Technological development, bureaucracies' forté, had a good headstart in Egypt during her early bureaucratic history, yet substantial technological development was not evident in Egypt's bureaucratic mid-years. On the other hand, many developments of other sorts, over which the ruling bureaucracy had little control, did occur. It would seem that processes only incidental to bureaucracy, frequently not characteristic of it, loom largest in development processes, and are slow in affecting it.

To characterize present-day Egypt, Western observers consider the country bureaucratically encumbered primarily due to the government's broad and deep presence in the society. In this sense, Egypt is similar to many other developing countries, especially those with a strong colonial precedent. Egyptian officials generally are educated, capable and perceptive. Villagers, as well, are impressive for their depth of understanding, astuteness, candor and independence. In a true sense, they are not a peasant population; rather they are small-scale commercial farmers and businessmen (Baer, 1969; Critchfield, 1978). For reasons as these, Egyptians consider themselves quite developed as nations go, but restrained by resource limitations and inhibiting regulations.

Following the 1952 revolution of independence, the country adopted a general strategy of development similar to that of Eastern European socialist states, while retaining private ownership of small businesses and farms (Binder, 1978). What emerged was a distinctly "mixed economy" and massive government, which aspires to operate as a "benevolent technocracy" or "bureaucracy with heart." Expert policy bodies, composed of administrative officials, applied researchers, professors and/or politicians regularly contemplate problems and goals, and revise or establish programs and policies for bureaucratic management, sometimes with institutionalized opportunities for citizen input. These procedures have yielded a set of well-conceived, ambitious, though conventional long-range national development plans and strategies. Unfortunately, the country lacks the capital and material resources to implement them very fully, and is hindered in deployment of human resources by preferences for urban amenities.

Current Surveys

During 1978 and 1979, applied research activities with the Egypt Water Use project,[1] a government-operated irrigated agricultural development effort, afforded the opportunity to collect data from a sample of farmers and officials that are relevant here. A sample of 75 case study villagers are generally representative of the rural population in sample villages of the three distinct areas of Egypt: the Nile Delta in the north; Middle Egypt in general proximity to Cairo; and central Upper Egypt in the country's south. A vast range of data were collected from them in successive rounds of interviews over the two years. Near the end of 1979, a number of comparable items were put to 88 government officials responsible for various ministries' and agencies' development work in the same areas of village study. These included personnel operating at the village level, district and governate levels and at the national level. Comparisons of general response distributions to selected items that bear on points raised above are offered here in simplest form, accompanied by interpretive narrative.

Table 1 compares villagers' and officials' perceptions on how helpful several bureaucratic and non-bureaucratic categories of people are thought to be in development processes. Most generally, we can conclude from these data that villagers perceive a lesser relative contribution to their development from higher government officials, but that the value of government personnel at the local level rises roughly to the same level as others' contributions. A noteable exception is that the greatest confidence is shown applied research specialists, who operate from the national level, but often come into contact with local people in the line of work, and are generally judged competent, productive in practical ways, and key in whatever success a technocratic government has with development. Officials at the local level, similarly, are in a critical position for affecting the practical success of programs and policies, know local conditions best, and are generally more flexible and particularistic in their handling of policy.

In a country where the government holds almost total jurisdiction and responsibility for development, and where a technocratic approach has long prevailed with considerable success, it might be thought surprising that non-bureaucratic groups are considered as important as they are by both villagers and officials. As shall be explored further in following data, Egyptians hold views of development processes that are quite similar to those of Western development-process experts oriented toward "basic" development. Accordingly, they recognize and understand the role of local initiative, participation and organization in combination with government efforts. The relatively low importance assigned local leaders and influentials reflects a judgment about their willingness and preparation to contribute much. Other data demonstrate villagers' desire for both strong local leadership and expert professional assistance with voluntary organization and local human resource mobilization.

The officials' responses in Table 1 most generally demonstrate they consider everything but local leadership of about equal importance, again indicating a belief in a balanced, broad-gauged approach to rural development emphasized in the professional literature. It is noteworthy that the only two items showing a significant difference in perceptions between villagers and officials concerns the importance of national and intermediate-level government. Presumably, this reflects the officials' belief in their bureaucratic work, and the villagers' occasional frustrations that their development, tied to unseen distant bureaucrats' claiming the responsibility, is not progressing as rapidly as it might.

Table 2 compares perceptions on the propriety and effectiveness of selected development strategies and tactics, some of which are more typical of bureaucratic approaches, and some less so. From these data, it is clear that neither villagers or officials put much faith in the use of bureaucratic power to force development. Officials and villagers alike think the professional planning approach has much merit, and emphasize the importance of the government providing services in the public works category (the first concept of development). Along with this, most think it essential that adult and youth education be emphasized as government's contribution, considering it both a condition greatly facilitating specific development aims and the main alternative to direct bureaucratic control/force. Understandably, villagers favor practical how-to-do-it education consistent with their personal interests and problems, which tends not to be typical of Egyptian "grammar school" public education.

It is interesting to note the relatively low ranking given to increasing local money or credit as a strategy in support of development aspirations. Egyptians, like many people, often give the impression they think all their problems would be solved if they had more money. But upon thoughtful reflection, they apparently think fiscal resources a much less important factor in development than many other things, including having a more caring, respectful, infomally organized social environment. A principle disagreement among the world's development professionals is precisely the issue of how dominant financial policy should be. The industrial/technology development emphasis, most associated with development via bureaucracy, gives high priority to fiscal growth as a principle means and end of development. Development professionals of other persuasions--particularly the "basic" development camp--downplay the fiscal factor on various pragmatic grounds. Egyptian villagers and officials alike demonstrate their intuitive belief here that a broad conception of development means, and perhaps goals, is most appropriate.

An important item in Table 2, G, shows strong support for having institutionalized provisions through which citizens can influence decisions of bureaucracies which affect them--to put pressure on them, in a sense. This is one of several similar items which showed essentially the same response pattern. Egyptians seem comfortable with a technocratic approach to development, but believe other "grass-roots" approaches are an essential complement. In fact, there is strong evidence that they believe more in a balanced citizen-government partnership approach than in dominance of either government or themselves (Sallam, et al., 1980). Such depends upon being able to directly influence bureaucratic processes, keeping them responsive to the prevailing public will and conditions. In other words, they assume bureaucracies' service in development will be most effective if they remain open and adaptive.

Finally, Table 2 shows four non-bureaucratic development matters to be extremely important in villagers' and officials' thinking: building local informal leadership; increasing informal organization; improving social incentives for those who work hardest for local improvements; and promoting a more "caring" community atmosphere. These matters, at the core of the "basic" development approach, can be made compatible with bureaucratic functioning, and supported by it, but presupposes the infusion of the same characteristic into bureaucracy. The Egyptian technocracy requires further development along these lines before a viable partnership with the people for more effective national development can be realized there.

Table 3 contains response patterns to several issues introduced above. Concerning perceptions of the main purpose of government, both officials and villagers overwhelmingly agree it is to promote and facilitate development (as contrasted with maintaining stability, minimizing deviance, etc.). By implication, it should function more as a future-oriented societal service organization rather than a present-oriented societal maintenance one. This, of course, is difficult for a large, centralized bureaucracy operating under conditions of high constituent expectations, severe resource limitations and external political and military pressures, as is the Egyptian government. A major strategic mistake such a centralized bureaucracy might make is to set on a path of forcing developmental changes when they suspect citizens would not understand enough to willingly go along with. Fortunately, Egyptian officials, like villagers, see this as an inappropriate strategy, perhaps because they know from experience it would not result in lasting effectiveness, or because they lack the resources required for enforcement, or because they know it to clash with other aims they are promoting. One of these other aims is to reform the basic ways things have tended to get done in the country which, presently, is mainly by bureaucratic dictate in the classic colonial tradition. Probably the Egyptian government has adopted this policy of bureaucratic reform because they realize it is the soundest, though not easiest,option to pursue in a setting where citizens hope for rapid change, but are still being trustingly patient.

In settings where fatalistic attitudes prevail, there is greater acceptance of bureaucratic control. Fatalism is often used as an indicator of basic underdevelopment, and made a first target of developmental attention, so that other development aims can be effectively pursued. Table 3 data show Egyptians are well along the basic development path by believing their option for effective grass-roots initiative is open. Importantly, when the people of a nation believe they shall not be controlled, they cannot be controlled, precluding the effectiveness of authoritarian bureaucratic tactics. Such a sense of independence within a nation is a precondition of basic development, but it also jeopordizes the ability or willingness of people to voluntarily combine forces for developments which require a common effort. This dilemma probably in part accounts for reasonably weak informal local leadership and voluntary social organization in Egypt. Table 3 data and impressionistic evidence suggest villagers are inclined to voluntarily come together and act on good ideas for local improvements. The ingredient which seems to let this happen is credible leadership with initiative--having respected persons with good ideas who are willing to step forward to advocate them. Probably local officials or trusted outside experts could, and do, serve this function as well as local informal leaders.

Often weaker local leadership initiative is a function of community intolerance of innovative ideas. People, understandably, often do not wish to risk their social standing by stepping forward to advocate an idea that may prove unpopular. But, again, the data suggest that this is not a seriously constraining factor among the Egyptian villagers sampled. In this sense, also, Egypt shows signs of considerable progress in her basic development.

Bureaucratic Reform Experiments

Reference has been made to the unique, bold experiments in bureaucratic reform Egypt has recently undertaken to facilitate her rural and national development (Mansfield, 1976). It is too early to know the eventual success of this emerging plan, but it is already noteworthy for what is being done, and that it is being done.

Following the 1952 revolution, very complex, centralized bureaucratic structures and processes emerged in Egypt. In time it became apparent to many, particularly President Sadat, that abuses and malfunctions within the government were proving counter-productive to development needs (Sadat, 1978). Accordingly, he initiated a "corrective revolution" in 1973 to reduce the excesses of the previous revolution. A first step was to open up the country and government bureaucracy to outside influence. This was risky in several contexts. It enabled "outsiders'" observation and review of authorities' performance throughout the ranks, which easily may have left them feeling threatened. Also, the "opening" allowed exposure to the world of Egypt's problems. Too, the opening raised potential for competition between powerful Western and Soviet-block nations to exercise their various ideological influences within Egypt. Soviet influence was evident early; Western influence has been evident more recently. Support of other Arab or Islamic countries was apparent until the recent split over Sadat's peace initiative.

A related facet of the corrective revolution has been to increase the capitalist "mix" in the basically-socialist economy. Private enterprise, rather heavily taxed, is viewed as a means to generate capital necessary to sponsor needed domestic programs and to arrive at a favorable international balance of payments. Increasingly, private sector initiative is being encouraged in areas as tourism, transportation, housing and agricultural development. Egyptian-national and "joint venture" (Egyptian with foreign) investments are sought, with a requirement that Egyptians hold controlling interest.

Modest emphasis is being placed on enhancing Egypt's infrastructure, particularly transportation and communication. Effort is being directed toward revitalizing and refurbishing industrial capabilities, without much additional industrial expansion. Also, the reopening of the Suez Canal signalled Egypt's open-door policy as well as her interest in commerce. Heavy emphasis is being placed on continued development in the agricultural sector, particularly on "old lands" of the Nile Valley. And, rural development of a more general nature is being promoted.

One major commonality of the 1952 revolution of independence and the more recent corrective revolution is the attention given to the basic survival needs of Egypt's citizens. The government provides extensive food, clothing, housing and medical subsidies, old-age, disability and accidental death benefits, along with a variety of other social welfare programs.

More significant than the changes noted above, though, have been the variety of actions taken to initiate and ensure progress toward bureaucratic reform. Enlightened leadership, provided by President Sadat and other high-ranking Egyptians, has encouraged bureaucratic reform through political processes, administrative policies and personal example. Political parties and Parliament have been dissolved and reformed in an effort to evolve what could best be described as a multi-party-of-the-middle system. Only extremist views of the far right and left are unrecognized in current political party structuring. More moderate, though differing, positions are included. A loosening of centralized control has, to be sure, been accompanied by safeguards intended to ensure stability. Periodically, when internal security/stability are thought to be threatened, controls are tightened and people are encouraged to "cool down." Increasingly, methods for "reform with stability" are of the sort that do not intimidate Egypt's citizens.

Vast decentralization of government bureaucracy is underway. Initiated in December, 1979, by President Sadat's granting of presidential powers for domestic concerns to each of Egypt's governors, this policy shift heralds what could prove to be a new and significant era in both bureaucratic structuring and functioning in, and development of, Egypt. Coupled with much increased power at the governate level has been a sort of revenue-sharing approach to distribution of funds. Also, governors and others are encouraged to develop pilot and demonstration programs to meet local needs, for which national grants are available. Much national publicity, recognition and honor are given these model programs and those who institute them.

Considerable emphasis has also been placed on the up-grading of abilities of middle-level bureaucrats at the governate and local as well as national levels. Many programs of in-service training have been implemented, with focus on managerial as well as technical skills. Thus, the first avenue used is an educational one; those who, after training, are not able to function according to expectations are first encouraged, then pressured to move out of these important bureaucratic positions. Throughout, emphasis is on promoting a coupling of individual initiative and innovation with commensurate individual responsibility, rather than bureaucratically-diffused responsibility.

Egypt has a long tradition of education and educational institutions. In recent years, emphasis has been placed on speeding the democratization of education. Free public school education for all and free university education for those who qualify academically have been practiced since the 1952 revolution. Today emphasis is on curriculum revisions (national curriculae has been used; governates are now being encouraged to develop new/adapt existing curriculae), and on less formal means to reach a large number of adults throughout the nation with needed information and skills. A recently-established national extension and rural development institute provides leadership in training and other support activities for local extension personnel. In addition, an extension component is frequently included in special-purpose projects of the various ministries and governates. Also, there are many Egyptian journals and newspapers, along with national television and radio stations, which serve an educational as well as news and entertainment function. Sadat, himself, serves as an educator as he travels throughout the country meeting with local groups for the purpose of explaining government policies, positions and programs. His often long and emotional speeches to Parliament (heard by millions via t.v. and radio) are an excellent example or his desire for "everything to be as clear to the people as it is with me" (Sadat, 1979, p.162).

Throughout these (and other) reform efforts, there are common elements. Taken together, they reflect a multi-faceted attempt to overcome the five bureaucratic problems noted earlier in this paper. And, a number of the characteristics necessary to fulfill the aim of restructuring bureaucracy are also evident.

More insight into the corrective revolution can be gleaned from a review of President Sadat's autobiography, <u>In Search of Identity</u> (1978). In particular, his references to and identification with Egyptian village life, the spirit of the people and the values of the village (e.g., freedom, beauty, dignity, love, sovereignty of the individual, collective effort) suggest the basis for common aspirations, goals and means consistent with those values. He describes love as "a human safeguard against all social pitfalls. To love means to give, and to give means to build..." (p.110). He is critical of materialism and power as human values. He states that the notions of a power-based community and a benevolent dictatorship are incompatible with the nature and temperament of the Egyptian people.

Finally, it is apparent that Sadat is a deeply religious man, as are most of his countrymen. The values noted above are consistent with the majority Sunni Moslem and minority Coptic Christian faiths, as they are with most other major religions. In the practice of Egyptian Sunni Islam, the earthly locus of authority and responsibility for decision-making rests with the community, through community concensus. Thus there is a strong value-basis for "basic" development in Egypt, as well as the pragmatic desire and unusual enlightenment in the highest bureaucratic circles. One hopes this is sufficient for success.

Conclusions

Consideration of the relationship between bureaucracy and development in Egypt prompts several general conclusions. Egyptians were among the first to embark on a systematic development course which, among other things, yielded a rudimentary form of bureaucratic organization to facilitate its civil progress. In time, the fuller development of this organizational form began to impede its development, particularly in the hands of aliens who wished to control and exploit the country. When periods of new influence were felt in the development of the culture, they tended to come in non-bureaucratic form, or during times when the bureaucracy of State was undergoing development or transformation.

The major exception to this generalization has been with the impressive technological developments during the last hundred years of Western influence, and, particularly, during the past thirty-five years of Egypt's revolutionary self-rule. There are consequences of this recent developmental history that are bothersome to Egyptians ranging from the President to the village farmer, however, and they are undertaking an insightful, voluntary "corrective revolution" before crisis befalls them. Their rationales and actions are instructive.

They begin with concerns for the "human spirit," independence, freedom and dignity, initiative and commitment to common social ideals rooted in their historic communal solidarity. They sense that their technocracy has brought benefits, but also problems they wish to resolve, like subverted initiative and communal solidarity. Perceptively, they look to building the institutional support structures in areas like education, religion, local services, etc. while increasing grass-roots "spirit," dignity and autonomy through decentralization and relaxed controls on the vast "moderate" population. Clearly, they do not believe the force of bureaucracy can effectively be used to mandate development--only to point the way while supporting and allowing it to emanate from the people. This process is resulting in an incremental basic reform of the national bureaucracy so it can more effectively support development processes. In the process, national bureaucracy gains credibility and popular support, strengthening it as a major force for on-going balanced societal development.

This process is not without problems, however. In the Egyptian case several matters are relevant. It must be realized that any unaccustomed approach will be viewed uneasily and suspiciously by many who are involved. President Sadat and his fellow-reformists are doubtless often thought naive by those who do not share their profound insights, and many within the country are left confused and disoriented when the familiar bureaucratic-authoritarian patterns are altered. Many Egyptians, in fact, show evidence of a wait-and-see attitude. Thus it is important that persistence of the reform/development be followed for sufficient time so that the indirect results of success can be felt throughout the society and so that methods the social experiment can be improved by experience.

In the meantime, the top levels of government must ensure the popular credibility that underpins good faith, and control the devisive influences of opportunists and extemists who could jeopordize the societal stability on which the process depends. More particularly, heightened inflation which accompanies developmental surges must be controlled; an equitable distribution of development benefits must be realized; long-term personal commitments to national development according to the previous model cannot be betrayed; reluctant key bureaucrats must sometimes be prodded into compliance with the new scheme; profiteering must be controlled; etc. A particular dilemma in the process is how to shift from hierarchial authority lines to a matrix form of national organization without unduly frustrating orientations and efforts. For instance, former hierarchies extending down to the village level have not been cancelled, but cross-cut by the investment of presidential powers to governors and their staffs. Only good faith, good informal communication and coordination patterns, and the congenial spirit of the Egyptian people have prevented this situation from becoming problematic.

The spirit and character of the Egyptian people is significant in another regard. The bureaucratic reform/basic development process is facilitated by the fact that Egyptians are strongly independent as individuals and a nation, yet highly value communal patterns and problem-solving processes. As a result, they do not take their bureaucracies as seriously as many do, perhaps because they have had to co-exist with them for centuries. For such people, real revolution means, more than anything else, finding an alternative to life-by-bureaucratic-imposition.

Perhaps the same people who invented bureaucracy as a by-product of their pioneering early development are now in the process of working out a new form for the organization of developmental efforts. This may provide the world with a model even more significant than that of bureaucracy. Unquestionably, their experiment with voluntary government-initiated revolution serves as a noteworthy pioneering effort in the quest of full development despite limited resources. One might even argue that the highest level of developmental achievement a nation can reach is the institutionalization of "basic" development patterns in their societal organization. If this is so, Egypt may now be among the most developed of nations.

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OPTIMAL DESIGN OF FURROW IRRIGATION SYSTEMS[1/] [3/]

J. Mohan Reddy and Wayne Clyma[2/] [4/]

Introduction

Surface irrigation is the most widely practiced method of irrigation (Goldberg, 1974). This widespread use of surface irrigation methods reflects its feasibility under many circumstances, low energy requirements and simplicity of operation (Pillsbury, 1968). The poor performance of surface irrigation systems suggest a need for better system design and management.

Water is one of the limiting factors of agricultural production. Improved designs of irrigation systems would result in more effective and efficient use of water resources. The purpose of this paper is to develop a design procedure using generalized geometric programming that results in optimal system design of furrow irrigation systems considering a number of design variables and system constraints.

An irrigation system has several variables that affect its performance. These are: the flow rate, slope of the field, field dimensions, roughness, furrow shape and soil infiltration characteristics. Time of inflow, inflow rate, field length, furrow spacing and net depth of irrigation are operational variables to be determined in the design. Variables such as infiltration rate, roughness and furrow shape are given for a particular field. Time of inflow, inflow rate and field dimensions usually are constrained for a particular design. An optimal design must consider these variables and any system constraints.

Optimal design of an irrigation system should consider returns from the crop and costs of system operation to maximize profit. Reddy (1980) has developed such an approach for border irrigation by relating system design variables to system performance and system performance to crop yield. Because these relationships are not yet available for a furrow irrigation system, optimal design of the system will be based on minimization of costs. In the design of an irrigation system, there are many combinations of values for the variables that would fulfill the requirements of the system, but with different costs. There will be a combination that will involve minimum design expenditure and at the same time meet all the system constraints.

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Literature Review

Research on optimization of surface irrigation system design has been limited. The works of Marjai, Oroszlany, and Wellisch (1958), Wu and Liang (1970) and Nugteren (1973) were restricted to optimizing a single variable. Marjai, Oroszlany, and Wellisch (1958) considered uniform wetting of the length of run as their objective, and derived theoretical equations for optimum inflow rate into closed end furrows under a given set of field conditions. The theoretical results were corroborated by experimental results. Wu and Liang (1970) considered length alone as the optimizing variable. They developed a cost function in terms of length assuming all the other system variables are constant. By simulating the cost function for different length combinations, they obtained the optimum length for a furrow irrigation system. Nugteren (1973) applied differential calculus in optimizing different single variables holding all other variables constant.

Mathematical optimization of furrow irrigation system design was not possible until recently for two main reasons. First, appropriate mathematical equations expressing the relationship between the quantity that needs to be optimized and the system variables were not available. Even empirical relationships were not available. Recently, the Soil Conservation Service (SCS) developed design equations for furrow irrigation (USDA, 1979). Second, the theory of mathematical optimization (geometric programming) to handle negative coefficients either in the objective function and/or the constraints was limited. Dembo (1972) presented a condensation technique to handle negative coefficients. Utilizing the available mathematical relationships for furrow irrigation and the theory of geometric programming, a furrow irrigation system can now be designed optimally.

Mathematical Features of Furrow Irrigation

Before optimizing any problem, the mathematical relationships between the system design variables, the function to be optimized and the constraints to be satisfied must be available. The mathematical relationships used in this paper for the design variables were obtained from Ley and Clyma (1980) as modified from the SCS furrow design procedures (USDA, 1979). The relationships are summarized here and further details are available in the references.

The equivalent average inflow depth is:

$$D_a = \frac{60Q_f T_i}{WL} \tag{1}$$

where D_a = equivalent average gross inflow or applied depth, mm

Q_f = average furrow inflow rate, lps

T_i = inflow time, min

W = furrow spacing, m

L = length of the furrow, m

The equivalent average intake depth for the furrow length is given by:

$$D_i = [a(T_i - \frac{g}{h+1} L^h)^b + c] (\frac{P+K}{W}) , \quad D_i \leq D_a \qquad (2)$$

where D_i = equivalent average intake depth for the entire furrow length, mm

a,b,c = constants in the infiltration function

g,h = advance coefficients for given intake family

(P+K) = equivalent average wetted perimeter where P is defined by Equation (5) and K is a constant of 0.21

The values of g, h and P are defined as:

$$g = \frac{3.289 K_1^d Q_f^d S_o^{d/2}}{C_2} \qquad (3)$$

$$h = 1-d \qquad (4)$$

$$P = 0.3304 (\frac{Q_f}{S_o^{1/2}})^{0.31524} \qquad (5)$$

where C_2,h,d = functions of intake family

K_1 = 4.831 for metric units

n = Manning's coefficient assumed equal to 0.04 for furrows

S_o = slope of the furrow

The equivalent average runoff depth, D_r, is given as:

$$D_r = D_a - D_i \qquad (6)$$

The relationship for equivalent design application depth for the design length is given as:

$$D_u = [a (T_i-T_x)L_d)^b + c] (\frac{P+K}{W}) \qquad (7)$$

where D_u = equivalent design application depth or requirement, mm

$T_i-T_x)L_d$ = intake opportunity time at point L_d, min

L_d = point along furrow at which the design application is to be infiltrated, m

The equivalent average deep percolation for this section, $x = 0$ to $x = L_d$, is given by:

$$D_{P)0-L_d} = D_{i)0-L_d} - D_u \tag{8}$$

where $D_{P)0-L_d}$ = equivalent average deep percolation depth for the section, mm

$D_{i)0-L_d}$ = equivalent average intake depth for the section, mm

The equivalent average intake depth is given by the following:

$$D_{i)0-L_d} = [a\ (T_{oa})^b_{L_d} + c]\ (\frac{P+K}{W}) \tag{9}$$

where $T_{oa)L_d}$ = average opportunity time for the section, min

The equivalent average deep percolation depth for the full furrow length is estimated as:

$$D_P = (D_{P)0-L_d})\ \frac{L_d}{L} \tag{10}$$

where D_P = equivalent average deep percolation depth for the full furrow length, mm

Finally, the equivalent average root zone storage depth is defined as:

$$D_{au} = D_a - D_r - D_P\ , (D_{au} \leq D_u) \tag{11}$$

where D_{au} = equivalent average root zone storage depth, mm

The relationships presented above are quasi-rational. The recession component was assumed negligible in the derivation of the above relationships. Hence, when the recession component is significant, this optimization technique gives only an approximate solution.

Optimization Technique

The system defined by the above equations can be analyzed by nonlinear programming. Generalized geometric programming (GGP), which is applicable to engineering design problems of this type, is a type of nonlinear programming that is most appropriate for this problem. The same technique was presented by Karmeli and Oron (1979) for closed conduit irrigation (sprinkle and trickle) systems. Generalized geometric programming is formulated with an objective function of the form:

$$G_o(\bar{x})_{min} = P_o(\bar{x}) - Q_o(\bar{x}) \tag{12}$$

$G_o(\bar{x})$ = objective function in terms of system variables and cost coefficients

with K_2 constraints in the form:

$$G_k(\bar{x}) = P_k(\bar{x}) - Q_k(\bar{x}) \leq 1.0 \ , \quad k = 0,1,2, \ldots, K_2 \ . \tag{13}$$

$G_k(\bar{x})$ = constraint function in terms of system variables and constants

The quantities, $P_k(\bar{x})$ and $Q_k(\bar{x})$ are called posynomials. They are the terms in the objective and constraint functions with positive and negative coefficients, respectively. They have the following forms:

$$P_k(\bar{x}) = \sum_{i=1}^{I} U_{ik}(x) \quad , \quad k = 0,1,2, \ldots, K_2 \tag{14}$$

$$Q_k(\bar{x}) = \sum_{j=1}^{J} V_{jk}(x) \quad , \quad k = 0,1,2, \ldots, K_2 \tag{15}$$

in which K_2 = number of constraints in the problem; I = number of terms with positive coefficients $[P_k(\bar{x})]$; J = number of terms with negative coefficients $[Q_k(\bar{x})]$. Each term in a posynomial is defined as the product of a constant and one or more system variables with exponents. These terms, U_{ik} and V_{jk}, are defined as follows:

$$U_{ik} = C_{ik} \prod_{\ell=1}^{L_1} \chi_\ell^{\xi_{ik\ell}} \quad , \quad k=0,1,2, \ldots, K_2; \ i=1,2, \ldots, I \ . \tag{16}$$

$$V_{jk} = C_{jk} \prod_{\ell=1}^{L_1} \chi_\ell^{\xi_{jk\ell}} \quad , \quad k=0,1,2, \ldots, K_2; \ j=1,2, \ldots, J \ . \tag{17}$$

where U_{ik}, V_{jk} = terms with positive and negative coefficients, respectively in the objective function and constraints

C_{ik}, C_{jk} = constants in each term of the objective function or constraints

χ_ℓ = system variable

$\xi_{ik\ell}, \xi_{jk\ell}$ = exponents for the system variables

L_1 = number of variables in the system

Equations (12) and (13) are called signomials. A signomial is defined as the difference of two posynomials. The major step in the formulation of GGP is the transfer of the signomials into posynomials with one term, called monomials. This is accomplished by a process of condensation as defined by Dembo (1972). After the monomials are obtained, the constraints and the objective function are linearized by taking the natural logarithm of the monomial function. This set of equations is solved by linear programming and convergence of the solution to the original problem is obtained by additional constraints called "cuts" to the original problem. By solving the linear program a finite number of times, an optimum solution to the original nonlinear problem is obtained. Verification of a global optimum solution must be performed. Dembo (1972) mentioned that the global optimum is assured if an initial feasible solution is available to initiate the algorithm. The global optimum is verified here by simulation.

The values of the variables obtainable from the above technique will be continuous (non-integer). In the design of an irrigation system some of the variables such as the number of lengths of run, number of sets, and number of furrows per set should have integer values. Therefore, a different technique must be attached to the above procedure to obtain an optimal solution that has the values of these variables as integers. The branch-and-bound (Benichou, Gauthier, Girodet, Hentges, Ribiere, and Vicent, 1971) technique is chosen here to express the related variables in an integer form.

Definition of Objective Function and Constraints

The most commonly chosen objective functions are either maximization of profit or minimization of costs. For an irrigation system, maximization of profit requires an explicit relationship between the system design variables and crop yields. Reddy (1980) has developed such a relationship for wheat and a border irrigation system. For this application to furrow irrigation systems, minimization of system design costs was chosen as the objective function for optimal design.

The costs involved in the design of a furrow irrigation system include: (1) the cost of water; (2) the cost of labor; (3) the cost of headland facilities such as the head ditch; and (4) the costs of environmental effects such as deep percolation and runoff on water quality. The effect of poor irrigation practices on yield, such as deep percolation on fertilizer leaching and reduced yield and underirrigation on crop stress and resulting yield, will be neglected in this analysis since returns have not been computed. The environmental effects will also be neglected for simplicity of presentation and because of a general lack of appropriate data on the costs of water quality degradation. When runoff recovery is to be included in the system design, then costs of the recovery can be considered in the water costs. Benefits of the recovery may also reduce other system design costs. The cost function for optimal design is as follows:

$$G_o(Q_f,T_i,L) = n_i n_\ell n_w \;(c_1 Q_f T_i n_{fs} + c_2 \alpha T_i) + c_3 n_\ell W_F \tag{18}$$

cost of water — cost of labor — cost of headland facilities

$G_o(Q_f,T_i,L)$ = cost function for system design, \$/field

c_1 = cost coefficient of water (from either a canal or a well), \$/ha-m

c_2 = cost of labor, \$/hr

α = fraction of the time labor is utilized during the irrigation time

c_3 = cost of ditch construction, \$/linear meter

n_ℓ = number of lengths of run in the field

W_F = width of the field, m

n_i = number of irrigations per season

n_{fs} = number of furrows irrigated per set

n_w = number of sets in the width direction

In addition to the cost function, there are limits on the system variables called constraints. These constraints limit the design variables to feasible values. Maximum flow per furrow based on physical or legal boundaries, or rainfall erosion, and furrow spacings based on crop, machinery or farmer preference are all examples of constraints frequently specified for a particular design. All these constraints must be met to have a feasible, optimal design.

The constraints for a given design are specified as follows:

$$Q_f \geq Q_{f)min} \;;\quad G_1 = Q_{f)min}/Q_f \leq 1 \tag{19}$$

$$Q_f \leq Q_{f)max} \;;\quad G_2 = Q_f/Q_{f)max} \leq 1 \tag{20}$$

But Q_{max} is given as follows:

$$Q_{f)max} = \frac{A}{S} \;;\quad G_2 = \frac{Q_f}{A} \leq 1 \tag{21}$$

$Q_{f)max}$ = maximum non-erosive stream, lps

A = coefficient dependent on erosiveness of soil and assumed 0.63

S = slope of furrow in percent

Usually the depth of irrigation is specified based on an optimal depletion level for a given crop for maximum yields. Reddy (1980) has used another strategy which consisted of simulating the results of a given set of field and hydraulic conditions to result in a specific field distribution of water. The resulting constant field distribution of water is used to simulate crop yield for segments of the field. Yield is then related to a constant, seasonal water requirement efficiency and a design depth of irrigation. Other strategies are possible to result in relationships that can be used to obtain both an optimal design depth and optimal seasonal performance. In this application the optimal design depth is assumed to be given.

The SCS furrow irrigation design procedure requires that the length of the field over which the design depth is to be met by a given irrigation be specified. This length, K_3L, is called the design length, L_d. An appropriate design strategy would be to determine the optimal design length. In this application, the frequency used design length of 0.9L (K_3 = 0.9) was assumed.

The design application depth at 0.9L should be greater than or equal to the optimum depth of requirement. The constraint for this condition becomes as follows:

$$D_u \geq D_{opt} \quad ; \quad G_3 = \frac{D_{opt}}{D_u} \leq 1 \tag{22}$$

where D_{opt} = optimum depth of requirement, mm

The constraint can be expanded as shown below:

$$G_3 = \frac{D_{opt}}{\{a[T_i - g(0.9L)^h]^b + c\}(\frac{P+K}{W})} \leq 1 \tag{23}$$

$$G_3 = \frac{D_{opt}\, W}{\{a[T_i - g(0.9L)^h]^b + c\}]0.3304(\frac{Q_f}{S_o^{1/2}})^{0.31524} + 0.21]} \leq 1 \tag{24}$$

The average amount of irrigation water supplied to the root zone is defined by the product of the water requirement efficiency and the design depth. Efficiency can also be restricted to be greater than or equal to some specified amount for optimum yields (Reddy, 1980). Therefore, the optimum average depth of water to be provided to the root zone is the product of the optimum water requirement efficiency and the optimum depth of irrigation water. The amount of irrigation water provided for the root zone should be greater than or equal to this optimum average. The constraint of Equation (22) can also be specified as:

$$G_3 = \frac{D_{opt}E_R}{D_{au}} \leq 1 \tag{25}$$

$$G_3 = \frac{D_{opt}E_R}{[\{a[T_i - \frac{g}{h+1}L^h]^b + c\} - \{a[T_i - \frac{g}{h+1}(K_3L)^h]^b + c\} + \{a[T_i - g(K_3L)^h]^b + c\}](\frac{P+K}{W})} \leq 1 \tag{26}$$

where E_R = water requirement efficiency. Equation (24) specifies that at 0.9L of the field length, the depth of irrigation should be at least equal to the optimal depth. This length can be any other fraction of the length of run. But for this case 0.9L is used. Equation (26), on the other hand, specifies that the average depth infiltrated into the root zone must be at least equal to the product of the optimal depth times the desired water requirement efficiency. In Equation (26), K_3 determines the fraction of the field length that is irrigated to the optimal level which is unknown at the start of irrigation. The value of K_3 is constrained by:

$$0 < K_3 \leq 1 \tag{27}$$

Either Equation (24) or (26) is sufficient. Equation (24) was used in this analysis.

The length of run cannot be greater than the actual field length given. A shorter length of run increases the cost of operation and the longest length may result in a less uniform distribution of water along the length of the field. Therefore, the field length could be restricted at both extremes:

$$n_\ell L \leq L_F \rightarrow G_4 = L_F/n_\ell L \leq 1 \tag{28}$$

$$L \leq L_{max} \rightarrow G_5 = L/L_{max} \leq 1 \tag{29}$$

$$L \geq L_{min} \rightarrow G_6 = \frac{L_{min}}{L} \leq 1 \tag{30}$$

where L_F = length of the field; L_{max} = maximum length of the run; and L_{min} = minimum length of the run

Similar constraints can be placed on time, number of furrows per set, and number of sets with a given number of furrows and furrow spacing for the width of the field. They are as follows:

$$n_{fs}Q_f = Q \rightarrow G_7 = \frac{n_{fs}Q_f}{Q} \leq 1 \tag{31}$$

$$n_\ell n_w T_i \leq T_{max} \rightarrow G_8 = \frac{n_\ell n_w T_i}{T_{max}} \leq 1 \tag{32}$$

$$n_w n_{fs} = n_f \rightarrow G_9 = \frac{n_f}{n_w n_{fs}} \leq 1 \tag{33}$$

where n_w = number of sets in the width of the field; n_f = number of furrows in the field; n_{fs} = number of furrows per set; T_{max} = maximum time availble per irrigation; T_i = time of application per set; and Q = total flow rate available at the field.

Application of Technique

An example field is analyzed and an optimal design for a furrow irrigation developed. The data for the field including the constraints and cost coefficients are given in Table 1. The optimal design is developed by generalized geometric programming and the optimal solution verified by system simulation.

Table 1. Data for optimal design for example system.

Field Variables and Constants

$S_o = 0.001$; $I_f = 1.5$; $D_u = D_{opt} = 76$ mm; $L_F = 805$ m; $W_F = 402$ m;

$n = 0.04$; $Q = 158$ lps; $W = 0.76$ m; $n_i = 5$

From USDA (1979): $I_f = 1.5$; $a = 2.283$; $b = 0.799$; $c = 6.985$; $h = 2.227$;

$d = -1.227$ and $C_2 = 13767$

Constraints

$D_{opt} \doteq 76$ mm; $K_3 = .9$; $L_{max} = 402$ m; $L_{min} = 91.5$ m; $Q_{f)min} = 0.63$ lps;

$Q_{f)max} = 3.2$ lps; $T_{max} = 8000$ min

Cost Coefficients

Cost of Water, c_1 = \$40/ha-m; Cost of Labor, c_2 = \$3/hr; Cost of

Ditch construction, c_3 = \$3.25/meter length; and $\alpha = 1.0$

The objective of the design is to minimize the cost of water, labor, and head ditch construction. The negative effects of environmental pollution by runoff and deep percolation, and reduced crop yield from stress are not considered. Therefore, the cost function becomes:

$$G_{o\ min} = n_\ell n_w \left[n_i \left(0.00024\, n_{fs} Q_f T_i + 0.05 T_i\right) + 2.5 n_{fs}\right] \tag{34}$$

The constraints of the system are given as follows:

$$G_1 = 0.63Q_f^{-1} \leq 1 \tag{35}$$

$$G_2 = 0.31Q_f \leq 1 \tag{36}$$

$$G_3 = \frac{(76)\ (.76)}{\{2.283[T_i-g(.9L)^{2.227}]^{.799} + 6.985\}[0.3304(\frac{Q_f(.04)}{(.001)^{\frac{1}{2}}})^{.31524} + .21]} \leq 1 \tag{37}$$

Similarly, length and time can be constrained as:

$$G_4 = 805/n_\ell L \leq 1 \tag{38}$$

$$G_5 = L/402 \leq 1 \tag{39}$$

$$G_6 = 91.5/L \leq 1 \tag{40}$$

$$G_7 = n_{fs}\ Q_f/158 \leq 1 \tag{41}$$

$$G_8 = n_\ell n_w T_i/8000 \leq 1 \tag{42}$$

$$G_9 = \frac{n_f}{n_w n_{fs}} \leq 1 \tag{43}$$

In constraint G_3 (Equation 37), a new variable v is defined to simplify the complexity of the constraint which is given as:

$$v = T_i-g(.9L)^h \rightarrow G_{10} = \frac{v+g(.9L)^h}{T_i} \leq 1 \tag{44}$$

In order to avoid the unboundedness of the variable, a penalty function is added to the cost function. Therefore, the cost function becomes:

$$G_{o\ min} = 0.0012Q_f T_i n_\ell n_{fs} n_w + 0.25T_i n_\ell n_w + 2.5n_\ell n_{fs} n_w + 10{,}000v \tag{45}$$

In the linearization procedure the cost function is added as an additional constraint to the problem. This constraint is formulated, again, as an upper bounding constraint by the introduction of an additional variable (u) into the problem of the following form:

$$\text{Min } u \tag{46}$$

$$G_o = 0.0012Q_f T_i n_\ell n_{fs} n_w + 0.25T_i n_\ell n_w + 2.5n_\ell n_w n_{fs} + 10{,}000v \leq u \tag{47}$$

All the constraints are linearized at an arbitrary initial point as described by Dembo (1972). The initial point need not be a feasible point. After linearization, the problem becomes a linear programming problem. A generalized geometric programming code was developed to solve the above problem.

Results and Discussion

By applying the generalized geometric programming technique, the following optimal values of the variables were obtained: L = 402 m, Q_f = 3.15 lps, T_i = 371 min, n_ℓ = 2, n_{fs} = 50 and n_w = 10.6. These values satisfy all the constraints imposed in the problem closely. If more refinement is needed, these values can be reiterated until every constraint is exactly satisfied. The above solution is optimum, but to verify whether this is the global optimum, a simulation study was done. This study revealed that these values are, in fact, the minimum values, i.e., the global optimal design was obtained. The optimal values obtained by simulation are: L = 402 m, Q_f = 3.15 lps, T_i = 375 min, n_ℓ = 2, n_{fs} = 50 and n_w = 10.6. These values are presented in Table 2.

The above values of the number of sets in the width direction (n_w) are not convenient because they do not represent an integer number of operating sets in the width direction (n_w = 10.6). Fractional sets do not have any physical meaning. Hence, after the optimum was obtained, the branch-and-bound technique was used in which the value of n_w was increased and decreased to the next integer number of sets. The optimal values of the other variables were obtained by similar procedure also for the two different values of n_w. A flow chart of the procedure is depicted in Figure 1. By comparing the cost of design for the two values of n_w, the minimum value was accepted as the optimal design. The values of the variables are given as: L = 402 m, Q_f = 3.15 lps, T_i = 357 min, n_ℓ = 2, n_{fs} = 48, and n_w = 11. The optimal cost of seasonal irrigation was $187.40/ha.

Summary

Generalized geometric programming and the Soil Conservation Service design procedure for furrow irrigation systems were combined to obtain an optimal system design considering a number of design variables and system constraints. The optimal design was verified by simulation using the design equations and considering the constraints. Generalized geometric programming and current quantitative design procedures can now be combined to obtain optimal system designs that result in improved on-farm water management at minimum cost to the farmer. Costs considered were water, labor and ditch construction.

Table 2. Seasonal cost ($/ha) of irrigation for a given field as a function of length, inflow rate, time of irrigation, and system constraints.

	Cost of Irrigation															
	L = 100 m				L = 201 m				L = 268 m				L = 402 m			
	Inflow Rate (lps)				Inflow Rate (lps)				Inflow Rate (lps)				Inflow Rate (lps)			
Time (minutes)	1.26	1.89	2.52	3.15	1.26	1.89	2.52	3.15	1.26	1.89	2.52	3.15	1.26	1.89	2.52	3.15
75	--*	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
125	--	412	--	--	--	--	--	--	--	--	--	--	--	--	--	--
175	407	--	--	--	--	--	244	264	--	--	--	--	--	--	--	--
225	430	--	--	--	--	241	267	--	--	--	--	219	--	--	--	--
275	--	--	--	--	--	258	--	--	--	--	217	--	--	--	--	--
325	--	--	--	--	234	--	--	--	--	207	--	--	--	--	--	--
375	--	--	--	--	249	--	--	--	--	219	--	--	--	--	--	190
425	--	--	--	--	261	--	--	--	--	--	--	--	--	--	--	--

*Missing data (--) represent infeasible solutions.

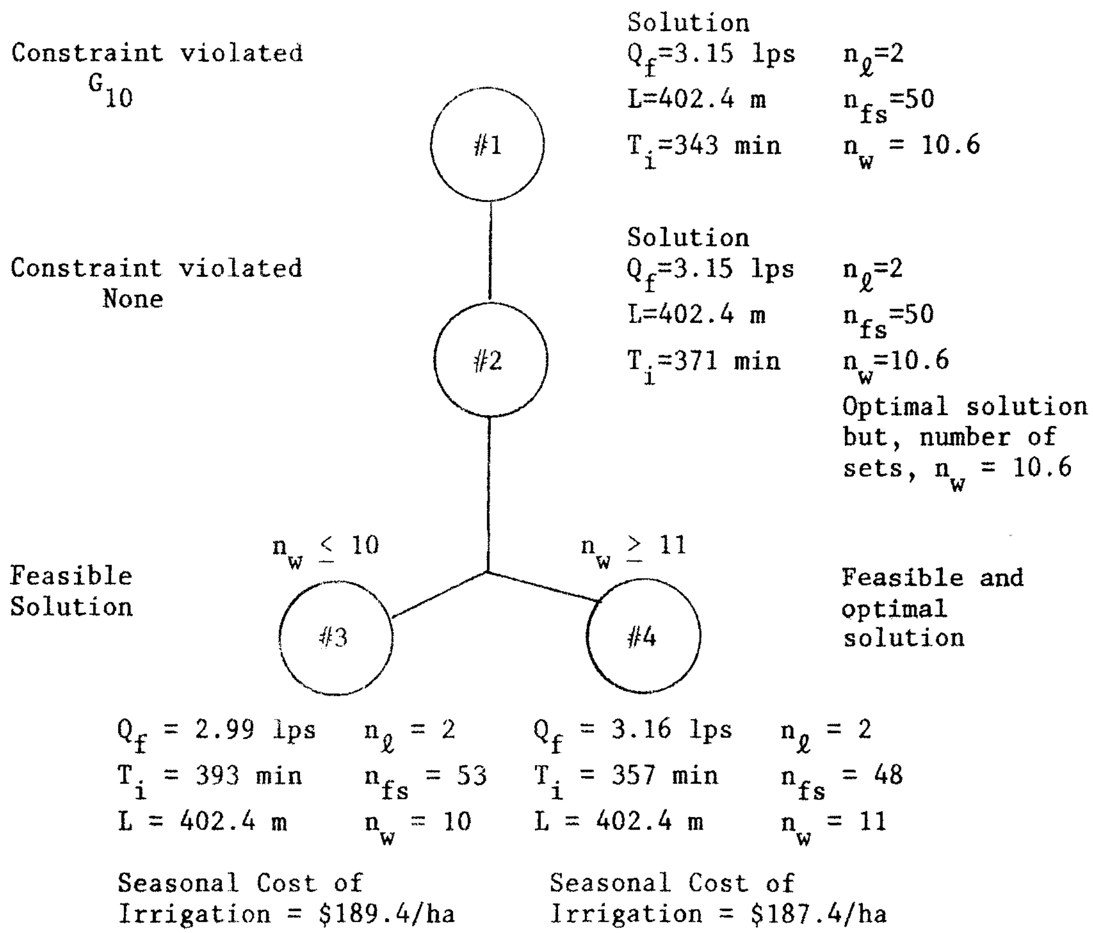

Figure 1. Flow chart of the solution procedure.

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LIST OF SYMBOLS

Symbol	Definition
D_a	= equivalent average gross inflow depth, mm
Q_f	= average furrow flow rate, lps
T_i	= time of irrigation, min
W	= furrow spacing, m
L	= length of the furrow, m
D_i	= equivalent average intake depth, mm
a,b,c	= infiltration constants
g,h,d,C_2	= advance coefficients for a given intake family
(P+K)	= equivalent average wetted perimeter, m
K_1	= 4.831 for metric units
S_o	= slope of the furrow
n	= Manning's roughness coefficient
D_r	= equivalent average runoff depth, mm
D_u	= equivalent design application depth, mm
$T_i-T_{x=L_d}$	= intake opportunity time at point L_d, min
L_d	= point along furrow at which design application is to be infiltrated, m
$D_{p(0-L_d)}$	= equivalent average deep percolation depth for the section $x = 0$ to $x = L_d$, mm
$D_{i(0-L_d)}$	= the equivalent average intake depth for the section $x = 0$ to $x = L_d$, mm
$T_{oa})L_d$	= average opportunity time for the section $x = 0$ to $x = L_d$, min
D_p	= average deep percolation depth for the full furrow length, mm
D_{au}	= equivalent average root zone storage depth, mm
$G_o(\bar{x})$	= the objective function in terms of system variables and cost coefficients

Symbol	Definition
$G_k(\bar{x})$	= constraint function in terms of system variables and constants
I	= number of terms in each constraint with positive coefficient
J	= number of terms in each constraint with negative coefficient
K_2	= number of constraints
L_1	= number of variables in the problem
C_{ik}, C_{jk}	= coefficients of cost function or constraints
x_ℓ	= variable of the system
$\xi_{ik\ell}, \xi_{jk\ell}$	= exponents of variables in the objective function and constraints
U_{ik}, V_{jk}	= terms in the objective function and the constraints
c_1	= cost coefficient for water ($/ha-m)
c_2	= cost coefficient for labor ($/hr)
c_3	= cost of ditch construction ($/meter length)
α	= fraction of the time labor is utilized during the irrigation time
W_F	= width of the field, m
n_ℓ	= number of lengths of run
n_{fs}	= number of furrows irrigated per set
n_w	= number of sets in the width direction
A	= a constant (.63)
D_{opt}	= optimum depth of requirement, mm
n_i	= number of irrigations/season
u and v	= variables
L_F	= length of the field, m
E_R	= water requirement efficiency
L_{max}	= maximum length of the run, m

Symbol	Definition
L_{min}	= minimum length of the run, m
Q	= total flow rate available at the field, lps
T_{max}	= maximum time available for irrigating the field, min
$Q_{f)min}$	= minimum flow rate into the furrow, lps
$Q_{f)max}$	= maximum non-erosive stream size into the furrow, lps

IRRIGATION SYSTEM IMPROVEMENT CONCEPTS[1/]

Wayne Clyma and Thomas W. Ley[2/][3/]

INTRODUCTION

There are nearly 227 million irrigated hectares in the world today and the rate of increase each year is not more than 4 million hectares. Thus, there is an opportunity to utilize techniques for improvement of irrigation systems at a ratio of more than 60 to 1 when compared to designing new systems. Increasing world food production and reducing energy costs both require more effective and efficient operating irrigation systems. Irrigation system improvement is the key to effective system improvement for an efficient irrigated agriculture.

The purpose of irrigation system improvement is to help farmers make decisions that result in better system operation. System design has traditionally specified appropriate values for the variables for operation of each system. Many farmers do not operate their systems according to the original design or may operate without an explicit design.

A major deficiency in irrigation water management today is the lack of follow-up in improving system operation. This follow-up involves evaluation of operating systems to identify deficiencies in design and system operation. Operational levels of performance that equal or exceed potential (design) levels are the objective.

Irrigation system design is perceived by engineers and emphasized in textbooks as an important activity in irrigation. System design principles embody the engineer's state-of-the-science and the farmer's state-of-the-art of irrigation to define the operational variables of the system for effective, efficient operation. System design specifies the potential level of performance of a system. Evaluation identifies the actual level of performance. Irrigation system improvement is the process of assisting farmers to change from their current level of operation to their potential level. This paper will define concepts and procedures for a systematic process of irrigation system improvement.

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IMPROVEMENT PROCESS

The irrigation system improvement process consists of the following three steps:

1. System design

2. System evaluation

   a. Field data collection and analysis

   b. Design

   c. Performance

   d. Management

3. System improvement

   a. Redesign

   b. Management

This three-step process should be applied to every irrigation system assumed to be in need of improvement. Step 1, consisting of system design, is necessary to determine the potential level of performance of the system. This can be an explicit system design used in developing a new irrigated area where the system is then constructed. If the system is already in operation, then system design defines the values of the variables for system operation and the potential level of performance of a particular field. The design values for system performance are selected according to appropriate agronomic, economic, engineering and sociological criteria.

System evaluation, Step 2, is the collection of specific field data which are used to quantitatively evaluate the design, performance, and management of the system (Ley and Clyma, 1980a; Ley and Clyma, 1980b). Explicit data are collected concerning slope, infiltration rate, flow rate of irrigation, runoff from the field, advance, recession, soil water content and other important design variables and system parameters as the first activity. These data are analyzed to define the values of each system variable and parameter.

The second activity is to use the specific field data collected during the evaluation to develop a new design. This design is compared explicitly with the design in Step 1. The results are evaluated to determine the adequacy of the design in terms of: (1) knowledge about specific values for system variables in the initial design (Step 1); and (2) the adequacy of the design procedure to represent the performance of the system. The results of these analyses indicate, for example, that a furrow design was inadequate because the infiltration rate was in error or incorrectly assumed. The results may show that the values for system variables for the design and the evaluation are different and a different level of system performance resulted. This indicates that the design procedure was not appropriate for this particular field.

The third activity in system evaluation includes determination of system performance. This is accomplished by calculation of the appropriate system efficiencies and the spatial distribution of applied water from the measured data. System performance as measured by the evaluation is compared directly with the values specified from the design which is the potential level of performance. The differences in performance between design and evaluation indicate the need for improvement.

A comparison of system design variables and performance parameters from the design and the evaluation allows a determination of the adequacy of management decision making as the fourth activity of an evaluation. The three basic management decisions of how to irrigate, when to irrigate, and how much water to apply can each be separately evaluated. System evaluation collects specific data on system operation and determines the adequacy of system design, performance and management decision making.

System improvement, Step 3, is achieved from a knowledge of potential performance derived from design and the actual performance measured by the evaluation. A new design for the system may be necessary because of farmer preference, system constraints, farmer constraints, or new knowledge by the designer about how to solve system or farmer problems. The design in this instance is a new strategy for specifying system operation that the farmer can more effectively manage. Examples of redesign include changes in the length of run, furrow spacing or border width, and flow rate for an irrigation.

The results of the design and evaluation will produce insight as to how the farmer makes his management decisions. Perhaps knowledge about how flow rate and time influences how much water is applied during an irrigation may be lacking. New knowledge from the evaluation can assist the farmer to make a better decision. Perhaps an inflexible water supply may be a constraint on when the farmer irrigates. A new design depth, flow rate and time of irrigation that improves system performance under this constraint may improve the farmer's management decision. Any improvements presented to the farmer would indicate the present level of system performance and the expected level after improvement. The key to the improvement process is the combining of system design with system evaluation to achieve a better understanding of system operation and thus better solutions to system problems.

DESIGN AND EVALUATION CONCEPTS

In system improvement, design and evaluation are integral components. Necessary to any design or evaluation is the requirement that the system be defined. This section will present concepts for the definition, design and evaluation of an irrigation system.

System Definition

The irrigation system consists of the following subsystems: (a) water delivery, (b) water application, (c) water use, and (d) water removal. In any study of an irrigation system (design or evaluation), the basic subsystem to define first is the water use subsystem. Providing water use for plants is the fundamental goal of the three other subsystems. Thus, the functions of the water use subsystem are the functions of the other subsystems.

In the definition of each subsystem, a three-step procedure is followed:

1. Define the functions of each subsystem.

2. Identify the subsystem state variables.

3. Specify the performance parameters and criteria for improvement.

The functions of each subsystem specify the reasons for the operation of the subsystem. A traditional function is to supply water for plant growth. Many other functions are evident to farmers. The engineer, who engages in system improvement activities, may find a particular irrigation by a farmer unnecessary. This classification may be contradicted by the farmer because he considers the irrigation essential. These farmer defined functions of an irrigation are important to system operation and essential in system improvement.

Subsystem state variables must be specified to encompass a complete description of the system. The values state variables take on in operation may be explicit cause for poor system performance. The classification of the system (border or furrow and level or graded) and the boundary and initial conditions for the particular system are all necessary in this systematic description of the system.

The performance parameters are those factors used to evaluate system performance and commonly would include the availability factor or other appropriate stress parameters (Hart, 1975). These would be specified for a particular crop, field, and climatic zone. Other performance parameters to be considered are water application efficiency, water requirement efficiency, and runoff and deep percolation ratios. A measure of the uniformity of distribution for a particular field may also be important. The desired values of these performance parameters would be selected based on socio-economic conditions for a farm in a particular area.

System Design

System design as a procedure has been described with both general and specific steps (Hart, 1975). Experience in combining system design with evaluation suggests several new concepts for design.

First, farmers operate their irrigation system over a season. Most approaches traditionally design for the peak use period. Gates (1980) suggested that these peak period designs may produce unacceptable performance. Further, farmers operate their systems to achieve better performance than current peak period designs.

Engineering designs traditionally use peak period consumptive use and some crop stress criteria to establish a design depth. This design depth more explicitly should be called a crop design depth criteria. Ley and Clyma (1980c) showed that by reducing the design depth by only 15 percent, with a water requirement efficiency above 90 percent, the application efficiency could be increased from less than 70 to 85 percent. Thus, a design depth based on system hydraulics criteria should be an additional design consideration. With the more explicit design procedures available for furrows (USDA, 1979), system hydraulics can effectively change design criteria. In the instance reported by Ley and Clyma (1980c), the low terminal intake rates of the soil required the application of much water to achieve the last few millimeters of deficiency. Thus, a hydraulic design depth should become a new design criteria.

Another system design concept needs application in irrigation scheduling. Irrigation scheduling implies the specification of how, when and how much to irrigate. Traditionally this has been the specification of when to irrigate based on some stress criteria and how much to irrigate based on a calculation or measurement of soil water deficiency. "How" includes the specification of the operational variables for the system. In the past, this usually has not been included but was implied in some of the earlier concepts of irrigation scheduling described by Jensen (1975).

Keller (1979) used the concept of specification of how to irrigate through an explicit system design for center-pivot irrigation systems in the San Luis Valley of Colorado. A comparison of system design parameters and variables to those existing during system operation was used to enumerate and classify system assumptions in a traditional irrigation scheduling application. Incorporation of the concepts of irrigation scheduling into an improvement process would lead to more effective water management. Gates (1980) and Ley and Clyma (1979) concluded that irrigation scheduling alone does not result in the greatest improvement in on-farm water management. System design and evaluation combined with irrigation scheduling would result in the greatest improvement.

System Evaluation

Evaluation of irrigation systems has not been accorded much importance in the past. For example, only recently did Merriam and Keller (1978) publish a book devoted to the evaluation of irrigation systems. Other texts dealing extensively with irrigation, especially system design, have dealt minimally or not at all with evaluation (Schwab et al., 1966; Hart, 1975; Israelson and Hansen, 1962; and Booher, 1974; Withers and Vipond, 1974).

The authors suggest the following purposes for irrigation system evaluation.

1. Evaluation of farmer practice in conjunction with irrigation system hydraulics.

2. Evaluation of irrigation system hydraulics.

The major emphasis of the first purpose is the identification of how farmers operate and manage an irrigation system. Thus, this activity of evaluation should be focused on observing and measuring the particular conditions and results of farmer irrigation practice. It is imperative that activities that are related to the evaluation do not influence farmer decisions. The data should be collected during an irrigation that is regularly scheduled by the farmer and not scheduled for the convenience of the evaluators.

Evaluation of system hydraulics may require the specification of a number of variables. In this instance an attempt is being made to compare the results of a design or a particular design model with the actual operation of the hydraulic system. Thus, it may be desirable to specify soil water deficiency, flow rate during irrigation, duration of irrigation, or a number of other variables which would make the comparison between model and actual system more explicit.

The functions of irrigation system evaluation are as follows:

1. Determine system variable values such as intake family, Manning's n or roughness, rate of advance, etc.

2. Measure the operation of a system to evaluate where improvements in the system can be made.

3. Determine the applicability of design models or procedures for refining system operation.

4. Determine in a geographic area the problems potential for improvement of irrigation system operation.

5. Understand decision-making processes and knowledge levels of farmers to define programs which would improve management decisions.

The emphasis of this particular evaluation activity is on irrigation engineering. Irrigation systems in general do not operate to accomplish the distribution of irrigation water but operate for the purpose of growing crops to provide economic or social benefits. Thus, a realistic evaluation of an irrigation system should consider agronomic, economic, and social aspects of a farmer's goals in addition to irrigation engineering aspects. Clyma, Lowdermilk, and Corey (1978) and Lowdermilk, Clyma and Early (1978) have discussed in substantive detail such an interdisciplinary evaluation of irrigation systems. Clyma and Ali (1977) have also suggested how a state-of-the-art concept can be applied to the evaluation of the irrigation engineering aspects of particular systems in a geographic area. El Kady, Clyma and Abu-Zeid (1979) and Ley and Clyma (1979) have also applied this particular process to a geographic area in Egypt and Colorado, respectively. Thus, the focus of this particular report is on the irrigation engineering aspects of irrigation system evaluation. The procedure is directly complementary to the research-development process for improvement of on-farm irrigation (Clyma, Lowdermilk, and Corey, 1977).

The first function of irrigation system evaluation is to determine values for system design variables and parameters for utilization in future designs. For example, in a particular geographic area the relationship between intake family and soil type may need to be established by field verification. Other irrigation system design parameters also may need field verification.

Measurements of an irrigation on a particular farmer's field to evaluate the system design, operation and management, and performance is the second function of system evaluation. This evaluation is with a specific farmer and a field at a specific time. Carefully coordinated data of the variables of system operation such as soil moisture deficiency, infiltration rate, irrigation stream, and other system variables are measured explicitly. These variables are measured while evaluating the knowledge and decision-making process that a farmer uses in selecting values for the operational variables. With this type of carefully collected and coordinated system data, an evaluation of system design, performance, and management can be accomplished.

Field evaluation of particular design models or improvement procedures is an important aspect of system evaluation in function 3. For example, Fangmeier and Strelkoff (1979) documented the validity of the zero inertia model from irrigation system evaluations. The SCS graded border design procedure was then validated using the zero inertia model (Fangmeier and Strelkoff, 1979).

Frequently, while accomplishing functions 1, 2, and 3 on specific fields and farms, function 4 is also accomplished. The emphasis in function 4 is a study of a geographic area to accumulate reliable data which will define the state-of-the-art of irrigation in an area. The state-of-the-art concept requires the identification of how farmers use known irrigation principles to manage and operate an irrigation system. This activity defines problems, suggests solutions, and provides insight in how to assist farmers to achieve system improvement. This function was fulfilled in studies by Clyma and Ali (1977), El Kady, Clyma and Abu-Zeid (1979) and Ley and Clyma (1979).

Function 5 required much thought before being included as one of the activities in irrigation system evaluation. The reason for this consideration is that this activity would best be accomplished as an interdisciplinary study as suggested by Clyma, Lowdermilk, and Corey (1977). The emphasis on this activity is on identifying explicitly the knowledge level of farmers, their decision-making process, and the physical results of their decision-making process or knowledge level to determine where improvement is needed. For example, documentation of this process in an area could result in identification of the fact that farmers did not understand the relationship between soil rootzone storage and the rate of consumptive use of a particular crop such as reported by Lowdermilk, Clyma and Early (1978). With this knowledge available, an education program could be designed to improve farmer understanding of rootzone storage and crop water use. Advice through irrigation scheduling would be another approach to assisting a farmer in this activity.

IMPROVEMENT PROCESS EXAMPLE

The improvement process is illustrated in the following example. The method of irrigation studied is furrow irrigation. A furrow irrigation system near Greeley, Colorado, was evaluated during the summer of 1979 (Gates, 1979). Data for the following example was taken from this particular system. The SCS furrow irrigation design procedure (USDA, 1979) was utilized for system design as modified by Ley and Clyma (1980c). System evaluation procedures utilized are found in Ley and Clyma (1980b).

An initial design was formulated from the system parameters and variables given in Tables 1 and 2, respectively. Step 1 in Table 2 is the initial design based on available data, site derived data and assumptions. The soil intake family was obtained from SCS soil survey data and the Colorado Irrigation Guide (USDA, 1978).

An evaluation of the field was conducted (Gates, 1979) at a regularly scheduled irrigation. The measured values of the system variables and performance derived from the evaluation are given in Table 2, Step 2a. The major discrepancies for the system variables are soil intake family, design depth, inflow rate and inflow time. The result is unacceptable levels of measured system performance in Step 2a, Table 2.

Before developing a new design, the adequacy of the design procedure should be evaluated. The results are shown as Step 2a, Table 2 under predicted performance. Some discrepancy between system performance from the evaluation and the design were obtained.

Study of the measured intake function and the SCS 1.5 furrow intake family function illustrates the problem. The measured intake function does not parallel the SCS intake functions but crosses several of them when plotted. This means that the SCS intake function will tend to overestimate the amount of intake during the initial stages of irrigation as compared to the measured intake function, resulting in an underestimation of runoff losses. During the latter stages of irrigation, the SCS intake function may be slightly underestimating the intake. The overall combined effect is the overprediction of water application efficiency. A certain amount of discrepancy in simulating system performance with a design procedure is to be expected. Other minor deviations may also be contributing to the discrepancy but overall deviation is still acceptable. It is assumed that in this particular instance, the deviations are acceptable and the design procedure deemed suitable, without further modification, as a tool to be used for suggesting improvements to the farmer's operation.

With data from the evaluation, a new design is formulated. The results are given as Step 2b in Table 2. The performance developed from the design provides a high level of performance for the system. There are a number of discrepancies between the new design (Step 2b) and the farmer's operation. The inflow time is 1.7 times the desired time and the inflow rate is slightly low. The major discrepancies between design and operation are that the farmer irrigated too soon and the amount of water applied was excessive because of the longer inflow time in system operation.

Table 1. System parameters for example system.

Total available water	= 19.3 cm	Bulk specific gravity	= 1.33
Field capacity	= 22.84%	Rootzone depth	= 1.2 m
Permanent wilting point	= 10.75%	Availability factor	= 0.4

Table 2. System variables and performance parameters for various steps of the improvement process.

Variable	Step 1 (initial design)	Step 2a (evaluation)		Step 2b&2c (new design)	Step 3b (management improvement)
Length(m)	275	275		275	
Slope(m/m)	0.0032	0.0032		0.0032	
Furrow Spacing(m)	1.5	1.5		1.5	
Intake Family	0.5	1.5		1.5	
Design Depth(mm)	76	42.5		76	Irrigated too soon
Inflow Rate(lps)	0.54	1.7		1.77	
Inflow Time	1200	495		300	Irrigated too long
Performance[1/]					
		Measured	Predicted	Step 2c	
E_a(%)	76	35	45	96	
E_r(%)	90	100	100	94	
R_t	0.24	0.08	0.05	0.04	
R_p	0.00	0.57	0.50	0.00	
s/x	-	-	-	-	

[1/] The performance parameters are application efficiency (E_a), water requirement efficiency (E_r), runoff ratio (R_t), and deep percolation ratio (R_p) (Ley and Clyma, 1980b).

System improvement, Step 3, is the next step of the improvement process. Comparison of the new design with the evaluation have already identified that the major improvements needed in the system operation are the farmer's decisions of when and how much to irrigate. This improved management of the system is presented to the farmer for his acceptance. The explicit recommendations are as follows:

1. The farmer should increase the flow rate per furrow from 1.7 to 1.77 lps (26.9 to 28.0 gpm).

2. The farmer should wait until the soil water deficiency is at the design level before irrigating. Perhaps he can make use of Colorado Extension Service information on irrigation scheduling to improve this decision.

3. The inflow time needs to be reduced to a five-hour set for this field to reduce deep percolation. Since a high water table is already a potential problem for this field, the more than 50 percent deep percolation resulting from his present practice may influence the farmer to accept the new inflow time and change the amount of water applied.

With the above analysis complete, the improvement process has demonstrated how a farmer can improve his system performance. Also, the improvement process provides direct insight into irrigation system improvement needs.

These irrigation system improvement concepts, both the improvement process and the design and evaluation concepts, are recommended to individuals and organizations for adoption as a systematic method for achieving more effective on-farm water management-both for the U.S. and the world.

SUMMARY

Irrigation system improvement concepts are presented as an improvement process. The improvement process explicitly combines irrigation system design with irrigation system evaluation to achieve an understanding of system operation and provide recommendations for system improvement. New concepts for design and evaluation are suggested. In design these were as follows:

1. Specification of design water requirements based on crop criteria and system hydraulics criteria.

2. Consideration of temporal effects on design criteria.

3. Use of design procedures to specify values for system variables during system operation to improve existing systems and as an explicit part of irrigation scheduling.

4. Use of design to specify potential levels of system performance for all operating systems.

Irrigation evaluation concepts were as follows:

1. Use evaluation to verify designs.

2. Use explicit comparison of values of design variables and performance parameters to evaluation values to identify needs for improvement.

3. Use evaluation results to identify operational and management problems.

4. Use evaluation to improve particulr fields but use area analyses to design programs to improve on-farm water management in an area.

5. Use the improvement process for an interdisciplinary approach to water management improvement.

An example of the improvement process was used to illustrate how deficiencies in design data result in unacceptable system performance. Recommendations to the farmer included changing inflow rate, inflow time and criteria for when he irrigated in order to achieve substantial improvement in system performance.

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ON-FARM WATER MANAGEMENT PROGRAMS IN EGYPT

by

Mahmoud Abu-Zeid* 1/

INTRODUCTION

Not a very long time ago, Egypt started to focus attention on water management. Among the most important reasons for that, was the need to facilitate additional water for future agriculture expansion, beside preserving soil fertility from salinity and water logging problems.

A central question for management of irrigation water in Egypt is whether water can be considered as a major constraint for agriculture. Several studies have indicated that lack of water management specially on the farm level is a major constraint.

The construction of the High Dam in 1970, changed the irrigation water regime of the River Nile. It was necessary, then, to review irrigation efficiencies estimates. Now is is possible to have full control of downstream discharges from the dam according to actual water requirements and optimize water supplies for irrigation. From the agricultural point of view, Egypt has nearly an ideal combination of environmental resources for crop production. Climate is excellent all the year round for most crops.

It may be useful to indicate that a close look to the subject of on-farm water management in Egypt was not realized due to several reasons among which the most important are the following:

1. Cooperation and harmonization between the concerned organizations responsible for water application, management, and agriculture. It is the policy that the Ministry of Irrigation is responsible for water distribution up to the farm outlet. From there on to the water courses and to the fields it is mainly the concern of the farmer with no means or capabilities to improve his practices in this domain.

2. Maximum concern to maintain irrigation systems and minimum involvement in farm water management.

3. Availability of irrigation water, all the year round, at no direct cost to the farmer.

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4. The inherent desire of the majority of farmers to continue traditional methods of irrigation.

5. Fragmentation of land into small and separated holdings.

6. The rigid system of water rotations.

7. The limited number of technicians trained in soil and water management with poor communications between farmers and extension agents.

8. Lack of institutions concerned with farm water management.

9. Poor links between irrigation engineering graduates and agricultural graduates. Courses for irrigation graduates are more concerned with engineering and hydrological questions while for agricultural graduates the agronomical and agricultural aspects are the predominent.

The great interest of the Egyptian government in developing policies and strategies for water resources planning, and agriculture has helped very much in focusing attention on the problem of on-farm water management.

The water policy for Egypt which was concluded in 1975 enables a better utilization of the present available water resources, and will allow a horizontal expansion of an area of about 2.8 million acres.

In the year 1977, the strategy for irrigation development in Egypt for the year 2000 was developed to comprise the following main objectives:

1. Irrigation should take place at the proper time and in the amount required by the plant.

2. Providing all agricultural land with proper and complete field irrigation and drainage systems which will enable optimum distribution of water, with minimum losses.

3. Pricing of irrigation water so that the farmer pays for what he uses.

Therefore, it was necessary to link between national water management programs of water resources planning and on-farm water management programs.

SUMMARY OF WATER MANAGEMENT RELATED ACTIVITIES BEFORE THE YEAR 1975:

1. Field experiments covering the country for crop water requirements conducted by the Ministry of Irrigation.

2. Experiments by the Ministry of Irrigation to improve and develop field irrigation outlets.

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3. Evapo-transpiration studies carried out by the Ministry of Agriculture.

4. Some dispersed activities by Agricultural Extension teams of the Ministry of Agriculture, mainly related to agronomical practices.

5. Some researches conducted by Universities staff (Engineering and Agricultural) on the same subjects mentioned above.

These previous activities indicate that the closer look to the problem of on-farm started to be at a serious level after the year 1975. Whatever, was the reasons, on-farm management became of main concern to authorities with the help of several problem identification studies and feasibility reports conducted by many national and international groups. All of these studies have indicated that on-farm water management is one of the main constraints to agricultural development in Egypt.

In the year 1975, the Ministry of Irrigation in Egypt initiated the Water Research Center with ten Research Institutes. One of these institutes is the Water Management and Irrigation Technologies Research Institute.

The institute has outlined its work program having the farm water management as its main activity. This was practically the first time in Egypt where an interdisciplinary approach is taken. Teams of specialists in all related fields work together in field applied programs. These teams comprise of: Irrigation Engineers, Agronomists, Soil Scientists, Agricultural Economists, and Sociologists.

CONSTRAINTS AND LIMITATIONS IN OPERATION AND MAINTENANCE OF THE EXISTING IRRIGATION SYSTEM IDENTIFIED BY ONGOING FARM MANAGEMENT PROGRAMS

Irrigation in Egypt has been always categorized as either basin or perennial irrigation. Basin irrigation was developed as a means to capture the flood water of the Nile and to release it after a period of ponding. With the construction of the High Dam, perennial irrigation became possible throughout Egypt and the practice of basin irrigation as described herein was continued. The major thrust during the years 1960-1972 was to establish an irrigation network and the capability to convey year-round water to the entire valley and to additional developed lands with lesser importance to water management practices and improved on-farm water management. Some irrigation practices followed by the farmers in basin irrigation had to be changed.

The approach which was developed for on-farm water management in Egypt was put under field implementation during the year 1976.

The old agricultural lands of Egypt were selected as a first phase to focus improvement programs on. This was for many reasons, among which is the early economical returns which could be gained, besides saving water at a minimum cost for horizontal expansion.

The program is structured to function on an interdisciplinary basis to improve the social and economical conditions of the small farmer through development and use of improved irrigation water management and associated practices. The program consists of several overlapping phases with the objectives of: 1) identify the major constraints to improve on-farm water management and optimal water delivery system operations; 2) determine and establish the use of optimal irrigation and related agronomic practices at the farm level in representative pilot areas; 3) establish improved water control practices for the water delivery and drainage systems in the project areas; 4) develop plans for organization and implementation of expanded future programs based on results in the pilot project areas; and 5) develop and train qualified scientists and technicians who will carry on and conduct on-farm water management national programs.

The key concepts of this process imply a system approach which includes the socio-economic institutional and physical aspects of the irrigation system implemented by an interdisciplinary team, with the farmer, as the primary concern and focal point.

On the previously mentioned basis, the Ministry of Irrigation and the USAID have initiated a five-year water management project in collaboration with the Ministry of Agriculture.

Activities are conducted in the pilot areas, totalling 124,000 acres, (each representing a particular cropping pattern and unique water management problems). Taken as a group, these three areas represent nearly the entire range for crops and agro-climatological conditions encountered in the old areas of Egypt.

With respect to water use on the farm level, one of the most significant findings has been with respect to excessive use of water. There has been several reasons for farmers to over irrigate, among which are: field geometry, infiltration rates, fields topography, water supply rates, the rotation system, and the depth of the water table. However, in other cases, within the same area served by the same canal or water course, some fields may suffer from lack of irrigation water. Surveys in such cases have indicated that such canals get in general fair average water duteis for all lands.

Coupled with the above mentioned reasons many farmers have abandoned night irrigation, and because the irrigation system is originally built on 24 hour operation, much of the water delivered to the branch canals at night flows directly to the drains.

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The lack of social organization among farmers, formal or voluntary, causes communication problems and does not promote cooperation among farmers with respect to water use. Many of the cases regarding water shortages at the end of irrigation ditches could largely be overcome through improved communication and improved respect for others.

Inadequate and inaccurate communication between farmers and government officials, leads to suspicion and distrust evident towards those technical specialists.

Several agronomical problems have been clearly identified. Although most Egyptian farmers are resourceful, yet they do not have the benefit of modern research and technology available through research in Egypt for improved agronomic practices.

Some of these poor practices identified include: low density of plants, deficiency in macro and micro nutrients in some soils, and salinity and sodicity management.

Agricultural economical surveys within the project have indicated that there are some reasons behind the present inability of a farmer to accumulate his reserves to improve and manage his system. Among these reasons are: 1) excessive cost of lifting water on the farm level, the present canal system designed on lifting bases, therefore most farmers in Egypt lift water with simple manual, animal or power means. Gravity distribution systems in some areas eliminate lifting costs but give the farmer a tendency to over irrigate. 2) Excessive slack time in crop rotation. The average slack time in crop rotation for project areas is about 16%. This non productive time is due to tradition or non-capital intensive methods, and could be reduced by better farm planning, efficient land preparation methods, and improved water distribution systems. 3) Lack of data for farm planning. Farmers have no farm records for farm planning and management. They depend on memory for recalling past performance of input-output data.

Among the engineering problems identified are: 1) unequal irrigation water distribution along canals, illegal intakes to private irrigation ditches, problems of weed growth in canals and drains, lack of water measuring devices, uneven water distribution in fields, seepage from the irrigation system, and inadequacy of field outlets and farm water control irrigation works.

APPROACHES AND SOLUTIONS APPLIED TO INTRODUCE WATER MANAGEMENT TECHNIQUES TO THE FARMER

Teaching and convincing a farmer to do a different job is quite a difficult task. It is obvious that he must be convinced through demonstrations in which he must participate with his own hands. Several demonstrations and field trials have been taking place at the various project sites. Some of these trials have been evaluated and proposed for national large scale implementation. Among these pilot trials are the following:

1. Land Leveling and Redesigning of the Field Irrigation System. Lack of precisely leveled fields is a consistent and major problem for many fields in Egypt. The project has initiated a land leveling program using project equipment at no cost to the farmer. The project engineers help the farmer also to redesign his field irrigation system. Small basins have been eliminated and replaced with long borders or furrows. Farmers are pleased and satisfied with the easiness irrigations are accomplished, with minimum labor inputs. More of them are asking for similar service.

2. Irrigation Scheduling. Some moisture determination instruments combined with soil sampling have been used as an indicator of when to irrigate. Under the rotation system, some limitations are faced. However, progress is being made to convince farmers to irrigate according to soil moisture storage in the plan-roots soil profile.

3. Lining Irrigation Ditches and Modification of Water Delivery System. In one of the project areas the branch canal is lined with several irrigation ditches using different materials. The water delivery in this area is changed to a continuous flow basis. Water scheduling alternatives have been tried on the irrigation ditch scale (water course, or Meska). The most difficult obsticle is the farmer's acceptance to carryout these trials. Assurance of the project to the farmer of a minimum crop yield or providing some farming implements proved to be successful.

4. Water Delivery by Pipeline System. In an attempt to eliminate seepage from open canals in lighter soils and provide better control of water delivery to farmers, a buried pipeline water delivery low pressure system is presently executed in one of the project areas. Water scheduling will be tried and operation and maintenance charges will be paid by the farmers. It is an attempt to get the farmers to cooperate with each other in the use of water.

5. Irrigation Water Control Structures. To monitor and measure water flowing in subcatchments of irrigation districts, many water measuring structures have been built in the three project areas. Continuous measurement of discharges, groundwater levels, and water quality sampling are being taken. These measurements when combined with evapo-transpiration data, collected from project agro-meteorological stations, will provide basis for water budget analysis.

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6. Improved Agronomical Practices. Many field trials have occurred with farmers to improve their agronomical practices by improving seed bed preparation and plant stands by use of agricultural machinery. Considerable efforts have been made in working with the farmers to demonstrate the effects of improved soil fertility and methods of controlling insects. Considerable confidence has been built between the farmers and project personnel in executing such agronomic practices.

7. Economic Analysis and Farm Records. Cost enterprise data have been prepared for 20 different crops. This information is valuable for planning at all levels including the farmer.

   Farm records are being maintained with the assistance of project staff and farmers are trained to see the value of these records in making future decisions regarding management alternatives.

8. Sociological Factors. Sociological surveys have been carried out by project staff. These surveys help in better understanding of the Egyptian farmers perceptions of alternative extension strategies and their cooperation in rural development. All extension service for the project is carried out by the sociology team who got special training. Contacts with farmers are first considered by the team. New ideas, farmers need and problems are always discussed in open meetings. The project has tried to work out water-course organizations elected by the group of farmers served by a single water-course. In some of these water-courses up to 50 farmers may irrigate from one water-course.

   In some cases, like introduction of irrigation frequency programs. The farmers' representatives played an important role. In other cases they took responsiblity of the watercourse and the field drainage systems and they succeeded to get all farmers on the water course to be involved. Good human relations between the team members and the farmers helped in breaking the barrier existing between extensive specialists and farmers in project areas.

9. Training. Considerable project time and effort are being made in training project and ministries personnel in water management. On-job training is given throughout the course of the project with particular emphasis during initiation of activities in each project site. Short courses of one to three months duration of applied training in various specialities are designed and conducted periodically in Egypt and abroad. Special field tours have been arranged in the U.S. and other countries to get participants acquainted with modern delivery systems and management practices in other countries. All levels of trainees have been

.../...

considered; decision makers, water management specialists and technicians.

The Ministry of Irrigation is initiating a national Water Management Training Center in the vicinity of Cairo to help in spreading water management techniques among irrigation, agriculture and other related subjects' graduates.

It was also possible to initiate in one of the local universities a new department for water sciences and technology where water management is one of the main majors.

INSTITUTIONAL FRAME-WORK REQUIRED TO IMPLEMENT THE PROGRAMS ON THE NATIONAL LEVEL

Whatever the importance and the contribution of the basic measures taken so far, which have indeed made a good start to handle a traditional problem in Egypt, the scope and tempo of activities have to be considerably enlarged to a scale to keep pace with the needs and urgency of massive and far reached development plans.

It can be stated that the main fundamental steps to implement a policy for on-farm water management have already started. However, there is no doubt that the ongoing pilot programs need a few years for evaluation before launching large scale projects.

One of the important steps taken already is the initiation of the Egypt on-farm water project (EWUP) with its associated training activities. Although this project is still in its early phases, but some of the findings and early recommendations are taking a national interest. Examples of that are micro land levelling, and lining of water courses.

The project is also facilitating better communication channels between all involved authorities. Spreading of recommended practices in areas adjacent to the project 124 thousand acres is considered now.

Within a few years through the ongoing training programs interdisciplinary water management teams shall be available to implement, monitor, and evaluate large scale projects.

It is being recommended that on the irrigation district scale (20 - 70000 acres) water management teams should be formed to work with the farmers and to help them initiating farmers organizations.

The Ministry of Irrigation is preparing a water management national project in one of the Nile Delta Governorates (350000 acres). Most of the Governorate is provided with field tile drains. It is one of the main concerns to justify the need for field drainage with on-farm water management.

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The EWUP Project is studying now the need and scale of formulating farmers organizations within or outside the existing semi-governmental cooperative systems on the village scale.

It is the belief now that special water management farmers organizations are needed.

ON-FARM IRRIGATION PRACTICES IN MANSOURIA DISTRICT, EGYPT[1/]

By Mona El Kady, Wayne Clyma and Mahmoud Abu-Zeid[2/][3/]

Background

Irrigation in Egypt began about 6000 years ago. The annual flood, occurring from August to October, led the inhabitants of Egypt to practice both river training and irrigation to improve their existence. Towards this objective, a series of control works such as the Delta Barrage (1840) and Aswan Dam (1902) were built. The works were mainly for irrigation purposes but were also for flood control.

The oldest known method of irrigation practiced in Egypt was basin (flooding) corresponding to the annual flooding of the Nile. Basin irrigation consisted of ponding water on areas flooded by the Nile and growing crops on residual soil moisture after the water receeded. Since the construction of the Delta Barrage, perennial irrigation has been practiced in lower Egypt. After the completion of the High Aswan Dam (1970), the entire cultivated area in Egypt was placed under perennial irrigation.

Before the High Aswan Dam, the cultivated area was decided by the annual storage in Aswan (5 billion m^3/year) and Gabal Aelia (2 billion m^3/year) reservoirs, the base flow of the Nile and some use from groundwater. This area averaged about 1.7 million ha (4 million Feddans*) under perennial irrigation and 0.42 million ha (one million Feddans) under basin irrigation of which about 0.25 million ha (0.6 million Feddans) were served by wells in the summer.

After the completion of the High Aswan Dam, 55.5 billion m^3/year was made available for irrigation purposes. This volume allowed the conversion of all basin into perennial irrigation as well as the irrigation of additional area. Perennial irrigation presently encompasses about 2.6 million ha (6.1 million Feddans) of which about 0.4 million ha (1.0 million Feddans) are new lands. The cropping intensity in Egypt in 1978 is very close to 2.0 or an average of two crops per year are grown on each field.

Present perennial irrigation receives water from storage behind the High Aswan Dam through scheduled releases of flow to the Nile (Fig. 1). Barrages divert water to major canals at selected points and deliver water to supply canals administered by Governorates and then Irrigation Districts. The districts range in area from 8 to 24 thousand ha (20 to 100 thousand Feddans). The major canal flow is based on the water

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*Feddan = 4200 sq. meter = 0.42008 hectare

Underlined words are those used in Egypt and could be unfamiliar for other countries.

[3/] Presented December 1980 ASAE meeting, New Orleans, Louisiana

requirements of the area served as determined by (1) the crops grown, (2) soil type, (3) the area irrigated, and (4) the expected distribution and farm area water losses. District supply canals (Wolfe, Shahin and Issa, 1979) serve branch and subbranch canals which provide water to private farm supply channels (Meskas).

Water is supplied to a District on a two or three interval rotation. The length of the interval depends on the crops grown. Intervals are typically 4 and 7 days. On the three interval rotation, for example, the upper, middle and lower reaches of the canal receive water for an interval in turn. For the four day and three interval rotation, a branch canal would receive water for four days and then for eight days would receive no water (Wolfe, Shahin and Issa, 1979).

Regulation of the flow to a branch canal is related to the available flow in the district supply canal; however, water is supplied based primarily on the water surface elevation on the downstream side of the inlet gate. Usually there is no determination or allocation of a specific flow rate at any point within the district. Thus, the more water a group of farmers use on a branch canal, the lower the water surface elevation and the more water supplied to that branch canal.

On a branch canal as shown in Figure 2, water is conveyed to farmers through an outlet which supplies a private channel (Meska) that serves individual farms. An outlet may serve only one or several farm supply points. One farmer or a small group of farmers may take water at one supply point. Flow through the outlet that serves each Meska is regulated hydraulically by the size of the outlet and by assuming that the supply rate to the branch canal results in a specific downstream water surface elevation. The top of the pipe outlet is located 25 cm below the design water surface elevation. This elevation is located up to 50 cm below the surface of the surrounding land. Actually, because of variations in supply and use rates, local topography and the installation by farmers of additional unauthorized outlets, flow rates through each Meska outlet vary widely.

Typically each farmer or group of farmers must lift the water from the supply channel to the field. Lifting is usually accomplished by the Shadouf*, Tambour**, or Sakia*** using animal or human power. Sometimes electrical or diesel powered pumps are used. The informal rotation or simultaneous use systems result in lifts widely varying from the official maximum lift of 50 cm. The official government policy is to supply water below the ground surface thus requiring farmers to lift water for irrigation. The stated purpose of this practice is to discourage excessive use of water by the farmers.

Primary, secondary and farm collector drains serve most irrigated areas in Egypt. Substantial numbers of surface field drains also have been installed. Many drains are not well maintained and as a result are not effective.

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*Shadouf - Consists of a bucket on a pole with a counter balance and a man lifting the water supply.

**Tambour - Archimedes screw powered by human labor.

***Sakia - water wheel usually operated by animal power (bullock, donkey or camel).

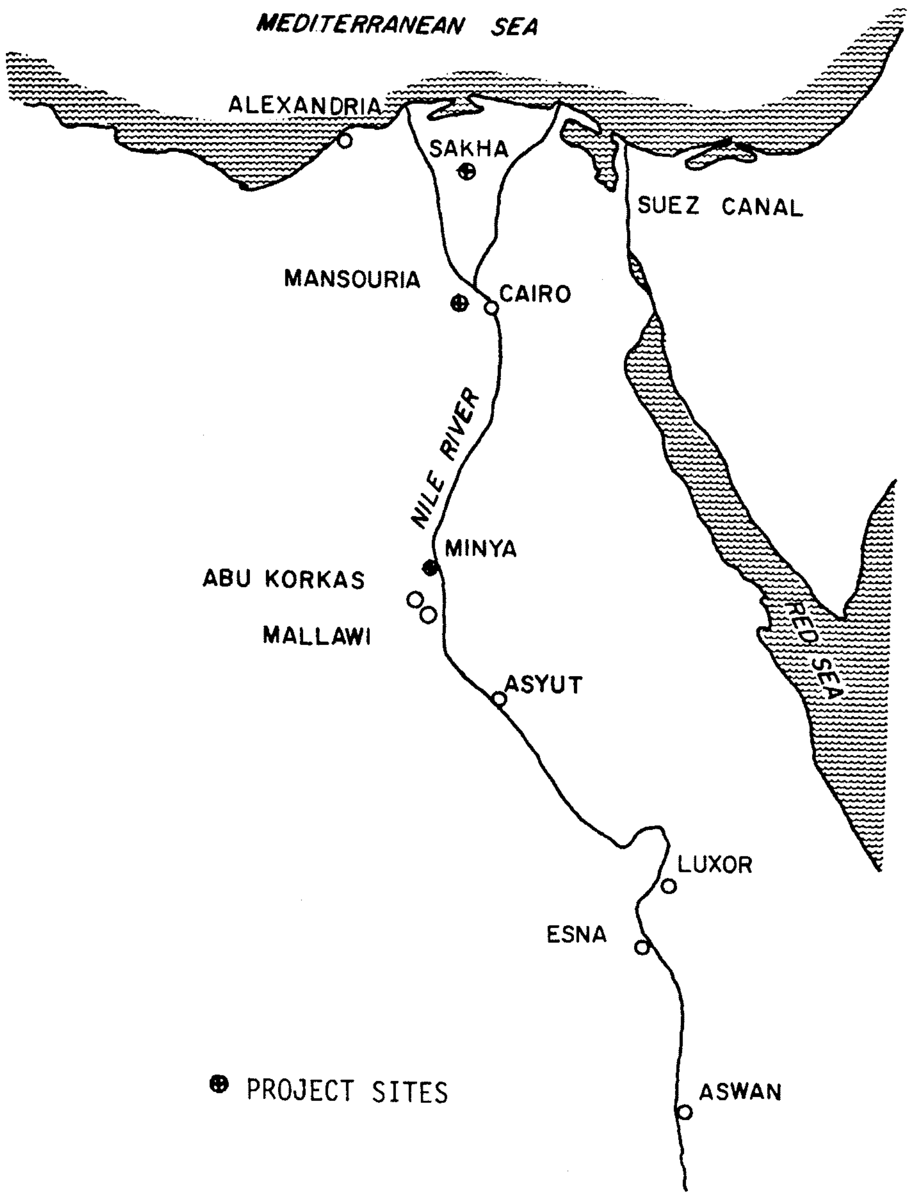

Figure 1. Location Map for Study Areas.

<u>State-of-the-Art Approach</u>

Art according to the American Heritage Dictionary (1976) is "A system of principles and methods employed in the performance of a set of activities: <u>the art of building</u>." The state-of-the-art of on-farm irrigation practices reveals the principles and methods employed by the farmers in their practice of irrigation. Clyma and Ali (1977) used this procedure to define priority problems and suggest proposed solutions for on-farm irrigation systems in Pakistan. Clyma, Kemper and Ashraf (1977) also applied the approach to define practices and problems for the water delivery system in Pakistan. This report describes the system, the procedure for data collection and uses state variables for water application to describe and define the state-of-the-art of farmer irrigation practices to identify priority on-farm irrigation problems in the Mansouria District.

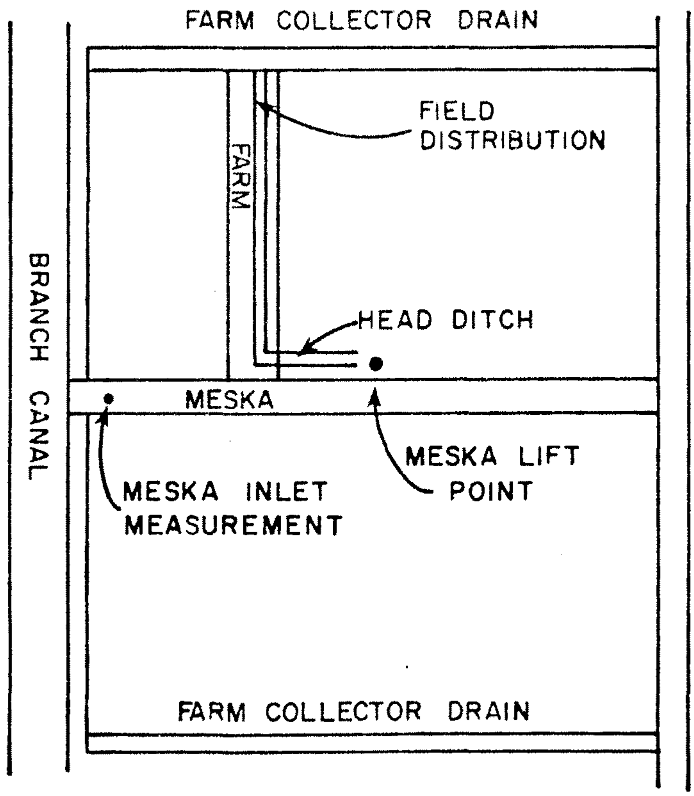

Figure 2. Arrangements of Branch Canal, Meska, Head Ditch, Field Ditch and Drains with Measuring Points for Fram Water Supply.

Water Application Subsystem

The water application subsystem is part of the on-farm irrigation system. The on-farm irrigation system consists of the following four subsystems:

1. Water Delivery
2. Water Application
3. Water Use
4. Water Removal

The water application subsystem serves the following functions:

1. Supplies designed amounts of water to a field.
2. Distributes desired amount of water with the designed uniformity.
3. Meets crop tolerances for seed germination and emergence, inundation, salinity control, aeration, temperature, crusting and other special requirements.
4. Meets minimum and maximum amounts criteria for crop production.
5. Satisfies erosion control standards.
6. Provides necessary surface drainage.
7. Is economically appropriate and socially acceptable to the management abilities of the farmer.

The processes of water application to a field can be described by the following state variables:

1. Field geometry (length and width)
2. Slope
3. Infiltration rate
4. Surface roughness
5. Channel shape
6. Water supply rate
7. Management

The boundary and initial conditions of the system must also be specified to completely describe the state of the system.

Water application system management is accomplished by the farmer by operating the system to meet functional objectives (usually unstated). In the process he answers the following three basic management questions:

1. How do I irrigate?
2. When do I irrigate?
3. How much water do I apply?

Qualitative and quantitative descriptions of the variables which define the water application process and of how a farmer arrives at answers to these management questions are used to describe the state-of-the-art of water application. In this section, the state variables will be discussed. First, however, the data collection procedure will be described.

Procedure - The Egypt Water Use and Management Project (1979) has selected three areas for improvement in Egypt of which the Mansouria District is the first such area (see location map in Figure 1). The project design involves four phases of a research-development process including (1) problem identification study of the existing system, (2) search for solutions to define problems, (3) assessment of solutions working with farmers and (4) implementation of a development program with all farmers in the area using farmer accepted solutions (Clyma, Lowdermilk and Corey, 1977). The process was developed from experience in Pakistan (Lattimore, undated). An interdisciplinary team of agronomists, economists, engineers and socialogists plans and executes the process (Egypt Water Use and Management Project, 1979).

Representative farms on three branch canals (Beni Magdoul, Kafret Nassar, and El Hammami) were selected for the study (Figure 3). The selection of the farms were based on agronomic, engineering and socio-economic criteria (Egypt Water Use and Management Project, 1979). In this study of irrigation practices, each irrigation was monitored for each field for the season.

On each site the following data were collected:

1. Water Delivery Data (see Figure 2)
   - Flow rate with time downstream of the inlet of the Meska
   - Flow rate near the site where water is lifted
   - Flow rate just out of the Sakia
   - Flow rate at the inlet of the field
2. Water Application Data
   - Field and bunded unit* dimensions
   - Time for filling the bunded units
   - Beginning and ending time of each irrigation
   - Elevations of selected fields and bunded units
3. Water Use Data
   - Soil moisture measured gravimetrically before and after each irrigation, initially at one location and subsequently at four locations in each field
   - Quantity of water used in irrigation
   - EC measurements for irrigation, groundwater and drainage water
   - Moisture tension at 15, 30, 45 cm depth in selected fields on soil
   - Crop evapotranspiration estimations using the Jensen-Haise method**(Jensen, 1973)
4. Water Removal Data
   - How much runoff occurred and where it went
   - Groundwater levels at several locations around the boundary and internal to a field on a daily basis.
5. Farmer Practice Information
   - Land preparation data: tools used, field geometry, leveling, fallow time between two successive crops
   - Planting data: date of planting, the farmer's planting practices, seeds (how much, kind, time), fertilizers (kind, amount, time)
   - Growing data: practices each time of irrigation, disease, weeds and insect control
   - Harvesting and yield data.

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*Bunded unit - This describes the smallest irrigation unit with a ridge or bund completely enclosing an area and cropped flat or on ridges internal to the boundary.

**Evapotranspiration estimation for El Mansouria district, Egypt, using different equations and field data are under preparation by M. El Kady, F. Shahin, M. Abu-Zeid.

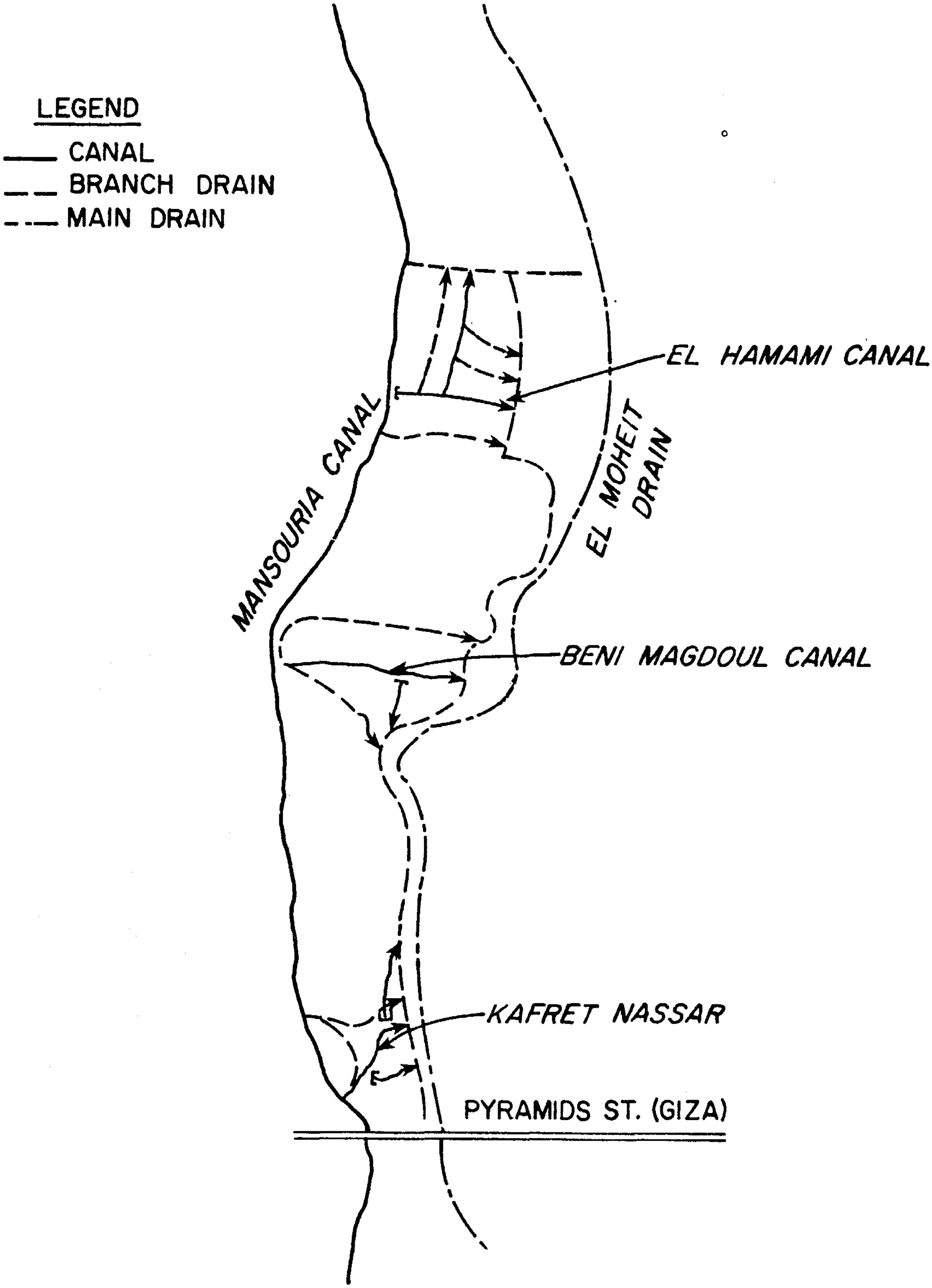


Figure 3. Location map for Kafret Nassar (K.N.), Beni Magdoul (B.M.C.) and El Hammami (E.H.C.) branch canals in Mansouria District.

System Classification - The class and type of irrigation system used by farmers must be determined before evaluating the appropriateness of each state variable for farmer practice. In the Mansouria district only surface irrigation is practiced (as opposed to sprinkler or trickle). In general two classes of surface irrigation systems are common, level and graded. In either system class water may be distributed by one of two types, basin or furrows. Standard critiera for evaluating an irrigation system vary with the class and type of system.

The principles by which each class and type of system operate are different and the method of management should reflect these principles. Level irrigation systems (zero grade) require the addition of a specific quantity of water to a field such that the time water covers near and distant areas of the field do not result in significant differences in total infiltration. While water is ponded on a field, infiltration and the distribution of water with length (or width) is approximately proportional to the elevation variation within the field (high spots and low spots). Thus, level irrigation systems require precision leveling if good distribution of water is to result.

Graded irrigation systems require the careful balancing of advance and recession times with the appropriate flow rate to apply the desired application depth. Degree of precision in leveling is not as stringent, but the management knowledge and experience of the farmer must be combined with an appropriate design. Otherwise, underirrigated or overirrigated sections in the field will result and appreciable runoff will occur. Greater skill and knowledge and more careful management by the farmer is required for good water management with graded irrigation systems.

Most farmers in the Mansouria district appear to assume their fields have zero grade. They introduce water into a bunded unit until the area is covered and allow the water to stand and infiltrate into the soil. This practice is followed in both the sandy soil of El Hammami and the clay loam soil of Beni Magdoul. They also irrigate bunded units with slopes that are opposite to the direction of irrigation indicating that they do not use the field grade in accomplishing the distribution of water. A more detailed analysis of how farmers use slope and field geometry to apply water will be given in subsequent sections.

In one particular area on the Beni Magdoul canal, farmers on one particular Meska appear to use a graded system of irrigation. The length of the field lies from Meska to drain and farmers appear to use criteria of inflow time and ponding on the lower end of the field to apply water. No other areas have been identified in the District which appear to use the graded system.

Farmers in the Mansouria District use both basin and furrow types of systems. Furrows are used for most summer crops including corn, vegetables, and peanuts. Major exceptions are citrus and rice. Winter crops broadcast in flat basins are berseem and wheat. Most other winter crops are grown with furrows, especially the vegetables. Critiera for appropriate slope (especially deviations and flow rate) are different for furrows as compared to basins. These differences will be discussed under the appropriate state variable.

Field Geometry - The length and width of a unit enclosed by a ridge is the irrigation or bunded unit for a farm. When a farmer establishes this unit, he establishes many characteristics of his irrigation system.

The head ditch as shown in Figure 2 transports water from the lift to the boundary of the field. This channel is always at the same location with respect to the field. However, internal field channels vary in location from one crop to the next. This is primarily because the farmer perceives that locating the ditch in the same place may make that land less productive. The result is more delivery losses through the field ditches because of the higher infiltration rates after plowing. The internal field channels use 8 to 14 percent of the field area.

Several field geometries and irrigation sequences will now be described. Typical arrangements of bunded units and their dimensions, field ditches, head ditches, lift, Meska and sequence by which the units are irrigated are shown in Figure 5 (a) through 5 (f) from actual case study fields. There are many minor variations of these arrangements but these represent typical field layouts.

The major points to observe are the following:

1. The size and size variation of the bunded units even within one field.
2. The area used by head ditches and field ditches and the distance water must travel.
3. The variation in the direction water travels in the delivery channels and within each bunded unit during an irrigation.
4. The range in number of bunded units simultaneous irrigated even within the same field.

One case study farmer (Figure 5 (a)) began his irrigation from the end farthest from the supply by irrigating two basins together (S_1). In the next sequence, S_2, four basins are irrigated and four are irrigated simultaneously for the rest of the field.

A second case study farmer (Figure 5 (b)) has a head ditch located at the side of his field. Some of the field ditches are used to supply basins on both sides of the ditch. Others serve only one side of the ditch. The farmer first simultaneously irrigates the four basins designated S_1 and then the four basins designated S_2. Then basins S_3, S_4, S_5 and S_6 are irrigated in sequence, one at a time.

A third farmer (Figure 5 (c)) irrigates four basins together beginning from the end nearest the water source. Four are irrigated each time in sequence until the field is completed. Note the variations in dimensions of each basin even though four are always irrigated together.

Figure 5 (d) shows a permanent head ditch along one side of a fourth farmer's field with an interior field channel between each basin. In every instance but the last, basins only on one side (the upstream side from the head ditch direction of flow) of the field channel are irrigated. They are irrigated in sequence S_1, S_2, S_3 ... and S_6 as indicated in Figure 5 (d). Only the last channel is used to irrigate two basins (S_7 and S_8) simultaneously, one on each side of the field ditch.

Figure 5 (e) illustrates a fifth farmer's field that is very long and narrow with a head ditch on one side and irrigation that begins from the far end. One basin is irrigated, then another, until the field is complete. Another farmer owns the adjacent area and has another head ditch to serve his field. The result is an extensive network of head ditches and field distribution channels which uses land and increase delivery losses from the lift to the field.

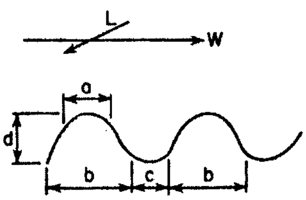
The relationship between flow rate and area irrigated is established by this unit. A farmer usually does not know nor manage an explicit flow rate. The deviations from mean elevation are determined by the boundaries of the bunded unit since a farmer usually establishes these boundaries after leveling. The sequence and number of units simultaneously irrigated usually become fixed by the selection of the size of the bunded units.

In the Mansouria district, farmers use bunded units that range in size from approximately 2 x 4 m to 8 x 18 m and areas that range from 0.0008 to 0.014 ha (0.002 to 0.03 Feddans). In general, furrows and ridges do not have exact spacings nor dimensions since they generally are formed by hand. Two types of furrows are prevalent with the following spacings:

1. Narrow furrows with spacings between furrows ranging from 20 to 40 cm, usually used for crops such as corn with one row of plants per ridge.
2. Wide furrows with spacings between furrows ranging from 60 to 80 cm, usually used for vegetables and sometimes having two rows of plants per bed.

The ridge height between furrows usually ranges between 12 and 15 cm. Figure 4 shows typical dimensions of furrow systems for various crops. The ranges for the different dimensions were taken from measurements of farmers' fields. Ridges which define each irrigation unit are usually not much, if any, higher than the interior ridges which form furrows. The boundary ridges are frequently overtopped by irrigation water. This may cause some damage to crops in nearby bunded units when irrigation water is not needed.

While a farmer knows very well that he should not overtop the furrow ridge nor inundate his plants, he frequently must do so in order to cover the high areas in a given basin.



Crop	Top Width	Base Width	Channel Width	Ridge Height	Basin Length	Basin Width
	a cms	b cms	c cms	d cms	L ms	W ms
Squash	70- 85	85-100	18-25	15-20	8-20	3- 8
Tomatoes	60- 90	70-100	20-40	12-18	8-20	3- 8
Cabbage	10- 20	38- 40	30-42	12-22	8-20	3- 8
Eggplant	10- 20	35- 40	18-25	10-20	8-20	3- 8
Watermelon	140-200	200-250	20-25	20-25	15-30	10-20
Corn	12- 20	35- 40	15-25	10-15	5-15	3-12

Figure 4. Typical Dimensions of Furrows for Various Crops in the Mansouria District.

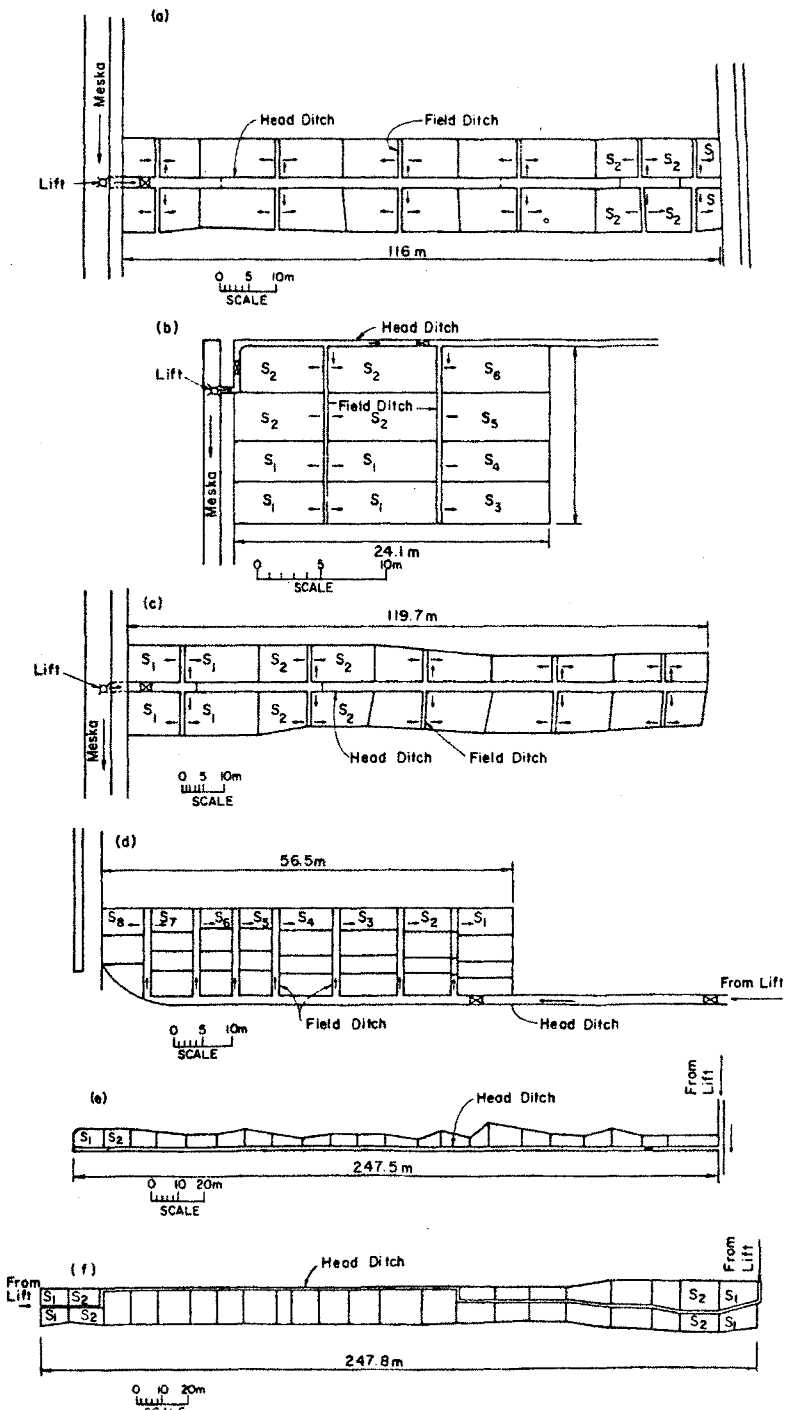


Figure 5. Field geometries of representative case study fields.

The field in Figure 5 (f) is irrigated with flows from both ends, most often at the same time. Two basins, one on either side of the head ditch, are irrigated at each end. In the middle only one basin at a time is irrigated. Farmers in an area between the two Meskas irrigate most of the fields in this manner. The reader should note the small size of each basin and the widely varying sequence of irrigation in a field.

In summary, analysis of field geometry suggests that the size and shape of the fields in Mansouria district are mainly a result of the unlevelness of the land and the traditional methods used in leveling, sowing, plowing and cultivation. The rate of the flow and the availability of water are not major factors for the farmer in designing his field. This is demonstrated by the fact that the size of bunded units do not change when a Tambour is used instead of a Sakia although the flow is reduced by at least half (Table 4)).

Slope - The slope and degree of levelness of a field is an important characteristic of irrigation systems if good water management is to be practiced. In graded irrigation systems, slope is combined with flow rate and infiltration rate to distribute the desired amount of water to a field. Slope variation is permitted but deviations are carefully incorporated into the design to prevent uneven distribution of water and to minimize excess runoff. Since graded systems are not common in Egypt, further analysis of graded systems will not be presented.

Level (zero grade) irrigation systems require precision leveling. The deviations from design elevation within a bunded unit may not exceed ± 0.05 ft (± 1.5 cm) as an acceptable standard (USDA, 1974). No difference between level basins or furrows are suggested as many fields change from furrows to flat planted each season. In no instance is a reverse gradient (in the direction of irrigation) permissible. Slopes of fields and variation of elevations within a bunded unit in Mansouria District will now be reviewed.

Table 1 gives the field length, the fall of the field from the end nearest the Meska to the end nearest the drain, the maximum difference in elevation measured in the field, and the slope computed as the fall divided by the field length. A fall between Meska and drain of approximately 10 cm commonly occurs in the Mansouria District. Farmers do not appear to use this slope to distribute water within the basin since water is introduced into basins from both directions.

More detailed data on bunded units, and as a result fields, are presented in Table 2. The basic elevation data consisted of 15 to 30 elevations in each bunded unit from three or four bunded units along the length of a field. The field elevations are computed from all units measured while the bunded unit elevations are restricted to that unit. Field elevations ranged from 9 to 20 cm between maximum and minimum. This is a significant elevation differences between basins.

The individual bunded unit elevations ranged from 5 to 20 cm in elevation. All exceeded the critiera for a level basin given as 3 cm. Only 10 percent were less than double the required range and 80 percent were more than double the required range. The minimum range of the other 10 percent was 5 cm. Furrow bunded units also exceeded the range in elevation criteria. In addition, 20 percent of the furrows had a reverse slope which is unacceptable.

Table 1. Slopes of Fields in the Mansouria District.

Canal	Site	Field	Field Length (m)	Fall (cm)	Max. Dif.	Slope
B.M.	1	1	147.2	2	9	0.0001
	2	1	26.80	4	4	0.0015
		3	64.60	9	11	0.0014
		4	118.00	8	10	0.0007
		5	119.75	10	10.5	0.0008
	3	1	145.10	9	9	0.0006
	4	1	163.0	13	14	0.0008
	5	1	58.30	0	9	0
		2	58.30	9.5	9.5	0.0016
	6	1	227.5	20	21	0.0009
E.H.	1	1,2,3	204.30	18	18	0.0009
	4	1	62	8	13	0.0013
	8	1	72.10	8.5	17.5	0.0012
		2	68.30	6.5	7.5	0.001

These data suggest that unlevel fields are usual in Mansouria since all fields exceeded the levelness criteria. Furthermore, serious unlevelness exists since the criteria are usually exceeded by several magnitudes. Lack of precision leveled fields is a consistent and major problem for the Mansouria district. Proper leveling is a prerequisite for application of the proper amount of water as well as for deriving the benefits of good water management and proper inputs for increased crop production (Johnson, Khan and Hussain, 1978).

Studies by Ali, Clyma and Early (1975) of level systems in Pakistan have shown that deviation from level of only 3 cm significantly affect farmer's irrigation practices. First, to cover a high area on a level field requires additional water. Farmers must cover the high area or salinization of the area will eliminate the growing crop or severe stress from inadequate water will drastically reduce crop yield. Second, since water is ponded on a level field, the distribution of water will be approximately proportional to the difference in elevation resulting in excess water in low areas and inadequate water in high areas.

Infiltration Rate - Infiltration data* for Beni Magdoul and the clay loam soil is characterized by a terminal intake rate of less than 0.2 mm/min (1.2 cm/hr). In El Hammami where a sandy or a sandy loam predominates, terminal intake rates of 1 to 2 mm/min (6-12 cm/hr) were measured. An evaluation of design criteria suggests that successful level and graded irrigation systems can be designed and managed for soils with infiltration rates exceeding 7.5 cm/hr such as exists at El Hammami.

*Developed by M. Semaika and Harold Golus, agronomists, using a double ring infiltrometer.

Table 2. Range in Elevation of Bunded Units for Selected Fields.

Location	Mean Field Elevation (m)	Range (cm)	Max.	Min.	Standard Deviation
	Field Variation		Unit°to Unit		
		Level Basin without Furrows - Field Variation			
B.M. Site 2, Field 2	16.59	.9	16.64	16.55	0.02
Field 4	16.58	20	16.67	16.47	0.07
Field 5	16.58	21	16.69	16.48	0.07
B.M. Site 6	16.40	13	16.46	16.33	0.03
B.M. Site 7	16.64	13	16.71	16.58	0.03
B.M. Site 1	16.70	17.5	16.795	16.62	0.05
B.M. Site 4	16.49	20	16.60	16.40	0.07
B.M. Site 5	16.43	12.5	16.485	16.36	0.03
		Level Basin Without Furrows - Bunded Unit Variation			
B.M. Site 3	16.43	10	16.48	16.38	0.03
	16.43	10.5	16.485	16.38	0.026
	16.43	12.5	16.485	16.36	0.026
B.M. Site 2	16.59	9	16.54	16.55	0.019
Field (2)	16.59	6	16.61	16.55	0.014
B.M. Site 2	16.59	8	16.62	16.54	0.0199
Field (4)	16.59	8	16.62	16.59	0.0199
	16.60	6	16.61	16.55	0.0166
	16.60	10	16.67	16.57	0.029
	16.59	5	16.62	16.57	0.017
	16.57	7	16.60	16.53	0.018
	16.56	7	16.60	16.53	0.033
	16.52	9	16.56	16.47	0.026
B.H. Site 2	16.61	9	16.66	16.57	0.022
Field (5)	16.61	8	16.66	16.58	0.019
B.M. Site 6	16.40	5	16.43	16.37	0.021
	16.42	10	16.46	16.36	0.024
	16.41	7	16.44	16.37	0.015
	16.37	9	16.42	16.33	0.02
B.M. Site 7	16.63	5	16.65	16.60	0.014
	16.62	6	16.64	16.58	0.015
	16.67	8	16.71	16.63	0.016
B.M. Site (1)	16.75	9.5	16.795	16.70	0.03
	16.72	8	16.76	16.68	0.025
	16.71	8	16.75	16.67	0.026
	16.69	10	16.72	16.62	0.030
	16.68	5	16.70	16.65	0.018
	16.68	10	16.74	16.64	0.021
E.H. Site (8)	17.04	20	17.15	16.95	0.07
	16.93	11	17.00	16.89	0.029

Level Basin with Furrows - Bunded Unit Variation

Location	Mean Field Elevation (m) Ridge	Mean Field Elevation (m) Furrow	Range (cm) R	Range (cm) F	Max. R	Max. F	Min. R	Min. F	Standard Deviation R	Standard Deviation F
E.H. Site 6	17.70	17.62	8	7	17.73	17.65	17.65	17.58	0.026	0.022
E.H. Site 6	17.72	17.63	4	5	17.75	17.65	17.71	17.60	0.016	0.016
E.H. Site 8(X)	16.96	16.86	9	6	17.01	16.88	16.92	16.82	0.026	0.017
-- --	16.92	16.78	8	23	16.95	16.93	16.87	16.70	0.023	0.071
-- --	17.66	17.54	10	8	17.705	17.575	17.61	17.51	0.0226	0.0196

Table 3. Amount of Water Applied Per Irrigation for First Irrigation and All additional Irrigations for Beni Magdoul, El Hammami and Kafret Nassar Canals for Summer Season, 1978.

Applied Water (mm)	First Irrigation			All Additional			All Canals All Irrig.	
	BM	EH	KN	BM	EH	KN	No.	Percent
	Percent			Percent				
0 ≤ 20				1	7		8	3
20 ≤ 40		8		4	26		32	13
40 ≤ 60	8	8		11	25	33	43	17
60 ≤ 80		8	40	37	24	42	70	28
80 ≤ 100	8	17		27	6	17	39	16
100 ≤ 120	8			10	4		15	6
120 ≤ 140	8		20	6	1		9	4
140 ≤ 160	22.5	26		2	3		11	4
160 ≤ 180	22.5	8	20	3	3	8	12	5
180 ≤ 200	15	17			1		5	2
≥ 200	8	8	20	1			4	2
Total (Pct.)	100	100	100	102	100	100		100
Total (No.)	13	12	5	104	102	12	248	

Table 3 suggests that the farmers apply heavy irrigations early in the season. Perhaps these irrigations are needed to leach salt from the soil surface during the time when plant seedings are most sensitive. However, previous studies (Clyma and Ali, 1977) have shown that these heavy applications are the accidental result of high infiltration rates after tillage and before or just after planting. The difference between the median amount of 60 to 80 mm (Table 3) for most irrigations and the median for early irrigation must be attributed to initial intake rate.

Infiltraion rates affect the distribution of water in a field. The time difference between when water first covers an area and when it recedes from an area is called the "opportunity time" for infiltration. On high infiltration rate soils, small differences in opportunity time result in large differences in amount of water infiltrated and poor distribution of water results. The average amount of water applied to a field may equal consumptive use estimates. When most of the water infiltrates in only one part of the field, major overirrigation and underirrigation still occurs. As discussed under slope for level (zero grade) systems, differences in elevation produce differences in opportunity time and result in low irrigation efficiencies because of poor distribution.

Surface Roughness - Surface roughness is variable throughout the season. In some areas surface clods formed during tillage may complicate water distribution and require a higher flow rate for the greater depth of flow necessary to cover the clods. Vegetation density especially in sugarcane and fodder crops, increases as the season progresses. The result is that the amount of water required to cover a field as well as the depth of flow are increased. On such crops the amount of water applied per irrigation may initially decrease after the pre-irrigation but then began to increase as vegetation density increases during the season. For many crops and fields, roughness is not a significant variable.

Channel Shape - A number of fields and crops are broadcast in small basins. Distribution of water to these fields is not materially affected by channel shape. A majority of the summer crops (except rice) and numerous winter crops (except berseem and wheat) are grown on ridges and irrigated by furrows. Furrows in the Mansouria District have a variety of dimensions but some typical spacings and profiles are shown in Figure 4. Farmers also appear to regulate the flow rate and depth of water applied to attempt to insure that most crops, especially vegetables, are not inundated during irrigation. This factor more than any other appears to influence the number of basins filled simultaneously and the time of filling according to farmers. Some fields appear to be drained if excess water is applied or the ponding time becomes excessive. No data are currently available on the effect of channel shape on infiltration rate, water distribution or salt movement.

Water Supply Rate - A farmer irrigates a field of a given geometry, slope, infiltration rate, surface roughness and channel shape. There is an appropriate flow for the given conditions that should be used for effective, quantitative water management. In some instances the value of one of the above variables on the values of a combination of variables result in limiting the level of water management that a farmer can achieve. For example, an unlevel field limits the efficiency of an irrigation even when the proper flow rate is used. An unlevel field combined with a high infiltration rate further reduces the efficiency of an irrigation for a given flow rate. If an inappropriate flow rate is used, the maximum achievable efficiency for an irrigation is further reduced. Flow rate may be considered to be the final variable by which farmers can make management decisions that result in good water management.

Quantitative approaches to water application to a field require that the flow rate and time of irrigation of a field be known. The conventional approach is to measure the flow rate. If the water delivery system supplies a constant, known flow rate, then the measurement of the time of water application can be used to quantitatively apply water to a field. The constant flow rate must be within a specific range if an efficient irrigation is to be achieved. The flow rate must also meet adequacy criteria for erosion control, for an appropriate flow depth and for proper distribution in the field.

Proper distribution of water within a bunded unit requires the flow rate to be sufficiently high such that the difference between opportunity times for each end of the basin will not result in substantial differences in total water infiltrated. With the very small bunded units, flow rates appear to be adequate for proper distribution within each bunded unit. Flow depth appears to be adequate for each bunded unit whether the crop is on ridges or flat. The depth of flow sometimes

Table 4. Summary of measured flow rates for case study farms.

Area	Farm No.	Field No.	Crop 1978	Type of Lift	Flow Rate lit/sec. Max.	Min.	Av.
K.N.	(1)	(1)	Corn	gravity	14.80	2.70	7.50
K.N.	(1)	(1)	Berseem		13.10	1.2	6.0
B.M.	(1)	(1)	Corn	Tambour	18.0	6.0	12.0
B.M.	(2)	(1)	Corn	Tambour	16.0	7.4	11.0
B.M.	(2)	(2)	Corn	Tambour	16.0	8.0	12.0
B.M.	(2)	(3)	Corn	Tambour	12.0	5.0	10.0
B.M.	(2)	(4)	Corn	Sakia	17.4	3.1	12.0
B.M.	(2)	(5)	Corn	Sakia	22.0	5.3	14.0
B.M.	(3)	(1)	Corn	Sakia	19.3	11.2	15.0
B.M.	(3)	(1)	Berseem	Sakia	13.5	6.8	11.0
B.M.	(4)	(1)	Corn	Sakia	29.4	6.2	18.2
B.M.	(5)	(2)	Corn	Sakia	23	8	16.0
B.M.	(5)	(1)	Veget.	Sakia	23	8	16.0
B.M.	(5)	(1&2)	Berseem	Sakia	20.4	5.5	17.0
B.M.	(6)	(1)	Veget.	Sakia	21.3	5.3	12.0
B.M.	(6)	(1)	Veget.	Tambour	12.6	5.2	8.7
B.M.	(7)	(1)	Corn & Veg.	Sakia	15.5	6.5	12.0
E.H.	(1)	(1)	Berseem & Corn	Sakia	50	20	40
E.H.	(1)	(2)	Corn & Veget.	Sakia	36	15	28
E.H.	(1)	(3)	Corn & Pepper	Sakia	61	27	40
E.H.	(1)	(4)	Corn	Sakia	50.5	28.5	35
E.H.	(1)	(5)	Corn & Pepper	Sakia	52	25	35
E.H.	(1)	(6)	Corn & Pepper	Sakia	38	16	29
E.H.	(1)	(7)	Corn & Pepper	Sakia	64	18.6	41
E.H.	(1)	(8)	Corn & Pepper	Sakia	65	26	45
E.H.	(1)	(1)	Squash	Sakia	38	13	28
E.H.	(1)	(7)	Squash	Sakia	54	20	35
E.H.	(1)	(8)	Squash	Sakia	46	25	35
E.H.	(1)	(6)	Squash	Sakia	58	25	35
E.H.	(1)	(5)	Squash	Sakia	38	15	28
E.H.	(1)	(3)	Squash	Sakia	37	13	25
E.H.	(6)	(1)	Veget.	Sakia	22	8	17
E.H.	(8)	(1)	Peanuts & Veget.	Pump	24	8	18

overtops ridges but this is probably related to high areas and reverse slopes with too large a flow rate. Inadequate ridge heights are provided in some instances for the ponded depth resulting in overtopping. The extremely short lengths of run largely prevent erosion from being a problem.

A constant flow rate can be substituted for a metered flow as mentioned earlier. Since farmers do not know or measure the flow rate in Mansouria District, an evaluation of the constancy of the available flow rate provides some measure of their ability to quantitatively manage water.

The water supply rate to fields depends on the method used for lifting water. Table 4 indicates the range in flow rates for each study farm as a function of the method of lifting water. A Tanbour supplies water at between 5 and 18 l/s while the Sakia flow ranges between 3 and 61 l/s. Another effect is also illustrated in Table 4. The flow for both methods tends to range from near zero to at least 50 percent more than the mean. Since the flow rate varies so widely, it is exceedingly difficult for a farmer to apply a uniform amount of water to each small basin in a field.

The farmer irrigating a variable number of basins of widely varying size with an unmeasured and highly variable flow rate is unlikely to achieve efficient application of water even if all other conditions are ideal. Since the farmer uses criteria other than flow rate to irrigate a basin, the geometry of his irrigation units makes good water management difficult if not impossible.

Two additional factors affect the rate at which water is supplied to a field. Water is supposedly supplied to the farmer at the necessary rate at an elevation. There is no internal regulation by farmers on a Meska of the time of use (formally or informally). Meska outlets also have been enlarged without authorization. Therefore, simultaneous and heavy use of the water at the upper reaches of the Meskas lowers the water level below the authorized level. The result is a higher lift for a given flow rate. Since the power required to lift a given flow rate is directly proportional to the lift, the lowered water level increases the effort required for a constant flow rate. Humans, when using the Tambour, or animals, when using the Sakia, must rest more often, otherwise there will likely be an overall reduction or variation in the flow rate as the lift increases and decreases. At a given lift point in a particular area, flow rates vary widely over time because the human and animal power supply, the power required, and the water supply available all are variable. The result is a constraint to good water management by farmers.

Management - The farmer operates his water application system based on his perceived objectives and manages the water based on his knowledge and skills. His management of the system results from how he answers the question: When do I irrigate? How much water do I apply, and how?

Mansouria District farmers use level basins or bunded units ranging in area from 8 to 120 m^2 with length to width ratios ranging from 1 to 2 (see Figure 5). Depending on the crop, the basins may be flat or have furrows, but each is irrigated as a level irrigation unit. The farmer basically introduces water until the area is covered, perhaps to a given depth, and this determines how much water he applies. Thus, the decision of when to irrigate is his primary management variable and

Table 5. Irrigation Frequency in El Mansouria District.

Irrigation Frequency in days	Distribution							
	El Hamami		Beni Magdol		Kafar Nasar		All Canals	
	No.	Percent	No.	Percent	No.	Percent	No.	Percent
1 $\leq$ 4	31	25					31	12
5 $\leq$ 8	17	14	25	21			42	16
9 $\leq$ 12	41	33	37	33	6	43	84	33
13 $\leq$ 16	19	16	23	20	5	36	47	19
17 $\leq$ 20	3	2	24	21	1	7	28	11
21 $\leq$ 24	8	7	6	5	1	7	15	6
25 $\leq$ 28			1	1	1	7	2	1
29 $\leq$ 32			1	1			1	0.5
33 $\leq$ 36	1	1					1	0.5
37 $\leq$ 40								
$\geq$ 40	3	2					3	1
Total	123	100	117	100	14	100	254	100

appears to be based on several considerations (Table 5). A farmer's objectives appear to be to manage his available water supply for adequate crop production including salinity control, for crop residue management, to facilitate tillage, to promote germination and emergence, to provide early seedling growth and to maintain adequate soil moisture.

The methods farmers use to irrigate limit severely the level of effective water management they can achieve. The methodology for regulating flow rate and amount of water applied results in much variation of the amount. Methods for distributing water result in an extensive distribution system. Fields are unlevel to an unacceptable degree, bunds are of inadequate height and the size of each field varies by several magnitudes. The system of irrigation limits the potential level of water management for farmers.

Amounts of water applied by farmers during an irrigation are extremely variable. This variability results directly from their method of determining how much water to apply. The time to cover a given area with water depends on the flow rate, slope, geometry, infiltration rate, surface roughness and channel shape. Farmers' criteria for applying water, when combined with the system of applying water, limits good water management. Other factors influence the amount of water applied.

The amount of water applied during the first irrigation and all additional irrigations are given in Table 3. On all three branch canals the first irrigation results in a greater amount of water applied than do subsequent irrigations. The median amount of water applied for the first and subsequent irrigations for each branch canal was as follows:

	First (mm)	Subsequent
B.M.	160 > 180	60 > 80
E.H.	120 $\geq$ 140	40 $\geq$ 60
K.N.	120 $\geq$ 140	60 $\geq$ 80

The results suggest the first irrigation is a large amount of water. The primary cause of the irrigation amount is probably the high infiltration rates after plowing for the irrigation. The estimates of soil moisture deficiency and observations of the water table both indicate the irrigation is excessive.

The median application for subsequent irrigations are much smaller and in the 60 to 80 mm internal for Beni Magdol and Kafar Nasar and 40 to 60 mm for El Hamami. The smaller median amount on El Hamami may not be statistically significant for the limited data collected but could be explained by the predominance of vegetables at El Hamami. Farmers' perceptions that vegetables need smaller irrigations may cause the result observed. A significant number of irrigations exceed 80 mm on all branch canals indicating considerable variability in the amount of water applied during an irrigation.

The next management decision farmers make is when do I irrigate. The frequency of irrigation for selected crops at Beni Magdol and El Hamami is shown in Table 5. The results are different for each site since at least both the rotation and soils are different.

Beni Magdol, an area of predominately heavy textured soils, was provided water continuously. Thus, farmers may irrigate whenever they feel their crops need water. Under the "demand" system, the median irrigation frequency was 9 to 12 days (Table 5). Furthermore, no farmers irrigated during the interval of four days or less. The longer intervals between irrigation (28 percent of the irrigations were 17 or more days apart) represent irrigations early and late in the cropping season or during the interval between crops.

El Hamami, an area of predominately sandy textured soils, was supplied water for four days and for eight days water was unavailable. Previous general observations had suggested that some farmers irrigated at the beginning and end of the four-day period when water was available. Twenty-five percent of the irrigations by study farmers came at a frequency of four or fewer days (Table 5). Fourteen percent at five to eight days and 39 percent were less than nine days. The median frequency was still 9 to 12 days with one-third of the irrigations coming during this time interval. In principle, all irrigations at El Hamami should have come in the 9 to 12 or 21 to 24 day intervals since those are the intervals on the rotation. Since 57 percent of the irrigations came at intervals other than a multiple of 12 days, then the water came from canal storage, drains, ground water, water made available outside the official rotation or from more than one irrigation during the four days water is officially available.

Limited data on Kafret Nassar suggest the same pattern of irrigation frequency. However, no irrigations came at a frequency of 8 days or less. The median frequency for all canals was 9 to 12 days.

The short irrigation intervals at El Hamami suggest farmers apply water at more frequent intervals than desired in attempting to provide water to crops from rotations that are longer than preferred. The high frequency irrigations probably increase over-irrigation. The farmer probably thinks the succeeding interval without irrigation would affect crop growth and yield. On some portions of the branch canal water supplies are inadequate (Wolfe, Shahin and Issa, 1979). When water is available, the farmer continues to irrigate all crops to insure against expected future shortage.

Farmers also appear to irrigate for reasons other than to replenish soil moisture. Need for tillage, for example, may require that a field be irrigated. Removal of crop residue may require an irrigation. Sometimes removal of residue and tillage are both accomplished from the same irrigation. Providing water for germination and emergence and salinity control would appear to be the purpose of the preplanting irrigation. While considerable excess water may be applied, the irrigation is still necessary for crop production. Perhaps a more careful inventory of why farmers give particular irrigations to particular crops at particular times may reveal additional reasons why farmers apply water in addition to soil moisture replenishment.

Seasonal application of water to crops, farms, fields and canals are given in Table 6. For corn the range in seasonal water applied was from 401 to 1170 mm. Seasonal evapotranspiration is estimated at 600 mm. Thus 40 percent of the fields received less water applied than the estimated consumptive use. However, the highest corn yield occurred on a field that received only 480 mm. Average seasonal water applied by canal was as follows:

Canal	mm
Kafret Nassar	518
El Hamami	650
Beni Magdol	712

The small number of observations for K.N. limits any interpretation. The difference between E.H. and B.M. is small and could reflect an unavailability of water rather than a difference in farmer preference of use. The continuously available water on B.M. did not result in a greatly increased average seasonal application of water.

Water application to squash at El Hamami ranged between 388 and 590 mm. The highest yield was on 12 percent less water than the maximum and the minimum amount applied resulted in only 25 percent less yield.

Water Table Conditions

Depth to water in the project area ranges from 60 to 150 cm with small, isolated variations on an annual basin. The water table fluctuates during the season with a rise immediately after each irrigation and a decline between irrigations, but usually an overall gradual build up of the water table during the season occurs. The rate of decline of the water table during the season between irrigations is greatest during the period of higher consumptive use suggesting that declines occur both from lateral outflow and water use from the water table by plants. A general decline occurs during the period of annual canal closure. Figure 6 illustrates this phenomena for the summer season.

Careful delineation of the relationships between water applied, water stored in the root zone, downward flow to the water table as deep percolation and subsequent use of water from the water table by the growing crop has not been quantitatively defined to date (1979). Careful, quantitative definition of these relationships is important to defining the exact effect of the application of irrigation water to the fluctuation of the water table. Approximate budgets based on estimates of consumptive use and published data on crop water use from a water table in a given soil at an approximate depth were used to develop a sample water budget for a field.

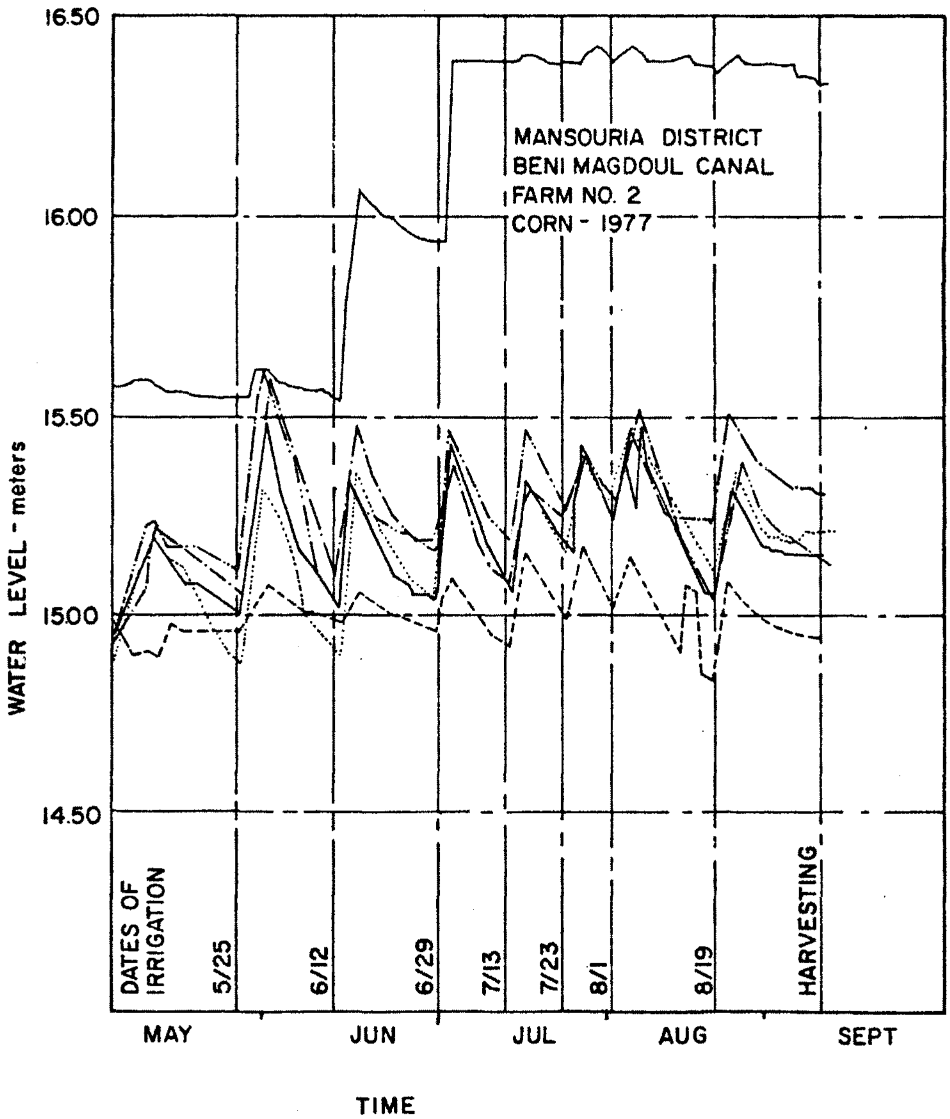


Figure 6. Water table fluctuation at each time of irrigation.

Table 6. Seasonal Applications of Water to Corn and Squash.

Area	Farm No.	Field No.	Applied Water mm	Yield Ard/f	
CORN					
B.M.	5	2	749	11.92	
B.M.	2	3	481	14.4	
B.M. (1977)	2	5	810	10	Min. 401 mm
B.M. (1977)	2	4	690	10	Max. 1170 mm
B.M. (1977)	2	3	700	8	
B.M.	2	1	850	11.07	
B.M.	2	2	870	11.0	
B.M.	2	1	1170	6.0	
B.M.	7	2	500	12	
B.M.	2	4	634.9	12	
B.M.	2	2	870	6.29	
B.M.	3	1	525	6.55	
B.M.	4	2	411	10.5	
K.N.	1	1	536.9	8	
K.N. (1977)	1	1	500	8.5	
E.H.	1	8	839.1	8	
E.H.	1	7	535.7	9.5	
E.H.	1	6	599.8	10	
E.H.	1	5	401	9	
E.H.	1	3	864.0	9.2	
SQUASH				kg/f	
E.H.	1	1	417.1	257.9	Min. 380
E.H.	1	8	525.5	5618.9	Max. 590
E.H.	1	6	590.7	5254	
	1	5	419.7	5071.3	
	1	7	380.4	4348	

Studies (Doorenbas and Pruitt, 1977; Clyma and Ali, 1977) have shown where the water table is less than one meter from the surface, 80 percent or more of the crop consumptive use can be supplied from the water table. When calculations of consumptive use are made and compared to water applied, excess irrigation water is applied early and late during the cropping season. When the high water table is considered, the resulting, estimated seasonal water balance suggests that more than 50 percent of the seasonal consumptive use was met by upward flow from the water table. Soil moisture tensions in a limited number of sites gave values greater than field capacity at the 15 cm depth but less than field capacity at all times for the 30 and 45 cm depths. Since no net annual rise in the water table presently occurs, the surplus seasonal water application is compensated by non-beneficial consumptive use and/or drainage outflow.

Circumstantial evidence of the rise in the water table and basic data on contributions of the water table to consumptive use both suggest that excess water is applied during each irrigation. This excess water causes the fluctuating water table and is very effective at leaching fertilizer out of the crop root zone. The presence of the water table at a shallow depth assures the upward migration of salts and salinization of the soil while preventing the leaching of salts past the water table. Areas that presently are rapidly becoming saline could be controlled or reclaimed if the water table were lowered. Preliminary data suggest that the fluctuating water table effectively restricts the root zone of crops to the minimum depth of the water table or less. This is 30 to at most 50 cm. During periods of peak consumptive use, the crop is stressed from the lack of an adequate root system. Crop stress can significantly reduce yields.

Factors Affecting Crop Yield

In connection with the study of on-farm irrigation practices, the yield of the crop and a number of factors that influence yield were measured. These variables and their values for each site are listed in Table 7. Because the number of sites were inadequate to provide sufficient accuracy for a step-wise multiple linear regression analysis, the number of independent variables were limited to three and a regression analysis conducted. Nineteen different combinations of three independent variables were evaluated. The results suggested that seeding rate, total water applied, and harvest data were the most significant variables (Table 8). That model and three additional ones are shown in Table 8. The coefficients for all variables were negative except manure and nitrogen fertilizer applied. Only the coefficient for total water applied appears to not include zero in the confidence interval which suggests that as the water applied increases, the yield decreases. Nearly 75% of the variation in yield can be explained by seeding rate, total water applied and harvest data and is significant at the .009 level. This effect is supported by the previous sections which suggested over-irrigation was the practice. A study by Johnson, Khan and Hussain (1979) suggested that when a factor or a number of factors are limiting, yield is not significantly affected by many of the factors of production.

Additional data and analyses are needed to identify the factors that affect production under traditional farming practices. The identification of these factors is important in determining those factors which limit crop production and would identify the priority problems needing solution.

Summary and Conclusions

Irrigation practices in the Mansouria District of Egypt were studied during the summer season of 1978. The principal crop was corn although a number of vegetable crops were also grown.

The state-of-the-art of farmer irrigation practices related to the state variables for water application were as follows:

1. Field geometry - Farmers irrigated small basins (0.0008 to 0.014 ha) with row crops on ridges or broadcast crops on the flat. The number and size of bunded units irrigated simultaneously vary. From 8 to 14 percent of the field area is consumed by field distribution ditches. The size of the basin does not appear to vary with the water supply rate.

Table 7. Regression Variables for Corn Yield.

	(1) K.N. 1978	(2) K.N. 1977	(3) BM78 F7	(4) BM78 F4F2	(5) BM78 F3	(6) BM78 F2F4	(7) BM78 F2F2	(8) BM78 F2F3	(9) BM78 F5	(10) BM77 F2F3	(11) BM77 F2F5	(12) BM77 F2F4
Yield (Ard/F)	8.0	8.5	12.0	10.5	6.6	12.0	6.3	14.4	11.9	8.0	10.0	10.0
Seed Rate (kg/f)	42.00	42.00	17.57	26.98	26.67	22.44	33.71	28.67	23,68	28.67	23.95	22.44
No. of Irrigations	6	6	9	5	6	10	7	6	10	8	8	7
Area (f)	1.90	1.90	0.34	0.44	0.44	0.52	0.09	0.21	0.55	0.21	0.49	0.52
Manure (dℓ/F)	200	230	250	0	220	300	200	250	0	0	200	200
Fertilizer N (kg/f)	66	57.75	105.5	118.8	33	33	132	82.5	138.5	66	33	66
Total Water Applied (m^3/m^2)	0.54	0.51	0.61	0.40	0.52	0.45	0.87	0.47	0.60	0.69	0.70	0.68
Pre-plant Irrigation	Yes	Yes	No	No	No	Yes	No	No	No	No	No	No
Planting Date 1/	39	8	13	56	45	27	18	18	-17	9	12	10
Plowing Date 2/	39	8	-42	47	41	27	12	18	-19	9	5	9
Harvest Date 3/	10	1	0	30	31	15	3	10	-13	7	6	7
Frequency of Irrigation (days) 4/	12.5	12.0	12.5	17.5	16.5	12.5	14.0	14.5	13.5	14.0	13.5	14.5

1/ Days from May 15   2/ Days from May 15   3/ Days from September 1   4/ Median value of range

Table 8. Results of 4 3 - Variable Models.

Model	Variables In Model	Value of Coefficient / std. error	F-Value / Significance	Beta / Elasticity	Overall r^2	Overall F / Significance (for) eqn.
	Seed Rate	-0.17/0.58	9.00/0.017	-0.54/-0.50		
1	Total Applied Water	-14.11/3.79	13.82/0.006	-0.76/-0.84	0.746	7.82/0.009
	Harvest Data	-0.12/0.41	8.34/0.02	-0.59/-0.11		
	(Constant)	24.08/3.01	64.14/0.00	--		
	Seed Rate	-0.17/0.82	4.33/0.071	-0.53/0.49		
2	Total Applied Water	-8.67/4.70	3.40/0.102	-0.47/-0.52	0.489	2.55/0.129
	Manure Applied	0.0021/0.0058	0.13/0.73	0.09/0.04		
	(Constant)	19.4/3.85	25.44/0.001	--		
	Seed Rate	-0.17/0.078	4.49/0.067	-0.51/-0.48		
3	Total Applied Water	-9.73/4.60	4.46/0.068	-0.52/-0.58	0.533	3.04/0.093
	N-Fert Applied	0.015/0.016	0.89/0.37	0.23/0.12		
	(Constant)	19.07/3.62	27.76/0.001	--		
	Seed Rate	-0.20/0.074	7.05/0.029	-0.61/-0.56		
4	Total Applied	-10.23/4.23	5.85/0.042	-0.55/-0.61	0.605	4.08/0.050
	Freq. of Irrigation	-0.55/0.35	2.52/0.15	-0.37/-0.78		
	(Constant)	29.06/6.70	18.83/0.002	--		

2. Slope - The bunded units in a field were irrigated without regard to slope (assumed zero or level). Elevation variations within a basin ranged from 5 to 20 cm while the maximum range specified (USDA, 1979) for level basins is 3 cm.

3. Infiltration rate - Early season infiltration rates appear to result in excessive applications of irrigation water at the first irrigation. Terminal intake rates ranged from 1.2 cm/hr on a clay sloam soil to 6 to 12 cm/hr on a sandy loam soil.

4. Surface roughness - No significant effects of surface roughness on irrigation practices were observed.

5. Channel shape - Furrows were used with crops that are sensitive to inundation. Farmers appear to attempt to regulate rate and amount of water applied to control inundation but are not always successful.

6. Water supply rate - Variable flow rates and variable areas for bunded units limit farmers ability to apply a specified amount of water to a field. Tambour flow rates range from 5 go 18 l/s and Sakia flow rates range from 3 to 61 l/s. The maximum flow rate is frequently twice the mean.

7. Management - Farmers appear to irrigate field systems which do not permit good water management because they are unlevel, and the area irrigated and flow rates are variable. His decision on when to irrigate is influenced by the canal rotation with 25 percent of his irrigations on a four day interval. When water is continuously available, no frequencies less than four days occurred and the median frequency was 9 to 12 days. The amount of water applied appears excessive with the seasonal average application estimated to be more than twice as much as can be stored in the soil. The result is leaching of fertility and a fluctuating water table. Both limit crop production.

8. The factors which affect crop yield were evaluated but inadequate data did not permit quantification. Preliminary results suggest that increased water application decreased yields suggesting that excess water was applied. No factors except fertilizer had a positive affect on yield out of 10 factors evaluated. More data are needed to define the cause and effect relationships but results from other studies suggest one or more factors are limiting with the result that supplying the traditional factors of production do not result in positive increases in yield (Johnson, Khan and Hussain, 1978). Level borders were recommended for improvement of the on-farm system. Evaluation of the new system is presently (1979) being conducted in Egypt.

Recommendations

The authors recommend the following activities be evaluated as potential solutions to the above defined problems.

1. Design an improved, precision leveled, water application system for a farm on both Beni Magdoul and El Hammami branch canals using the criteria defined by USDA (1974) for level borders.

2. Construct the irrigation system and provide irrigation advisory assistance to the farmers on the operation and management of the system.

3. Collect evaluation data on the social, economic, crop production and engineering aspects of the operating irrigation system. The results for the improved system will be compared with the traditional system to evaluate appropriateness of the new system and further

understand the farmer's management decisions. Final recommendations must await these results before suggesting solutions to the above defined problems.

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FURROW IRRIGATION PRACTICES IN NORTHERN COLORADO[2]

T. W. Ley and W. Clyma[1] [3]

INTRODUCTION

For the past three irrigation seasons, furrow irrigation evaluations have been conducted on several farms in the Fort Collins and Greeley areas of Northern Colorado. A data base consisting of six farms has been established. These data were used in a structured analysis to define irrigation practices in the area. This analysis provides a definition of priority problems in furrow irrigation in the area. The solution of these problems is the basis for improvement of on-farm water management. This paper presents an analysis of irrigation practices and a definition of priority problems.

PROCEDURES

The on-farm irrigation system consists of the following four subsystems:

1. Water delivery.
2. Water application.
3. Water use.
4. Water removal.

This paper focuses on a study of the water application subsystem. The state variables affecting the application of water to field are as follows:

1. field length
2. field slope
3. furrow inflow rate
4. furrow intake rate
5. furrow roughness
6. channel shape

With the boundary and initial conditions specified, the state of the system is defined. Qualitative and quantitative descriptions of the above variables and of farmer decisions on management of the system in terms of how to irrigate, when to irrigate, and how much water to apply, completely define and describe the state-of-the-art of water application for the irrigation system.

A structured analysis of the state variables and farmer management has been used by Clyma and Ali (1977) and El Kady, Clyma and Abu-zeid (1979) to define irrigation practices in areas of Pakistan and Egypt, respectively. In these traditional irrigation systems no explicit design

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[3]Presented December 1979, ASAE meeting New Orleans, Louisiana

procedures were available. When explicit design procedures are available, a detailed analysis of operational and design values for each state variable and each farmer management descision provides a quantitative comparison of the appropriateness of irrigation practices in the area. Not only are irrigation practices defined, but deviations of system performance from potential performance (as determined by design standards) are quantified. The suitability of present irrigation practices are evaluated and priority problems identified by the magnitude of these differences.

A detailed furrow irrigation system evaluation procedure presented by Ley (1978) was used to collect system operation and management data during a total of 21 irrigations on 9 furrow irrigated fields of six different farms in the area. On several of these fields evaluations were conducted throughout the irrigation season. Only limited data are available on two of the fields. The evaluation procedure and methods of data analysis (see Salazar, 1977 and Ley, 1978) were originally designed to evaluate each of the state variables and farmer management of the system as previously listed. In all cases, the water application subsystem under study was classified as graded furrows with the free-outflow downstream boundary condition. Corn, sugar beets and field beans represent the majority of crops grown in the area irrigated by furrows. Other crops were cucumbers, onions, carrots, sorghum and other vegetables.

Results obtained from the data collection and analysis procedures were combined and categorized by state variable. Actual system performance as a result of management decisions by farmers was determined. Values of the state variables observed were compared to overall design recommendations as formulated using an SCS design procedure for furrow irrigation systems.[2] SCS design recommendations (USDA, 1978b) such as maximum lengths of run for erosion control and erosion control criteria for maximum slopes and furrow flow rates were also compared to farmer practice. Actual levels of performance were compared to design (or potential) levels of performance in conjunction with the state variable and management decisions to determine key state variable and management deficiencies. This leads to identification of priority problems and ultimately improvement of on-farm water management.

The SCS furrow irrigation design procedure uses a volume balance approach to determine appropriate set time and furrow inflow rates for storing a given depth in the root zone given design parameters such as length of run, irrigated furrow spacing, furrow slope and a furrow intake family. Design levels of efficiency (irrigation performance) can be specified and then only acceptable combinations of variables result. This design level represents the potential performance of the system.

A design was formulated for each of the systems studied. The approach was to design the system to apply the crop requirement during the peak use period. Thus, an irrigation scheduling procedure based on climatic data for the area; crop growth characteristics; design availability factor f, the fraction of the total available water within the root zone of the crop that is readily available (Hart, 1975); and soil water holding characteristics was used to determine design application depths for the peak use interval of each crop. Soil intake characteristics

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[2]Harlan Collins, USDA, Soil Conservation Service, Private Communication.

for each field were represented using a single furrow intake family. The value was taken roughly as the mean intake family determined using irrigation evaluation data. In the formulation of each design, an attempt was made to select values for the design parameters as close as possible to the actual operation, i.e., the same slope, length, irrigated furrow spacing, etc. This allows direct evaluation of farmer operation and management of the system when successful designs could be formulated.

The following sections present the state variable analyses by comparison to design recommendations and summarize the results of the designs as compared with the actual system. The same comparison of farmer management decisions with recommended management decisions follows to illustrate deficiencies in management. Finally, key results and conclusions concerning the state-of-the-art of furrow irrigation practices in the area are presented. Recommendations for improvement of on-farm water management in the area are also suggested.

STATE VARIABLE ANALYSIS

Field Length-- Although furrow lengths ranging from 175-725 m (575-2380 ft) were observed, the majority of observed lengths fall between 350-650 m (1150-2130 ft). Depending on the farm size and farm boundaries, fields generally were laid out between established roadways [i.e., county roads nominally spaced at 800 m (one-half mile) intervals] or traditional farm roadways. This accounts for the prevalence of longer run lengths. In general, little or no regard was given soil boundaries or soil intake rates in determining run lengths, e.g., lengths of run much too long were found on sandier soils, while shorter lengths were found on loam and clay loam soils. The prevalence of the longer lengths of furrows allows more efficient use of farm equipment, less labor during irrigation and less investment in field distribution facilities.

The SCS (USDA, 1978b) provides a procedure for determining maximum run lengths based on adequate drainage of rainfall-runoff without erosion or overtopping of furrow ridges. The process involves determining a maximum furrow length for a given spacing and slope such that the predicted runoff volume from a 6 hr-2 yr storm for a given hydrologic soil group is drained at a non-erosive flow rate. The average rainfall from a 6 hr-2 yr frequency storm for the Larimer and Weld county areas of Northern Colorado is approximately 33 mm (1.3 in). From SCS (USDA,1964), the soils in the area were classified in hydrologic soil groups B and C with runoff curve numbers 80 and 85 assumed. Predicted runoff depths ranged between 4.8 to 8.4 mm (0.19 to 0.33 in). Based upon a predicted runoff depth, field slope and furrow spacing, a maximum run length was determined. The results of this analysis for the fields studied are presented in Table 1. Several of the actual run lengths (nearly 50 percent) observed were slightly longer than recommended. These were furrow lengths greater than 600 m (1970 ft) on the soils with higher clay content.

Maximum design furrow lengths are a function of soil intake rate, depth of application, furrow grade and maximum non-erosive furrow stream. In most instances, farmers appeared to be aware of these factors and acted accordingly. They generally achieved uniform applications, though usually inefficient due to lack of proper management. One farmer used a length of run more than twice the maximum recommended (as determined from SCS Colorado Irrigation Guide, USDA, 1978a). Although he actually

Table 1. SCS Maximum Lengths of Run as Limited by Rainfall Erosion.
(Average 6 hr-2 yr rain ≅ 33 mm (1.3 in.). Hydraulic condition of furrows assumed good.)

Site	Hydrologic Soil Group/ Runoff Curve No.[1]	Predicted Runoff depth (mm)	Slope (percent	Length (m) Allowable[2]	Actual
1	C/85	8.4	0.45	600	625
2	B/80	4.8	0.38	> 900	183
3	B/80	4.8	0.43	1227	183
4	C/85	8.4	0.36	1091	175
5	C/85	8.4	0.98	374	364
6	B/80	4.8	0.66	625	640
7	C/85	8.4	0.33	762	285
8	B/80-C/85	6.6	0.50	700	725
9	C/85	8.4	0.41	625	640

[1]From SCS (USDA, 1964)

[2]From SCS (USDA, 1978b)

was doing a fair job of irrigating, problems with over-irrigation at the upper end and under-irrigation at the lower end naturally occurred.

In all but one instance, acceptable designs were formulated for the actual furrow lengths studied (see Appendix 1 for tables of design results and evaluation results). For that case [site 1 where the actual length was nearly 800 m (one-half mile) on a clay loam soil], an acceptable design was formulated for a length one half of the actual length. All of the designs for furrow lengths approaching 800 m (one-half mile) were only marginally acceptable (designs were acceptable if water application efficiency, the fraction of total water applied made available for plant use, was greater than 70 percent, with less than 10 percent deep percolation and 20 percent runoff losses, while water requirement efficiency, the fraction of the plant water requirement actually met by an irrigation, was greater than 85 to 90 percent). There is a definite indication that the longer furrow lengths, 400 m to 800 m (one-fourth mile to one-half mile) place a limitation on efficient water application in the area. Designs formulated for shorter runs on the same fields indicated improved system performance could be attained. Agronomic, economic and institutional factors may constrain the farmer's ability to change his system and improve his water management. The more efficient use of water in the future may become an important factor in the arid Western states causing farmers to alter their length of run.

Field Slope-- Furrow grades ranging from 0.3% to 1% were observed on the fields studied. The average grade and several measures of the variation in the slope along the evaluated length are provided in Table 2. Included is the root mean square (RMS) error (see Table 2 for definition) of the actual field elevations versus a least squares prediction of field elevations at stations along the run. The RMS error is an indication of the uniformity of the actual furrow grade. Larger values indicate larger variation in the grade, while smaller values indicate a more uniform grade. Although somewhat large values were encountered (10 to 15 percent RMS error), the uniformity of application for an irrigation on these particular fields was still acceptable. In all cases, the furrow grades observed were less than the SCS maximum grades for erosive soils based on a 30 min-2 yr frequency rainfall and given in Table 2 as 1.3 to 1.9 percent.

All of the fields studied had at one time or another been graded or land-planed supposedly to a uniform grade. Seedbed preparation, planting and cultivation operations contributed to the deviations observed.

In all cases, there were no problems in formulating acceptable designs for the actual field slopes (least squares slopes) studied. The uniformity of grade, however, is an important factor in obtaining uniform water application. In at least one-third of the cases studied, the uniformity of grade should be improved (as indicated by RMS errors greater than 10 percent) to improve the uniformity of application.

Furrow Inflow Rate-- Furrow inflow rate is perhaps the most easily controlled state variable and the single most important factor in efficient water application given particular field and site conditions. In all the fields studied, water was introduced to the furrows by means of siphon tubes. Farmers usually knew a rough estimate of their total water supply rate and would accordingly set a specific number of siphon

Table 2. Furrow Slope Data Analyses.

Site	Length Evaluated (m)	Least Squares[1/] Slope (m/m) (r^2)	Root[2/] Mean Square Error	Total Fall (m)	Max. Fall in 25 m (m)	% Diff. from L.S. Slope	Min. Fall in 25 m (m)	% Diff. from L.S. Slope
1	625	0.0045 (0.999)	0.1062	2.61	0.134	+19.2	0.043	-62.1
2	150	0.0038 (0.995)	0.0512	0.58	0.122	+28.3	0.079	-16.6
3	150	0.0043 (0.994)	0.0574	0.62	0.140	+30.43	0.067	-37.6
4	175	0.0036 (0.991)	0.0210	0.64	0.149	+66.0	0.050	-44.1
5	350	0.0098 (0.999)	0.0320	3.42	0.268	+ 9.4	0.223	- 9.2
6	625	0.0066 (0.985)	0.1545	4.14	0.270	+63.6	0.060	-63.6
7	275	0.0033 (0.997)	0.0162	0.94	0.120	+45.5	0.060	-27.3
8	725	0.0050 (0.999)	0.0411	3.46	0.149	+19.5	0.058	-53.7
9	640	0.0041 (0.996)	0.1654	2.51	0.177	+72.8	0.028	-72.8

[1/] SCS (USDA, 1978b) recommended maximum slopes for erosion control: $S_{max} = P_{30}^{-1.3}$

where P_{30} = 2 yr-30 min rainfall (in.)

for N. Colorado $P_{30} \doteq 0.6 - 0.8$ in. (15 mm - 20 mm)

$S_{max} = 1.3 - 1.9\%$

[2/] RMS error = $\sqrt{\dfrac{\sum_{i=1}^{n} (Y_{act} - Y_{pred})^2}{N-1}}$

where Y_{act} = actual elevation of station

Y_{pred} = least squares prediction of elevation of station

N = number of stations

tubes per irrigation set with a particular size and number of siphons per furrow. The farmer's experience and general knowledge of what happens on his field from irrigation to irrigation was his basis for determining how many tubes to set and how to set them. Only limited knowledge of siphon discharge versus head relationships seemed to be used by farmers. By visual inspection of the tubes and conditions in the head ditch, farmers attempted to achieve equal flow rates into all furrows by use of ditch checks in the head ditch. In a few instances, an irrigated furrow was a "guess row" (the result of overlap in tillage operations) and the farmer used a larger flow rate there. However, the observed prevalent practice was to attempt to compact all furrows equally during tillage operations to eliminate variations in intake.

In most cases, mean furrow flow rates for each irrigation, $\bar{Q}_i$, generally decreased from irrigation to irrigation through the season (Table 3). The furrow inflow rate was much larger for the first irrigation than for other irrigations on two sites (Sites 6 and 7) where seasonal data are available. With more friable soil conditions and higher intake rates early in the season, farmer use larger inflow streams in order to obtain faster rates of advance. Other reasons for the trend in decreasing inflow rate as the season progresses include reductions in total water supply available and farmer perception that reduced flow rates are required to get the water through the field as the soil intake rate changes.

Other seasonal furrow inflow characteristics are shown in Table 4. The mean seasonal inflow, $\bar{Q}_s$, for each site when compared to the individual irrigation mean, $\bar{Q}_i$, shows that for three sites where seasonal data are available the flow rate decreases during the season. The standard deviations ($s_{\bar{x}}$) for these sites ranges from 0.17 to 0.27 ℓps, another indication of this change. The standard deviation of individual furrow flows from the mean flow for a set, $(s_{\bar{x}})_f$, is a measure of the farmer's ability to regulate the same flow rate to each furrow. These ranged from 0.08 to 0.18 ℓps, about 5 to 15 percent of the average flow. Variations in individual observations of flow rate down a furrow are given by standard deviations, $(s_{\bar{x}})_t$, for individual furrows that ranged from 0.03 to 0.26 ℓps representing about 2 to 30 percent of the average flow. In three of the seven sites flow variation with time down a single furrow was 10 to 30 percent of the average flow. Salazar (1977) states these variations in observed flows are due to:

a) head stabilization in the head ditch and water level fluctuations in the head ditch during an irrigation,
b) obstructions to siphon discharges such as weeds,
c) farmer adjustment of siphon discharge after start of irrigation,
d) errors in measurement of furrow inflow rate.

No farmers attempted to use cutback inflow rates during an irrigation.

In 90 percent of the irrigations studied, farmers used non-erosive furrow streams. Erosion criteria for limiting the maximum allowable furrow stream to 3.15 ℓps/furrow (50 gpm/furrow) or ($0.79/S_o$, percent) ℓps/furrow [($12.5/S_o$, percent) gpm/furrow] whichever is less were used.

Table 3. Mean Furrow Inflow Rate, $\bar{Q}_i$ (ℓps), for Three Furrows for each Irrigation.

SITE	IRRIGATION NO. 1	2	3	4	5	6
1	NA	1.53	1.48	1.12	1.09	--
2	1.19	1.34	--	--	--	--
3	0.85	0.81	--	--	--	--
4	0.62	--	--	--	--	--
5	NA	NA	0.77	0.73	--	--
6	1.41	1.14	1.10	NA	1.06	0.96
7	1.70	1.17	1.32	--	--	--
8	2.47	--	--	--	--	--

NA = not available

Table 4. Seasonal Characteristics of Furrow Inflow Rates.[1]

Site	No. of Observations	Seasonal Mean Inflow Rate (ℓps) $\bar{Q}_s$	Standard Deviation (ℓps) Season $s_{\bar{x}}$	Furrow n	Furrow $(s_{\bar{x}})_f$	Single Observation n	Single Observation $(s_{\bar{x}})_t$
1	4	1.31	0.23	11	0.08	126	0.06
2	2	1.27	0.11	6	0.12	48	0.03
3	2	0.83	0.02	6	0.16	65	0.26
5	2	0.75	0.03	6	0.15	72	0.04
6	5	1.11	0.17	15	0.18	345	0.17
7	3	1.40	0.27	9	0.11	250	0.15

[1]Only one irrigation was observed at Sites 4 and 8.

$s_{\bar{x}}$ = Standard deviation of seasonal mean furrow inflow (ℓps).

$(s_{\bar{x}})_f$ = Standard deviation of mean individual furrow inflows from mean inflow for an irrigation set.

$(s_{\bar{x}})_t$ = Standard deviation of single observations of furrow inflow rate from mean individual furrow inflow rate.

The average inflow rate for two out of the 21 irrigations evaluated exceeded the maximum allowable inflow rate. These were both during the initial irrigation. In those instances, post-irrigation furrow profile data showed that substantial erosion at the upper end and sedimentation at the lower end of the furrows had occurred when compared to perirrigation furrow profiles.

In practically all instances, farmers used furrow inflow rates larger than those formulated from design (see Appendix A). The differences ranged from one to two-and-one-half times the design flow rate in 18 out of 21 irrigation evaluations. This is particularly obvious for the initial irrigation of the season. The direct impact of this practice was that runoff losses greater than 25 percent occurred in nearly 60 percent of the cases. In the designs, runoff losses were consistently held to a maximum of 20 percent and frequently less.

Furrow inflow rate is indirectly part of the farmer's management decision of how much water to apply. An inflow rate/inflow time combination defines an average application depth for given irrigated furrow conditions. Design results for various inflow rate/inflow time combinations result in the same applied depth but yield different levels of performance. Thus, while farmer's ofter perceived a need to use larger heads for quicker advance rates, they may not be aware that better performance may be achieved with smaller inflow rates and longer set times. Further discussion is presented in the analysis of farmer management.

Furrow Intake Rate-- A volume balance procedure was utilized to determine the SCS furrow intake family (I_f) for each of the irrigations evaluated. The results are presented in the right hand column of Table 5. The trend of these data show a decrease in furrow intake rate as the season progresses. This general trend is to be expected and has been observed by other researchers (Clyma and Ali, 1977; El Kady, et.al. 1979). The seasonal mean value and the most likely design value (taken as the seasonal mean value rounded to the nearest furrow intake family) are also given. Table 5 also includes a determination of furrow intake family for each of the fields studied based on an SCS soil series classification and use of the SCS Colorado Irrigation Guide (USDA, 1978a) design group and furrow intake family tables. Determination of furrow intake family for design purposes based on a soil series classification is fair but in some instances may yield unreliable designs, as can be seen by comparison of the two different intake family values in Table 5 determined by different methods. Information on soil type and texture only may not be adequate for design purposes. Field trials are then necessary to determine intake characteristics.

Seasonal values of furrow intake family obtained by volume balance methods were utilized in the formulation of designs for each of the fields studied. In general, the value used in design was nearly equal to the mid-season (peak use interval) value.

Evaluation results (see Appendix A) show that the trend for decreasing intake rates as the season progresses made it increasingly difficult for the farmer to meet the crop requirement. Farmers did not appear to be fully aware of the effects of decreasing intake rates on the amount of water applied. The results showed that in several instances management decisions of farmers resulted in the development of cumulative soil water deficits causing crop stress as the season progressed. Other

Table 5. Comparison of Furrow Intake Family as Determined by SCS Soil Series Classification Versus Values Obtained by Volume Balance Procedure for each Irrigation.

			SCS Colorado Irrigation Guide Data Based on Soil Series[2]			Determination of Furrow Intake Family (I'_f) by Volume Balance	
Site	Soil Type[1]	SCS Soil Series Classification	Design Group	Ave. AWC in 1.2 m (mm)	Furrow Intake Family (I'_f)	Irrig. #	I'_f
1	Clay loam	Nunn Clay loam, 0-1% slopes	5	208.3	0.5	#1	0.40
						2	0.40
						3	0.50
						4	0.35
						5	0.45
						mean =	0.42
						design value	(0.45)
2 & 3	Sandy clay loam	Mixture of:				Site 2	
						#1	1.40
	Soils have been highly mixed	Altvan L & SL, 0-1% slopes	11	172.7	0.5 - 1.0	2	1.00
						mean -	1.20
		Otero SL & FSL, 0-1% slopes	16	129.5	0.5 - 1.0	design value	(1.00)
		Nunn CL, 0-1% slopes	5	208.3	0.5	Site 3	
						#1	1.00
						2	0.45
						mean	0.72
						design value	(0.70)
4	Clay loam	Nunn Clay loam 0-1% (dominant) (some Santanta loam)	5	208.3	0.5	#1	0.45
						design value	(0.45)
5	Clay loam/ SCL	Kim loam 0-3% (dominant) (some Nunn CL)	12	193.0	0.5	#3	0.45
						4	0.30
						mean -	0.42
						design value	(0.45)
6	SL	Vona LS and SL, 0-3%	14	142.2	1.0	#1	0.50
						2	0.35
		or				3	0.45
		Ascalon SL, 0-3%	14	142.2	1.0	4	0.40
						5	0.40
						6	0.30
Map shows large part of field to have moderate salinity and W.T. effect. Smaller area has severe salinity and W.T. effect.						mean	0.40
						design value	(0.40)
7	SCL CL/C	Haverson L, 0-1%	12	193.0	0.5	#1	1.7
		Otero SL, 1-3%	16	129.5	0.5 - 1.0	2	0.9
						3	1.0
		(mostly Haverson L)				mean	1.20
						design value	(1.0)

[1]Results from particle size analysis of samples collected in field.

[2]SCS Colorado Irrigation Guide (USDA, 1978a).

design deficiencies such as improper furrow lengths and improper inflow time/inflow rate combinations also contribute to this effect.

Furrow Roughness-- Manning's equation and roughness factor was assumed to adequately represent furrow flow conditions in all case studies. Although furrow irrigation represents non-uniform, spatially varied flow, a condition of steady state flow is approached as the soil reaches its basic intake rate. Assumptions are that the furrow is prismatic and that the cross section is symmetrical about a vertical centerline.

Salazar (1977) presents procedures to determine Manning's n which were utilized to determine roughness for each furrow. Values measured ranged from 0.010 to 0.047. The majority of values were less than 0.03. Ramsey and Fangmeier (1976) determined Manning's n values ranging from 0.02 to 0.04 with a mean near 0.03 in controlled furrow irrigation trials. Values of Manning's n in the literature (King and Brater, 1963; Chow, 1959; Schwab, et.al., 1966) for straight, uniform earthen channels range from 0.015 to greater than 0.04 depending on the conditions of the channel. In furrows, where the hydraulic radius is small and the relative effects of channel obstructions (clods, weeds, etc.) are large, higher values near 0.04 are feasible. The SCS furrow design procedure assumes a constant n value of 0.04.

Salazar (1977) showed that assuming a constant value for n in a furrow irrigation simulation model does not significantly affect predictions of irrigation performance. The study did show that significant variations in furrow roughness can occur along a single furrow length for an irrigation and through the irrigation season. Roughness variations, however, cause differences in total furrow intake due to the corresponding changes in furrow wetted perimeter. The real effect of roughness variations on predicting irrigation performance is dependent on the relationship between furrow intake and furrow wetted perimeter. Ramsey and Fangmeier (1976) showed that intake rate varied as a linear function of furrow wetted perimeter. Ley (1978) showed that roughness variations from a constant average value can result in moderate deviations in predictions of irrigation performance when a 1:1 linear relationship between furrow intake and furrow wetted perimeter is assumed. For instance, changing the furrow roughness over a range from 40 percent to 160 percent of a given average value for an irrigation resulted in corresponding changes in predicted water application efficiency from 84 percent to 110 percent of the measured value (Ley, 1978). Further study of the effects of furrow roughness variation on furrow intake and ultimately prediction of irrigation performance is indicated.

Channel Shape-- Channel or furrow shape defines the furrow wetted perimeter for a given set of flow conditions and ultimately may have an effect on total furrow intake. Assuming other factors constant, it is obvious that two different cross sections will yield two different flow depths, two different wetted perimeters and most likely two different intake volumes. The actual relationship between furrow wetted perimeter and intake has not been substantially quantified as previously stated.

Salazar (1977) found that describing furrow cross-sectional flow area as a power function of flow depth was most representative of the cross-sectional profile data collected through an irrigation season.

Even though the cross sections approached a trapezoidal shape as the season progressed, a power function fitted better because the bottom of the furrows actually never became horizontal. Salazar (1977) also presented results which showed that the assumption of a single furrow shape to represent the entire season did not result in significant error in volume balance computations of irrigation performance. This was true even when significant shape changes occurred along the furrow length from the beginning to the end of the season. Furrow profile data from these studies showed that the average cross-sectional flow area increases through the irrigation season (Table 6). The cross sections become wider with flatter bottoms. In all cases, at the end of the season the furrows exhibited deep, wide, nearly flat-bottomed cross sections at the upper end and somewhat shallower sections at the lower end. The occurrence of erosion and sedimentation at the upper and lower ends, respectively, seemed to produce this effect.

Misrepresentation of the furrow cross-sectional flow area can result in significant error depending, of course, on the relationship between furrow wetted perimeter and intake. Ley (1978) showed that, when a 1:1 linear relationship between furrow wetted perimeter and intake is assumed, changing the cross-sectional flow area over a range from 70 percent to 130 percent of the average value resulted in corresponding changes in predicted water application efficiency from 70 to 130 percent of the measured value. Errors in measuring cross-sectional flow area therefore produce equivalent errors in determining system performance under this assumption. Further study of this phenomenon in furrow irrigation is indicated.

The SCS furrow design procedure assumes furrows are represented as small trapezoidal channels. An empirical relationship (which encompasses a range of trapezoidal shapes) defines furrow wetted perimeter as a function of the hydraulic characteristic $(Qn/S_0^{\frac{1}{2}})$. A constant is added to this relationship to convert the trapezoidal wetted perimeter to an equivalent horizontal wetted width. The resulting value is ultimately used to define equivalent and equivalent average infiltration depths using the SCS infiltration functions. The procedure is not meant to account for the effects of wetted perimeter variations on furrow intake. Instead, it is a means for converting intake volume through a curved furrow surface to an equivalent average depth as is commonly defined for other surface irrigation methods where the entire surface is inundated.

FARMER MANAGEMENT

In determining how farmers irrigate, the conclusion is that they use furrow irrigation as a traditional method for irrigation of row crops. It is a practice used from generation to generation with refinements mainly being made in the methods of in-field delivery and distribution. While gated pipe is used in the area, the prevalent practice uses siphon tubes for directing water into each irrigated furrow. Another decision farmers make about how to irrigate is whether to irrigate every furrow or alternate furrows. Design results indicate either method is acceptable. Lighter, more frequent applications are necessary, however, when irrigating alternate furrows on a heavier soil in order to satisfy the crop requirement at each irrigation. On the other hand

Table 6. Seasonal Variation in Channel Shape and Surface Storage for Various Flow Depths.

Site	Irrigation No.[2]	Cross-sectional Flow Area Equation $A_F(cm^2)$, y (cm)	Cross-sectional Flow area (cm^2) for Flow Depth (cm): y = 1	y = 2	y = 3
1	1b	$7.7\ y^{1.50}$	7.7	21.8	40.0
	1a	$12.2\ y^{1.29}$	12.2	29.8	50.3
	2a	$12.7\ y^{1.39}$	12.7	33.3	58.5
	5b	$16.5\ y^{1.26}$	16.5	39.4	65.7
5	3 ave	$11.6\ y^{1.27}$	11.6	28.0	46.8
	4 ave	$10.6\ y^{1.39}$	10.6	27.8	48.8
6	2 ave	$14.1\ y^{1.28}$	14.1	34.2	57.5
	3 ave	$16.4\ y^{1.21}$	16.4	37.9	62.0
	5b	$19.7\ y^{1.10}$	19.7	42.2	66.0

[1] after Salazar (1977)

[2] b--before irrigation profiles
a--after irrigation profiles
ave--average of before and after profiles.

irrigation of every furrow on lighter soils may result in over-irrigation and leaching of nutrients from the crops root zone. Both extremes were observed as can be seen in Appendix A, Tables A1 and A6, for Sites 1 and 6, respectively. The most common practice in the area is to irrigate alternate furrows.

As a result of this practice and combinations of other factors such as improper application times, incorrect irrigation timing and decreased soil intake rates as the season progresses, farmers were not meeting crop requirements. Cumulative soil water deficits formed through the season as opposed to a given deficit level at each irrigation (see evaluation results in Appendix A). The compensating factor seems to be that fairly consistently overirrigation at initial irrigations of the season provides soil water storage in the potential crop root zone for the crop to draw upon later. In one instance, a farmer realized he was not applying the desired amount and changed his management at the third irrigation of the season to irrigate every furrow. Evaluation results indicated the crop requirements were thusly satisfied at the expense of some deep percolation losses through the rest of the season (Table A6, Appendix A).

It may often be the case, however, that farmer's are constrained by their available water supply to irrigate only every other furrow in order to sequence through in time to start the irrigation process again and in doing so, are doing an inadequate job of irrigating. This indicates a design deficiency attributable to possibly several factors or combinations of factors. These include improper stream sizes, furrow lengths which are too long, insufficient system capacity, etc. Information needs to be supplied to farmers concerning their particular operation as to whether or not they should be irrigating every furrow, if they have the system capacity for this and if not, if they can sucessfully irrigate alternate furrows. System design alterations may be required.

Several factors appear to determine how farmers decide when to irrigate. The decision is based on experience from previous seasons, visual observation of the crop, a fixed time interval, or the time required to cycle through his fields. Institutional factors may often require him to "call" for water on a particular day to have water on a later day in the week. This may require the farmer to use the water even though he is aware that he doesn't need it. Depending on the water supply available, farmers may start irrigation based on visual observations of the crop. They then continually irrigate through the peak use period or some stage of crop growth with the irrigation interval the time required to cycle through their fields.

In approximately two-thirds of the irrigations studied, results indicate farmers had decided to irrigate too soon (i.e., the actual availability factor at irrigation time was less than the design availability factor). Approximately half of those irrigations resulted in some deep percolation. The remainder were underirrigations and resulted in the cumulative root zone soil water deficit (see Appendix A). For the other one-third of the irrigations studied, in approximately 60 percent of those, the farmers waited too long (soil water deficit larger than design allowable) and in general water requirement efficiencies much less than 50 percent resulted. Thus, in only 14 percent of the cases studied did a farmer decide, by coincidence, to irrigate at the correct allowable depletion. When this did happen only marginal performance was still the result, as the farmers were not using inflow rate/inflow time combinations to achieve good levels of performance. Poor irrigation timing and the observed inability to apply the correct amount of water combined with such factors as decreasing intake rates and decreasing water supply through the season result in the cumulative soil water deficits and poor water requirement efficiencies.

The farmer's decision on how much water to apply is linked to the fact that they often will operate with a constant set time through the season. The set time chosen was based on farmer experience and most often was two 12-hr sets per day on the fields longer than 400 m (one-fourth mile) and was anywhere from 3 to 8 hours on the shorter fields studied. In combination with this, farmers would set so many tubes per furrow to achieve an advance time within two-thirds to three-quarters of the total set time, indicating that advance time is often a factor in a farmer's decision on how long he should irrigate. There are no conclusive data to support this, however, at this time. At any rate, evaluation results (Appendix A) show highly variable application depths even though set times were fairly constant. This is due to the variation in inflow rates from irrigation to irrigation as described earlier.

With basic knowledge of his total flow rate and the area irrigated per set in a given set time, the farmer can obtain a rough estimate of the average applied depth. However, there does not seem to be any account for runoff or deep percolation losses in adjusting this amount to some stored depth. Thus, a large variability in the root zone storage at each irrigation with corresponding variability in irrigation performance at each irrigation also resulted.

The inability of farmers to apply the right amount of water at the right time is more closely related to improper system design and lack of knowledge of total available water supply, siphon head-discharge relationships and correct inflow rate/inflow time combinations to achieve good system performance rather than to lack of knowledge of plant-soil-water relations. This seems to be evident in that some of the farmers and irrigation systems evaluated were achieving fairly good seasonal performance even though there may have been large deviations from system design recommendations.

IRRIGATION PERFORMANCE

Furrow irrigation performance was defined by four parameters:

1. water application efficiency (previously defined),
2. water requirement efficiency (previously defined),
3. runoff ratio, the fraction of applied water lost as runoff from the end of the field,
4. deep percolation ratio, the fraction of applied water lost as deep percolation and not beneficially used by the plant system.

Irrigation performance at all sites was unacceptable based on previous criteria for acceptable water application and water requirement efficiencies, and allowable losses. At two sites, (Sites 6 and 7), some acceptable performance occurred. However, only one of six irrigations (Site 6) and two of three irrigations (Site 7) were at acceptable levels of performance. Thus only three of the 21 irrigations monitored had acceptable performance. Eighty-five percent of the irrigations needed improvement.

Water application efficiencies ranged from 35 to 88 percent with a median near 70 percent. Water requirement efficiencies ranged from 33 to 100 percent with a median near 86 percent. Deep percolation ratios ranged from 0.00 to 0.57 with a median of 0.00. Runoff ratios ranged from 0.08 to 0.48 with a median near 0.26.

SUMMARY AND CONCLUSIONS

Structured analysis of the state variables and factors which define the state of irrigation practices in an area have been performed with a limited set of furrow irrigation evaluation data on several furrow irrigation systems in Northern Colorado. A preliminary description of the state-of-the-art of furrow irrigation practices in this area has thus been presented. Detailed analysis of the evaluation data and comparison of actual conditions with design standards and recommendations yield the following conclusions:

1. Field Length. -- Nearly 50 percent of the systems studied had furrow lengths longer than recommended for erosion control. These occurred, in general, on the heavier soils. Design results show that while marginally acceptable results can be achieved on the longer run lengths from 400 m to 800 m (1/4 mile to 1/2 mile), improved system performance can be attained on the run lengths of 400 m (1/4 mile) or less.
2. Field Slope. -- Acceptable grades ranging from 0.3 percent to 1 percent were observed. The uniformity of grade in at least one-third of the fields studied could be improved to increase uniformity of application. No grades greater than the 1.3 percent to 1.9 percent maximum recommended grades for erosion control in the area were encountered.
3. Furrow Inflow Rate. -- Furrow inflow rates were observed to generally decrease through the season. In most instances, the inflow streams observed were less than the maximum allowable non-erosive stream, except for the first irrigation of the season, when farmers tended to use relatively larger streams. In nearly 85 percent of the irrigations evaluated the observed inflow rates were larger than those formulated by design. The result was large runoff losses.
4. Furrow Intake Rate. -- Intake rates were observed to generally decrease through the irrigation season. Determination of an SCS intake family based on soil series classification may be unreliable as compared to values obtained using volume balance. Farmers do not appear to be aware of the effects of decreasing intake rates on the amount of water stored in the root zone.
5. Furrow Roughness. -- Furrow roughness was characterized using Manning's n. Values ranging from 0.010 to 0.047 were observed. SCS design procedures use an n of 0.04. The effects of roughness variations on total intake volume and finally on irrigation performance needs further study. Roughness was found to vary significantly along a single furrow and from irrigation to irrigation through the season.
6. Channel Shape. -- Furrow cross sections were represented by a power relationship between cross-sectional flow area and flow depth. SCS design procedures define furrow shape as

a trapezoidal cross section. Significant shape changes were found to occur along a furrow from the beginning to end of the season. The effects of shape variations on total intake volume and irrigation performance requires further study.

7. Management. -- A significant decision farmers make in deciding how to irrigate is whether to irrigate every furrow or only alternate furrows. The prevalent practive is to irrigate alternate furrows, however, this may be a major factor in the underirrigation which is occurring, particularly on the heavier soils. Farmers may be influenced on when to irrigate by delivery constraints. In approximately two-thirds of the cases studied, farmers irrigated too soon. In combination with an inability to apply the right amount of water, inefficient (over- and underirrigation) irrigations often resulted. Improper inflow time/inflow rate combinations result in this inability to apply and store the right amount of water efficiently.
8. Irrigation Performance. -- Eighty-five percent of the irrigations evaluated had unacceptable performance. High runoff losses resulted in low water application efficiencies. Low water requirement efficiencies resulted from cumulative soil water deficits, poor timing and insufficient applications.

RECOMMENDATIONS

1. There is potential for improvement in on-farm water management in the area, particularly in aiding farmers in determining the correct amount of water to apply, using the appropriate range of inflow rate/inflow times for effective application and then determining when to irrigate. Perhaps the greatest aid can be accomplished offering design recommendations to farmers on the ranges of furrow inflow rates and set times they should be using. Irrigation advisory services through extension or by irrigation scheduling can effectively improve timing and amounts of water applied.
2. Design recommendations should be readily available and implemented on the longer fields to improve system performance on these fields.
3. Social, economic, agronomic and institutional constraints to improved system designs and management alternatives need to be fully developed to determine the most feasible problem solutions. The ultimate goal would be to improve existing water application and water requirement efficiencies from observed ranges of 35 to 88 percent and 33 to 100 percent, respectively, to potential values of 75 to 95 percent and 85 to 100 percent respectively.

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Appendix A.

Table A1. Design and Evaluation Results for Site 1.

PARAMETER	DESIGN	IRRIGATION NO. 1	2	3	4	5
Furrow spacing, m (ft)	0.76 (2.50)	1.52(5)	1.52(5)	1.52(5)	1.52(5)	1.52(5)
Furrow length, m (ft)	312 (1025)[1]	625 (2050)	625 (2050)	625 (2050)	625 (2050)	625 (2050)
Furrow slope, %	0.45	0.45	0.45	0.45	0.45	0.45
Design depth or soil water deficit, mm (in)	88.9 (3.5)	40 (1.6)	44 (1.7)	67 (2.6)	87 (3.4)	128 (5.0)
Furrow inflow rate, ℓps (gpm)	0.50-0.63 (8-10)	1.22 (19.3)	1.53 (24.4)	1.48 (23.3)	1.12 (17.8)	1.09 (17.3)
Inflow time, min	720	670	714	698	705	691
Average depth applied, mm (in)	91-115 (3.6-4.5)	53.3 (2.1)	68.4 (2.7)	64.4 (2.5)	43.5 (1.7)	48 (1.9)
Average root zone storage, mm (in)	76-83 (3.0-3.3)	35.2 (1.4)	43. (1.7)	49.6 (1.9)	35.7 (1.4)	42.2 (1.7)
Furrow intake family (I_f')	0.45	0.40	0.40	0.50	0.35	0.45
Availability factor (f)	0.4	0.18	0.20	0.30	0.39	0.57
Irrigation interval, days	13	--	11	13	9	12
Water application efficiency, E_a (%)	72-84	66	63	77	82	88
Water requirement efficiency, E_r (%)	86-93	88	98	74	41	33
Runoff ratio, R_t (dec)	0.16-0.28	0.33	0.36	0.23	0.18	0.12
Deep Percolation ratio, R_p (dec)	0.00	0.00	0.01	0.00	0.00	0.00

Soil type is clay loam. Total available water = 0.19 m/m (2.24 in/ft). Crop is corn with assumed maximum root zone of 1.2 m (4 ft).

[1]Note that design is for irrigation of every furrow and one-half of observed length.

Table A2. Design and Evaluation Results for Site 2.

PARAMETER	DESIGN	IRRIGATION NO. 1	IRRIGATION NO. 2
Furrow spacing, m (ft)	1.52 (5.0)	1.52 (5.0)	1.52 (5.0)
Furrow length, m (ft)	175 (575)	175 (575)	175 (575)
Furrow slope, %	0.38	0.38	0.38
Design depth or soil water deficit, mm (in)	73.1 (2.9)	NA[1]	72 (2.8)
Furrow inflow rate, ℓps (gpm)	0.63-0.82 (10-13)	1.19 (18.9)	1.34 (21.3)
Inflow time, min	480	430	300
Average depth applied, mm (in)	68-89 (2.7-3.5)	119 (4.7)	91.1 (3.6)
Average root zone storage, mm (in)	65-70 (2.6-2.8)	NA	58.3 (2.3)
Furrow intake, family (I_f')	1.00	~1.30	1.00
Availability factor (f)	0.4	NA	0.4
Irrigation interval, days	11	--	10
Water application efficiency, E_a (%)	79-96	(<75)[2]	64
Water requirement efficiency, E_r (%)	89.5-96	(100)	81
Runoff ratio, R_t (dec)	0.04-0.21	(>0.25)	0.36
Deep percolation ratio, R_p (dec)	0.00	(>0.00)	0.00

Soil type is sandy clay loam. Total available water = 0.15 m/m (1.83 in/ft). Crop is corn with assumed maximum root zone of 1.2 m (4 ft).

[1]NA = not available

[2]Estimated values for performance parameters.

Table A3. Design and Evaluation Results for Site 3.

PARAMETER	DESIGN	IRRIGATION NO. 1	IRRIGATION NO. 2
Furrow spacing, m (ft)	1.12 (3.67)	1.12 (3.67)	1.12 (3.67)
Furrow length, m (ft)	175 (575)	175 (575)	175 (575)
Furrow slope, %	0.43	0.43	0.43
Design depth or soil water deficit, mm (in)	50.8 (2.0)	NA[1]	50 (1.97)
Furrow inflow rate, ℓps (gpm)	0.44-0.57 (7-9)	0.85 (13.4)	0.81 (12.9)
Inflow time, min	360	418	300
Average depth applied, mm (in)	49-63 (1.9-2.5)	111.6 (4.4)	73.1 (2.9)
Average root zone storage, mm (in)	46-49	NA	38 (1.5)
Furrow intake, family (I_f')	0.70	1.00	0.45
Availability factor (f)	0.35	NA	0.35
Irrigation interval, days	7	--	10
Water application efficiency, E_a (%)	78-95	(<73)[2]	52
Water requirement efficiency, E_r (%)	91-97	(100)	76
Runoff ratio, R_t (dec)	0.05--.20	(>0.27)	0.48
Deep percolation ratio, R_p (dec)	0.0-0.02	(>0.00)	0.00

Soil type is sandy clay loam. Total available water = 0.16 m/m (1.93 in/ft). Crop is dry beans with assumed maximum root zone of 0.9 m (3 ft).

[1]NA = not available

[2]Estimated values for performance parameters.

Table A4. Design and Evaluation results for Site 4.

PARAMETER	DESIGN	IRRIGATION NO. 1
Furrow spacing, m (ft)	1.12 (3.67)	1.12 (3.67)
Furrow length, m (ft)	175 (575)	175 (575)
Furrow slope, %	0.36	0.36
Design depth or soil water deficit, mm (in)	58.7 (2.3)	80 (3.2)
Furrow inflow rate, ℓps (gpm)	0.25-0.35 (4-5.5)	0.62 (9.8)
Inflow time, min	720	202
Average depth applied, mm (in)	56-77 (2.2-3.0)	42.4 (1.7)
Average root zone storage, mm (in)	50-55 (2-2.2)	27 (1.1)
Furrow intake family (I_f')	0.45	0.45
Availability factor (f)	0.30	0.41
Irrigation interval, days	7-10	--
Water application efficiency, E_a (%)	71-90	64
Water requirement efficiency, E_r (%)	86-93	34
Runoff ratio, R_t (dec)	0.1-0.3	0.36
Deep percolation ratio, R_p (dec)	0.00	0.00

Soil type is clay loam. Total available water = 0.18 m/m (2.2 in/ft).
Crop is cucumbers with assumed maximum root zone of 1.05 m (3.5 ft).

Table A5. Design and evaluation Results for Site 5.

PARAMETER	DESIGN	IRRIGATION NO. 3	4
Furrow spacing, m (ft)	1.12 (3.67)	1.12 (3.67)	1.12 (3.67)
Furrow length, m (ft)	365 (1200)	365 (1200)	365 (1200)
Furrow slope, %	0.98	0.98	0.98
Design depth or soil water deficit, mm (in)	61 (2.4)	70 (2.8)	95 (3.7)
Furrow inflow rate, ℓps (gpm)	0.57-0.76 (9-12)	0.77 (12.2)	0.70 (11.1)
Inflow time, min	720	450	696
Average depth applied, mm (in)	60-80 (2.4-3.2)	53 (2.1)	80.9 (3.2)
Average root zone storage, mm (in)	52-56 (2-2.2)	38 (1.5)	44 (1.7)
Furrow intake family (I_f')	0.45	0.45	0.30
Availability factor (f)	0.33	0.38	0.52
Irrigation interval, days	9	12	12
Water application efficiency, E_a (%)	70-86	71	54
Water requirement efficiency, E_r (%)	85-92	54	46
Runoff ratio, R_t (dec)	0.14-0.30	0.29	0.46
Deep percolation ratio, R_p (dec)	0.00	0.00	0.00

Soil type is clay loam. Totat available water = 0.15 m/m (1.83 in/ft). Crop is sugar beets with maximum assumed root zone of 1.2 m (4 ft).

Table A6. Design and Evaluation Results for Site 6.

PARAMETER	DESIGN	IRRIGATION NO[1] 1	2	3	5	6
Furrow spacing, m (ft)	0.76(2.5)	1.52(5)	1.52(5)	0.76 (2.5)	0.76 (2.5)	0.76 (2.5)
Furrow length, m (ft)	625(2050)	625 (2050)	625 (2050)	625 (2050)	625 (2050)	625 (2050)
Furrow slope, %	0.66	0.66	0.66	0.66	0.66	0.66
Design depth or soil water deficit, mm (in)	65(2.56)	47.1 (1.85)	46.6 (1.8)	56.3 (2.2)	84 (3.3)	51 (2.0)
Furrow inflow rate, ℓps (gpm)	0.76-0.88 (12-14)	1.41 (22.3)	1.14 (18)	1.10 (12.5)	1.06 (16.8)	0.96 (15.2)
Inflow time, min	720	596	574	561	674	671
Average depth applied, mm (in)	68-80 (2.7-3.2)	52.6 (2.1)	40 (1.6)	100.9 (4.0)	92 (3.6)	85 (3.4)
Average root zone storage, mm (in)	55-58 (2.2-2.3)	40 (1.6)	31 (1.2)	56.3 (2.2)	66 (2.6)	51 (2.0)
Furrow intake family (I'_f)	0.40	0.52	0.35	0.45	0.40	0.30
Availability factor (f)	0.40	0.29	0.29	0.35	0.52	0.31
Irrigation interval, days	9	--	8	7	13	21
Water application efficiency, E_a (%)	72-81	76	78	56	71	59
Water requirement efficiency, E_r (%)	85-89	85	67	100	78	99
Runoff ratio, R_t (dec)	0.16-0.21	0.21	0.22	0.20	0.29	0.25
Deep percolation ratio, R_p (dec)	0.04-0.07	0.03	0.00	0.24	0.00	0.16

Soil type is sandy loam. Total available water = 0.14 m/m (1.63 in/ft). Crop is corn with assumed maximum root zone of 1.2 m (4 ft).

[1]Incomplete data for Irrigation No. 4. Irrigation interval from No. 3 to No. 4 was 8 days. ET data show a soil water deficit of only 44 mm (1.7 in), every furrow was irrigated, over-irrigation was indicated.

Table A7. Design and Evaluation Results for Site 7.

PARAMETER	DESIGN	IRRIGATION NO. 1	2	3
Furrow spacing, m (ft)	1.52 (5.0)	1.52(5.0)	1.52(5.0)	1.52(5.0)
Furrow length, m (ft)	285 (938)	275 (902)	275 (902)	275(902)
Furrow slope, %	0.32	0.32	0.32	0.32
Design depth or soil water deficit, mm (in)	85.3 (3.4)	42.5(1.7)	54.4(2.1)	85.8(3.4)
Furrow inflow rate, ℓps (gpm)	1.01-1.39 (16-22)	1.7 (27)	1.17(18.6)	1.32(20.9)
Inflow time, min	600	495	378	504
Average depth applied, mm (in)	83-115 (3.3-4.5)	122.5(4.8)	71.3(2.8)	96.3(3.8)
Average root zone storage, mm (in)	81-84 (3.2-3.3)	42.5(1.7)	54.4(2.1)	77.7(3.1)
Furrow intake family (I_f)	1.00	1.50	0.9	1.00
Availability factor (f)	0.40	0.20	0.26	0.40
Irrigation interval, days	14	--	10	13
Water application efficiency, E_a (%)	73-97	35	76	81
Water requirement efficiency, E_r (%)	95-98	100	100	91
Runoff ratio, R_t (dec)	0.02-0.21	0.08	0.19	0.19
Deep percolation ratio, R_p (dec)	0.01-0.06	0.57	0.05	0.00

Soil is loam. Total available water = 0.18 m/m (2.13 in/ft).
Crop is corn with assumed maximum root zone of 1.2 m (4 ft).

A Data Management System for Interdisciplinary Research in Agricultural Water Use[1/]

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and

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Abstract

Interdisciplinary applied research in on-farm water management involves the collection, analysis, storage, and utilization of large amounts of data. A carefully defined system of data management is, therefore, an important part of the total research effort.

This paper describes such a data management system which has been developed by the Egypt Water Use and Management Project. The system includes the following components: (1) realization of information requirements (2) an identification of data needed to provide this information (3) design of data collection program (4) procedures for recording and preparing data for computer processing (5) methods of data analysis including the necessary computer programs (6) methods of data storage and retrieval and (7) strategies for data utilization.

The operation of the data management system is described for a study of irrigation practices for a cotton crop in the region near Kafr El Sheikh, Egypt. An identical framework for data management is suggested for other intimately related sociological, agronomic, and economic agricultural subsystems. The combined data management program applied to the project as a whole provides for interdisciplinary data utilization.

Introduction

The Egypt Water Use and Management Project is one of several interdisciplinary research/demonstration efforts which have sought or are seeking to facilitate increased crop production in developing countries through improvement of on-farm water management. Such research projects involve the collection of large amounts of data. Consequently, the problem frequently encountered is that data tend to "pile up" without being analyzed and shared among the various disciplines for the intended purpose of answering the questions addressed in the project's goals and objectives.

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Out of recognition of this rather serious problem, the Egypt Water Use Project has recently devoted considerable effort toward a study of data management systems and has begun to apply a "systems approach" in some of its data management activities. The purpose of this paper is to present the results of a general study of data management systems and to illustrate the application of these results through an example data collection program.

General Considerations in Data Management

The term "data management" is often thought to refer merely to the mechanical and procedural means whereby data are placed into some organized storage so that they may be easily retrieved at a later time for analysis. A data management system would then consist of a storage device along with a catalog or index for finding stored data.

This is a rather limited view of data management, though, and one which poses several problems. The most serious of these problems is probably that no account is taken of the quality or usefulness of the data. Quality is used to refer to the degree to which the data collected actually represents the field situation. Usefulness refers to the suitability of data for its intended purposes. Another problem is that the medium for storing the data might not be suitable for the types of analyses which will need to be performed.

Still a third problem exists, namely that a given observation can have different meanings, depending on the method of collection or laboratory analysis. This is particularly a problem when data are collected in an interdisciplinary research effort since individual disciplines often have very different accepted procedures for measuring the same quantities.

Because of these and other problems commonly encountered in data management, it becomes necessary to expand and generalize the common perception of the term to include design of data collection procedures, methods for processing data and a plan for ultimate utilization of the information. The broader or "systems" perspective for data management has been discussed by Ward (1978) and Ward (1979) for water quality monitoring networks.

The terms "data" and "information" will sometimes be used interchangeably; however in the strict sense, data refers to observations as they are recorded in the field or laboratory while information refers to the results obtained from analysis and synthesis of data. There is, of course, considerable overlap between the two terms.

Defining Information Needs

An outline of a generalized data management system is shown in Table 1. The first phase of the system is the definition of information needs. The investigator must ask several questions: What system am I working with? What are the boundaries of that system? In how much detail do I need to describe that system? What do I need to know in order to make an adequate description? etc. Once the information needed to describe the nature and operation of the system has been identified, the investigator may proceed to list as many of the factors which may limit the performance of the system as possible. This second step of course assumes that the research objective is to improve the performance of the system.

As an example of defining information needs, consider the water application subsystem of the on-farm irrigation system. Conceptually, this subsystem is bounded on one side by the water delivery subsystem and on the other by the water removal subsystem (El Kady, Clyma and Abu-Zeid, 1979). The unit of interest is the field which has well-defined physical boundaries. This system must be described in enough detail to perform a reasonably accurate water balance for the system for individual irrigations with particular emphasis on the quantity of water supplied to the root zone of the crop or water use subsystem. Thus, the quantities of water (input, output, and storage) for the system as a function of both time and space (uniformity over the field) must be determined. The factors which limit the performance of the system are nonideal rates and timing of water input to the field and nonideal distribution of infiltrated water volumes over the field surface.

Defining Data Needs

The second phase of the data management program is a definition of data needs. This is largely an extension of the first phase, but on a more specific level.

The performance of a system under consideration is conveniently evaluated in terms of a set of performance indices. For example, a useful performance index of an agronomic system is crop yield. It is important to select and carefully define those performance indices which will be used for each system or subsystem under consideration as early as possible. Much thought must be devoted to the issue of whether the selected performance indices actually contain the information one wishes to know.

Performance indices may be measured directly or may be a function of one or more measured variables. The second phase of data management should include a listing of all variables which must be measured in order to evaluate the underlying nature of the system, the state of the system at a particular time, or the performance of the system.

Returning to the water application subsystem example, two useful performance indices are application efficiency and water requirement efficiency. Application efficiency is defined as the volume of water stored in the root zone for a particular irrigation divided by the volume applied. Water requirement efficiency is defined as the volume of water stored in the root zone divided by the volume available for storage or the deficiency.

In order to adequately characterize the operation of the water application subsystem, the appropriateness of the state variables must be determined and the system parameters (both variables and constants) measured to determine the performance of the system. Since management decisions of the farmer also influence system performance, these decisions should be evaluated.

The state variables of the system (El Kady, Clyma and Abu-Zeid) are as follows:

1. Field geometry
2. Field slope
3. Surface roughness
4. Infiltration rate of soil
5. Channel shape
6. Water supply rate

The system constants and variables necessary to evaluate performance are as follows:

1. Soil properties (bulk density, field capacity and wilting point)
2. Soil water status
3. Runoff from the field as a function of time
4. Advance and recession of water on the field
5. Infiltration volumes as a function of time and space
6. Inflow to the field as a function of time

Management decisions to be evaluated are how, when and how much to irrigate. These are evaluated with the performance indices and the system variables and constants.

From a systems modeling viewpoint, the first six of these variables (field geometry, slope, roughness and soil properties) may be considered as state variables, those which describe the state of the system at a particular time. Additionally inflow would be considered as an input to or excitation of the system while runoff and infiltration would be considered as outputs from or responses of the system.

Evaluating the performance of this system involves measuring and comparing the useful output of the system (water stored in the root zone) against inputs (water applied) or against nonuseful outputs (runoff and excess infiltration). The comparison is made using the irrigation efficiency parameters described earlier.

Design of a Data Collection Program

The third phase of data management is the design of a data collection program. The design begins with the listing of variables to be measured as discussed above and goes on to specify the number of observations to be taken for each variable and how these observations are to be located in both space and time. The design is based on the answer to a question from phase one, "In how much detail must the system be described?" and on the additional consideration of what degree of confidence must be placed in the resulting description.

The design problem should generally be viewed in a statistical context. A common approach is to determine the number of samples required in order to achieve a specified confidence interval width about the sample mean of the measured variable. In order to utilize this approach, it is necessary to have some estimates of the spatial and temporal variability of the measured variable.

As an example, the design of the data collection program for the water application subsystem should include the frequency in time with which inflow measurements are made. If the inflow rate is nearly constant or slowly variable, as might be the case with a canal gravity flow system or pumped well, flow measurements taken every two hours or so might be sufficient. On the other hand the use of manual or animal-operated lift devices (such as Sakia or Tambour*) would produce highly variable flow rates which should perhaps be measured continuously or very frequently. Consider also the case of measuring infiltration rates and soil properties at various points in the field. The number of points at which observations are to be taken will be larger for fields which have a large spatial variability of soil properties. A more complete discussion of the confidence interval approach to sampling frequency selection is presented in Ward et al (1979).

A further consideration in sampling program design is the quality control of data in the field. This item must be dealt with by the investigator on an individual basis and should include such things as preparation of easy-to-use data forms and supervision and spot checking technicians who collect data.

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* Sakia - draft-animal powered water wheel

Tambour - Archimedes screw type pump, hand powered

Data Analysis

Data analysis is the process by which measurements from field or laboratory experiments are converted into information which is useful to the investigator. The types of data analyses which are to be performed are determined by information needs and intended uses of the data. It is, therefore, important to outline intended data analysis procedures in the planning stages of a project.

Common methods of data analysis include (1) calculation of summary statistics, (2) analysis of variance and regression, (3) tests of hypotheses, and (4) mapping and graphical display of data. Summary statistics are used for the purpose of condensing the information contained in many recorded pieces of data into a single number. Two commonly used summary statistics are the sample mean and variance of a set of observations. A measure of "how good" an estimate of the mean is may be obtained by placing confidence limits on it. Although less straightforward, it is possible and quite desirable to place confidence limits on the estimates of other summary statistics as well. Irrigation efficiency parameters are examples of summary statistics which are appropriate for the water application subsystem. These parameters summarize large amounts of data including advance and recession data and soil moisture data.

Analysis of variance and regression are used to determine cause and effect relationships between variables under investigation and to evaluate whether or not these relationships are significant. An example application of analysis of variance for an agronomic subsystem would be a study of several years of corn yield data from several farms to see whether or not there is a statistically significant difference in yield among the farms. For the water application subsystem example, an application of regression is the determination of the functional relationship of infiltration depth to opportunity time. Confidence limits may be placed on regression coefficients, just as they can for summary statistics, providing a useful measure of the "goodness" of the estimate.

The analysis of variance example mentioned earlier was a test of the hypothesis that there was no significant difference in corn yields among several farms. Many other types of tests of hypotheses are useful. For example it might be desirable to test whether the regional mean value of some irrigation efficiency parameter in an area where lift devices are used was statistically different from the regional mean value of the same parameter in an area where gravity flow is used.

Data may also be analyzed in a sense simply by displaying it properly through the use of maps, charts, graphs, etc. Visual presentations such as these are probably one of the most effective means of conveying information on a particular subject to a nonexpert in that field, and should, therefore, have much potential application in interdisciplinary research.

The possibilities are almost limitless, and an exhaustive list of data analysis procedures is not necessary. The key point is that the types and amounts of data which must be collected for the data to convey meaningful information without being redundant is highly dependent on the nature of the analysis to be performed. Data analysis should, therefore, be considered well before the collection process is begun.

A final consideration in data analysis is that of quality control of recorded data. This would usually take the form of a preanalysis check to eliminate data points which are obviously incorrect. Simple preliminary analysis may often be performed to eliminate data which are counter-physical. For example data which indicate that a mass balance is violated should not be included in one's analysis.

Data Storage and Retrieval

Data storage and retrieval are the terms which commonly come to mind when data management is mentioned. The important considerations in planning a data storage and retrieval system are (1) minimization of time and effort required in both the storage and retrieval operations (2) minimization of errors due to handling of data, and (3) maximization of availability of data to potential users. Decisions must be made regarding the method of data recording in the field and the means by which data are to be converted into a form suitable for electronic data processing and storage.

Data forms for use in the field should be constructed in such a way that they are easy to use and are as self-explanatory as possible. In addition, calculations involved in filling out forms and transferrring data from one form to another should be minimized. The use of pencil-marked computer cards or of precoded data forms suitable for direct keypunching is therefore desirable. Computer cards could then, if necessary, serve as the primary storage medium for the data.

More compact forms of data storage are afforded by computer tapes or disks. Small desktop computers such as the HP9825 calculator system allow data to be stored on tapes or disks without a card punching operation. Data may also be transferred to tapes or disks from punched or pencil-marked cards. Disk storage is preferable to tape storage because it allows faster access of the data.

Although the choice of a storage medium is important, the critical decision is one of how the data are to be organized within the storage medium. Proper selection of file content and arrangement on a tape, for example, can greatly facilitate future efforts at data analysis. A logical approach to this problem is to prepare data analysis programs and data storage programs at the same time and perhaps to incorporate both in one program. Data can therefore be stored on the same tape, or disks, as are the primary analyses routines. An important concept in preparing programs of this type is that provision should be made for convenient updating of the files by adding, substracting, or correcting data entries.

A practical means of providing for interdisciplinary data utilization is the establishment of a data bank. Under a data bank system one or two sets of all of the data collected for a project would be kept in a central location for convenient accessibility by all investigators.

Each investigator would also maintain his own data files and would be responsible for regularly adding his data to the data bank.

Some important considerations in establishing a data bank system are the following:

1. Data should be stored along with appropriate identification. This would normally include the time and place of collection. The method of collection or analysis and the person or group doing the collecting should often be recorded also.

2. Provisions should be made for investigators to duplicate parts of the data bank for their own analysis. Storing the data on computer tapes and disks will allow this to be done easily.

3. A single storage medium, i.e., computer tape, disk, or punched cards should usually be chosen as the primary storage medium.

4. A regular time-table for updating the data bank should be agreed upon in order to minimize the time lag between data collection and data availability to other investigators.

5. An extensive data index or catalog should be prepared in order to let all the researchers involved know what data is available and how to access it.

Data and Information Utilization

A plan for data utilization closes the loop of the data management system by defining the ways in which data and information will be used to meet the needs set forth in the first phase. As discussed earlier the data may be used initially to describe the system and to identify problem areas or factors which limit system performance. Also the data collected early can serve as a baseline or standard of comparison for evaluation of proposed solutions in the future. As time goes on data may be used for the actual formulation and evaluation of alternative solutions.

An important consideration in the data utilization plan is the identification of potential data users, including those outside the discipline by which the data are collected. Data collection and storage efforts may then be adjusted so that collected data may be utilized to the fullest. For example soil moisture data is needed for agronomy, irrigation engineering, and groudwater budget studies. In order to be useful to the various disciplines, the meaning of recorded observations, as dictated by the methods of analysis, must be clear. The data catalog should therefore specify that soil moisture data are recorded as "grams of water per gram of soil, dry weight basis, samples dried at 105°C" or whatever is appropriate. Furthermore, an irrigation or agronomy study would probably need soil moisture data only as deep as the root zone, while a groundwater budget study requires data throughout the soil profile to the water table. An early definition of such needs would allow a collection procedure to be developed which could serve both purposes without unnecessary duplication of effort.

Example Application: Regional Measurement of Irrigation Water Volumes

Let us now consider the application of each of the above components of the data management system to a single study with well-defined information needs. One of the goals of the Egypt Water Use Project is to evaluate the adequacy of the existing system of water delivery by canals considering the distribution of water to the fields in both space and time.

Information Needs

In order to study this question in detail for a specific situation, the following hypothetical information need is established. "How much water is applied (under the present system) to the cotton crop in the Nile Delta region near Kafr El Sheikh?"

Data Requirements

One would like to know the volume of water applied to each field of cotton in the region during each irrigation of the cotton season over a period of several years. This would be very costly to measure. Since time and money are both in short supply, the first step in agreeing on reasonable data requirements is to select a small study region of a couple of hundred hectares (corresponding to the current Abu Riah study region of the EWUP) and to decide to limit the study to a single season. It would still be very costly to measure all of the water applied within the study area. The next step, therefore, is to design a program of sampling or measuring water applied at intervals in both space and time rather than measuring continuously. The design problem consists of deciding how often to sample.

Design of the Data Collection Program

The physical variables to be measured periodically are flow rates into fields and times associated with each flow measurement. Initially, field areas must also be measured so that measured water volumes may be translated into application depths and then extrapolated into volumes of water used for the entire region.

There are two major criteria for deciding how often to sample water applications. The first consideration is to sample often enough so that the results will contain sufficient information. The second is minimize costs by sampling at the lowest acceptable frequency. A statistically sound way of dealing with this problem is to choose sampling intervals in space and time such that an acceptable confidence interval width about the desired statistic (regional volume of water used) is achieved. For present purposes a confidence interval may be defined as an interval containing the sample estimate of the regional volume of water used for which there is a given probability that the true volume lies with the interval. For example if 95% confidence interval about the regional application volume is given by [X - A, X + A], where X is the sample estimate of volumes, there is a 95% chance that the true volume is contained within the interval. It is apparent that the smaller the interval, the more information is obtained by the sampling program.

An expression for a 95% confidence interval width about the sample estimate of regional water application may be developed as follows:

The estimate of water applied is given by

$$R = \frac{N_T}{N_1} \sum_{i=1}^{N_1} \sum_{j=1}^{N_{2,i}} Q_{j,i} \Delta t$$

where R = estimate of water volume applied to entire region (cubic meters)

N_T = total number of hectares occupied by crop

N_1 = number of hectares over which water applied is actually measured

$N_{2,i}$ = number of flow measurements taken for hectare i during the season

$Q_{j,i}$ = jth measured flow (m^3/min taken for hectare i)

Δt = time interval between observations (assumed constant for sampling program)

In order to find a confidence interval about R, we need to know the variance of the estimate as given below.

$$\text{var } [R] = \frac{N_T}{N_1}^2 \text{ var } \sum_{i=1}^{N_1} \sum_{j=1}^{N_{2,i}} Q_{j,i} \Delta t$$

Now assume that the variance of the flow rates is a constant for the region. (Let var $[Q_{j,i}] = \sigma^2$ for all i and j). Let us further assume that the measured flow rates are independent and remember that Δt = constant. We can now write

$$\text{var } [R] = \frac{N_T}{N_1}^2 \Delta t^2 \sigma_q^2 \sum_{i=1}^{N_1} \sum_{j=1}^{N_{2,i}} (1)$$

Now observe that $\sum_{j=1}^{N_{2,i}} (1) = N_{2,i}$

and that $\sum_{i=1}^{N_1} N_{2,i} = N_1 \ (N_2,avg)$

where $N_{2,avg}$ = the average number of flow measurements taken at each point during the season.

In addition, $N_{2,\ avg} = \frac{N_{3,avg} T_{avg}}{\Delta t}$

where $N_{3,avg}$ = the average number of irrigations during the season for an individual farm in the region

T_{avg} = the average length of an irrigation (minutes)

Δt = time interval between flow measurements (minutes)

Therefore, $\sum_{i=1}^{N_1} \sum_{j=1}^{N_{2,i}} (1) = \frac{N_1 \ N_{3,avg} \ T_{avg}}{\Delta t}$

and var $[R] = \frac{N_T^2}{N_1} \ \Delta t \ \sigma_q^2 \ N_{3,avg} \ T_{avg}$

Finally, a 95% confidence interval above R is given by

$[R - 1.96 \text{ var } [R]^{1/2}, R + 1.96 \text{ var } [R]^{1/2}]$

where 1.96 is the standard normal deviate corresponding to a probability level of 2.5%, and var [R] is given by the above expression.

One can now select a sampling frequency in time, Δt, and in space, $\frac{N_1}{N_T}$, which will provide any desired confidence band or level of precision in the estimate, R. An underlying assumption here is that sufficient information has already been gathered in order to obtain reasonable estimates of the quantities σ^2; $N_{3,avg}$;T_{avg}. This assumption is justifiable for the Egypt Water Use Project, which has at present been collecting data for over a year, but might be restrictive if one were to apply this approach to sampling program design to a brand new research effort.

The remainder of the sampling program design, such as the selection of fields to monitor, will be based on more subjective criteria including representatives, accessibility, and farmer cooperation.

Note that this design approach assumes that the same farms will be monitored during the entire season, which is reasonable since it provides for simpler operation and for dealing with a minimum number of farmers.

Data Analysis

Routine analysis would include computation of applied volumes and equivalent depths for each monitored plot for each irrigation. Regional mean depths and variances from field to field should also be computed for each irrigation. In addition monthly and seasonal means of application depths should be computed along with variances over time (from irrigation to irrigation) for individual forms. An average temporal variance for all monitored farms is also a useful statistic.

The ultimate quantity of concern is the total volume applied over the study area for the season expressed as a depth and converted to a total water volume for the region.

Data Storage and Retrieval

Data forms are designed for convenient recording of heads in flumes and times of measurement. Computer programs are designed so that data can be entered directly from farms for computation of flow volumes for each irrigation. The data management policies of the Egypt Water Use Project provide for data storage on both the original form and on computer cassette tape. For irrigation flow measurements one file is used per irrigation, and a file catalog is kept separately. The user is able to retrieve the raw data from the tape as well as from the original forms.

Data Utilization

Water application data is routinely used by the engineering group in Cairo in order to assess the effectiveness of traditional and improved irrigation methods. This particular study is designed to provide information for evaluating the existing delivery system and for performing a cost-benefit analysis of improvements in that system. The main portion of the study is to be performed by an engineering graduate student at Colorado State University in cooperation with both the engineering and economics groups in Fort Collins and in Cairo. It is important, therefore, to provide for the smooth exchange of information and ideas between Egypt and the U.S.

The mechanics of the study will involve the comparison of actual water use with estimated requirements of the crop, accounting for system and field efficiencies.

If it appears that substantially more water is being used than is necessary - "substantially" is evaluated via confidence limits on the results - the water saved by reduced allocation can be estimated. Also the water savings from improved system efficiency can be estimated. Conversely, if less water than required is being used, the economic benefit due to increased water allocation can be estimated from crop production functions.

The important consideration is that the required accuracy of results for the economic study should have some influence on the design of the sampling program.

Summary and Conclusions

The general data management system discussed here consists of seven components, beginning with a delineation of information needs and ending with a statement of data utilization strategies. The system should be viewed as a closed or "feedback" loop which constantly updates and improves itself over time. It is extremely important that each data collection effort of a project should give attention to all seven components, leaving none out as trivial or irrelevant. It is equally important that all data users (disciplinary groups) should have adequate input in the design of data collection programs. As an illustration of this point, consider the water application measurement example. One would normally look to an engineering group alone to design the water measurement system. If however the accuracy of estimated water application volumes required for a reasonable cost-benefit study is not considered in the data collection program design, it is probable that either too little or too much data will be collected. The input of economists should, therefore, be solicited at the outset.

This illustration of the relevance of the ultimate uses of data to the design of sampling programs may also serve to illustrate one final point. The interactions of the various components of a data management system are extremely complex. There are, therefore, no cut and dried approaches toward effective data management. The problem is one which deserves the careful and continual consideration of all scientists involved in a joint research effort and requires an extreme amount of communication and cooperation for an effective solution.

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TABLE 1. OUTLINE OF GENERAL DATA MANAGEMENT SYSTEM

I. Information Needs

A. Description of System
B. Identification of Limiting Factors

II. Data Needs

A. Performance Indices (such as yield)
B. Measured Variables

III. Design of Data Collection Program

A. Sampling in Space
B. Sampling in Time
C. Quality Control of Data in Field

IV. Data Analysis

A. Summary Statistics
B. Analysis of Variance and Regression
C. Tests of Hypotheses
D. Mapping, Graphical Displays, etc.
E. Quality Control Checks on Recorded Data

V. Data Storage

A. Data Forms
B. Computer Cards
C. Computer Tapes, Disks

VI. Data Retrieval

A. Data Bank
B. Data Catalogs

VII. Data and Information Utilization

A. Description of System
B. Identification of Problems
C. Baseline or Standard of Comparison for Evaluation of Proposed Solutions in Future

AN ECONOMIC ANALYSIS OF WATER LIFTING WITH A DIESEL PUMP FOR A FARM AT EL HAMMAMY 1/

Studies suggest mechanization of lifting water could generate more food production and income for Egypt. Any general shift to mechanical lifting, however, will require thousands of individual farmer decisions. This paper looks at this question from the point of view of a typical Egyptian farm.

The analysis is focused on a farm of 2 feddans and 11 kerats located near Kafr Hakime Village in the Giza Irrigation District. It emphasizes the economic aspects but the engineering, sociological and agronomic relationships are apparent.

We identify and show the economic interrelationships among variables which are important to farmer's decisions about water lifting methods. Simply on the basis of intuition one would expect that capital intensive systems would not likely be profitable for small farms of 2 or 3 feddans. The authors believe the important point is to consider the decision making framework herein presented rather than the absolute gains or losses to the specific farm.

The analysis considers the net economic effect to a specific farm measured as changes in net farm income, from shifting to a system of lifting water with a diesel pump. It evaluates the

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1/ This paper was prepared by Economists Gene Quenemoen and El Shinnawi for presentation at a training seminar on water management for middle eastern countries sponsored by the Research Institute for Water Management and Irrigation Technology, Ministry of Irrigation, November 1979.

profitability to the farmer of purchasing a portable diesel pump. In the first case he will use the pump only for irrigating his own land; in the second case he will pump water for his neighbors as an additional area. The first case assumes he will abandon his share in two sakias; the second case assumes he makes an agreement with his neighbors to sell the two sakias and he will pump their water for an annual fee.

The Existing Situation

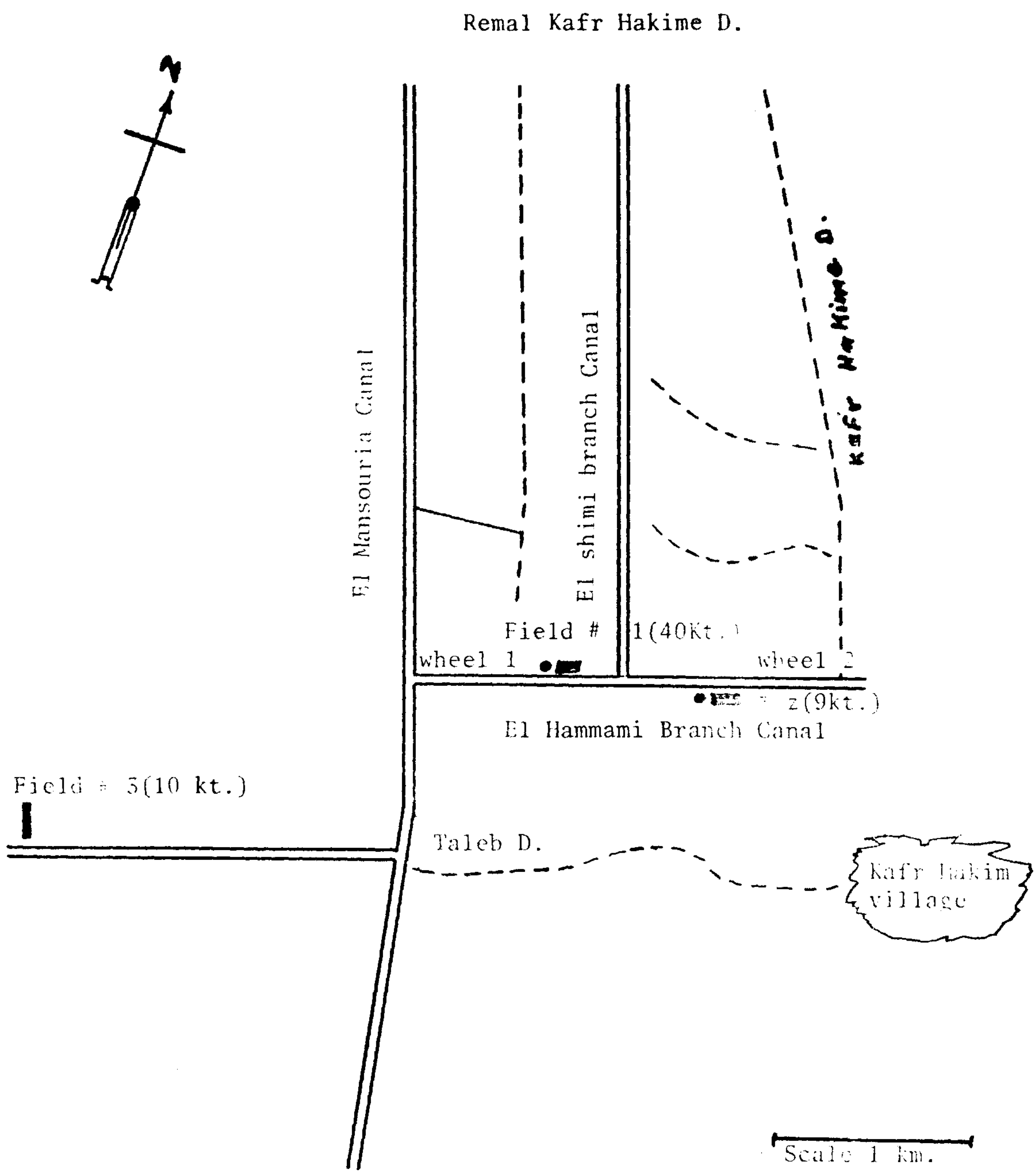
The farm consists of three parcels of land. Two feddans and 1 kerat are owned, while 10 kerats are rented. The map on page 4 shows the general location of these parcels. Note the rented parcel is more than 3.0 kilometers from the farmer's home in Kafr Hakime Village.

A farm plan for the agricultural year October 1, 1978 to September 30, 1979, indicates that the farm expects to have gross receipts of LE 1,900, expenses of LE 333, and a net farm income of LE 1,567. The economic objective of most farm families is to maximize net farm income within certain constraints reflecting family attitudes toward risk, work, leisure, and conformity to social norms. Many of the variables in the following analyses reflect these constraints which were determined by talking to the farmer. The changes in income shown in the following analyses then, may be considered as changes in net farm income subject to certain family determined constraints.

The Farm Plan, in the form of a complete farm budget, depicts cropping patterns and practices, livestock production, resources controlled and general production technology. The analyses of two systems using a diesel pump are intended to be specific to this farm.

The farmer in this example is probably representative of many rational and progressive Egyptian farmers. He is interested in considering alternatives which would make his life better through higher income and/or non/monetary amenities. He is not, however, interested in adopting technology of any kind if it makes him worse off.

The two cases which follow are presented as partial budgets. They consider the <u>changes</u> in income and expenses. Using the Farm Plan as a base we ask, "What things will change if the farmer decides to lift water with a diesel pump?" Such changes may: (1) add costs; (2) reduce returns; (3) add returns and (4) reduce costs for the entire farm considered as a whole. The <u>net</u> effect of all these considerations interacting will indicate the magnitude and direction of change on the farmer's net farm income.


Remal Kafr Hakime D.
N
El Mansouria Canal
El shimi branch Canal
Kafr Hakime D.
Field # 1(40Kt.)
wheel 1
wheel 2
z(9kt.)
El Hammami Branch Canal
Field # 3(10 kt.)
Taleb D.
Kafr Hakim village
Scale 1 km.

Each case is presented on a single page as a partial budget. This is followed by a detailed explanation of the computations for each entry.

CASE NO. 1

CHANGE FROM USING TWO SAKIAS TO USING A DIESEL PUMP

Added Costs:		
1.	Annual cost of storage and security	LE 22
2.	Annual fixed costs of pump, motor and carriage	76
3.	Annual cost of fuel, oil and grease	10
4.	Labor to operate the pump	0
5.	Annual average maintenance and repairs	5
6.	Moving pump between land parcels with donkey	0
Reduced Returns:		
7.	None	0
	TOTAL ANNUAL COSTS	LE 113
Added Returns:		
8.	Value of more crops produced	LE 10
9.	Value of more milk production	42
10.	Value of more calf production	11
Reduced Costs:		
11.	Boy to drive cow turning sakias	16
12.	Repairs and maintenance of sakias	2
	TOTAL ANNUAL BENEFITS	LE 81

TOTAL ANNUAL BENEFITS	LE 81
TOTAL ANNUAL COSTS	113
	LE 32 (loss)

DATA AND COMPUTATIONS FOR CASE NO. 1

This analysis assumes the farmer would purchase a pump for use on Field #1 and #2. They are 49 kerats in size. He would not use the pump on Field #3 because this field is three kilometers away and it is already irrigated by an electric pump on a fee basis.

The following data and computations explain the entries in the partial budget for Case No. 2:

1. The farmer lives approximately 1500 meters from fields #1 and #2. Consequently he feels it would be necessary to construct a building for the security of a portable pump. A small building could be constructed at a cost of LE 200.

Depreciation, LE 200 ÷ 20 years	LE 10
Interest on investment $\frac{\text{LE } 200 \times .10}{2}$	LE 10
Maintenance and repairs	LE 2
Total Annual Cost	LE 22

2. Basic information and assumptions about the pump:

Make: Klisler, made in India (K . D_1)

Size: Motor, 6.5 horsepower diesel

Pump, 6 inch intake, discharge $150cm^3$/hr. or 42 liters/second.

Initial investment is LE 765 for pump, motor, carriage and intake/discharge pipes.

Depreciation, LE 765 ÷ 20 years 1/		LE 38
Interest on investment	$\frac{\text{LE } 765 \times .10}{2}$	LE 38
Total Annual Fixed Costs		LE 76

3. Fuel, oil and grease is computed at LE 0.066 per hour. This is based on fuel consumption of 1.4 liters per hour at a price of LE 0.025 per hour. The remaining cost is for grease and oil. The hours of use assumes 24 irrigations per year of 3 hours each on 2.08 feddans.

$$24 \times 3 \times 2.08 \times .066 = \text{LE } 9.88$$

4. Labor to operate the pump would be furnished by the farmer. He has experience with diesel pumps and is willing to assign an opportunity cost of zero for his time.

5. Based on experience with other portable pumps it is estimated that on the average for 20 years the annual maintenance and repair costs would be about LE. 2.5 per feddan or LE 5.0 for the farm. Maintenance and repairs are primarily associated with use and are assumed to increase in direct proportion to the numbers of feddans irrigated.

1/ The manufacturer estimates the working life of this pump to be 50,000 hours. Its annual use on 2.08 feddans will be about 150 hours. Because of uncertainty about potential obsolescence we choose to place the life at twenty years recognizing that wear-out life is longer.

6. The pump weighs about 350 kilograms. It will be moved between Fields #1 and #2, a distance of ½ kilometer, with the farmer's donkey. The farmer assumes zero opportunity cost for the donkey time required to move the pump.

7. After discussing the matter with the farmer it is believed that a shift to lifting water with diesel pumps would not reduce the production from any farm enterprises.

8. It is expected that lifting water with a diesel pump, which has a capacity of 42 liters per second compared to 35 for a sakia, will result in higher crop yields. A larger flow of water should permit more timely irrigation of crops, better distribution of water in the fields and less leaching of nitrogen. The combined effect is expected to add at least LE. 5.0 per feddan annually or LE 10.0 for the farm.

9. The cow will produce more milk when relieved of the work of turning the sakias. The expected increase is:

With no work: 183 days lactation x 4 kg. x LE. 0.15	LE 110
Current production	LE 68
Increase	LE 42

10. The cow would be expected to produce a larger calf if she did not work the sakia. Also she would produce more consistently. This can be represented by an increase of 25 percent over present.

25 percent x LE 45	LE 11.0

11. Presently the farmer finds it necessary to pay a boy LE 0.08 per hour to drive the cow when turning the sakia. He estimates irrigating time to be 96 hours per year for each feddan.

96 hours x 2.08 feddans x LE 0.08	LE 16.0

12. The farmer currently pays his share of repairs for the two sakias each year which he estimates at LE 2.0 per year. If he used a diesel pump he would avoid this obligation.

CASE NO. 2

CHANGE FROM USING TWO SAKIAS TO USING A DIESEL PUMP, SELL COW, DISMANTLE AND SELL SAKIAS, LIFT WATER FOR FORMER SAKIA OWNERS ON A FEE BASIS

Added Costs:		
1.	Annual cost of storage and security	LE 22
2.	Annual fixed costs of pump, motor and carriage	46
3.	Annual cost of fuel, oil and grease	57
4.	Labor to operate the pump	86
5.	Annual average maintenance and repairs	30
6.	Moving pump between land parcels with donkey	0
7.	Purchase of fertilizer to replace cow manure	12
Reduced Returns:		
8.	Milk produced from cow	68
9.	Value of calf	45
	TOTAL ANNUAL COSTS	LE 366
Added Returns:		
10.	Value of more crops produced	LE 10
11.	Fees collected for pumping water	168
12.	Rent of land formerly occupied by sakias	1
13.	Sale of crops used for cow feed	161
Reduced Costs:		
14.	Boy to drive cow turning sakias	LE 16
15.	Repairs and maintenance of sakias	2
16.	Breeding services and misc. expenses for cow	1
	TOTAL ANNUAL BENEFITS	LE 359

TOTAL ANNUAL BENEFITS	LE 359	
TOTAL ANNUAL COSTS	LE 366	
	LE 7	(loss)

DATA AND COMPUTATIONS FOR CASE NO. 2

This analysis is similar to Case No. 1. However it also includes the effect of selling the sakias and the cow and lifting water on a fee basis for the former co-owners of the sakias.

The following data and computations explain the brief entries in the partial budget for Case No. 2.

1. The building for storage and security is the same as for Case No. 1.

2. The annual fixed costs for the motor, pump and carriage is computed the same as for Case No. 1 except that the salvage value of the sakias and cow is subtracted from the initial investment of the pumpset.

Salvage of sakias:

	Sakia No. 1	Sakia No. 2
Sale of sakia	LE 130	LE 130
Labor for dismantling	-10	-10
Net Salvage	LE 120	LE 120

The farmer shares one-fourth of sakia No. 1 and one-sixth of sakia No. 2 for a total of LE 50. The sale of the cow is for LE 250. Therefore, the initial investment in Case No. 2 is LE 765, the amount in Case No. 1, less LE 300 which equals LE 465.

Depreciation LE 465 ÷ 20 years	LE 23
Interest on investment $\frac{\text{LE } 465 \times .10}{2}$	LE 23
Total Annual Fixed Costs	LE 46

3. Fuel, oil and grease is computed at LE 0.066 per hour just as in Case No. 1. The number of hours pumping was determined for 12 feddans rather than 2.08 as in Case No. 1.

24 times x 3 hours x 12 feddans x LE 0.066 = LE 57.02

4. The farmer requires some hired labor to operate the pump for 12 feddans. He will hire and train a boy to help him and will pay the boy LE 0.10 per hour for the running time of the pump.

24 times x 3 hours x 12 feddans x LE 0.10 = LE 86.40

5. Maintenance and repairs are charged at LE 2.5 per feddan. Twelve feddans times LE 2.5 equals LE 30.

6. The same as in Case No. 1 - no charge will be made for this operation.

7. In order to maintain the soil condition at its present level the farmer believes he will have to purchase manure to replace that lost resulting from the sale of his cow. The cow produces 80 camel loads annually which will cost him LE 0.15 per load. He will use his camel to transport the manure at zero

charge.

80 camel loads manure x LE 0.15 = LE 12.0

8. From the farmer's Farm Plan it will be seen that the cow produces milk valued at LE 68 per year.

9. The Farm Plan indicates that on the average, calf production is valued at LE 45 per year. This takes into account the fact that some years it is higher but some years no calf is produced.

10. As in Case No. 1 we assume better irrigation efficiency will result in LE 10 more income from the farmer's 2.08 feddans each year.

11. We assume the owners of the dismantled sakias will agree to pay the pump owner for lifting water. These owners have a total of 10 feddans and will pay at least LE 0.70 per time of irrigation for each feddan.

10 feddans x 24 times x LE 0.70 = LE 168.00

12. The farmers will be able to farm the land formerly occupied by the sakias. To capture this value without considering all the income and expenses associated with farming this land let us simply use the market rate of land rental, LE 3 per kerat. The farmer's share of the sakias, land rents and net

gain are computed as follows:

.25 share x LE 3 =	LE 0.75
.17 share x LE 3 =	LE 0.50
Farmer's share of rent	LE 1.25

13. A significant savings to the farmer from selling his cow will be the value of crops formerly fed to cow. These are taken from the farmer's Farm Plan.

90.0 kilograms of concentrate	LE 3
7.5 kerats of berseem x LE 15.0	113
2 camel loads of straw	20
5 kerats maize forage x LE 5	25
Total Value of Cow Feed	LE 161

14. Presently the farmer finds it necessary to pay a boy LE 0.08 per hour to drive the cow when turning the sakia. He estimates irrigating time to be 96 hours per year for each feddan.

96 hours x 2.08 feddans x LE 0.08 LE 16.0

15. The farmer currently pays his share of repairs for the two sakias each year which he estimates at LE 2.0 per year. If he used a diesel pump he would avoid this obligation.

16. The Farm Plan indicates the farmer has been paying LE 1 per year for breeding services and miscellaneous expenses for the cow.

Evaluation of Case No. 1

Case No. 1 indicates the farmer will lose LE 32 per year if he invests in the pumpset. In other words his net farm income would be reduced from LE 1,567 to LE 1,535. Even though not large, a negative change in income does not provide justification for the farmer to learn a new system of irrigation and take the added risks. It would provide nothing for the farmer's labor to operate the pump or for the use of his donkey to move the pump between parcels of land. It is also likely that if the farmer and his resources were more fully employed he would assign a positive opportunity cost to his labor and the use of his donkey. This would result in an even greater loss of income.

It is not surprising that this case indicates a negative change in income. The capacity of even a small diesel pump exceeds the requirements of a farm which would use it for only two feddans.

Evaluation of Case No. 2

The bottom line of Case No. 2 indicates the farmer would lose LE 7.0 per year if he purchased and used a diesel pump according to the specified plan. The potential gains neighboring farmers may receive from this arrangement are not included in the analysis. Even though fixed costs are spread over twelve feddans in Case No. 2, other costs change so that the alternative is nearly as unprofitable as Case No. 1. Hired labor for pumping becomes a significant factor in Case No. 2. This illustrates that farm management decisions involve production variables which are not necessarily linear and/or continuous with respect to scale or farm size.

The results of Case No. 2 are contingent on the neighbor farmers paying LE 0.70/feddan/irrigation for hiring the pump to lift irrigation water. The variable costs of lifting water (fuel, oil, grease, maintenance/repairs and labor) are LE 0.60/feddan/irrigation. The difference is LE 0.10, assuming twenty four irrigations per year, we can see the farmer would gain LE 2.40 annually for each additional feddan he irrigated on a fee basis. For example if he could convince other farmers having 10 feddans to hire his pump he would gain LE 24.0.

This is shown clearly in Figure 1. At point E, with 12 feddans of land being irrigated by the diesel pump, the farmer will lose LE 7 per year. If he could add 10 feddans at LE 0.70 per irrigation, his annual net income would increase LE 24 (point C). If he charged the neighbor farmers LE 0.80 per irrigation his income would increase LE 48 (point D).

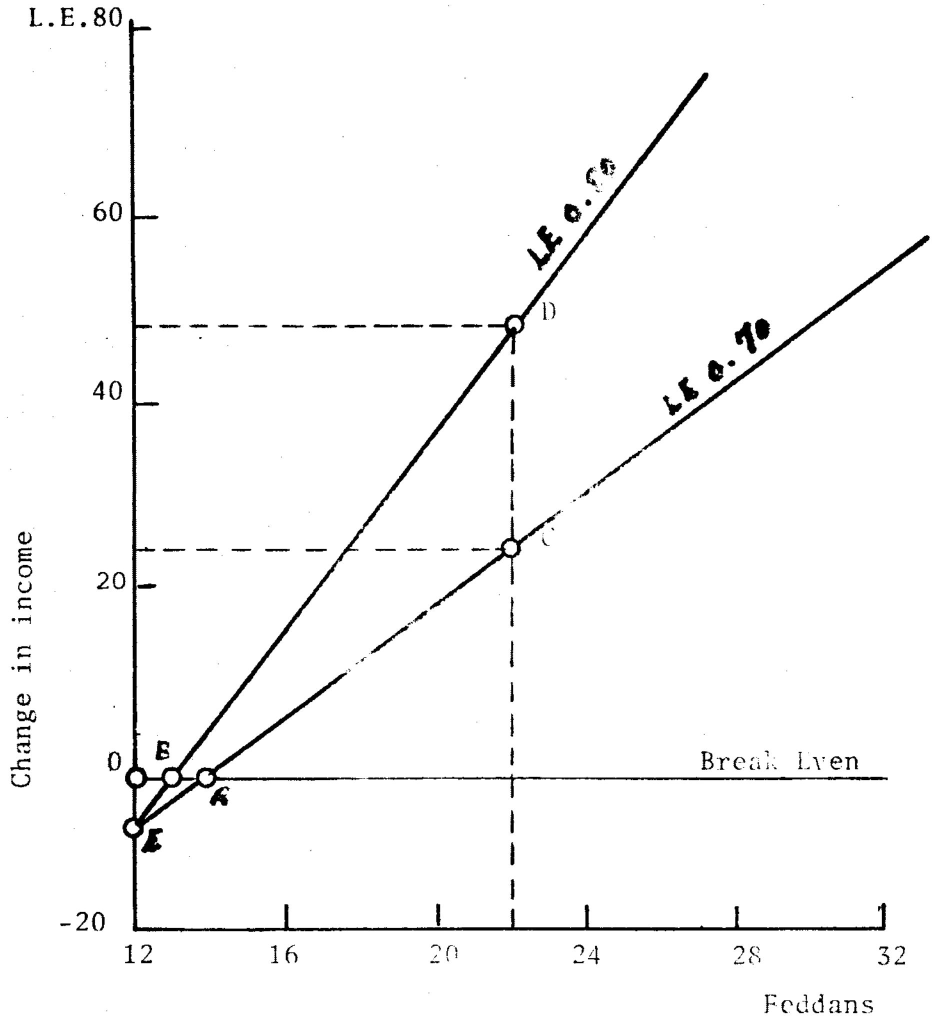


Figure 1. Relationship between acreage, price charged for using the diesel pump and changes in farm income for case No. 2

Points A and B show the break-even acreage for this farmer at pumping charges of LE 0.70 and LE 0.80 respectively.

The maximum acreage which could be irrigated depends on the number of hours each day the pump will run. At Kafr Hakime water is delivered 4 days on and 8 days off. With a pump capacity of 3 hours per feddan it can be seen the maximum is 32 feddans per irrigation turn.

$$\frac{\text{4 days x 24 hours}}{\text{3 hours per feddan}} = \text{32 feddans maximum}$$

If farmers are willing to pump only 12 hours the maximum would be 16 feddans.

It has been demonstrated that the rate charged the neighbor farmers for pumping water is a sensitive variable in the analysis. Notice also that a part of the variable cost of pumping irrigation water is labor, LE 86 for the diesel pump and LE 16 for the sakias. If family labor is used the "cost" of these factors may be retained as family income. In Case no. 2 the potential net gain to the farm family would be the difference between diesel and sakia "labor costs" or LE 70.0 per year. These gains could also be extended if additional contracts were made with neighboring farmers to hire the pump.

In both cases 1 and 2 it may not be necessary to construct a building for security of the pump. Some farmers would find it convenient to keep it in their house. This would, of course, save LE 22 of expenses per year.

Case No. 2 has important agronomic implications. The loss of cow manure needs to be compensated for in soil maintenance and management. Are there more economical methods of doing this than purchasing manure? Also what alternatives are appropriate if many farmers dispose of animals and the supply of manure for purchase is exhausted? Another agronomic question involves crop alternatives for berseem and maize forage which are no longer needed for cow feed. Are there more profitable alternatives?

The farm family's "way of life" may be substantially disturbed by the alternative proposed in Case No. 2. The family ~~is now~~ would be dependent on outside sources for the 450 kilograms of milk which is lost with the sale of the cow. Also the social arrangements involving the operation of the two sakias are affected. Perhaps the disturbances are not serious. However they are almost certain to enter into the farmer's decision framework as he ponders the feasibility of alternative system.

Conclusions

The analysis indicates that small acreages are not likely to show a ~~position~~ positive response to alternative water lifting systems that require substantial amounts of capital. It also indicates there are inter-relationships between family food requirements, family labor supply, water delivery capacities, soil maintenance, animal numbers and cropping patterns. When one factor is changed, e.g. the method of lifting water, each of the inter-related factors must be considered.

This analysis suggests that lifting water by diesel pumps may be one method of increasing farm family income if substantial scale can be achieved. As with most capital intensive technology sufficient size or scale of operation must be achieved to reduce unit fixed costs to acceptable levels.

FARM WATER MANAGEMENT IN THE NILE VALLEY

E. V. Richardson and R. H. Brooks

Conference on Water Resource Planning

In Egypt

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ABSTRACT

Egypt is moving forward to take advantage that the completion of the Aswan High Dam has given her to improve the living conditions of her people. To optimize the utilization of the Nile water, studies are being conducted to improve the total utilization of the Nile River. These studies range from the macro level "Nile River master plan" to the micro level "on-farm water management." Both are needed. This paper describes the on-farm water management project and some of the findings to date.

FARM WATER MANAGEMENT IN THE NILE VALLEY

E. V. Richardson[1/] and R. H. Brooks[2/]

Introduction

The completion of High Aswan Dam in 1965 changed the irrigation water regime of the Nile River. Prior to High Aswan Dam the Egyptian irrigation farmer through centuries of irrigation practice had developed water management systems in coordination with the Nile River fluctuations. The construction of High Aswan Dam with its immense storage capacity of 1.9 times the average annual flow of the Nile River (127.6 million acre feet) gave the Egyptian government complete control of the Nile River. Prior to completion Egypt and her irrigation farmers were at the mercy of the fluctuations that naturally occurred in the Nile River. Flows could be as low as 36×10^6 million acre feet or as high as 122×10^6 million acre feet per year. Average annual flow is 87×10^6 million acre feet. With the low flows there would be no flooding and no crops would grow. With the high flow, excess flooding would occur. In either case disaster of major proportions did occur.

There are those who disparage the accomplishments of the High Aswan Dam saying the side effects are too costly a price to pay to obtain an assured water supply. The side effects of High Aswan Dam have been mostly overstated, for example, the loss of fertility. Recent studies on the loss of fertility indicate that the loss of nitrogen, potassium and other nutrients supplied by the flooding Nile waters are insignificant in comparison to the amounts needed in order to take advantage of the potential production that could be provided by Egypt's soil, water and plant resources.

To obtain the maximum benefits of this new resource, the High Aswan Dam, the Egyptian government has started many significant studies. These include the Nile Master Plan study to optimize the use of the Nile waters and studies at the farm level to determine the appropriate irrigation practices to maximize food and fiber production from the abundant water resource that is available.

With the assured water supply of the magnitude that will be available from the High Aswan the Egyptian Government now has the

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opportunity for both vertical and horizontal expansion of the irrigated agriculture industry. Simple calculations from the amount of water available and the water requirements in the old lands indicate that there is approximately 12 million acre feet of water available for horizontal expansion of the agricultural industry. More sophisticated studies looking at the return flow, drainage water and available ground water in the old lands significantly increase this amount. Horizontal expansion will probably require more sophisticated irrigation techniques such as sprinkler, drip, macro-drip or bubbler, because the new lands, or soil do not have the excellent characteristics as the alluvial soils in the Nile Delta and Valley. Vertical expansion will require new irrigation techniques. The irrigation techniques that the farmer practiced in the old lands will probably have to be changed because now the Egyptian farmer has an entirely new system under which to operate. Prior to High Aswan there were frequent shortages of water. These shortages by necessity required the farmer to very carefully manage the water. With the abundant water supply that is now available from High Aswan, the Egyptian farmer has become careless. His old methods with an abundant supply wastes water. His old methodologies of irrigation and related practices will need to change. The On-Farm Water Management Project objective is to work with the Egyptian farmer and determine those modern practices of irrigation and related agronomic practices that are best suited for the old lands of Egypt and the Egyptian cultural and social characteristics.

Egypt Water Use and Management Project

Project objectives are to (1) identify the major constraints to improve on-farm water management and optimal water delivery system operations; (2) determine and establish the use of optimal irrigation and related agronomic practices at the farm level in representative pilot areas; (3) establish improved water control practices for the water delivery and drainage systems in the project areas; (4) develop plans for organization and implementation of expanded future programs based on results in the project areas; and (5) develop and train qualified scientists and technicians who will carry on and conduct on-farm water management activities.

Activities are conducted in three pilot areas, each representative of a particular cropping pattern, soil conditions and unique water management problems. Taken as a group, these areas represent nearly the entire range of crop and agro-climatological conditions encountered in the "old lands."

The El Minya area in the Upper Nile is typical of areas with loamy soils, fragmented holdings, drainage problems, a gravity-fed irrigation system and cropping pattern centered on sugarcane, cotton, maize and sorghum. The Mansouria area near Cairo typifies lighter sandy alluvial soils, lesser drainage problems, a lift irrigation system, fragmented holdings and a cropping system largely of citrus, fruits and vegetables. The Sakha area in the north central Delta contains heavy clay loam soils, somewhat larger holdings, major drainage and salinity problems, a lift irrigation system and major crops of paddy rice, cotton and wheat.

In each of the areas, project activities will be implemented in three overlapping and interrelated components. The first component involves on-farm surveys to obtain the data base concerning existing farm production, identify problems (Problem Identification), and to determine the research required to solve the problems (Solution-Search). Information gained would serve as the basis for design of applied research programs with farmers and eventually for the design of production/demonstration programs in the pilot areas (Implementation).

The second component of the project is to develop a data base concerning quantity and quality of water entering and leaving each irrigation district. This data will be used for management decisions for water delivery and drainage on a district basis. Activities in the first two components would be undertaken in the earliest stages of the project to provide a basis for applied research and demonstration programs to be conducted as the third component and would continue throughout the project as a source of feedback information for continual improvement of water management practices.

The third component has two major stages in which the first stage will involve on-farm research programs based on information developed in the first two project components and on results already obtained from on-going research in Egypt. The on-farm testing may vary from a few farmers and a few feddans to several hundred farmers and their holdings depending on the type of research involved. Included in the first stage of the third component are studies of delivery systems improvements which will, by necessity, require relatively large blocks of land determined by delivery canal configuration. These studies will include evaluation of water delivery on a demand basis as well as studies of water delivery on a gravity basis at various rates of flow. Outlet design and a continuous evaluation of the delivery system will also be major aspects of the program.

Other aspects of the first stage of on-farm research include salinity balance experiments, particularly in Kafr El Sheikh district, and correlation between soil tests and fertility experiments. The latter will depend on results from a soil test program undertaken as part of the first component and will be directed toward otpimization of fertilizer input for small farmers.

A second aspect of the first stage of on-farm research will be that of improvement of farm application systems. Studies will be conducted to develop optimum combinations of such factors as flow rate, field configuration, slope, infiltration rates and field leveling, all leading to higher application efficiencies. Studies will also be conducted related to replenishment of soil water deficit and control of water-logging and soil salinity.

As a result of the above research activities and based on data developed by the on-farm surveys, optimal management systems will be designed for on-farm use. Programs will be conducted with farmers to determine their feasibility of adoption and acceptability. Management factors will include irrigation methods, field cultural practices, seed and fertilizer application and pest control. Experiment station research will also be suggested where basic data are not available and where new problems surface from applied research.

The second stage of the on-farm research program is the design and implementation of pilot programs in each of the three areas, incorporating high benefit technologies developed in the first stage. These programs will test the acceptability and rate of adoption by farmers of improved management practices. Of equal or greater importance will be the determination of the most efficient organization approach or approaches, the technical competence of personnel required and the costs and benefits involved for the successful conduct of such programs. The emphasis during the pilot demonstration/production phase will be on the development of a program or programs which farmers will accept and adopt and which can be reasonably replicated for production programs at the regional and national levels.

The program is planned and implemented by an interdisciplinary team of Egyptian and U.S. professional staff. General supervision and training will be handled from the main office in Cairo with field office personnel in each pilot location executing day-to-day programs. Each project site is expected to have a team of five or more Egyptians with training at the MS level in the specialties of irrigation, engineering, agronomy, agricultural engineering, agricultural economy and sociology.

Training is an essential element of this project and will be coordinated and supervised by the main office staff in Cairo. In-service training will be given throughout the course of the project with particular emphasis during initiation of activities in each project site. Short courses of one to four months' duration of applied training in various specialties will be designed and conducted periodically in the U.S. and in Egypt. Training tours to other countries may also be organized as appropriate and as required.

Preliminary Findings

With the objective of improving existing management practices of irrigated agriculture in Egypt, the problem identification work is proceeding as outlined above for the three areas. At present preliminary findings are available for Mansouria. A summary of the problems identified are presented below in qualitative form. Supporting quantitative data and detailed findings will appear in subsequent reports pertaining to individual disciplines.

Social and Economic Problems

Social Problems: The social problems in Egyptian agriculture relate both to the farm level organization of agriculture and to national policy and controls:

1. Social Organization Among Farmers. Presently in the Mansouria District there is a virtual absence of formal, voluntary organization among farmers on contiguous lands, and at the village level. Standing cooperative relationships, on a large scale, are not evident. Unquestionably, the project will have to give emphasis to assisting farmers to form voluntary mutual-aid associations, perhaps along the lines of U.S. local water-users associations, but probably broader in function here.

2. Problematic Communications. There exist various problems with inadequate and inaccurate communications among neighboring farmers and with government officials. This situation leads to ineffective decision-making by farmers. It also underlies much of the suspicion and distrust evident between farmers and toward government officials and technical specialists. Such conditions are counter-productive to development processes. Accordingly, improving the frequency and quality of information flow must be implemented as a part of project activities.

3. Low Mutual Understanding and Respect Between Farmers and Official Technical Personnel. Common perceptions of problems, shared knowledge, consistent definitions of abilities, and so forth, are now not an apparent feature of relations between farmers and the technical experts with whom farmers have contact. Such has obviously deleterious consequences for rural development activities which depend upon close working cooperation and trust between these parties to agricultural improvement.

4. Tendency Toward Simple Technical Solutions When More Appropriate, Enduring and Efficient Alternatives Exist. Many examples could be offered; one related to project activities should serve this purpose. Presently there is a tendency to assume that less irrigation water will be applied to fields if the farmer must "work harder" to lift the water a greater distance to field level and if amounts of water supplied are curtailed. Thus, control structures are built and the levels of ditches are lowered. Hardship is imposed on all farmers but particularly on those at the last reaches of watercourses who, even now, often do not receive the water they need at appropriate times. Demanding more effort from the farmer takes him away from other priority alternative activities which contribute to increased agriculture

production. He may even be forced to make heavy expenditures for alternative irrigation methods such as pumps.

If the farmer perceives the crop needs water, observations indicate he will lift the amount of water he thinks is required regardless of the effort. From his knowledge base it is better to over-irrigate, even if it costs him in time and effort, than risk poor yields or loss of crop from not applying enough water.

Education about topics such as efficient water management, farmer-policed local agreements about appropriate water application, scheduling of irrigations, are far more appropriate solutions to the problem of excessive applications of irrigation water, both from the standpoint of the small farmer and for the nation as a whole.

5. Small-Sized Land Holding and Fragmentation of Plots. In addition to problems noted by others of poor economies of scale and difficulties of using many implements and procedures which would improve farming practices, there are socio-political implications. Some of these fall under the general heading of complicating organizational processes and cooperative arrangements among farmers. Others under divided loyalties and commitments, and still others under impeded rationality.

Economic Problems: The economic team presented three problems for consideration in developing project plans:

1. Excessive Costs of Lifting Water. Most farmers in Mansouria lift water with sakias and tambours. Lifting water with a tambour costs three times more than with a diesel or electric pump; a sakia about two times more. Gravity distribution systems should, in some areas, eliminate lifting costs completely. However, one should recognize that changing the present canal systems to a complete gravity system could entail considerable cost in construction of barrages, new canal system, etc. The analysis here deals only with small scale lifting on a meska basis.

The determination of water lifting costs is based on the assumption that human and animal labor has a market value. The studies indicate that human labor has a value of not less than L.E. 0.15 per hour at Mansouria even during seasons of low labor demand. The market rate for animals is about L.E. 0.32 per hour for turning a medium sized sakia. Assuming further that the opportunity cost of power on farms supplying their own labor and animals closely approximates the market rate at the margin.

2. Excessive Slack Time in Crop Rotation. The average slack time in crop rotations for the study farms at Mansouria was 16 percent (58 days per year) for the agricultural years 1977 and 1978. This slack time should be reduced by better farm planning, cooperation on more capital intensive land preparation methods and improved water distribution systems (some land was idle because water was not available in the meskas).

3. Lack of Data for Farm Planning. Farmers lack the data needed for farm planning and management. They have no farm records and must recall past performance of input-output relationships from memory. Furthermore, they have almost no access to secondary sources of input-output information. Substantial increases in productivity and net farm income could result if farmers were (1) given assistance in establishing record systems, (2) provided access to secondary input-output data, and (3) helped to utilize this information in systematic budgeting and farm planning.

Agronomic and Engineering Problems

Agronomic Problems: The agronomic team identified three problems which are limiting agricultural production in the Mansouria area:

1. Crops Stand Population. The number of plants per unit area of land is low as percent of optimum number of plants per feddan. Table 1 shows the optimum number of plants per feddan for many of the major field crops grown in the Mansouria area. Table 2 summarizes the percent of the optimum stands found on the on-farm work sites in the El Hammami and Beni Magdoul areas of Mansouria. In the case of corn, stands were from 24 to 49 percent below optimum. Beni Magdoul had better stands of corn than did El Hammami farms. However, considerable improvement in both areas can be made. One factor that may explain why stands are better in Beni Magdoul than stands in El Hammami are the differences in soil. The soils in El Hammami being sandy and coarse have a lower water holding capacity and also have higher bulk density values.

2. Fluctuating Ground Water Table. High ground water levels affect crop growth by affecting soil aeration and the crop rooting zone. High crop yields can be obtained under high water table conditions providing there is a low level of salinity in the ground water

Table 1. Optimum Number of Plants per Feddan for Some Field Crops Grown in Egypt.

Wheat	600 fertile heads per m^2	
	if plant has 6 tillers - $\frac{600}{6}$ = 100 plants m^2	
	4200 (m^2/feddan) x 100 = 420,000 plants per feddan	
Cotton	60,000 plants per feddan	
Corn	24,000 plants per feddan (10 rows in 7.10 m and 25 cm between plants within plants in a row)	
Rice	33,000 hills per feddan and 3 plants per hill which totals 99,000 plants per feddan	
Berseem	1st cut	5 - 6 tons/feddan on green weight basis
	2nd cut	7 - 8 tons/feddan on green weight basis
	3rd cut	9 -10 tons/feddan on green weight basis
	4th cut	5 - 6 tons/feddan on green weight basis
Vegetables	Squash	4,000 plants per feddan
	Cucumber	3,000 plants per feddan
	Watermelon	2,000 plants per feddan
	Pepper	12,000 plants per feddan
	Eggplant	10,000 plants per feddan
	Tomato	10,000 plants per feddan
Oilcrops	Peanuts	16,000 plants per feddan
	Sunflower	13,000 plants per feddan

Table 2. Percent of Optimum Plants Per Feddan

Site	Corn	Eggplant	Tomato	Corn + Other Crops*	Pepper
El Hammami	51.4	73.3	--	62.2	--
Beni Magdoul	75.5	--	84.0	79.8	128.0

*Other crops tomato, okra, jew's mallow, cucumber, eggplant and sunflower.

and that the level of ground water does not fluctuate during the growing season. In the Mansouria area the ground water quality is good but the level fluctuates markedly. Ground water depths on the on-farm work sites in El Hammami and Beni Magdoul were measured during the months of June and July. The data are summarized in Table 3.

Table 3. Ground Water Depth Before and After Irrigation Average Depths of Water Table Below the Soil Surface Before and After Irrigation - cm

Location	Before Irrigation	Range of Depth Values
El Hammami	69.6	55-90
Beni Magdoul	79.8	46-105
	After Irrigation	
El Hammami	58.1	54-65
Beni Magdoul	70.0	43-104

3. Soil Salinity and Sodicity. Soil survey and classification pointed out that salinity is a problem or could be a potential problem on 25 percent of the land area in Beni Magdoul and on 17 percent in El Hammami. Soil sodicity as measured by SAR shows that 9 percent of the area in Beni Magdoul and 23 percent in El Hammami pose potential problems if present management practices continue.

Engineering Problems: The problems identified by the engineering team deal with both the delivery system and on-farm use of irrigation water:

1. Unequal Irrigation Water Distribution Canals. Irrigation water delivered by the Mansouria canal system is not distributed equally among all the lands it serves. Water available per feddan decreases with increasing distance from the intake of a canal or branch. As a result some land receives more water than it needs, while some gets an insufficient amount. Identified reasons include:

a. Extra (illegal) pipe intakes to private ditches have been constructed. Those near the canal intake can rob water from legitimate pipe inlets further down the canal. In El Hammami there are three times as many illegal as legal intakes. The other regions have only a few less.

b. A severe problem of submerged weeds occurred in the concrete-lined Beni Magdoul canal, during the spring and early summer 1978. Apparently the weeds were nourished by an accumulation up to 20 cm of silt in the canal. El Hammami canal was also affected, but it had a severe infestation of emerged weeds as well. Two cleanings were required in each canal during the spring and summer. Prior to cleaning, irrigations were delayed for lack of water.

c. Water delivery to a canal or to a private ditch is not usually measured, but is controlled only by the head at the inlet. Consequently, the users on a branch canal can get more by using more because the gradient is increased. On the other hand, they get less when weeds choke the canal.

d. Those users near the canal intakes, who have more water available, are less inclined to irrigate at night. Consequently, water is more likely to spill over the tail escapes of the first branch canals, due to the diurnal fluctuations, than it is over the last or lower branches. The result is less total water remaining for delivery to the last branches.

2. Uneven Water Distribution in Fields. Irrigation water is often not evenly distributed over a field. High spots and low spots appear as water infiltrates after an irrigation of a basin. One observed consequence is a poor stand in the low spots due to prolonged ponding. A high spot could suffer from too little water absorbed, especially if the low spot receives no excess.

3. Excessive Water Table Fluctuation. The average water table in Beni Magdoul rose to within 0.72 m, 0.80 m, and 0.76 m from the soil surface, respectively, at different times during the spring and summer. Just before the canal closure in January it was observed at only 0.5 m below the ground surface. In an individual field, it usually rises sharply with each irrigation. Very little sustained root activity has been observed below these points of highest rise.

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PRICE POLICY IMPLICATIONS FOR SMALL FARMS IN KAFR EL SHEIKH GOVERNORATE [1]

Historically government has played an important role in the agriculture of the Nile Valley and the Delta. Egyptian agriculture development has taken place within a relatively complex man-made irrigation water delivery system. As a result the institutional arrangements which have evolved in agriculture include a strong central role for government.

The current Government policy is to set farm prices for certain crops at levels below world prices. Although there may be justifying "public interest" reasons for these policies they do have a significant effect on the incomes of small farmers. This is pointed out in the case of twelve farmers in Kafr El Sheikh Governorate. Prices assumed for cotton, wheat and rice, the crops in that Governorate most seriously effected by price discrimination, are as follows:[2]

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(1 Prepared by M. E. Quenemoen, Agricultural Economist, Egyptian Water Use Project, Ministry of Irrrigation for "Workshop on Improved Farming Systems for the Nile Valley", FAO Project EGT/77/001, Cairo, May 7-13, 1979.

(2 These are the approximate prices which prevailed during the agricultural year 1977-1978.

Crop	Unit	Farm Price	World Price
		LE	LE
Wheat	ardab	8.0	10.0
Rice	ton	65.0	130.0
Cotton	kantar	37.0	74.0

The price differences represent a form of taxes on farm earnings and even though farmers do not pay directly for water they do pay indirectly into the national treasury. Examination of Table 2 indicates that income to the farm families in Kafr El Sheikh would be substantially higher if world prices prevailed at the farm level. Some of these gains would be absorbed by higher food costs as rice and wheat are used directly by the farm families for home use. Also there are subsidies for fertilizer, insect control, tractor rental and for some other inputs which maybe would be discontinued if public funds were reduced through elimination of price discrimination.[1]

Although we could argue the magnitude of the effect of price discrimination policies on individual farmer income it seems to be irrefutable that farmers producing controlled

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(1 Input subsidies are substantial in the case of cotton amounting to approximately LE 45 which must be added to the farmer's cost of approximately LE 185 per feddan if one wants to account for full costs. However, this is relatively insignificant when compared to gross income differences of LE 350 per feddan for farm gate prices and LE 750 per feddan for world prices. These were typical price relationships in Egypt during 1978.

le 1: Summary of Case Study Farm Budgets from Kafr El Sheikh Governorate, Agricultural Year 1978-1979.

Size	Crops Grown								Animal Units of Livestock	Gross Value Crops Grown	Gross Farm Income	Farm Expenses	Return to Water, Land and Management	Average Return to Water, Land and Management Per feddan	Average Return to Water, Land and Management per farm family member
	Wheat	Flax	Berseem	Beans	Cotton	Rice	Maize	Other							
f-k	f-k	f-k	f-k	f-k	f-k	f-k	f-k	f-k	AU	LE	LE	LE	LE	LE	LE
6-9	1-15	0-16	4-2		2-20	2-21	0-16		5,0	1389	1315	528	787	123	87
6-19	2-16	0-12	3-10		1-2	3-16	0-10	1-13	7,6	1329	1805	923	882	130	147
8-8	1-12	1-12	4-8	1-0	2-0	5-8	1-0		6,7	1626	1667	751	916	110	51
4-0	2-0		3-0		1-12	2-0	0-12		2,8	872	901	471	430	108	54
6-16	1-0	0-12	4-16	0-12	3-16	2-0	1-0		3,6	1326	1422	770	652	98	65
10-18	1-0	2-0	5-6		5-6	4-0		1-0	10,7	2226	3027	1260	1767	164	221
4-14	0-14		2-19			1-14	0-10	3-19	3.8	1037	1042	277	464	101	116
10-6	3-3	1-12	4-22	0-17	3-6	5-14	1-10		7,2	2375	2841	919	1922	188	91
3-0	1-0		2-0		1-0	1-0	1-0		5.0	646	831	274	557	186	111
3-0	0-0	0-12	1-16		2-12	0-12		0-20	8,9	857	3314	2316	998	333	250
3-4	0-18		2-10		2-10	0-18			4,4	764	1104	534	570	180	114
3-4	1-0	0-9	1-19			2-8			6,2	721	1014	284	730	231	91
70-2	16-6	7-13	40-8	2-5	25-12	31-15	6-10	7-3	72,9	15,168	20,281	9,307	10,977	---	---
5-19	1-8	0-15	3-9	0-5	2-3	2-15	0-13	0-14	6,1	1264	1,59[illegible]	776	915	157	104

Table 2: Effect of Using World Prices on Planned Income for Case Study Farms in Kafr El Sheikh Governorate, Agricultural Year 1978-1979.

Farm No.	Increase in Gross Income Per Farm by Crops			Increase In Return to Water, Land and Management		
	Wheat	Cotton	Rice	Per Farm	Per Feddan	Per Capita
	LE	LE	LE	LE	LE	LE
1	29	407	428	864	135	96
2	48	241	546	834	122	139
3	20	444	794	1258	151	70
4	36	333	298	667	167	83
5	18	814	298	1130	169	113
6	18	1166	595	1779	165	222
7	11		235	246	54	62
8	20	722	831	1573	153	75
9	18	222	149	389	130	78
10		555	74	629	210	157
11	14	536	112	662	209	132
12	18		299	316	100	40
Σ	250	5439	4658	10347	---	---
$\bar{X}$	21	453	388	862	147	98

crops have substantially lower incomes than they would have under world prices.

Implications for Crop Enterprise Selection

The signals given farmers under a price discrimination policy will lead them toward resource allocation which may not be consistent with national objectives. Following an analytical procedure explained by Upton[1] we present a partial budget for shifting one feddan of land from cotton to soybeans for a specific farmer at Kafr El Sheikh.

Before proceeding with a discussion of the analysis let us describe briefly the economic logic of a partial budget. In its simplest form a partial budget involves the following questions for a specified farm and a specified change to be analyzed:

(a) What extra returns (gains) can be expected?

(b) What extra costs will be incurred?

Where the proposed change or new activity substitutes for something already existing on the specified farm, as

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(1 Martin Upton, Farm Management in Africa - The principles of Production and Planning, Oxford University Press, London, 1973. See pages 282-286.

when one crop substitutes for another or a machine substitutes for labor, then we must also ask:

(c) What present costs will no longer be incurred?

(d) What present income will be sacrificed?

Hence the gain will be (a)+(c), the extra returns plus the saved costs, and the total cost will be (b)+(d), the extra cost plus the present income foregone. The total gain minus the total cost then represents the net gain or expected increase in profits.

Table 3 suggests that a specific farmer at Kafr El Sheikh would gain LE 33.0 per year if he shifted one feddan of land from the production of cotton to the production of soybeans.

Given current cost-price relationships faced by farmers, soybeans look profitable. It should be noted that a large part of the cost of producing soybeans, to the individual farmer, is the income he foregoes by not producing cotton. We see that the returns associated with cotton have an important influence on the profitability of producing soybeans.

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Table 3: Partial Budget of the Economic Effect on a Farmer, Kafr El Sheikh Governorate, from Shifting one Feddan of Land from Cotton to Soybeans.

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1. Specification:
   Planting of soybeans and the replacement of an existing crop of cotton. Farm prices are used in the calculations.

2. Items in the present system likely to be changed:
   Cotton and cotton stocks no longer available.
   Soybeans require four months growing season in the middle of the 8 month growing season for cotton.
   Soybeans will apply as credit toward required cotton area.
   The cost of producing cotton will be eliminated.

3. Estimated gains and losses:

a. Extra value of soybeans and forage crops. LE 170	b. Extra production costs of soybeans and forage crops. LE 80
c. Saved costs of producing cotton. LE 134	d. Reduced return from cotton. LE 191
Total gains LE 304	Total costs LE 271

Net gains LE 33

If all the prices and costs used to construct Table 3 were generated in the market system (and if no externalities existed) we could conclude our analysis. It implies that shifts from cotton to soybeans would be appropriate in Kafr El Sheikh. However the real world is more complex than this. Egypt, like most countries of the world, has national policies which cause deviations from market prices. Hence it is important to ask a second question which can also be dealt with by using a partial budget, "What is the effect at the national level of shifting from cotton to soybeans?"

For analyzing the economic impact of this question at the national level it is necessary to adjust costs and returns in order to represent the real prices (shadow prices). For example the price a farmer pays for fertilizer is a good indication of its cost to him but if the government subsidizes part of this cost then the amount of the subsidy should be considered for national analysis. Likewise the price the farmer receives for cotton may represent his return adequately but the return to the nation may be more correctly represented by world prices.

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The problems of determining "shadow prices" are complex. Estimates have been made by others and are used in the construction of Table 4.(1 Compare Tables 3 and 4. Note that (a), Extra value of soybeans and forage crops, is the same in each table. This implies that soybeans and forage crops are priced at market values to the farmer and to the nation. The cost of producing soybeans, (b), is higher in Table 4 reflecting the subsidy value of fertilizer and other inputs to the government. The saved costs of producing cotton, (c), is also higher in Table 4 for the same reason. The biggest change takes place in (d) Reduced returns from cotton. This value is much larger in Table 4 than in Table 3 reflecting the loss of foreign exchange to the government based on world prices. The bottom line of Table 4 shows a net loss of LE 108 compared to a net gain in Table 3 of LE 33. This reflects the difference in using "farmgate prices" and "shadow prices". The latter account for the national opportunity costs associated with shifting resources from producing cotton to producing soybeans.

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(1 See James B. Fitch, Khedr and Whittington, "The Economic Efficiency of Water Use in Egyptian Agriculture: opening Round of Debate" unpublished draft of paper from the Ministry of Agriculture and the Ford Foundation, 1979.

Table 4: Partial Budget of the Economic Effect on Egypt of Shifting One Feddan of Cotton to Soybeans.

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1. Specification:

   Replacing one feddan of cotton, an export crop, with one feddan of soybeans, an import crop. Shadow prices are used to estimate costs and returns.

2. Items in the present system likely to change:

   Costs of producing cotton will be reduced.
   Foreign exchange from exporting cotton will decline.
   Foreign exchange needed for importing vegetable oil will decline.

3. Estimated gains and losses:

a. Extra value of soybeans and forage crops. LE 170	b. Extra production costs of soybeans and forage crops. LE 92
c. Saved cost of producing cotton. LE 196	d. Reduced return from cotton. LE 382
Total gains LE 366	Total costs LE 474

Net gains LE <108>

Of course there are other considerations which must be considered in national policy decisions. For example food sufficiency goals may weigh heavily in favor of producing soybeans in order to be more nearly self sufficient in vegetable oil rather than generating foreign exchange with cotton exports. The most important point is that national policy should be carefully developed to give the desired signals to farmers. As suggested by Tables 3 and 4 the outcome of resource use analysis may be greatly effected by the selection of prices attached to input-output relationships.

Capital Formation

Partial budget analyses of mechanical technology for individual or groups of farms often show substantial potential income gains.[1] The adoption of such technology invariably requires some investment capital. Examination of the budget summaries from Table 1 indicates that income per capita on even larger than average farms in Kafr El Sheikh Governorate is low indeed, ranging from LE 51 to LE 250 per year and averaging LE 104. After obtaining only bare necessities of

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[1] For examples see M. E. Quenemoen and Shinnawi Abdel Aty El Shinnawi, "An Economic Analysis of Water Lifting With a Diesel Pump for a Farm at El Hammami", a paper presented at the UNESCO training conference on irrigation development, EWUP, February 1979.

life these incomes cannot leave much balance for capital investment.

Would increased income, of a level associated with world prices at the farm gate, result in more capital investment? The answer is almost certainly yes but the magitude is important. It may be interesting to conduct experiments in pilot areas to assess this magnitude.

For example a package of higher farmgate prices, available proven technological alternatives, extension type educational programs, credit, birth control information and general home economics assistance may prove to be a good way of generating capital formation, new investment and economic growth. Such packages are appropriate to "farming systems" and should be of interest to this project.

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THE AGRICULTURAL ECONOMICS PROFESSION
IN EGYPT - CURRENT STATUS AND SPECIAL NEEDS 1/

The agricultural economics profession got its start in Egypt in the 1940's under the leadership of Professor Monear Zalaki who is still active in the Agricultural Economic Department at the University of Alexandria. At least a dozen of his best students were sent to the United States after World War II, for training (the University of Wisconsin was especially favored). Several of these individuals occupy top posts in Egypt today, e.g. president of a major university, director of the Agricultural Economic Research Institute and special economic advisor to President Sadat.

Prior to 1950 agricultural economics training in the Egyptian universities was insignificant. However with the influx of U.S. trained agricultural economists, departments were established in the major universities and leadership by agricultural economists was established in units of government responsible for gathering agricultural statistics.

1/ Prepared by Gene Quenemoen, EWUP and Jim Fitch, Ford Foundation for the American Agricultural Economics Association, March 1979.

.../...

In the early 1960's the University of Cairo had an exceptionally strong agricultural economics department with a large component of Iowa State University trained professors. However a combination of factors including economic ideology drift in Egypt, internal departmental dissention and attractive out-of-country positions for agricultural economists caused a gradual decline in this department which has never been restored to its former position.

During the 1960's the balance of emphasis moved from Western to Eastern ideology in Egypt. Opportunities for graduate training in Western countries was replaced by Eastern Bloc nations. From 1965 to 1975 there were practically no Egyptian graduate students being trained in American universities and only a few in Western Europe. Graduate training in agricultural economics shifted to U.S.S.R., Bulgaria, Czechoslovakia, East Germany, Rumania and Hungary. Agricultural development was not given high priority during these years of Egypt's history.

During this period another change was taking place which worked against the establishment of centers of excellence in agricultural economics training. Regional universities were established and professors from the urban universities were required to staff them. At the present time all ten of the public universities in Egypt have faculties of agriculture and agricultural economics departments.

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By 1975 the Egyptian government abolished many general economic organizations - the holding companies that owned and controlled the nation's business. This was precipitated by a definite policy shift toward a more market oriented economy and an obvious need for bold action to relieve a strangling economy. A concurrent diplomatic break with U.S.S.R. dried up the opportunity for sending Egyptian students to Eastern Bloc countries for graduate training.

The Present Situation

Colleges of agriculture in Egypt offer most students a general degree in agriculture. Classes are large. Lectures typically include 300 to 500 students. Some of the better students are allowed to specialize during the last two years in disciplines such as agricultural economics. Most of the professors at the regional universities live in Cairo or Alexandria and spend only three or four days per week on their respective campuses. Thus students have very limited interaction with professors. In addition books are scarce and foreign books are both scarce and expensive. Libraries and dormatory space are minimal. With these and other limitations undergraduate training is weak compared to developed countries.

The ten Egyptian universities, number of faculty in agricultural economics and number of graduate students is shown below.

.../...

University name/Location	Approx.Size of Faculty in Agricultural Economics	Estimated Number of Students Enrolled in Graduate Programs in Agricultural Economics
Cairo U., Cairo	6 *	20
Ein Shams U., Cairo	8	45
Al-Azhar U., Cairo	8	25
Alexandria U., Alexandria	7	25
Assiut U., Assiut	4	18
Mennofiya U., Shebin El Kom	4	18
Minya U., Minya	3	20
Mansoura U., Mansoura	3	8
Tanta U., Kafr El Sheikh	3	15
Zagazig U., Zagazig	10	25
TOTAL	56	219 **

* Includes four holding degrees in Extension and Rural Sociology.

** Approximately one-fourth are Ph.D. candidates.

These figures were obtained by indirect inquiry in some cases, and could be off by as much as 20 percent. Nevertheless, the picture of scattered resources and small faculty sizes emerges quite unmistakably.

As indicated above there are approximately fifty Ph.D. agricultural economists on the faculty of agricultural economics in Egyptian universities. There may be an equal number in private business and government ministries but no one seems willing to make this estimate with much confidence. It is estimated from 15-20 Egyptians are now enrolled in graduate programs in Western countries. The Institute of Agricultural Economics Research employs 20 Ph.D. agricultural economists and eleven are employed by the Institute of National Planning. The directors of both are Ph.D. Agricultural Economists.

We estimate that the source of training for Ph.D. agricultural economists presently professionaly active in Egypt is about evenly divided among U.S., Eastern Bloc, and Egyptian universities with a few from Western European countries. Since attempts to organize a professional society have not been successful there is no central source of information on numbers and training of agricultural economists. The Institute of Agricultural Economics Research has 5 Ph.D. trained agricultural economists from the U.S., 8 from Eastern Bloc countries and 7 from Egyptian universities. It also employs 35 M.Sc. trained agricultural economists, all from Egyptian universities. The Institute of National Planning has two Ph.D. agricultural economists from Egypt, 5 from Eastern Bloc countries and two each from U.S. and Western Europe.

As a general rule all M.Sc. agricultural economists receive their training in Egypt. There is no financial aid for students without an M.Sc. degree to go abroad for training.

System of Training in Egypt

The general structure of agricultural economics graduate training in Egypt is patterned after the U.S. Most departments have been strongly influenced by graduate training systems developed in Wisconsin, California, Iowa and Cornell. Each professor will typically have at least one teaching assistant. Graduate level courses are offered in areas which parallel the standard offerings of U.S. universities, e.g. economic theory, mathematical economics, statistics, production economics, marketing, econometrics, agricultural policy, economic development, etc. In most cases graduate courses are taught in English, however, comprehension is a serious problem so the discussion frequently resorts to Arabic. English textbooks and references are used almost exclusively.

Monthly salaries of university professors in Egypt are estimated to be about $ 140 for beginning professors, $ 210 for associate professors and $ 280 for full professors. Some professors supplement this income by working for international research organizations and/or by selling their books to students.

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Most professionals feel the graduate programs in Egypt are analytically weak. This is due in part to weakness of courses at the graduate level and to lack of significant research experiences by the faculty who help plan and supervise the research. A review of graduate research theses reveals a strong orientation toward descriptive research. The infrequent cases where analysis is attempted often demonstrate the use of techniques which are either inappropriate to the data being analyzed or are simply exercises in the use of techniques on irrelevant data.

About half the graduate students are supported by assistantships from the university. The others are usually employed by a government ministry which permits them to be away three days per week to pursue graduate study. Admitance to a graduate program requires approval by the respective department and college. Generally an undergraduate average of "very good" is required for admission (at graduation B.Sc. students are ranked "pass", "good", "very good" and "excellent").

The usual time required to complete an M.Sc. degree in agricultural economics is four years. Seven years are usually required for a Ph.D. These time periods can be shortened somewhat but the shortage of staff, books, library facilities, transportation and communications makes it unlikely. In many cases the student finds that more time is required rather than less.

Quality of Training

As indicated before the political-economic ideologies of Egypt have undergone rather abrupt changes in the past quarter century. The present trend is toward market oriented democracy. This should be kept in mind when considering the response of Egyptian professional agricultural economists to inquiries about the quality or appropriateness of graduate training.

All U.S. trained Egyptian agricultural economists rate U.S. training first, Egyptian training second and Eastern Bloc training third. Some even go so far as to say Eastern Bloc training is completely irrelevant to the current needs of Egypt's market oriented economy. Some economists with Eastern Bloc training agree that what they learned is largely inappropriate to Egypt's institutional setting and present directions.

The interviews with in-country agricultural economists and employers of agricultural economists was somewhat helpful in determining weaknesses of U.S. training. Except for individuals who completely disregarded Eastern Bloc training there seemed to be general agreement that the U.S. universities should give more attention to marx/socialist ideology in order that U.S. trained professionals could better understand their Eastern Bloc trained colleagues.

Several respondents mentioned the need for more attention to economic development strategies for developing countries. As discussed in the last section of this report they were divided on how U.S. and Western European trained professionals should be assisted to make the transition from working with the problem of developed countries to the problems of less developed countries.

Project evaluation (feasibility analysis) was frequently mentioned as important in Egypt at the present stage of her development. Under the present "open door" economic policy the Egyptian government is attempting to attract foreign capital into partnership arrangements with Egyptian firms. Carefully developed feasibility reports support this process.

Other areas suggested for more emphasis in U.S. training include (1) administrative skills, (2) quantitative analysis, (3) techniques of data collection and (4) computer analysis of economic data. Administration or management of public and private organizations is considered by many people to be the single most serious constraint to Egypt's development. Agricultural economists who have had administrative responsibility especially recognize this need.

Major Problems Ahead

The most pressing problem for agricultural economists to address in Egypt during the next decade is that of increasing food production for a burgeoning population. Population growth currently exceeds 2½ percent per year and most people expect it to continue at that rate at least through the next decade. Given the base of some 40 million this means the addition of about one million people per year. The most recent Five Year Plan projects a population of 67 million by the year 2000.

Meanwhile growth rates for agricultural production are disappointing. The five year period from 1971 to 1976 produced growth rates in yield per feddan of less than 2 percent for wheat and maize and actual declines in yield for rice, beans, sugar cane and cotton. Although yields per unit of land are higher than many developing countries they fall short of average yields in developed countries by 20 - 40 percent. As stated in the most recent Five Year Plan these poor yields are attributed to an inefficient agricultural policy for research and extension of research results.

The Plan calls for expansion of agricultural mechanization, implementation of a price policy aimed at optimal crop formation, land reclamation and establishment of new rural communities, expansion of animal and fish protein production, expansion of private sector activity, agricultural integration with other Arab countries for the purpose of attracting capital funds, integration and coordination of agricultural research, improvement of food storage facilities, and re-building of cooperative societies. These are objectives which clearly offer a vital role for persons trained in agricultural economics.

Achievement of these objectives require the solution of difficult and complex economic problems. For example political considerations apparently require national subsidization of bread which is priced to Egyptian consumers at about ten percent of U.S. prices. As a result of such policies Egyptian farmers received only 80 percent of world prices for their wheat in 1977. Yet at the same time government policy calls for increasing production of wheat. Similar situation occur for cotton and rice where farmers received 50 percent of world prices in 1977. Meanwhile meat is priced throught the free market where high prices result in strong incentives for farmers to allocate resources to livestock. Other resource allocation problems include loss of one sixth of the water from the River Nile due to use inefficiencies, shortage of foreign exchange for commercial fertilizers and misallocation of existing supplies, land reclamation, exploitation of underground water and under-employment of labor.

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How Can American Universities Help?

All the persons interviewed reacted positively regarding the potential role of American universities in building the Egyptian agricultural economics profession. It was hard to find a consensus, however, in what this role should be.

One of the most experienced and respected Egyptian agricultural economists stated there is no substitute for thorough training in a developed country which has a favorable academic climate (implying books; library; quiet places for study, reflection and discussion; scientifically oriented colleagues; etc.). He felt research should be done by the Ph.D. candidate in the developed country and that if the result of such education was a thoroughly trained scholar than transference of methods to the developing country would be a trivial problem.

On the other hand a majority of the Egyptian professionals felt that other useful measures could be implemented by American universities short of complete reliance on U.S. training for Ph.D. course work and thesis research.

Faculty exchange between American-Egyptian universities was frequently mentioned. This would have a two-fold effect of providing useful opportunities for Egyptians to update their training and to keep up on developments in the U.S. The latter would be helpful in advising Egyptian students who are slated for U.S. training. Secondly it would give American professors who are teaching and guiding research of Egyptian students knowledge of conditions in Egyptian universities and the Egyptian research environment.

Collaborative research between American and Egyptian professionals was also mentioned . It was pointed out that this is now taking place with joint work between Egyptian professionals and U.S. professionals from Ford Foundation and several American universities supported through USAID grants. There did not appear, however, to be much interest in joint degree offerings for Ph.D. candidates. The problem of communications was given as the most important reason for making this impractical. A slight modification of joint degrees, favored by several professors, would be to approve a specified body of coursework to be taken in the U.S. with the thesis and administration of the degree handled by an Egyptian university. This could be done at the M.Sc. or Ph.D. level.

Post doctoral programs in the U.S. was encouraged by some respondents but they mentioned the problem of developing serious and meaningful work. Post doctoral work should not be considered as a vacation. Faculty exchange between U.S. and Egypt, with specified teaching and research responsibilities, was judged to be a more satisfactory alternative.

None of the interviewees suggested training in the U.S. for M.Sc. degrees as important. They were unanimous, however, in their support for selecting M.Sc. graduates from Egyptian universities for U.S. training. Every respondent mentioned the need for an inflow of at least a few foreign trained Ph.D. agricultural economists over the next decade and most volunteered the opinion that the U.S. was the best place for this training.

Lack of English skills by faculty and students was often mentioned as a serious constraint to the development of the agricultural economics profession. The ability to read the literature and discuss economic ideas in English needs improvement at all levels of the profession within Egypt. In this respect all people interviewed were encouraged at the prospect of increased interaction with American universities.

The following topical list summarizes the needs of the Egyptian agricultural economics profession and potential roles of American universities.

1. <u>Comprehensive Ph.D. training in the U.S</u>. All respondents mentioned the need for training at least a few Egyptian agricultural economists in the U.S. There was generally high regard for U.S. trained people. Opinions differed about the magnitude of this activity. One highly respected senior Egyptian felt there was no substitute for

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U.S. training while others felt a mix of U.S., Egyptian and Western European training would be realistic and desirable. All agreed that some means of outside financing for U.S. training must be found. As one Egyptian stated, "Egypt can hardly afford the wheat it must purchase from abroad to say nothing of graduate education." Egypt has a large supply of people trained at the M.Sc. level who could benefit from U.S. training.

2. U.S. course work for credit in Egyptian universities. This assistance would be planned under the guidance of the students' graduate committee in Egypt. In certain cases the students' graduate committee may include qualified Americans residing in Egypt. It was pointed out that some courses are weak in Egypt, especially in resource economics. Specially selected courses from U.S. universities could help strengthen a graduate program for an Egyptian Ph.D. candidate.

3. Faculty exchange. The potential benefits from faculty exchange were perceived as important. Egypt needs the assistance of U.S. professors for teaching and research counseling. At the same time these professors would gain understanding of the teaching-research situation in Egypt which would help them work with Egyptian students in the U.S. Egyptian professors on leave to American universities could update their skills and prepare their abilities to advise students going to the U.S. for training.

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4. Visiting professorship. Egypt is woefully short of well trained academic staff to meet the needs of the many students. U.S. professors could help with teaching, graduate student advising and research counseling. Also the opportunity for presenting seminars at gatherings of faculty and students could contribute substantially to the establishment of an Egyptian community of scholars in agricultural economics.

5. Post-doctoral work for Egyptian professionals. A well designed post-doctoral program especially for agricultural economists trained in Egypt and Eastern Bloc countries should be considered where a faculty exchange program cannot be arranged. Exposure to economic and social institutions gained from travel to developed countries could have a valuable impact on the present development process in Egypt.

6. Short term specialized training. This may be considered for periods of 2 to 6 months when a specialized need is recognized for training Egyptian professionals. Often times there are no good substitutes for hands-on training and the opportunity to make personal observations.

7. U.S. graduate students come to Egypt for research on Ph.D. theses. This would be welcomed by qualified Egyptian agricultural economists in several Egyptian universities. However it would probably require more development of professor exchanges, collaborative research, etc. before it could be successful.

8. Collaborative research. Several Egyptian professionals are already involved in collaborative research with American agricultural economists. They welcome more opportunity for such contacts.

9. Provide textbooks, journals and related reference books. It may not be possible for American universities as such to fulfill this need but it was mentioned as a serious problem by most respondents. The development of well stocked libraries with multiple volumes of the most important works would be highly useful.

EGYPTIAN FARMER'S PERCEPTION OF ALTERNATIVE EXTENSION STRATEGIES AND TACTICS IN IRRIGATED AGRICULTURAL DEVELOPMENT[4]

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Abstract

The paper reports field data characterizing 43 Egyptian farmer's perceptions of the suitability and effectiveness of various extension strategies and tactics which might be used by an irrigated agricultural development project beginning applied research work in their several communities. The sample of farm operators were given inventories of structured interview items measuring a) beliefs about who might have the greatest effect on improved local living conditions; and b) judgements about how valuable alternative extension approaches would be in local development efforts.

A range of specific findings are presented in the paper which are generally consistent with the theories found in the social science and extension literatures. Most generally, these Egyptian farmers show a realistic understanding of the value and appropriateness of specific alternative development strategies and tactics, probably far beyond that which is usually assumed by technical scientific personnel and government officials. Likewise, they believe they, themselves, can be the most effective category of people guiding and implementing non-technical local improvement.

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DEVELOPMENT AS PROCESS

Many people hold the understanding of "development" as the level of material and economic accomplishments of a nation. This leads them to conclude some rich and powerful nations have achieved development, while most others who are poor and less powerful or prestigeous remain clearly "underdeveloped". On the other hand, when development is viewed as a problem-solving or goal seeking process (as most development experts view it), the conclusions can be quite different. Although material wealth is part of the development picture, it is more a result of development than the process itself.

The process is what deserves our attention, for it is what we have to work with when we hope to benefit our nation or others. Most simply, development is best thought of as realizing a growth in our human abilities to achieve our realistic aspirations. Mostly, it is progressing in our effectiveness as human beings, given that we have desires and appreciations for others. Growth in human sensitivities and abilities is both development's basic method and objective.[1]

Given this "process" meaning of development, it is the way people deal with their natural and social environment. Put another way, it is their activity in "developing" more than their level of material worth of power that lets us call them "developed". Perhaps the word "progressive" is a better way to think of development, for it emphasizes a society which makes opportunities available for citizens to grow in their capacity to accomplish their goals. The progressive society also provides educational, social and economic incentives to encourage people to use their productive energies at a very active level. In contrast, the under-developed or non-progressive society is that which is not showing its dynamic human potential, even if it has achieved a rather high level of material and economic accomplishments.

Problems in the development of poor nations largely concern conditions of the rural population, which typically forms the society's massive base. In these cases, improving agriculture plays an important part in the society's development processes both because so much of the society is directly involved in it, and also because it is often the primary basis of the society's welfare and stability.

In Egypt, agriculture depends upon the productive activities of more than one-half of Egyptian society, and provides satisfaction of the basic needs of every one of its 40 million people. Also, agricultural produce and processed goods make up the largest portion of Egyptian exports. These are a major source of hard currency which supports many basic development processes in the country.

Egypt has limited agricultural lands, industrial capacities and natural resources, and a high rate of population growth.[2] These factors make it essential that human efforts be stimulated and effectively used as a basic means to achieve goals of a high level of social welfare, security and standard of living for all.

The approach Egypt has taken for realizing development depends largely on applied research. As national development activity has increased, so have its applied research institutions. Particular attention has been paid developing new means for increasing agricultural production (most Egyptian agriculture is irrigated) and improving the welfare of the rural population.

It is clear that having found answers to rural problems is not enough to solve them, however. The results of the research must be diffused and utilized effectively before advantage can be realized. Much of the research, in fact, must be on the processes by which the rural population can receive and understand information on improved irrigated agricultural practices. In many cases this includes the processes by which farmers themselves must cooperatively implement improved practices.

THE EGYPT WATER USE AND MANAGEMENT PROJECT (EWUP)

To meet applied research needs in Egypt, the EWUP was begun just over a year ago to provide unique guidance and support to the development of irrigated agriculture in selected target areas of Egypt representing different types of old lands strategically located as diffusion points of the country. The project approach to irrigation development has three emphases:

1) development of new appropriate technologies for field diffusion, including both material and social (procedural) techniques and tools;

2) extension work--bridging the often large and critical gap between scientists and farmers (the emphasis of this paper); and,

3) training/institutionalization among professional workers so that more effective means for accomplishing sustained agricultural development processes may be realized.

The project is jointly funded by the Government of Egypt (GOE) and the U.S. Agency for International Development (USAID). It brings together a team of Egyptian and American professionals from several disciplines (agricultural and civil engineering, agronomy, economics, sociology and

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extension) to provide a broadly balanced team in true interdisciplinary fashion.[3] Part of the uniqueness of the EWUP approach is that it honors the themes and cautions of the more recent rural development literature 1) that natural diffusion processes be the ultimate/basic means of extending the program; 2) that it focus on economically feasible approriate technology for farmer adoption; 3) that the intermediate objectives be broad and balanced to keep the development process unitary and appealing to general felt needs of constituent farmer population; 4) that the ultimate objectives be the most basic ones--improving social living conditions for the farmers (e.g., not "development for appearance's sake", having "signs of development", but actually realizing general processes for achieving improvement of farmers' living and labor conditions, of community and society).

The conceptualization of the project identifies the general objective to be improved socio-economic conditions for the small farmer in Egypt. This is to be accomplished through improved management practices of precious water, land and other agricultural resources.[4] As background, it should be understood that a factor generally believed to be effecting present agricultural production and, more importantly, threatening sustained future agricultural production of Egypt on limited old lands, is high water table, soil salinization and by-products of sub-optimal on-farm water management--leaching nitrates, etc. Expressed as a casual sequence, beginning with the most immediate concerns, it is assumed that improved management of irrigation and related agricultural practices will result in improved crop yields and conservation of scarce land and other agricultural input factors. This provides the basic means for general rural and societal development so that farmers and all Egyptian citizens can experience more satisfying and effective lives.

The operational approach of the project conforms to what is often called "action research"--or, the applications of the procedures of relevant scientific areas to the identification and solution of present and anticipated problems of irrigated agriculture, with constant feedback and involvement of the constituent population. For instance, the "on-farm" emphasis of work means that all development experiments are conducted on the field being worked by participant farmers (vs. separate "demonstration plots") who have been invited to join the project in a full working partnership, and who are thoroughly integral in the process at all stages and in all ways. This means, as well, that the research foci include both determining 1) technical improvements in irrigated agriculture practices and 2) procedures for being more effective in facilitating farmer understanding and cooperation in the joint venture activity. The latter concern is emphasized in this paper.

Some of the philosophy contained in the development/ extension literature deserves summary to provide a fuller explanation and justification of the EWUP approach.

EXTENSION PROCESS AND METHODS

In the extension process, considerable time and effort must be invested between the time a new idea is available and the time it is widely adopted and applied. This often is due the existence of impediments which slow or prevent the diffusion and/or application of an idea. Some of these impediments are due to psychological or cultural factors related to society, individuals or to situational factors surrounding them. Every society has cultural, social, econ-

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omic and political circumstances which make that society distinct from other societies. Impediments may also result from characteristics of the innovation itself. Or, there may be problems with the systems which are concerned with diffusing the alternatives and innovations and the methods or aids which they employ.[5]

Extension always aims to remove impediments to effective diffusion and application, in order that desirable and necessary behavioral changes be effected in the client population. It has created and used a variety of methods and aids to diffuse agricultural alternatives and innovations among farmers. It encourages farmers themselves to participate in the process by diffusing information to other farmers.

Since the choice of extension methods is of great importance to program effectiveness, it is necessary for extension workers not only to know advantages and limitations of available extension methods, but also to know farmers' perceptions of these methods. This allows extension workers to make decisions about which methods to use taking into account both what the literature advocates and what the farmers consider appropriate. In this way we can be more sure of using the most effective and efficient methods for the particular circumstances in which the work is taking place.

Concerning extension methods, the professional literature emphasizes several basic themes[6].

1) The development process should be flexible and involve farmer participation in all development activities aimed at his realizing satisfaction of felt needs, so that he not only enjoys concrete gains, but even more importantly, gets an understanding of and confidence-building experience with grassroots development processes themselves.

2) Extension strategy should emphasize capitalizing on "felt needs" of farmers to facilitate their personal interest and involvement in the process, making relations with constituents largely a learning/experimenting process for them.

3) Tactics should emphasize activities (or other tangible "proofs" of the process), keeping decision-making as close to grassroots level as possible, improving communications and social organization in support of the process, allowing it to be a flexible, incremental process with ample, early, if small successes to justify enthusiastic participation and broad-based interest in the development process.

In brief explanation of these themes, we begin with the fact that extension workers must fully understand and consider worthy and appropriate the alternative or innovations to be diffused. This implies that the extension worker must have good knowledge of the innovation itself and of the client population and its environment. To understand new or alternative agricultural practices is a matter of technical knowledge. Understanding of the client population and its environment is accomplished through studying those people and their circumstances. Of critical importance, the worker must learn about: the needs, interests and characteristics of the client population; social, cultural, economic and political conditions/setting of the local area and the nation; formal and informal communication and leadership patterns; how receptive the client population is to general change (e.g., receptivity to adoption of new practices, ideas) and how knowledgeable they are about particular innovations; and how and why all of these various factors are related one to another[7].

Such background gives the extension worker the insights and understanding to be able to decide if a particular agricultural practice is of relevance and appropriate to farmers in a given area. It also provides the basis for making decisions about how to encourage diffusion and adoption of new or alternative practices.

A variety of general methods, too many to specify here, can be used to promote diffusion and adoption[8]. Briefly, several broad categories include mass media, public meetings, on-farm visitations and use of experimental or demonstration plots. Decisions about which method(s) to use when and with which people, are guided by insights gained from previous information the extension worker has collected. For example, if the worker knows that many farmers are completely unaware of a new practice, a large number of them can be reached quickly and with little effort through a mass media and public meeting information campaign which focuses on explanation of the practice, its advantages and limitations. Later, when farmers are aware of the new idea, more personal contact and perhaps the opportunity to view results of the practice (on a demonstration plot, for example) may be appropriate. At these later stages in the adoption-diffusion process, background information about the client population and its context is particularly important, as it suggests to the extension worker whether his appeals should be based in psychological, economic, social or other motivational approaches[9].

Finally, it is important to note that farmers themselves are critical to the extension process. The most effective proponent of a new practice is the person who has had successful experience with it. Thus, the extension worker who convinces a small number of farmers to experiment with a new practice on a part of their own lnad, often finds that his efforts are multiplied many times when the few farmers experience success and tell their neighbors about it.

STUDY PROCEDURES

We began this research aware that local and societal circumstances vary and can have an effect on the applicability/perceived appropriateness of tactics. As well, the situation in recent Egypt is one whre farmers are not accustomed to much openness, informality and collaboration between technical agriculture personnel and themselves. Therefore, the question arose early, "is the general extension literature, resulting largely from other situations quite different than the Middle East and Egypt, good guidance in this case?" Expressed another way, we wondered: "are the advocated approraches too different from the expectations and recent experiences of Egyptian faremrs, government personnel and institutional structure, and technical/scientific personnel to be easily accepted by them?" Thus a first extension research priority fell on studying constituent population perceptions of what were appropriate, acceptable and effective ways of working with them in irrigated agricultural development.

Data were collected by structured interview with a sample of 43 farmers who had agreed to work closely with the project on all or a portion of their farms. The selection of these farmers was based on engineering, agronomic and socio-economic criteria. Main criteria were: 1) Farm location with respect to source of irrigation water; 2) Irrigation systems and methods (gravity, different types of lift); 3) soil types; 4) Ownership and other social aspects; 5) Kinds of crops; 6) Shape and leveling of fields; and 7) Continuous flow and rotational delivery[10].

The study units were case study farm operations, from which a range of detailed information is being collected by all scientific disciplines represented in the project.

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Presently two geographic areas are included in the intensive study work: 1) several water course areas in Giza Governate--a small-farm area of broadly mixed crops including vegetables, near Cairo; and 2) a water course area in Kafr El Sheikh Governate, in the center of the Nile delta area. Work is just beginning in a third area representative of old lands--along the upper Nile near El Minya--though data are not yet available from this area for reporting.

Three separate rounds of structured interviews were conducted in colloquial arabic by the project field sociologists, who received supervision and training from the project's two senior sociologists. The interviews were conducted in 1978. The first interview largely concerned agronomic and irrigation practices of the case study farmers and used many open-ended questions. The second round represented more conventional rural sociology measurement of social participation, leadership, communication, organizational matters, and some follow-up focused on attitude questions, agricultural and irrigation practices and policies. The interview schedule used contained mostly structured items with relatively few open-ended questions. The third round of interviews focused on perceptions of appropriate development strategies and tactics and other general attitude matters like community satisfaction, general receptivity to innovation and change processes, self-confidence in decision-making, etc. The third round, emphasized in this paper, was entirely forced-choice items, frequently using Likert-type "agree-disagree" response categories[11].

The schedule was developed by a normal social science procedure. A literature review and long discussions of conceptual issues was involved. Extended discussions were held with social science collegues on other projects in Egypt and elsewhere known to be experienced in handling such topics as ours. Sample items wre compiled and discussed. The translation process was a critical, difficult and extremely important part. It involved extensive discussion of the comparability of local Egyptian conceptions and western-oriented social science conceptions of the ideas involved. This was a particularly valuable learning experience for all participants. Attention had to be given finding empirical referents that could be offered farmers as clarification of the general item without "leading" them. The discussions led to much clarification of concepts and measurement procedures. Before use, the interview schedule was pre-tested and revised. It will undergo further revision before use in a large-sample study to be undertaken later.

We are just beginning systematic analysis of data from the subjects whose responses are reported here. Shortly, the results of computer analysis will be available to determine the scale characteristics of these and to enable correlations with a range of other data collected (including farmer's demographic characteristics, irrigation and agronomic practices, social participation and communication characteristics, and attitudinal variables like community satisfaction, recéptivity to change, self confidence with decision-making, etc.)

It should be noted that data other than these interview responses were used in the interpretation of findings. We have drawn personal recollections and impressions from fieldwork contacts, data and impressions of other social science researchers working in similar Egyptian circumstances, and secondary data available on related rural development matters in Egypt.

FINDINGS AND INTERPRETATIONS

Data are summarized here in percentage distributions accompanying the actual interview questions used in their collection. Following data presentation, comments call attention to major features of the separate results, and note implications of them. In the interpretation process, insights from various other data sources are introduced when they contribute background or clarification.

The data on farmers' perceptions of extension strategies and tactics are presented in response to three basic questions: 1) What kinds of people make the biggest contribution to local rural development success? 2) What, generally, should be done to promote and facilitate rural development processes (i.e., what are good strategies)? and, 3) How, more specifically, should these strategies be implemented (i.e., what are effective tactics)? For each of these questions, respondents were asked to choose from a range of often-advocated or used options, in this way indicating the importance or value of that particular item.

Contributors to Rural Development

Responses to the first issue, "Who makes the biggest difference?" are summarized in Table 1. The data show the farmers hold views consistent with professional views in the rural development and extension literature. That is, people at the local ("grassroots") level, assuming they are functionally viable as individuals or groups, are thought to be the main ones who provide the initiative and practical insights upon which effective rural development depends. As a person moves upward in levels of administrative power and responsibility, the presumed contribution he makes diminshes. In the farmers' view, persons in central government ministry

TABLE 1. FARMERS' PERCEPTIONS OF WHO MAKES THE BIGGEST DIFFERENCE IN RURAL DEVELOPMENT PROCESSES IN PERCENTS (N=43)

Item: "What are your ideas about how much help each of the following groups of people can help improve life in a village like this?"

	can be most helpful	might be some help	would be no help at all	Total
A. Ministry officials and Parliament	27.9	18.6	53.5	100
B. Government officials at governorate and district level.	37.2	44.2	18.6	100
C. Chairman and members of the governorate council (elected).	41.9	18.6	39.5	100
D. Government officials at village level.	83.7	14.0	2.3	100
E. Chairman and members of village council (elected).	27.9	37.2	34.9	100
F. Local informal leaders/ influentials.	72.1	20.9	7.0	100
G. Local citizen's organizations (as coop.)	88.4	9.3	2.3	100
H. Experts in applied scientific research.	76.8	20.9	2.3	100
I. Village people making an effort to solve their problems by themselves.	81.4	14.0	4.6	100
J. Can you think of any other groups of people who might be helpful? What kinds?				

and political positions are thought to make the least difference.

Several factors help account for limited local feelings of dependence upon direct assistance from high levels of central government for their development. It must be noted that this is a healthy national situation and realistic as well as insightful on the part of the local population. This attitude of local self-reliance is doubtless partly a reaction to extensive national-level regulation of agricultural production and marketing, which is more oriented to satisfying national needs than local farmer interests directly. Thus many farmers often see government activities in the agriculture sector as an unwelcomed imposition (as seems to be a common characteristic of farmers around the world). As well, most assume intervening factors make national-level actions less effective or efficient than local ones. Specifically, a) the farmers assume their local situations and problems have limited visibility to high officials; b) the layers of bureaucracy between them and the ministries/assemblymen are often thought to filter information flow up and implementation of policy down; c) most understand that national leaders are faced with a range of highly pressing problems (national security, urban growth, development resource limitations, etc.) that occupy attentions of the top; d) importantly, too, the rural populations know that the national design and implementation intentions for rural development in Egypt are good. They recognize that only problems of limited resources and the sometimes ineffective functioning of intermediate-level bureaucracy interfere with the realization of local development according to plans. They are also aware that national-level policy must be uniform in order for justice to be served, but that a uniform national policy often interferes with the government's ability to deal with

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differing local circumstances in different ways. In realization of these facts, the Egyptian President, as of January, 1979, set an official course of decentralization of authority, vesting governors with presidential powers, and District officials with a Vice-Minister status so that autonomy and localized initiative in problem-solving might become reality.

The point is, the farmers realize what the President does: that people nearer the local level who know the problems the best and feel them the strongest are the same people who are most critical in their solution. Intermediate levels of government are viewed as being the most appropriate for coordination and institutional factilitation.

It is important to note that one category of participants in the rural development process--scientists and technical experts--are outside of the adminstrative heirarchy. They are valued by farmers as contributors who can give practical advice directly at the local level where they are working. They can also give general counsel to the top levels, where they have an input into policy deliberations.

A final observation about this set of data is important. Since rural development is largely a process depending upon realistic perceptions of possibilities and prerogatives at the local level, these farmers give evidence of being well along the path of development. They are already quite "developed" in important ways. They display basic attitudes and understandings in support of the process. They assume that local initiative and responsibility are a major factor in their enjoying a better life in the villages. They should not be considered "ignorant undeveloped peasants" (although they often seem to enjoy playing this role for non-local audiences). In fact, they are best thought of as clever,

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hard-working people who are "developing" in the truest meaning of the term.

Rural Development Strategies

We turn now to the second basic question raised: "What are farmers' perceptions of effective strategies for local rural development?" Themes in the professional literature on this matter have been summarized above. Table 2, presents the farmers' views on the relative effectiveness of alternative strategies.

High priority (i.e., "essential") approaches acknowledged by most respondents include: 1) improved adult and youth educational programs; 2) better information on things that affect village life; 3) more effective local leadership; 4) improved cooperation and organization among local people; 5) improved public-sector service structure (roads, potable water, etc.); 6) better availability of occupational and other tools; 7) additional locally-based industry to supplement employment opportunities; 8) strengthened morality (or conscientious propriety) in daily behaviors; 9) greater respect and privileges for those who invest themselves in community improvements.

The views of sample farmers on needed elements of development strategies are highly consistent with the emphases of the professional literature. Both agree attention should be given providing learning experiences for the constituents, so their personal effectiveness can be increased as a basic part of the process. This includes acquiring improved abilities to successfully attend to both routine farming, home and community tasks, and to the special challenges of changing local life through locally-based developmental processes.

TABLE 2. FARMERS' PERCEPTIONS OF ALTERNATIVE RURAL DEVELOPMENT STRATEGIES IN PERCENTS (N=43)

Item: "I have a list of some general things other people have thought might be helpful for improving conditions in the village. As I read each idea on the list, would you tell me whether you, yourself, consider it: essential, somewhat important or not important for improving life in the village?"

		essential	somewhat important	not important	Total
A.	More and better education for adults and children.	97.7	2.3	-	100
B.	More effective local leadership.	93.0	7.0	-	100
C.	Having local people care more about each other's needs.	76.7	14.0	9.3	100
D.	Having the government do more developments like roads and water systems for the village.	100.0	-	-	100
E.	Having more money or credit for the village.	55.8	14.0	30.2	100
F.	Having new industry come to the village area.	93.0	7.0	-	100
G.	Having better cooperation or organization among local people.	90.7	7.0	2.3	100
H.	Having more morality (basic good and proper behavior) in village life.	100.0	-	-	100
I.	Cotrolling population growth.	46.5	9.3	44.2	100
J.	Having new machines and tools available in the village to use for one's farming or other work.	100.0	-	-	100
K.	Having more respect and privileges for those people who work hard for village improvements.	97.7	2.3	-	100

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TABLE 2 CONTIN. FARMERS' PERCEPTIONS OF ALTERNATIVE RURAL DEVELOPMENT STRATEGIES IN PERCENTS (N=43)

	essential	somewhat important	not important	Total
L. Having better information on what is going to happen that will affect the village.	95.4	4.6	-	100
M. Having the government make new rules to require that some people change their ways (behaviors) in the village.	39.5	25.6	34.9	100

This second matter involves procedures for improving the effectiveness of local leadership and local communication and coordination patterns as key private-sector parts of the facilitating structure of development. Related, public-sector supports that help satisfy basic needs of the population--roads, food and water supply--must be developed as a facilitating condition. As well, technical supports for development processes like tools used in improved processes need to be obtained. In places where population pressures are having effect, acquiring additional employment opportunities may be important support for more basic development processes.

There is also a qualitatively different dimension, but one as important as all the others. It provides the sense of values that are central in the process, and also functions to prevent unreasonable local disruptions as a by-product of development. Specifically, farmers realize that common conceptions of moral standards generally, and respect for and recognition of human contributions, specifically, must be strengthened as a part of the development processes.

The number and range of items given highest priority demonstrate a mature perspective on rural development processes among these farmers; they do not naively look for simple or single approaches to their development. This is particularly evident when items judged relatively less critical (i.e., lower proportion of people thinking them essential) are considered. For instance, a factor often thought to be the basis of development (even, unfortunately, among many professionals) is feeding money or credit into the social system. Given the farmers' understanding of grassroots development processes, they are realistic enough to know that the purpose of new capital can only be in support of other development efforts, and that it often carries with

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it distribution injustices (i.e., the quesion of who really benefits, or has access to new fiscal resources). Further, they assume it would probably involve sufficient application and regulation difficulties to discourage its effective utilization by them. Islamic cultures promote concepts of fiscal self-sufficiency within families or among friends, and do not accept the concept of "interest." Recent changes in the local bank system have made some new sources and conditions of credit available, without much immediate effect on local development processes. In balance, most farmers probably feel they have sufficient access to investment capital to satisfy their immediate private-sector development expectations, and are suspicious of the "strings" often attached to new capital.

Population control as part of integrated rural development strategies doubtless received relatively low ranking for several reasons. In part, it is commonly thought of as and indirect casual component of development (if it is thought of at all). More importantly, however, the Islamic tradition is generally thought opposed to contraceptive birth control, and farmers feel basic needs for nutrition and shelter are being satisfactorily met in Egyptian villages thus supporting both Islamic and Christian conceptions that God will provide for those He has created. Given this, it is perhaps most noteworthy that almost half of the sample thought growth control a very important strategy matter.

It is not surprising that farmers see the lowest-priority strategy option as government coercion to effect changes, even if the changes are thought important ones. This approach appears a most commonly practices one in recent Egypt (although changes are presently underway in this regard). There is a negative reaction to the approach by some; among

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others it is a familiar approach thought to be an effective, though not always pleasant, means of getting change. Farmers, like extension professionals, seem to realize the coercion strategy yields "development" only in the sense of material accomplishments, but not as a path to greater individual initiative, cooperation or satisfaction.

Rural Development Tactics

These matters of general strategy set the stage for a consideration of farmers' perceptions of operational tactics. We consider here their perceptions of how appropriate strategies can be effectively implemented by development field programs. As before, sample farmers were presented a series of frequently used tactics which they were asked to rate in terms of probable value of each in realizing their aspirations. These data are summarized in Table 3.

It is noteworthy that farmers give emphasis to three general themes: 1) they put more value on tactics intended to facilitate their learning how to be more effective farmers and village citizens, which they assume to be tactics emphasizing highly visible demonstration teaching keyed to their present personal interests; 2) they put more value on tactics that interface farmer interests and efforts with the special abilities and powers of development resource experts so that a balanced development partnership can be realized as a process largely implemented by their actions, which, in turn, are guided and facilitated by specialized knowledge and resources; 3) they understand that it is essential in this process to have and use good local leadership in support and coordination of the process. For instance, specific items which are judged highest-priority tactics include:

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TABLE 3. FARMERS' PERCEPTIONS OF ALTERNATIVE RURAL DEVELOPMENT TACTICS IN PERCENTS (N=43)

Item: "How valuable do you think each of the following ideas would be in helping change things that need improvement in the village?"

	most valuable	somewhat valuable	no real value	Total
A. Films and rural theatre telling how to do things better.	83.7	11.6	4.7	100
B. Pamphlets telling how to do things better.	25.6	46.5	27.9	100
C. Expert speakers telling how to do things better.	83.7	14.0	2.3	100
D. Occasional demonstration by experts that show how to do things better.	93.0	4.7	2.3	100
E. Permanent demonstration farms and shops that prove how to do things better.	95.4	2.3	2.3	100
F. Having experts available to answer questions when you want to know how to do things better.	93.0	4.7	2.3	100
G. Posters and slogans reminding people what they should do for improvements.	27.9	44.2	27.9	100
H. Having local public meetings at which citizens can speak their minds to influence decision-makers.	95.4	2.3	2.3	100
I. Having citizen's opinions and ideas collected by researchers so decision-makers can know how the people feel about things.	55.8	41.9	2.3	100
J. Having expert consultants make recommendations for change.	62.8	37.2	-	100

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TABLE 3 CONTIN.: FARMERS' PERCEPTIONS OF ALTERNATIVE RURAL DEVELOPMENT TACTICS IN PERCENTS (N=43)

	most valuable	somewhat valuable	no real value	Total
K. Local citizens discussing what they need and what they can do to get it.	51.2	16.3	32.5	100
L. Having an effective, representative village council to influence government decisions.	95.4	2.3	2.3	100
M. Having a village committee or association for guiding local development.	53.5	30.2	16.3	100
N. Having trained government planners direct and coordinate local changes.	65.1	23.3	11.6	100

A) Permanent and special demonstration activities, showing how things can be done better, so farmers can understand and consider personal adoption of innovative practices;

B) Availability of expert resource persons whom farmers can turn to for information and guidance;

C) Expert speakers, films and rural theatre that present information on practices in a way that is easy for them to understand and relate to.

Written materials were understandably judged less valuable by these farmers, the majority of whom do not read. Since they were asked to view the development process from their personal perspectives, many specifically commented that written materials would be useful for Agricultural Cooperative personnel and others who advised them on improved practices. Side comments reported by interviewers indicated posters and slogans were judged relatively less valuable for several reasons. First, they are recognized as superficial actions that don't contain enough substance to provide meaningful guidance. Second, they are often thought to symbolize an approach to local development--decisions imposed from the top down--which the farmers have limited confidence and trust in;

D) Highly valued is the bringing together of local citizens and public decision-makers for dialogue, so that locals can have a direct influence in that substantial portion of their lives that is administered for them;

E) Related, they put very high value on having an effective village council structure (which includes lay citizens and local representatives of the local government service structure).

In both of these last cases, as was generally true of education tactics noted earlier, citizens and experts or officials are combined as an interactive force for local development, each having something important to cotribute, in complementary fashion. This point is clarified when we consider some similar tactics that were not rated so highly. For instance, having researchers collect opinions, analyze them and present them to decision-makers was considered distinctly inferior to having the opportunity for direct dialogue with the same people (although in many ways it would be easier and safer to work through intermediate data collectors).

Similarily, they put less value on having the process be entirely their own, without expert or official support. Autonomous local citizen discussions or a grassroots organization guiding activities do not hold as much promise, largely because the farmers realize they lack certain competencies necessary to make it work well.

In contrast, they also do not think it valuable to turn the development process over to the experts alone. Their confidence in the performance of expert consultants operating independently of normal community processes, or of government planners implementing the process in their behalf, is less than with a combined local-expert effort.

IRRIGATED AGRICULTURE APPLICATIONS

Based on this review of local perspectives on general development strategies and tactics, we should briefly consider their specific implications for the development of irrigated agriculture practices, where they are equally applicable.

First, we should note that the development of Egyptian agriculture is primarily a process of improving farmer's irrigation and agronomic practices so that their efforts and production inputs are used more effectively, resulting in improved yields. As a process, it must emphasize encouraging and facilitating farmer's understanding the value and techniques of alternative farm management practices so they will voluntarily adopt appropriate practices, later adapting them to fit new situations and problems. Further, they must be so satisfied with the results that they encourage their neighbors to do the same, serving informally as the most effective possible extension agents. Good knowledge of when to apply how much irrigation water or fertilizer or herbicides is basic in the process, of course.

As well, the development process must emphasize coordination among neighboring farmers in the Egyptian irrigated agriculture case, for many aspects of improved farm management require alternative practices be adopted by groups of adjacent farmers rather than just some individuals. Coordinating in the maintenance of private ditches and drains, cooperating to obtain equipment or services, practicing area-wide insect control, etc., are important parts of developing agriculture. They are recognized by both farmers and experts as some of the more difficult aspects of the process, but ones which must be included as the complement of improved individual practices. Improve understanding among farmers for how and when to pursue voluntary coordination of individual efforts is a matter requiring a different sort of expert assistance--the extension of alternative "social technology"--but is as basic to the agricultural development process as anything else, and the extensive "spill-over value" to improvements in other areas of community life as well.

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Improving information flow between farmers and experts, and among farmers themselves, is central in the process. Experience has shown that canal closures, new water measuring devices or structures, the presence of agricultural equipment, etc., must be understood by farmers to alleviate disruptive suspicions and rumors, as well as work in support of the adoption and diffusion of innovative practices they enable.

Strengthening local leadership, cooperation and organizational effectiveness is likewise an important aspect of the process. If farmers who adopt procedures for more efficient application of water to [illegible] fields are strengthened in local influence, their role in extending these procedures will be more effective. The process, in fact depends upon them, for there are not enough extension agents available to convincingly reach all Egyptian farmers. In the same vein, the effectiveness of land-leveling efforts as part of improving irrigation efficiency and crop yields depends upon farmers coordination in planning and implementation. Land plots are usually too small to do this on a single-farmer basis and the government does not hold the legal or manpower resources to effectively accomplish this by itself.

Building the public-sector service structure in support of irrigated agricultural development largely means assisting the Cooperatives or Village Service Centers to be more effective in Egypt. Partly, this can be done by increasing the technical knowledge and sense of responsibility of its officials, but also it may involve augmenting the implements it has available, arranging it to be exempted from some locally imprudent policy passed down from above, or encouraging farmers to learn how to use it and appreciate what it can do for them.

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Encouraging and facilitating support industry may be a part of the process. As small-scale land scrapers or new canal lining materials are developed, there comes need for their production. Promoting the government or private sector manufacture--preferably in a "surplus labor" rural area--is something that is part of the technical expert's role that is often easily fulfilled.

It may not seem, on first consideration, that promoting morality or mutual respect among farmers is a part of developing irrigated agriculture. It is a very important part, however. Acknowledging, capitalizing upon and strengthening major value themes of the target community can be critical to the success of development if, for instance, village people think proposed changes will undermine their value positions. In contrast, beliefs about the almost-sacred qualities of water or congenial relations among family and friends can be used effectively in support of irrigation or agronomic objectives. In the final analysis, any social problems which occur among Egyptian farmers that can be even hypothetically traced to development processes underway will lead to a general negative reaction that can undermine the permanency of accomplishments and the prospects for more. Experience has shown that using the assembly at the mosques on Friday, working through religious leaders and supporting local conceptions of morality by one's example is something irrigated agriculture experts must pay attention to.

When attention turns to techniques for successful agriculture development, several matters deserve emphasis. A farmer's energetic participation in the process will come primarily by his seeing personal value in its accomplishments for him. If experts pay first attention to what farmers think their farm management problems are, what methods

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farmers consider appropriate, and what contributions technical expertise can make to these within the limits of local resources, then there should be little trouble in getting the farmers attention. Once attention is obtained, the farmer's extensive input to the solutions of these problems should be added. The simple rule of thumb is: never do for farmers what they could possibly do for themselves with your help, and never encourage them to undertake efforts that cannot be successfully replicated by farmers once they have learned how they are done. This enables innovations to diffuse through the national agricultural sector at the hands of farmers, and builds in a "safety valve" for screening out innovations which will likely not work out well.

Whenever a new practice can be demonstrated in advance of its trial application, it should be. Similarily, it should be explained as fully as the farmer's level of understanding will allow. The use of a variety of the most visual and enjoyable educational techniques available produces the greatest comprehension. With this understanding comes the ability to explain to others, and to find modified applications of the technique thus adding to its value.

From small successes the farmers had a role in realizing comes pride and enthusiasm for more of the same. In this way, simple development efforts in time lead to more ambitious ones that may be more basic to the development of irrigated agriculture. Encouraging three neighbors to cooperate in uniform leveling of their adjacent fields, for instance, may be a significant step toward getting all farmers on the watercourse to develop a schedule for their irrigations. Although the process may be a slow and indirect path to achieving those objectives the experts in the process value,

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it is often the only way to be effective in the longer run.

Since the data considered here show Egyptian farmers in the areas of Egypt Water Use Project activities to have a developed understanding of and preference for the strategies and tactics discussed here, and elaborated in the development process literature, the major implications for development success among the farmers seem to be: respect them, their desires, their ideas and their efforts; work with them primarily as a resource person, and in time the fruits of the partnership for progress should be a wide range of specific benefits for all parties concerned.

ENDNOTES

1. Of the numerous sources that elaborate on this interpretation, the following represent ones which develope the concept and its implications in somewhat different directions: Ronald Lippit, Jean Watson and Bruce Westley, The Dynamics of Planned Change, New York: Harcourt Brace, 1958; R. R. Carkhuff, The Development of Human Resources, New York: Holt, Reinhart and Winston, 1969; C. G. Bennelo and D. Roussapoulos, The Case for Participatory Democracy, New York: Grossman (Viking), 1971; Denis Goulet, The Cruel Choice, New York: Atheneum, 1973; Harvey A. Hornstein, et al., Social Intervention, New York: The Free Press, 1971; D. W. Thomas, et al., Institution Building, Cambridge, Mass.: Schenkman, 1972; Szyman Chodak, Societal Development, New York: Oxford University Press, 1973.

2. Mohamed Kamel Hindy, et al., Egypt: Major Constraints to Increasing Agricultural Productivity, Washington, D.C.: USAID (Foreign Agricultural Economics Report No. 120), 1976; H. A. El-Tobgy, Contemporary Egyptian Agriculture, Cairo: Ford Foundation, 1976; Elias H. Tuma, "Population, Food and Agriculture in the Arab Countries," Middle East Journal, 28 (3), 1974.

3. The E.W.U.P. approach is consistent with that called for by Gekee Y. Wickham, "The Sociology of Irrigation: Insights from a Philippine Study," Teaching Forum of the Agricultural Development Council, New York (No. 31), 1973, p. 2ff.

4. Wayne Clyma, Max Lowdermilk and Gil Corey, "Rapid Technology Transfer for Improvement of On-Farm Water Management by a Research-Development Process," Fort Collins, Colo.: Engineering Research Center, Colorado State University, 1978.

5. Excellent examples in the irrigated agriculture context are found in Michael Cerna, compiler, "Background Papers ... for the Workshop on Sociological Dimensions of Irrigation Projects," World Bank, February, 1977.

6. Conrad Arensberg and Arthur Niehoff, Introducing Social Change, Chicago: Aldine, 1964.

7. W. G. Bennis, K. D. Benne and R. Chin, eds., The Planning of Change, New York: Holt Rinehart and Winston, 1969; H. C. Sanders, ed., The Cooperative Extension Service, Englewood Cliffs, New Jersey: Prentice-Hall, 1966.

8. Good summaries from somewhat different disciplinary perspectives are: H. C. Sanders, Ibid.; M. S. Knowles, The Modern Practice of Adult Education, New York: Association Press, 1970; Arensberg and Niehoff, Op. Cit.; Ronald G. Havelock and Mary C. Havelock, Training for Change Agents, Ann Arbor, Michigan: Institute for Social Research, University of Michigan, 1973.

9. Everett Rogers, Diffusion of Innovations, New York: The Free Press, 1962; E. Rogers and F. Shoemaker, Communications of Innovations, New York: The Free Press, 1971.

10. When case study of common research units is done by disciplines with quite different data needs and methodological traditions, it is usually necessary for all to compromise some desires for case selection criteria so that comparable observations are available for cross-disciplinary analysis. This situation prevailed here.

11. As a methodological note on the use of structured schedules for such a population, we began by being skeptical that it would work well, but had reason to try so that comparable cross-cultural data on these matters could be collected and analyzed. Also, we thought it might expedite the collection and processing of such a range of specific items. Generally, we found the procedure worked well, and only had the deficiencies that apply to the use of the procedure in other settings where forced-choice items are more commonly used (e.g., referents must be clear, as subjects do not ordinarily deal in abstract conceptions in a very meaningful way, and so they must be anchored in real, familiar circumstances that can be more easily visualized). We found the use of this type of item on these and other scales provoked careful thought in these subjects; there was little evidence of any cliche-conditioned response patterns.

Irrigation Technology for Desert Land Reclamation[1/]

E. V. Richardson and V. A. Koelzer[2/]

Introduction

The irrigation of desert lands provides both an opportunity for agricultural development and economic gain and the potential for an economic disaster. Aridisols of the desert with irrigation can be very productive. However, those lands outside of alluvial valleys may contain large quantities of salts, have no organic matter, may be low in fertility and often have low moisture holding capacity. These quantities require very careful water management. Sprinkler, drip and bubbler irrigation systems provide an effective method of water management and can usually provide better water management than the traditional basin, furrow and border surface irrigation systems.

This paper is confined to a discussion of center pivot sprinklers, drip and bubble irrigation systems. There are many different sprinkler systems, such as buried solid set, side roll, tow-a-line, big gun, hand move, traveling, or boom in use today. But by far the largest single sprinkler system in the development of new lands in the United States is the center pivot system. It has unique capabilities that recommend its use for field crops in desert land development.

Drip and a variation of drip called the bubbler have special qualifications for certain applications, in particular, for orchards and some vegetable crops, in water scarce areas and in the use of

[1/] Presented at the International Conference on the Applications of Science and Technology for Desert Development. The American University in Cairo, Egypt, September 1978 and published in Advances in Desert and Arid Land Technology, Volume 1, Adli Bishay and McGinnies Editors, Harwood Academic Publishers 1979.

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highly saline waters. Because there is considerable interest in these two systems for desert land development; discussion of these methods is included in this paper.

The paper cannot discuss all aspects of these systems, but can only briefly describe them. For more information the reader is referred to the literature cited. However, the bibliography is not all inclusive. The paper will describe some of the general advantages of the three systems in contrast to surface irrigation and then will describe each system in more detail. In general, the paper deals with the experiences and investigations of the authors in developing new croplands in Nebraska and Colorado. In the process of our work we have had to investigate various sprinkler systems, drip and bubbler rather than the traditional basin, furrow and border surface irrigation because the former systems provide more effective water management.

General

Water Management is applying the correct amount of water to the soil to meet plant water requirements, evaporation from the soil and any additional water needed for salinity control without excess runoff or deep percolation.

The water requirements of plants is not constant but changes with plant growth with the largest requirements generally occurring during flowering. Water available for plant use is that water held in the soil between field capacity and the wilting point. Field capacity is amount of water soil will hold against drainage by gravity and wilting point is the amount of water in the soil when plants begin to wilt. Saturation is the amount of water in a soil when all air space is occupied by water. Plants ability to extract water from the soil decreases with a decrease in the amount of water available in the soil and with an increase in concentration of soluble salts. Soils at saturation for any length of time adversely affect plant growth.

Water holding capacity and infiltration rate (rate water moves down and into the soil) of soils depends on its texture and structure. Coarse textured soils--sandy soils--have low water holding capacity and high infiltration rates. Whereas fine textured soils--clay and silty clay soils--have high water holding capacity and low infiltration rates.

Salinity management is required on all irrigated lands but is especially important with desert soils. Salinity management requires efficient irrigation and is necessary not only to maintain the productivity of the lands being irrigated but also to prevent deterioration of the groundwater aquifer or surface water supplies by the return flow from excess irrigation.

All irrigation waters contain a certain concentration of salts. Salt concentrations may range from one to two hundred parts per million (ppm) of total dissolved solids to as large as 2 to 3,000 ppm. Successful surface irrigated agriculture has been maintained in the Arkansas River Valley of Colorado, USA, using surface irrigation techniques with concentrations of salts of 2,000 ppm. However careful water management practices have to be used.

Traditional salinity management practice has been to put excessive amounts of water on the field to leach the salt from the soil. Excessive water is watering greatly in excess of the water required by the plants for transpiration and the water lost from the soil surface by evaporation; the evapotranspiration (ET) requirement of the crop. This ET varies with crops and there are various equations for calculating the ET of various crops such as the Penman, 1948; Blaney, Criddle, 1947; Jensen, Haise, 1963 equations.

Water greatly in excess of the ET of the crop leaches the salts from the root zone. However, the excess water returns to the aquifer contaminating it or returns to the river via surface and subsurface drains. These return flows either to the aquifer or to the surface water system create problems downstream.

Research has shown (Agricultural Research, 1974) that crops utilize mostly the water from the top portion of the root zone and that plants can tolerate larger salt concentrations near the bottom of the root zone. Thus, it is not necessary to apply excess water to leach the salts from the profile. With proper water management whereby excess salts are moved out of the upper part of the root zone, good yields are maintained, and deep percolation and salt water contamination is prevented. The applicability of the research has been demonstrated in field studies in Colorado (Agricultural Engineering Department, 1976), Arizona and other areas.

Not only does good water management decrease the hazards of salinity but is saves water that can be used elsewhere, decreases the capital costs of the irrigation system (smaller ditches, laterals or pumping plants and decrease drainage requirements) and leaves valuable nutrients in the root zone.

All good irrigators, regardless of the irrigation methods, practice good water management and profit from the increase in crop production. Water management increases yields. Good fertilization practices increase yields. Good agronomic practices increase yields and good seeds increase yields. But any one of the practices doesn't increase yields as much as all of them would in total. In fact, there is a multiplying effect of water management in combination with the others. Yield often triples and quadruples when water management is used along with the others.

Sprinkler, drip, and bubbler provide an effective method of providing good water management. That is not to say that good water management cannot be obtained with surface irrigation but only that with sprinkler, drip and bubble and other controlled closed conduit systems that bring the water from source to the consuming plant water control is easier to accomplish. These methods can be utilized on land that is too rough for surface irrigation (center pivot sprinklers can be used on any land that can be farmed). In Nebraska, where over 16,000 center pivot sprinkler systems are installed, the only requirement with regard to land slope is that farm machinery can traverse it.

Sprinkler, drip and bubble, because they apply the correct quantity of water to the crop at the time it is required can be used on soils ranging from light sandy soils with large infiltration rates and small holding capacity to heavy clay soils with small infiltration rates and large holding capacity.

In sandy soils surface irrigation methods, even with lining of ditches, small runs, etc. will use excess water and cannot replenish the soil moisture content often or fast enough to prevent crop loss. This is often also the case for hand set, wheel roll and drag sprinkler systems. In the sandhills of Nebraska and Colorado, USA, crops of 100 to 200 bushels of corn are raised on sand with less than two percent organic matter. All nutrients are supplied, often by the center pivot sprinkler.

In heavy soils surface irrigation may require that water be held on the land for excessive times in order to replenish soil moisture. This may result in excessive tail water runoff with furrow irrigation or excessive ponding with basin irrigation. However, level basins with or without furrows, or tailwater return system and other improved surface irrigation techniques that are being developed provide methods to utilize surface irrigation on these soils. With any soils except for the very rough or the very sandy good water management can be obtained with surface irrigation. However, training farmers, water distribution managers and government officials to practice good water management (both on-farm and in the distribution system) with surface irrigation is more difficult than with center pivot sprinklers, drip or bubble.

Center Pivot Sprinkler System

A center pivot sprinkler system consists of a machine that has a series of sprinklers (either impact type or spray nozzles) mounted on a pipe (pipe diameter being 4, 6, or 8 inches in diameter or combination of diameters depending on size of area to be irrigated) that is in turn mounted or carried by a row of five or more mobile towers. The towers move in a circle around a center pivot where water is pumped into the pipe. The source of water may be a well located near the pivot or from a canal with ditch or pipe to the pivot. The movement of the towers around the pivot is controlled by the outermost tower and an alignment device that uses simple micro switches to move the other towers to keep up with the outer tower. The rate of advance is variable--usually from a complete circle in 18 to 24 hours to a complete circle in three or four days. Water application rate is directly proportional to the rate of travel. Thus, the moisture needs (ET) of the crop can be exactly met by varying the rate of advance. The towers are driven by either electric motors or water drive and the pumps may be electric, diesel or gas driven. Pipe pressure at the pivot range from 60 to 100 pounds per square inch (psi) for high pressure systems and 30 to 70 psi for low pressure systems. The systems as developed are simple to operate, easy to assemble, relatively fool-proof, and need few spare parts. In fact, plants to manufacture the machines using some readily available components would be relatively easy to construct in any country and do not require a large capital outlay.

Because center pivots cover a circular area they miss the corner and thus only cover 79 percent of the area in any square. If land is scarce then the loss of 21 percent of the land from production could be important. By nesting the circles, the use of cornering devices or other sprinkler systems, the land loss can be decreased. However, if land is not expensive then it is usually better to leave the corners fallow or utilize them for storage, homes, etc.

If one center pivot is used in isolation crop production is less at the outer edge because of the large loss of soil water to the surrounding land and higher evaporation from the land and transpiration from the plants resulting from the dry desert air. That is, the inner part of the circle benefits from the oasis effect. A big gun sprinkler on the end tower enlarges the circle and helps decrease crop loss. To take advantage of the oasis effect it is well to install a number of center pivots on a block of land and confine the loss of production to the outer edge of a large area rather than around a single center pivot.

In a recent land development (1977) in eastern Colorado ten center pivots were installed on 1900 acres. In total 1475 acres were irrigated.

The land was hilly, in one area the slope was so steep that tractors could not go up the slope and had to operate downhill. The soil was sand (less than two percent organic) and all nutrients had to be supplied using commercial fertilizer. The installation started in September and the first corn crop planted the following April. The crop averaged 137 bushels or 4.1 tons per acre.

Cost of installing the center pivots were as follows:

Pumps and motor	$ 99,744
Wells	74,343
C.P. Sprinkler	308,260
P.P	24,182
Concrete pads	2,367
Power (line, transformer etc)	26,350
	$ 535,246

or $363/acre. In addition to the above costs, $26,600 was spent in land development--filling in some gullies, eliminiating a small ephemeral lake so that the towers and farm machinery could operate.

Operating costs, exclusive of labor, insurance, taxes, etc. were as follows:

Seed	$ 14,140
Herbicides, pesticides, and fertilizer	54,159
Utilities (electric)	46,024
Repair & Maintenance	7,150
	$ 121,473

Overall the capital and operating cost can be recovered with an average yield of 130 bushels per acre at a price of $2.00/bushel.

The above costs are for installation where irrigation equipment, labor and equipment to install the machines and the total infrastructure is all set up. In desert lands of Egypt near Cairo a recent estimate of the installation of a single machine pilot project for 130 acres using a tubewell was $1270/acre. These costs would decrease as the infrastructure to install and service the machines developed. A pilot project would of course help develop the needed infrastructure needed to construct and operate the system and develop the methodology for farming with center pivots. For example, the towers tend to cause ruts in heavy soils. Sands normally are no problem. It is easier to operate farm machines in straight lines (across tower tracks) than in circles. The pilot project would develop techniques to farm where rutting may be a problem.Also, other questions that a pilot project would answer are costs, water efficiency method of applying fertilizer, maintenance and so forth.

Trickle Drip

Trickle or drip irrigation systems are a network of closed conduits that supply small amounts of filtered water periodically to the soil at each plant. The system operates at low pressure (5 to 14 lbs per square inch). Only the soil in the root zone of each plant is supplied with moisture. The network of conduits (usually plastic pipe of 1/2 to 3/4 inch in diameter) is laid on the ground along the crop row. The crop is usually fruit trees and grapes, but vegetables and in Hawaii, sugar cane, have been irrigated by trickle systems. From these lines outlets called emitters are placed to provide the water to the plant area. These emitters are needed to dissipate the pressure of the pipe network and provide a trickle of water to the plant.

The soil moisture in the root zone of the plant is kept in the desired range by intermittent operation of the system. This intermittent operation can be either manually or automatic. Water scheduling can be accomplished by calculations whereby on and off times are established or by soil moisture sensors that determine when a given water deficiency should be replenished.

The advantages of the system as given by Keller and Karmeli (1975) and K. Shoji (1977) are efficient use of water, because only a small surface area of the soil is wetted evaporation is a minimum. Weed growth, and loss of water by weeds, is inhibited. Although weeds grow around the emitters, in orchards, there are large areas of bare ground that trickle irrigation keeps dry. Trickle, as with the other systems mentioned, allows for good water management and the control of salinity. Also, because it can provide a continuously high soil moisture content trickle is advantageous when water with large concentrations of salt must be used. Trickle also moves the large concentrations of salt to the outer or fringe area of the root zone which keeps the salt concentration in the soil in the major part of the zone at tolerable levels. Trickle in contrast to sprinkler irrigation eliminates leaf burn and fruit spotting because of salt accumulations on the plant. Of course, fertilizer can be applied through the system and it is only supplied to the root zone of the plant being irrigated, thus, decreasing the amount of fertilizer required.

The major disadvantage to trickle is clogging of the emitters either by sediment in the water, algae growth or chemical precipitates. To prevent clogging by sediments filters must be used, chemicals are added to prevent algae growth and possibly acids or other chemicals are added to remove or precent precipitates. Rodents sometimes damage pipes. All of the above increase cost and in particular filtering increases energy requirements and the complexity of operating the system. In general, trickle will be an efficient, effective and economical system of irrigation for high value crops, scarce water supply, sediment-free water, and high labor costs.

Bubble Irrigation Systems

The bubble irrigation is a closed-conduit system similar to trickle but operates at much lower pressure (0.7 psi or less vs. 5 to 14 psi for trickle) and no emitter. Pressures available from open ditches are often sufficient. Bubble does not require filtered water but if surface water is extremely dirty a method of flushing the main lines and laterals may be needed. This can be simply a valve at the end of the line so that most of the pipe flow can be periodically discharged. Generally the main line and laterals are buried (about 2 ft) to protect the pipe and to aid in cultivation.

The bubble system consists of a network of low pressure pipes of 2 to 4 inches in diameter. Inexpensive, thin-walled, corrugated plastic pipe is sufficient. Small hoses (1/4 to 1/2 inch) go from the plastic pipe to the plant to be irrigated. Water flows full in the pipe by gravity and delivers the water to the plant by way of small hoses which take the place of emitters in the trickle system. The flow rate to the plant is controlled by the elevation of the end of the small hose either by fastening the end to a stake or the tree.

The proper elevation of the hose end is determined by trial and error with the system in operation until each plant is getting the proper amount of water to replenish the soil moisture as determined by calculations. Simple calculations of head loss and surveying in a preliminary elevation line speeds up the trial and error process.

Bubble irrigation is well described by Rawling (1977) and is an attractive alternative to trickle. It has the same advantages and doesn't require the filtering and associated high energy requirements.

It does, however, require fairly uniform land. The land can be sloping but because the system operates by gravity large changes in grade cannot be tolerated. Costs for materials for the bubble irrigation system is estimated by Rawlins (personal communications) as around $370 per acre. Materials for the same system in Polyvinyl chloride pipe required for trickle would be $690 per acre.

Summary

Successful irrigation of desert lands requires good water management which is difficult to obtain with surface irrigation systems. In particular, when developing new lands center pivot irrigation systems provide an excellent method of obtaining good water management and large crop yields at relatively low overall costs for field crops such as beans, corn, sugar beets, and cotton. The system is particularly well suited for rough ground and is a good method for soil types from sand to light.

For fruit trees, and some vegetables, a low head, closed conduit irrigation system called bubble has many advantages such as low cost, simplicity of operation, low energy requirements and water savings. It does require relatively uniform land surfaces although it can be engineered for fairly steep slopes if they do not have large adverse breaks in grade. Where, energy may not be a problem and rough land, a system called trickle or drip may be a good alternative to the bubble.

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