IMPROVING EGYPT'S IRRIGATION SYSTEM IN THE OLD LANDS

FINDINGS OF THE EGYPT WATER USE AND MANAGEMENT PROJECT

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FINAL REPORT

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EGYPT WATER USE AND MANAGEMENT PROJECT

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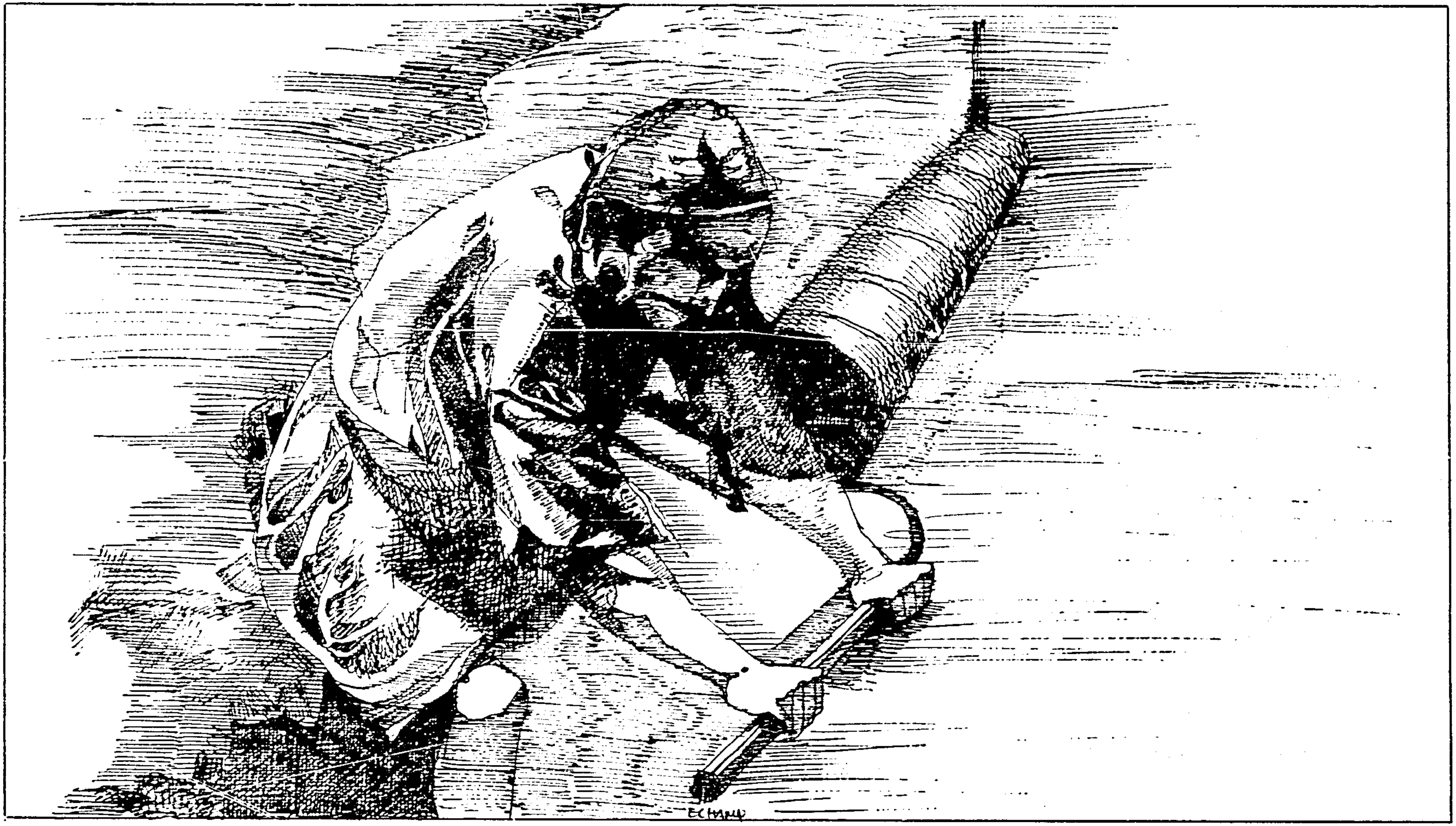
EDITOR'S NOTE: Most of the references in this Report are drawn from EWUP Technical Reports. For reader convenience, these references are noted as (TR --). EWUP manuals are noted as (M --). Documentation of these references appears in the References section at the end of the Report. References marked with an asterisk (*) were still in process at the time this Report was published.

ADMINISTRATIVE CREDITS

The Egypt Water Use and Management Project (EWUP) is funded jointly by the Arab Republic of Egypt and by the United States Agency for International Development (USAID). The United States Agency for International Development in Egypt is under the directorship of Mr. Michael P. W. Stone. Mr. John Foster is the USAID Project Officer for the Egypt Water Use and Management Project.

The Egypt Water Use and Management Project is implemented under the auspices of the Ministry of Irrigation's Water Distribution and Irrigation Systems Research Institute and in collaboration with both the Ministry of Irrigation and the Ministry of Agriculture through the Soil and Water Research Institute and the Agricultural Economics Institute, which provide the Project with personnel and services.

The Consortium for International Development (CID), with executive offices in Tucson, Arizona, is the USAID contractor for the Project. American Project personnel are drawn from the faculties of Colorado State University, the lead American University taking part in the Project, Oregon State University, New Mexico State University, and Montana State University. The Project Director is Dr. Hassan Wahby and the Project Technical Director is Dr. Eugene Quenemoen. Dr. E. V. Richardson is the Campus Project Coordinator at Colorado State University.



INTRODUCTION

Rainfall is scarce in Egypt. Even the small amount which normally occurs over the Delta comes during the winter when crop demands are low. Consequently, the nation's farmlands are and have been since time immemorial, almost entirely dependent on irrigation from the River Nile. These farmlands include approximately 6 million *feddans* of alluvial soil along the Nile and in the Delta, the so-called "old lands." Some additional land has been and is being reclaimed from the bordering desert and the tidelands along the northern coast.

The last century witnessed a radical change in Egyptian irrigation methods. The ancient system of basin irrigation and cultivation of one crop per year, which prevailed since the dawn of civilization, has been superseded by perennial irrigation. Due to the construction of many control structures, including the High Aswan Dam, water is now available for year-round crop cultivation.

Perennial irrigation has provided new opportunities for more intensive crop production, but at the same time, it has generated new problems. The use of more water on a relatively fixed area of land has caused waterlogging, buildup of salts in the soil and excessively high water tables in various farming areas. Management of the delivery and drainage systems has become more difficult under conditions of year-round irrigation and changes in crop patterns. The challenge is to minimize or solve these problems while fully exploiting the new opportunities for the benefit of the nation.

In recognition of these new opportunities and problems, the Egypt Water Use and Management Project(EWUP) was created in 1977 through action by the Ministry of Irrigation (MOI), the Ministry of Agriculture (MOA) and the United States Agency for International Development (USAID).

Egypt's Irrigation System

The High Aswan Dam presently ensures Egypt's annual quota of 55.5 milliard cubic meters of water for irrigation and other purposes. The discharge of water from the High Aswan Dam is under full control. The release of water for irrigation is adjusted throughout the year to provide all agricultural areas with sufficient water for crop needs. Distributary canal cross sections are designed to serve command areas according to specified water duties. *Mesqas* (private canals) are served from distributary canals which are on a two or three-turn rotation. The time interval between periods when water is turned off and when it is later turned on depends on the cropping patterns and seasonal climatic conditions.

The on-days of a canal rotation are considered 24-hour periods (starting at sundown) without any adjustments between daytime and nighttime use. The number of on-days in a turn is sometimes modified to meet farmers' requests for more irrigation water.

The water supply for any given area is monitored by observing water surface levels in delivery canals. The water is typically delivered from 50 to 75 cm below the ground surface of the fields, so irrigators must lift the water onto the land.

Delivery canals are closed for approximately one month during the winter to permit maintenance and construction of structures. In general, the winter closure is preceded and followed by a general irrigation for 10 days.

Farmers are not required to pay for water. Its use along the *mesqa* is determined by custom, which usually favors the farmers at the head of the *mesqa*. Similarly, *mesqas* at the head of a distributary canal have an advantage over those at the tail end.

After lifting water from the *mesqa*, a farmer is free to distribute it over his fields by his own methods. Generally, he distributes the water through a *marwa* (field ditch) to small bunded units called basins. The surface of the fields may be furrowed for row crops or smoothed for basin crops. Excess surface water may be drained-off into open field drains or, in some cases, back into the *mesqa*.

The best environment for crop production is achieved when the plants' root zones are kept adequately moist. Either inadequate or excess water in the root zone causes plant stress and reduces yields. Good irrigation management should maintain optimum root zone moisture conditions without using excessive water. Poor irrigation management wastes water, sometimes wastes plant nutrients, contributes to potentially harmful high water table conditions, and tends to overload drains. It may also waste labor and energy required for lifting excess water to the fields and from the drains.

Good on-farm water management requires level fields, appropriately designed on-farm distribution systems, and knowledge of when to irrigate and how much water to apply. It also requires a dependable source of water, available when needed, in a quantity which can be distributed efficiently over the farmer's field. Consequently, there must be close communication and interaction among all farmers served by a *mesqa* and with the district irrigation engineer who regulates the water upstream from the *mesqa* intakes.

The potential for achieving benefits from better water management is substantial. Approximately half the water resources available are presently required for evapotranspiration by crops (see "Egypt, Major Constraints to Increasing Agricultural Productivity"). Of the remainder, most is lost from the system in the delivery process through seepage, evaporation, and flow-through. Some, of course, must be allocated for domestic, industrial and navigation uses. Any measure which conserves water and reduces losses provides an opportunity for increased agricultural production through horizontal expansion as well as reducing drainage costs.

EWUP Goals and Purposes

EWUP was created out of an understanding of the close dependency and interaction between the irrigation water delivery system and the on-farm water management system. The MOI recognized that while its major responsibility was water delivery to farms, it must have knowledge of on-farm management and drainage in order to improve the efficiency and effectiveness of water delivery.

The general objective of the Project was *to improve the social and economic conditions of Egyptian small farmers through development and use of improved irrigation water management and associated practices which increase agricultural production, promote efficient water use and decrease drainage problems.* The Project was also designed to increase the institutional capacity of the MOI and MOA to develop and implement improved on-farm water management programs. These programs were to be tested and proven for technical applicability, farmer acceptability, and organizational replicability. If they met these criteria, they would be expanded to the regional and/or national levels.

The Project would conduct an applied research and extension program with small farmers in three representative pilot areas. The Project was expected to:

- Identify the major constraints to improved on-farm water management and optimal water delivery system operations.

- Determine and establish the use of optimal irrigation practices at the farm level in representative pilot areas.

- Establish improved water control practices for the farm water delivery systems and farm drainage systems in Project areas.

- Develop plans for organization and implementation of expanded future programs based on results obtained from Project areas.

- Develop and/or train qualified professionals and technicians for the conduct of Project activities.

National Goals

EWUP has provided experience and a knowledge base which have been used to formulate plans for expanded irrigation improvement programs in Egypt. These programs reflect national goals. As a part of Egypt's most recent Five-Year Plan, the MOI intends to implement a National Irrigation Improvement Program which includes the following goals:

- Improve management of irrigation water.
- Minimize seepage losses from delivery canals.
- Reduce water table levels.
- Reduce the pressure on drainage networks.
- Control water through the distribution system from the barrages to the *mesqa* outlets.

- Improve water availability at the tail ends of canals and *mesqas.*
- Improve and renovate irrigation networks.
- Increase crop production.

Most of these objectives have been addressed by EWUP.

EWUP's Approach

EWUP has nearly six years of experience at three field sites developing methods of watercourse improvement and packages of practices for better on-farm water use. The Project demonstrated the value of an interdisciplinary approach which included engineers, agronomists, sociologists and economists who worked together to increase crop production and promote efficient water use.

The Project research plan called for: (1) problem identification; (2) search for solutions; (3) testing solutions through pilot programs, and (4) developing procedures for disseminating practices which were proven through the pilot programs. Watercourse management programs were launched at each of the three Project sites which involve command areas of 1,200 to 6,300 *feddans.* This work provided a proven interdisciplinary model of water delivery system and on-farm irrigation management improvement. Farmers were involved and helped the professional staff identify irrigation problems, consider alternative solutions and field test those most promising solutions. In applied research, these steps are necessary before developing large-scale plans for implementation at regional or national levels.

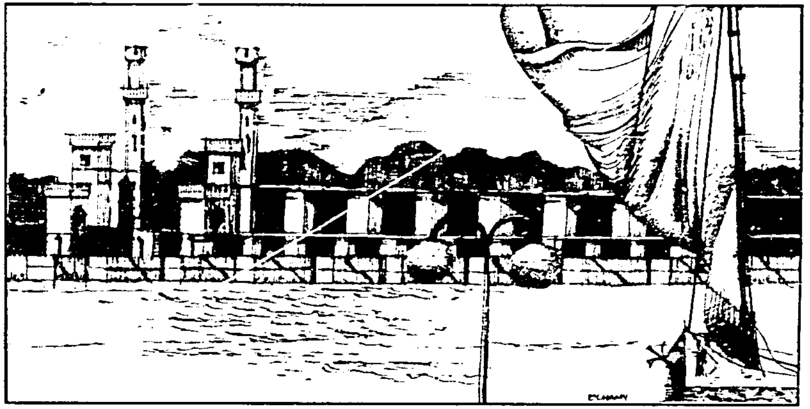
Field Sites

The Project's work plan called for establishing field offices and water delivery command areas at three locations in Egypt. Selections were made in Giza, Kafr El-Sheikh and El-Minya Governorates (Figures 1 through 4).

El-Mansuriya site is located along El-Mansuriya canal in Giza Governorate. The land within the field site is served by Beni Magdul and El-Hammami distributary canals. This site was selected because it represented the vegetable-producing areas serving the Cairo market. The soil of the Beni Magdul command area is predominately alluvial clay while that of El-Hammami area is sandy. Each area covers approximately 800 *feddans.* The work emphasized at this site included channel lining, elevated *mesqas,* buried pipeline and continuous-flow water delivery.

Abu Raya site is located along the third reach of Daqalt distributary canal near Abu Raya village, 35 km northeast of the city of Kafr El-Sheikh. This field site was selected to represent the major rice-producing regions. The work concentrated on command areas served by Hamad, Om Sen and Manshiya *mesqas* which consisted of 219, 235, and 246 *feddans,* respectively. Land leveling, appropriately designed level furrow and basin irrigation systems and farmer-organized *mesqa* cleaning were emphasized at this site. In 1983, work at this field site was expanded to include water delivery system improvement for the entire area, approximately 6,300 *feddans,* served by all three reaches of Daqalt canal.

Abyuha site consisted of approximately 1200 *feddans* served by the Abyuha distributary canal, 20 km south of the city of El-Minya. The site was selected to represent upstream areas of Egypt which produce broad beans, cotton, sugarcane and other crops in the Nile River Valley. Work emphasized at this site included land leveling, long level furrow and basin irrigation, and renovation of the distributary canal and *mesqas* for improvement of the gravity irrigation system.



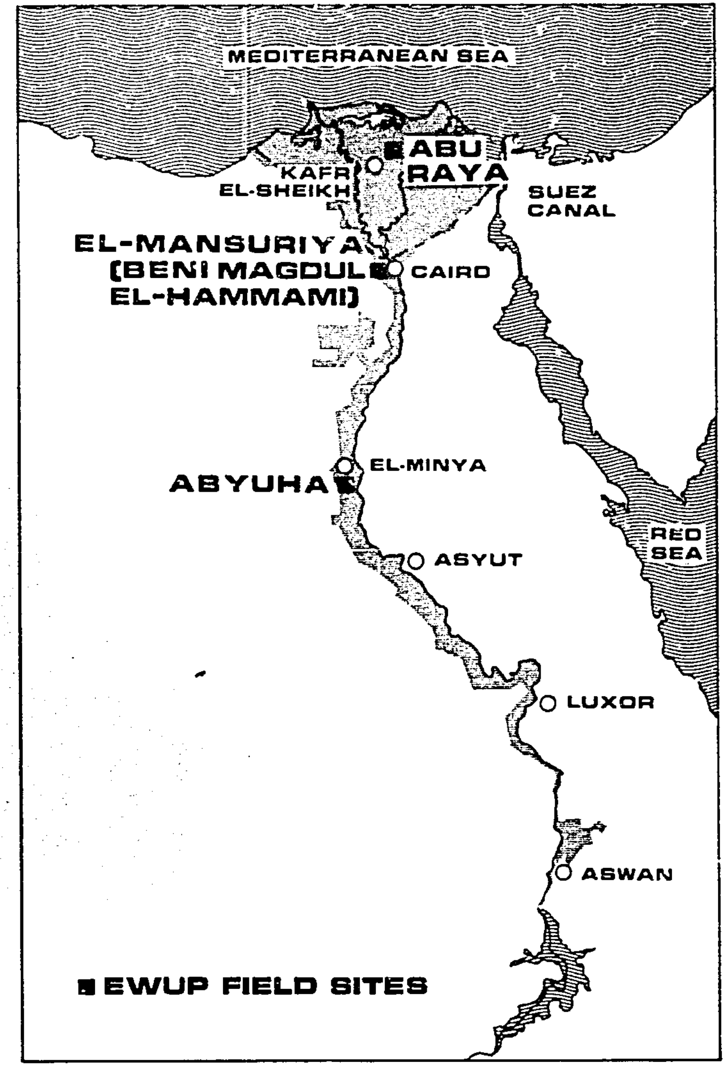


Figure 1. Location of EWUP field sites.

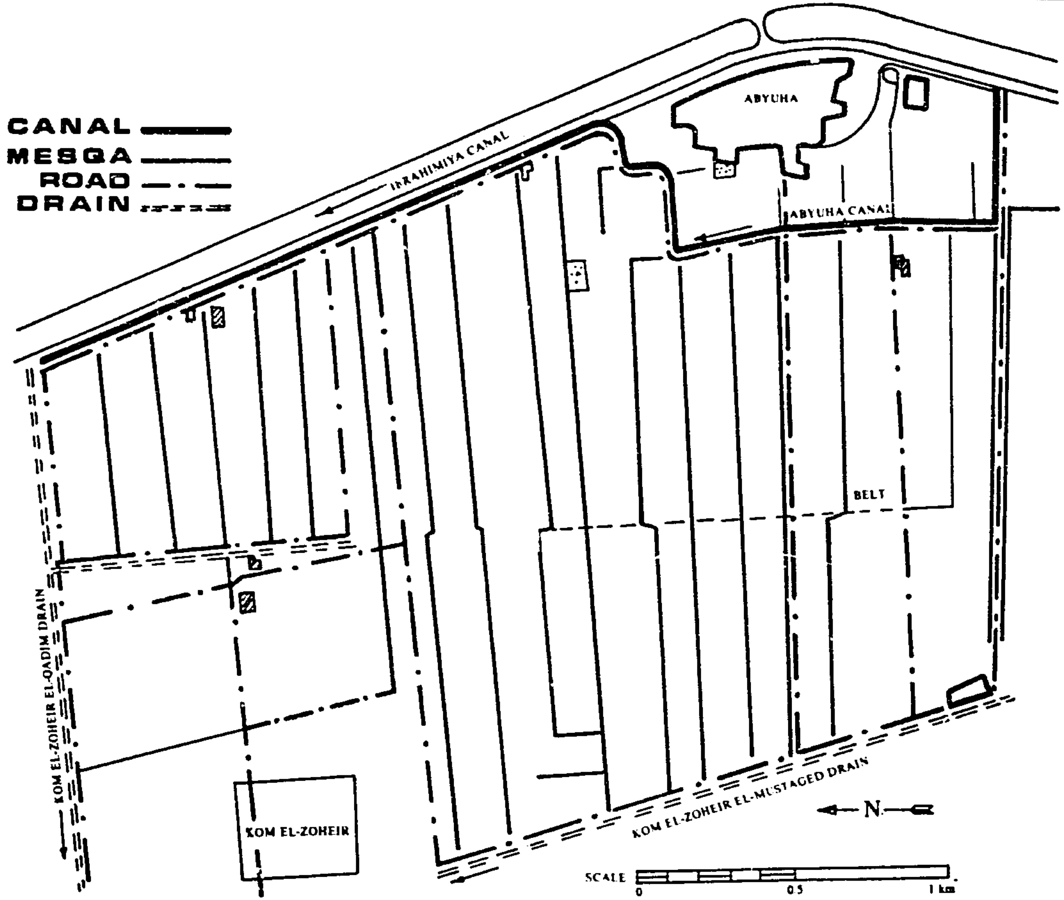


Figure 2. Abyuha field site.

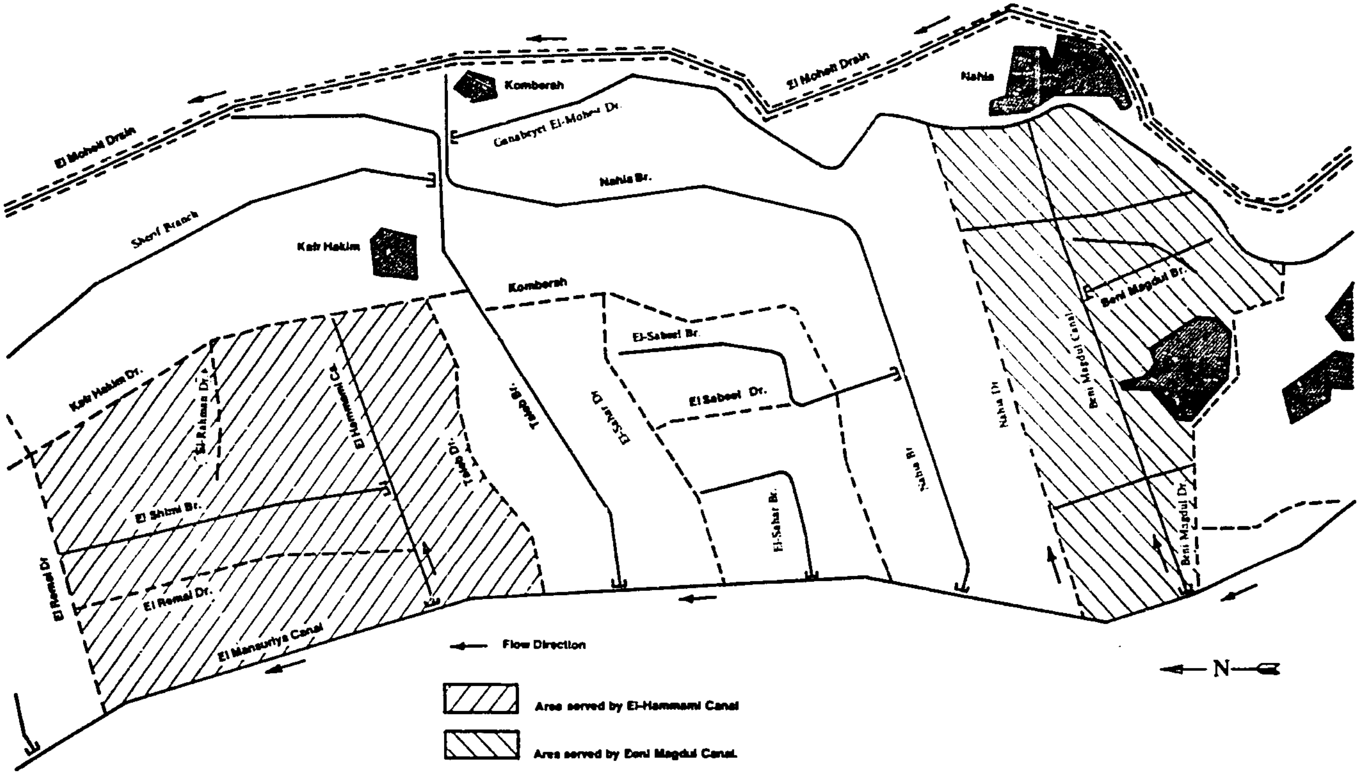


Figure 3. El-Mansuriya field site showing Beni Magdul and El-Hammami regions.

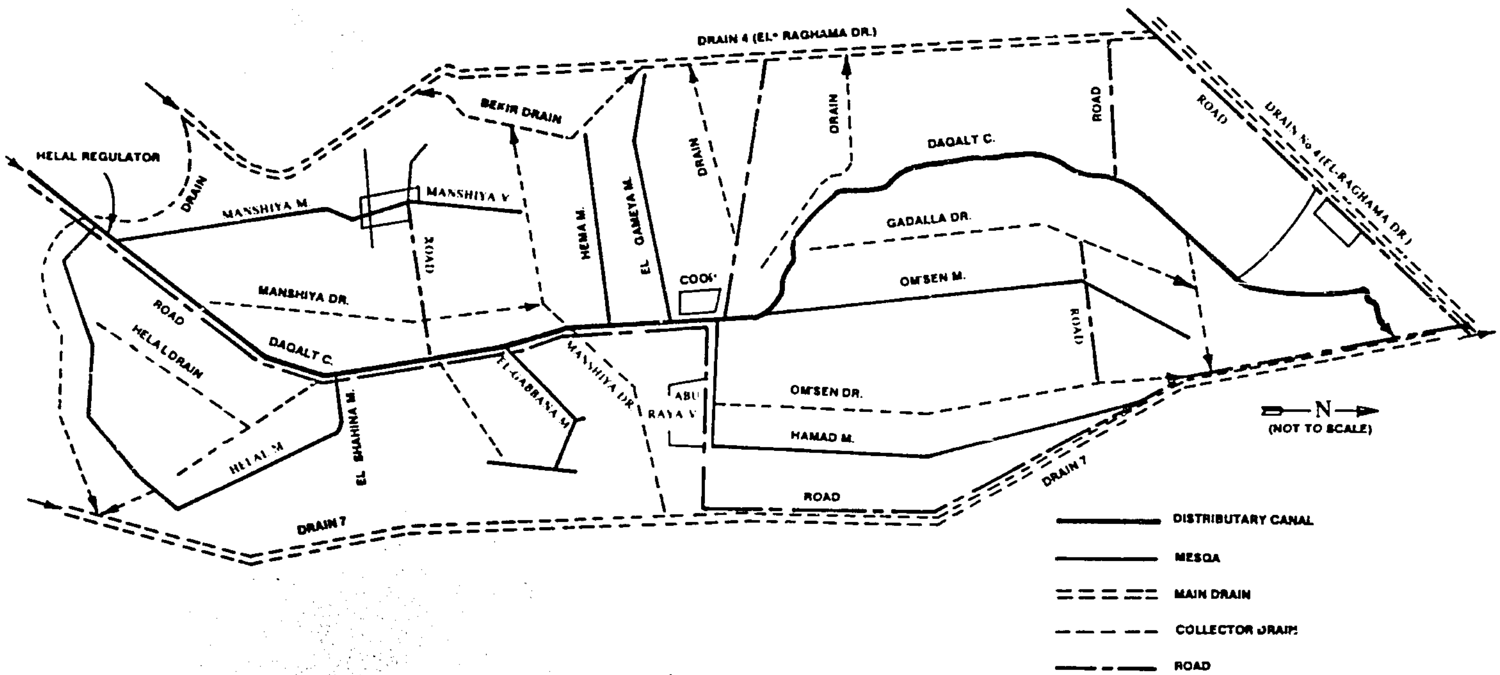


Figure 4. Abu Raya field site on the third reach of Daqalt canal.


ELHAMY NAGUIB

CHARACTERISTICS OF THE SYSTEM

Characteristics of the Farming Systems

The farming systems studied by EWUP are highly complex biological production systems in which the physical environment determines possible production alternatives. Economic and social environments then determine what farmers actually produce and how well they produce it. An evaluation of the total farming system is beyond the scope of this presentation. This report focuses only on those aspects directly related to irrigation and water management.

Farm Enterprises

Egyptian farmers in EWUP study areas derived their income from several sources. These sources included crop production, animal production and off-farm income. Of these activities, crop production accounted for more than 50% of the farmers' incomes in all locations. Animal production accounted for most of the remaining income, with off-farm income accounting for the least. El-Mansuriya study area had the largest off-farm income, averaging 20% of the total income, because of its proximity to Cairo (TR 8, 23).

Farm Size and Tenure

The farm size for those farmers included in EWUP records varied from 0.5 to 15 *feddans*, with an average of approximately 3 *feddans* (TR 49). According to EWUP farm records, El-Mansuriya farmers had the smallest holdings averaging only 2 *feddans* followed by Abyuha farmers with an average of 4 *feddans* and Abu Raya farmers who had an average of 6 *feddans*. In most cases, the farms were fragmented with each farmer managing 2 to 5 parcels of various sizes. The larger of these parcels were frequently subdivided into several individual fields (Figure 5). The greatest degree of field subdivision occurred in El-Hammami portion of El-Mansuriya. In this area, subdivisions to which irrigation was applied were often as small as 0.25 *feddan*. In other areas, the final field size was about 1 *feddan*.

Farmers operated their land under three forms of land tenure: ownership, cash rent, and share-cropping. The most common tenure was direct ownership, which accounted for more than 50% of the land tenure at Project sites, with the exception of Beni Magdul. The next most common tenure form was cash rent, with share-cropping used the least. Frequently, farmers operated their total holding under two or more of the possible tenure arrangements, i.e. they owned some parcels, and cash-rented or share-cropped others.

Cropping Systems

Most Egyptian cropping systems produce two crops per year, one in winter and one in summer. Few crops are adapted to both winter and summer temperature regimes, so there tends to be seasonal specialization (TR 49). The MOA provides some supervision on the cropping system by specifying the land area for cotton and rice. Specifying the land area for cotton also restricts the winter crop to berseem, since the April 1 planting deadline of cotton precedes the harvest date of other potential winter crops. The irrigation system is designed to provide water to meet the needs of the cropping system.

The general cropping patterns for the three EWUP study areas are:

Abyuha: This is a berseem-cotton-wheat-maize area. However, broad beans are usually substituted for berseem. Broad beans are harvested in early April forcing the cotton to be planted up to one month late. At Abyuha, there is also substantial area planted to sugarcane. Soybeans have recently become a major crop, replacing cotton.

Abu Raya: The basic cropping pattern is berseem-cotton-wheat-rice. Sometimes, more rice lands than allocated are planted along the *mesqas*. This rice planting increases pressure on the irrigation system, particularly during the puddling period. Sugarbeets are becoming an important winter crop replacing wheat.

El-Mansuriya: This area has an open cropping system because of its proximity to Cairo. It is an important vegetable-growing region, but berseem occupies the largest land area in winter and maize in summer. Following these crops, vegetables account for the most land area. Vegetables are frequently grown in some very intensive multiple crop combinations that could occupy the land for an entire year. For example, at El-Hammami, hot peppers are relay-cropped to green beans and then groundnuts, prior to the final pick of the hot peppers. The groundnuts then continue until the planting date of the hot peppers. Such complex land use makes irrigation planning difficult.

In addition to the regular cropping patterns, small areas are planted to vegetables for home consumption and local markets.

Soils

Soils at the Project sites are alluvial clay soils (order Entisols and Vertisols according to soil taxonomy), with the exception of the sandy soils at El-Hammami. Chemical, physical and morphological analyses from soil surveys indicated that high water tables, salinity, and sodicity were the main constraints to plant growth and crop production. Special irrigation problems were created by the characteristically low infiltration rates of the clay soils and their physical instability. This instability was caused by shrinking and swelling during wetting and drying cycles.

Profiles of clay soils at Project sites were almost homogenous to a 150 cm depth of sampling (TR 2, 33, 34). The combination of the soil type and water table conditions restricted the root zone and the measured soil water changes to the upper 30 to 40 cm of the soil profile. This resulted in an available soil moisture content of only 5 to 7 cm.

The infiltration rate of the clay soils could average a hundred-fold decrease during a single irrigation, from 720 mm/hr during the first minute to 7.2 mm/hr after 2 hours (TR 57). This allowed fairly uniform water application, even under the wide range of field sizes and variable flow rates which occur in irrigating Egyptian farmlands. Often the final infiltration rate was nearly zero, resulting in ponds that remained in field depressions for detrimentally long periods of time even after fields had been precision leveled. Surface drainage was then required, in the judgement of farmers, to prevent crop damage. This problem was more severe in winter when evaporation rates were low. In summer, higher evaporation rates helped dry ponds before they damaged crops.

Another problem with working in the alluvial clay soils was that the cracking and heaving caused by the clay expansion could make maintaining compaction on elevated canal banks difficult and could lead to seepage losses. This soil cracking was one of the primary causes of *marwa* conveyance losses at Abu Raya (TR 41).

Soil fertility studies conducted at Project sites showed the need for evaluation of soil nutrient status (TR 10). Data indicated there was a wide range between the very low to very high fertility index of the different nutrients depending on the soil and the preceding crop. The most common element deficiencies were zinc and phosphorus.

Topography

The topography at all sites has an overall slope less than 1% and would generally be classified as "flat" according to most land use classification systems. However, few individual fields meet the criteria for precision land leveling desired for efficient surface irrigation (TR 35, 41).

Abyuha area is at a base elevation of approximately 40 m above sea level. The land slopes to the west 50 cm/km (0.05%). Field layout is generally parallel to the contour, extending from one *mesqa* to the next. A typical variation of 0.16 to 0.19 m frequently occurs in fields due to a depression midway between the two *mesqas* serving the field.

Beni Magdul area has a general elevation of 16 m. There is an overall difference of only 20 cm/km (0.02%) throughout the area. Individual fields have elevation differences of 0.0 to 0.20 m (TR 41).

Abu Raya has a base elevation of only 1 m above sea level. It has a general northern slope of 10 cm/km (0.01%). Individual fields have elevation differences of 0.06 to 0.20 m (TR 41). Farmers, particularly at Abu Raya where rice is an important crop, appreciate the importance of land leveling. They attempt to level their lands within their limits of available time and equipment.

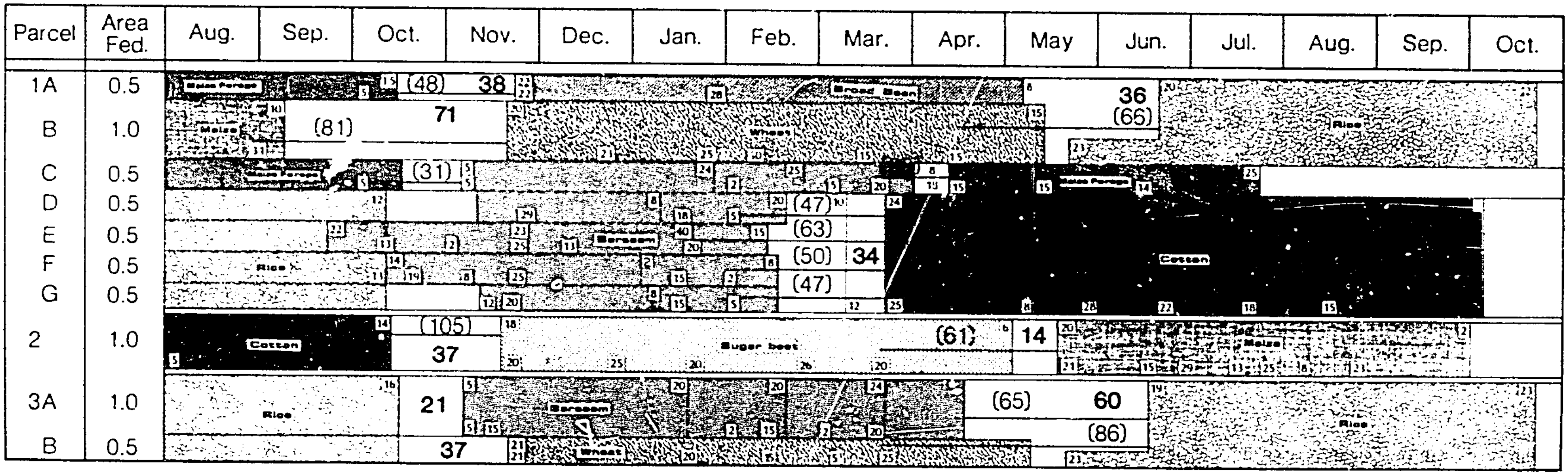


Figure 5. Cropping pattern of a single farmer in Abu Raya illustrating the mixture of crops, the crop irrigation, and the fragmentation of the farm into parcels and the parcels into fields. The numbers at the bottom are the irrigation dates, the numbers at the top are the planting and harvest dates, the dark lines with numbers in parentheses are the irrigation gaps, and the large numbers in the space between crops are the turnaround times.

Irrigation Practices

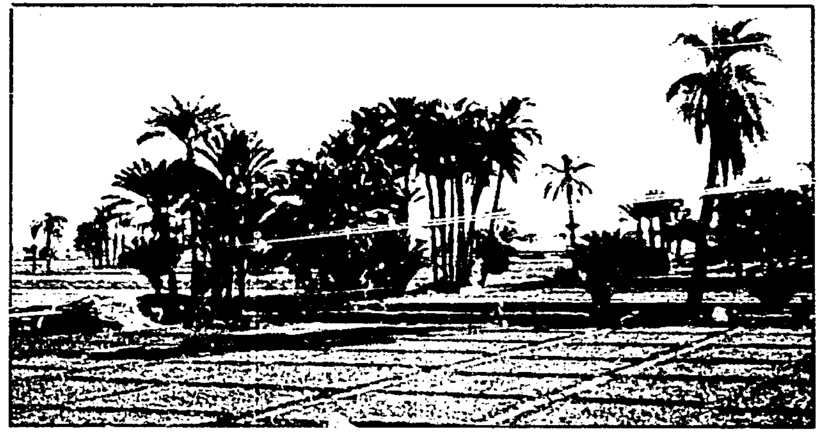
• *Traditional System*

Egyptian farmers have traditionally irrigated by dividing their fields into small basins of not more than 10 m x 10 m served by a within-field *marwa*. These basins provided the farmer with fairly good water control and allowed application of fairly uniform amounts of water even when fields were somewhat unlevel. The small basins with internal *marwas* also allowed surface drainage when the soil sealed. However, these basins hindered mechanization, particularly operations of large four-wheel type tractors commonly used in Egypt.

The lifting of water at the farm level was usually done by animal-powered *saqias*, hand-operated *tambours* and increasingly by diesel-powered pumps. The cost of lifting water ranged from L.E. 30/*feddan*/ year to L.E. 80/*feddan*/ year for each period (TR 7).

According to EWUP farm record summaries, the number of irrigations the farmers applied were generally consistent with those reported by the Egypt Water Master Plan Project in its technical report number 17. The actual dates of water application varied because farmers usually planted their crops later than anticipated (TR 45).

According to the farm record data, the farmers frequently had prolonged "irrigation gaps" between the last irrigation of one crop and the first irrigation of the next. The duration of the irrigation gaps depended on the two crops involved. Typical examples at Abu Raya were 83 days for wheat going to rice and 118 days for cotton going to wheat (Figure 5, Table 1). Even though these irrigation gaps were prolonged, the individual crops received appropriate final and initial irrigations when viewed separately. The irrigation gaps represented periods of general decline in the irrigation demand, even though crop consumptive use and potential evapotranspiration remained relatively high (Figures 6, 7). When large volumes of water were released during these periods, much of the water flowed through the system and was discharged directly from *mesqas* into the drains (TR 48). Irrigation planning, therefore, had to be based on the entire cropping pattern rather than individual crops.



Traditional small basins served by within-field *marwas*.

Lifting water at the farm level is traditionally accomplished by *saqias*.

One traditional lift system is by hand-operated *tambours*.

Table 1. Irrigation Gaps for Abyuha and Abu Raya EWUP Study Cases, 1980 - 1981

First Crop	Second Crop	Number of Fields	Average Date: Of Last Irrigation	Average Date: Of First Irrigation[a/]	Number of Days Between
		Abyuha			
		Winter to Summer			
Berseem	Maize	11	May 14	June 22	39
	Cotton	3	January 13	March 30	76
Wheat	Maize	16	April 12	June 14	63
Broad beans	Maize	7	March 28	June 10	74
	Cotton	16	March 26	April 28	33
	Soybeans	3	March 22	May 8	47
		Summer to Winter			
Maize	Broad beans	20	September 13	November 8	56
	Berseem	7	September 7	October 6	29
	Wheat	3	September 17	November 28	72
Cotton	Wheat	12	September 2	November 24	83
	Berseem	7	August 31	October 7	37
	Broad beans	3	September 3	November 7	65
Sugarcane [b/]	---	2	December 10	April 6	117
		Abu Raya			
		Winter to Summer			
Berseem	Rice	12	May 1	June 27	57
	Maize	6	April 18	June 7	50
	Cotton	12	January 10	March 24	73
Wheat	Rice	10	April 3	June 25	83
Broad beans	Rice	2	March 4	June 25	113
	Maize	3	January 8	May 26	138
Sugar beets	Rice	4	May 10	June 23	53
		Summer to Winter			
Maize	Berseem	7	September 6	October 17	41
	Wheat	2	September 7	December 1	85
	Sugar beets	1	September 11	November 27	77
Cotton	Wheat	8	August 10	November 23	105
	Sugar beets	8	August 13	November 10	89
	Berseem	5	August 10	November 7	89

a/ First irrigation includes pre-planting irrigation.
b/ Includes only crops grown a full year with a harvest.

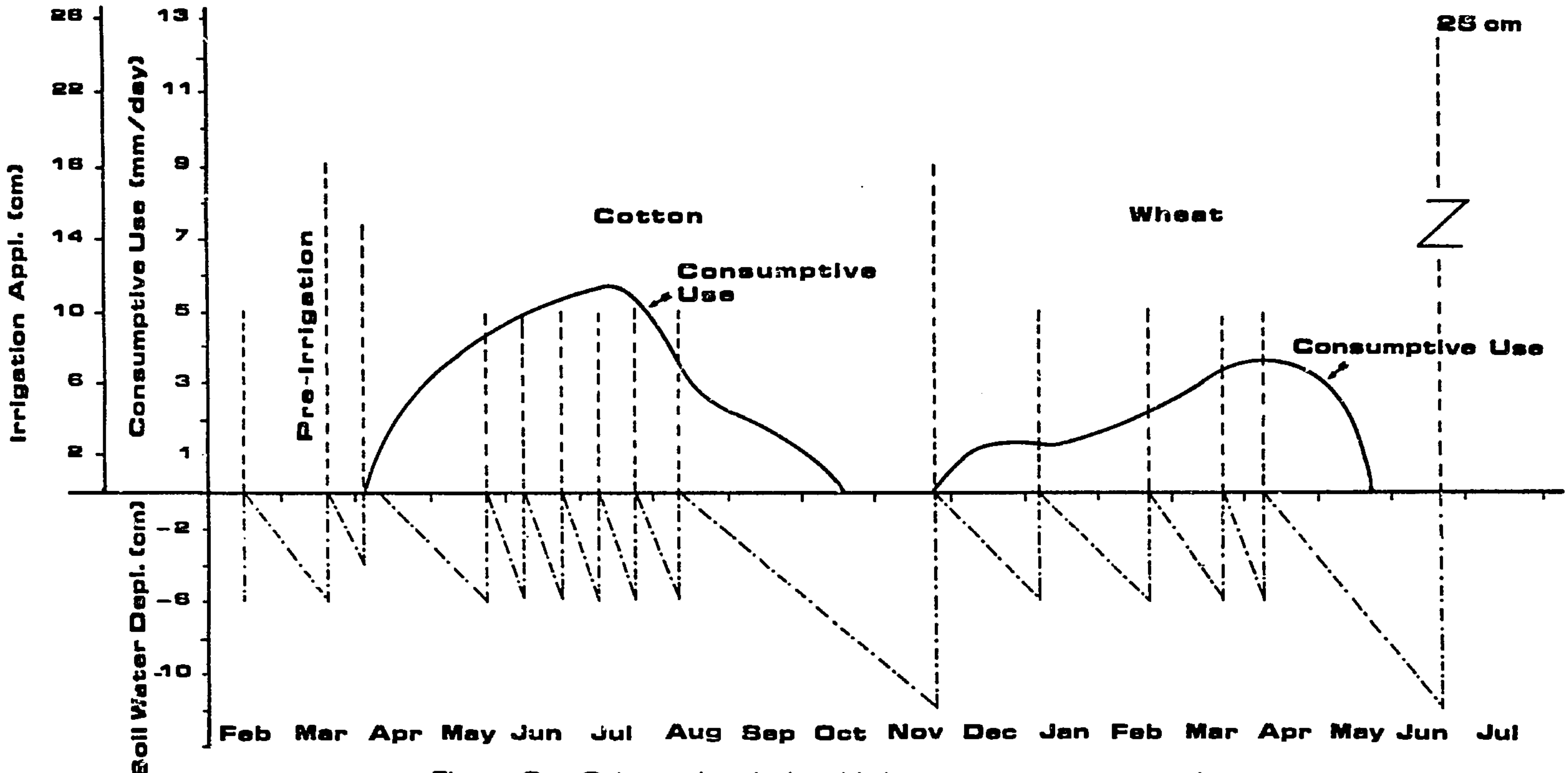


Figure 6. Schematic relationship between crop consumptive use, actual irrigations, and soil water depletion for the crop sequence of cotton followed by wheat in Abu Raya. The cotton was preceded by berseem with a pre-planting irrigation. The wheat was followed by rice with a puddling irrigation.

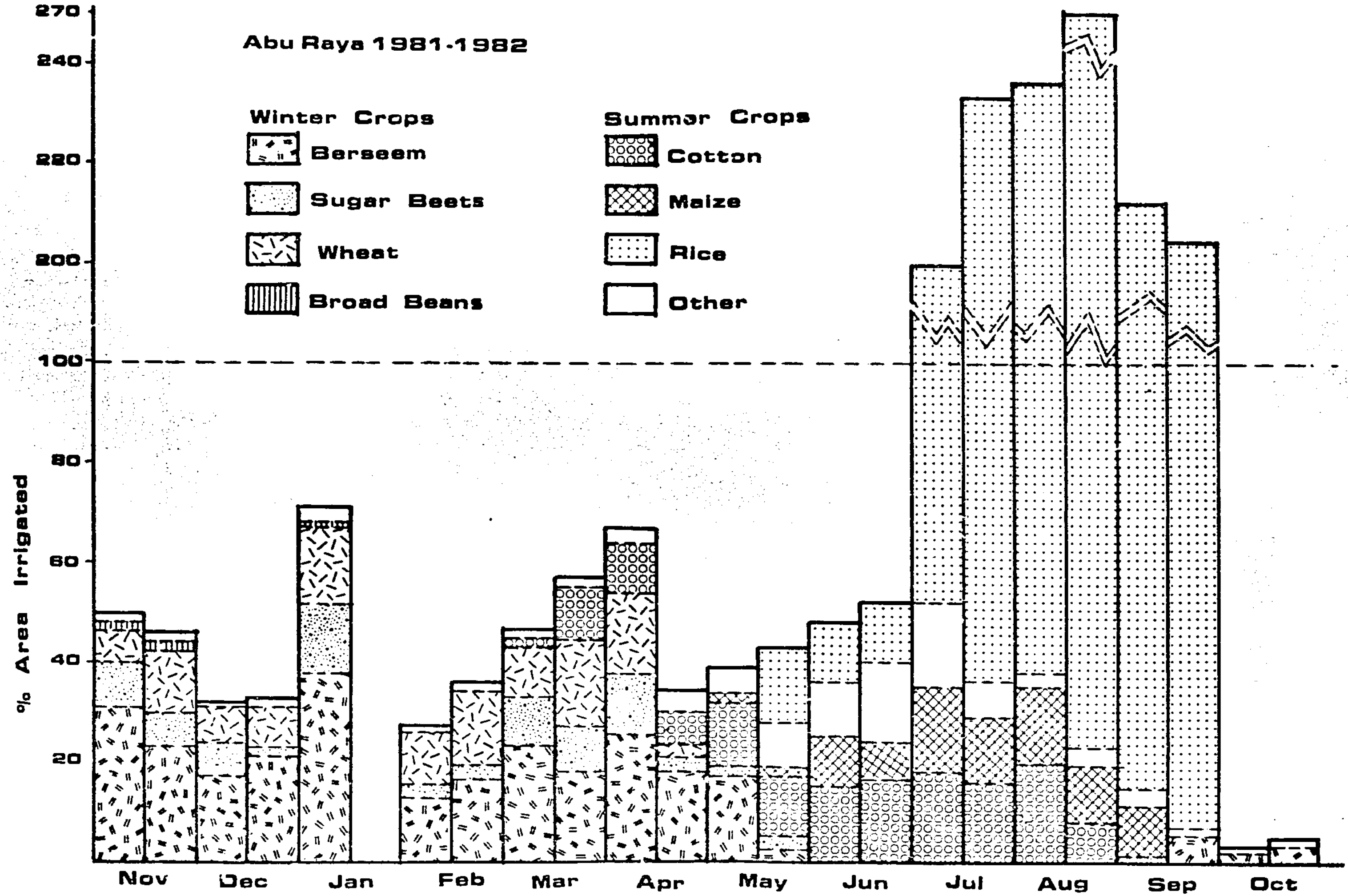


Figure 7. Aggregate irrigation demand for crops in Abu Raya. Values in excess of 100% reflect the multiple irrigations of the rice paddies during the half-month intervals.

Additional studies indicated the Abu Raya farmers preferred to irrigate during the morning, ending around 1 p.m. In summer, the irrigations started around 4 a.m. and in winter they began around 8 a.m. (TR 48). During the remainder of the day, the canals would refill and any excess water would flow into the drains.

The amount of water applied during an irrigation depended largely on whether or not it was the first or a subsequent irrigation. The first irrigation following a long irrigation gap required 15-18 cm of water. Subsequent irrigations which only had to replace normal water depletion (5-7 cm) required an application of 7-10 cm. An exception was the puddling irrigation for rice which required 25 cm of water. This puddling irrigation, which occurred during the last half of June, placed the greatest annual demand on the irrigation system (TR 9). In all cases, each irrigation completely recharged the soil water profile. The presence of prolonged irrigation gaps and the difference between initial and subsequent irrigations indicated a need to view the irrigation demands as a continuum over the entire crop rotation, rather than looking at the irrigation demands of individual crops.

The actual application efficiencies of all areas (except El-Hammami) tended to be exceptional for surface irrigation systems. Typical values ranged from 40 to 90%, but were mostly in the 60 to 90% range. This was probably a result of the low infiltration properties of the soils. In the sandy soils of El-Hammami, the application efficiencies were much lower (in the range of 14 to 40%). However, in El-Hammami, the ratio of estimated consumptive use to water applied was much higher than the application efficiency. The difference indicated a substantial water table contribution. Low on-farm irrigation efficiencies at Abu Raya were due to excessive losses between the *saqia* and the field. An average of 40% of water lifted was lost before reaching the field through leakage, seepage, and dead storage (TR 35).

•*On-Farm Irrigation Flow Rate*

In most cases, the flow rate available to the farmers at Project sites was very low and highly variable. Farmers were unable to exercise much control over this rate. When *saqias* were used, the discharge rates generally slowly declined because the pumping lift increased as the canal water level dropped. Typical flow rates available in the Project areas were 5 to 18 *l*/sec for *tambours*, and 3 to 61 *l*/sec for *saqias* at El-Mansuriya, and 15 to 56 *l*/sec for *saqias* at Abu Raya (TR 4, 35). The small and variable flow rates probably affected the time required to irrigate more than the amount of water applied. Since labor costs were increasing, the time factor was considered important by the farmers.

•*On-Farm Drainage*

In areas with high water tables, exceptionally slow final infiltration rates, and very low vertical drainage rates, both surface and subsurface drainage may be necessary. This was the case in both Beni Magdul and Abu Raya areas, where the farmers commonly drained the remaining surface water from their fields almost immediately after they finished an irrigation. In El-Mansuriya, this was frequently done by draining back through the *marwas* and into the original *mesqa*, which then discharged into the drains. There were some open field drains (*zawariq*) between certain *mesqas*, but they were neither maintained nor used. In Abu Raya, draining was more commonly done through a series of field drains that occupied 10-15% of the land. The field drains at Abu Raya actually served the following purposes:

- Removed excess irrigation water.
- Separated crops, particularly rice.
- Delineated property boundaries.
- Prevented flooding from closed *mesqas*, at the end of Daqalt canal, by providing a means of conveying excess water directly from the *mesqa* to drains

•*Overirrigation*

Much of the Project's concern focused on farmers' overirrigation which was defined as the application of more water than the crops required. Under this definition, overirrigation occurred in Project sites for several reasons.

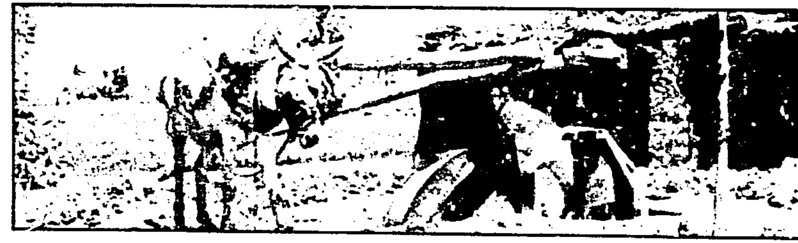
It was estimated that a large part of the overirrigation was caused by unlevel fields, which had a variation of 5 to 20 cm. Under these conditions, farmers had to apply more water than necessary to assure high spots received adequate amounts. Much of this excess water went to surface drainage.

Farmers sometimes overirrigated because they were uncertain about delivery schedules and they lacked knowledge of actual soil moisture conditions. This caused them to irrigate too soon because they feared plant stress would develop before the next on-period or in anticipation of winter closure. Under poorly managed gravity and lift irrigation, especially at night, some farmers allowed water to flow unattended across their fields and into drains. Irrigation was also sometimes used to soften the soil for the removal of cotton stalks by hand pulling after harvesting.

For these and other reasons, overirrigation sometimes occurred. As a consequence, farmers at the tail end of *mesqas* sometimes suffered water shortages and were inclined to request compensatory water releases.

System Dynamics

During the time EWUP worked in the study sites, several changes took place that reflected the continued evolution of the farming systems. The most noticeable changes in EWUP's areas were the introduction and spread of soybeans in Abyuha and sugar beets in Abu Raya. Another visible change was the increase in the number of pumps used at Abu Raya. Less noticeable, but perhaps more important in the long run, was the continuing increase in the cost of labor. This resulted in delayed planting of some crops and the elimination of the second pick of cotton on some fields. Other changes included the continuous fluctuation of various economic parameters that reflected changes in production cost and returns to those costs (TR 50). A major change in El-Mansuriya was the continued urban sprawl from Cairo, which has rapidly consumed farmlands. One neighboring distributary canal was totally covered by apartments during the life of the Project.



Flow rates available to farmers at EWUP sites were often very low and highly variable. When *saqias* were used, the discharge rates generally slowly declined because the pumping lift increased as the canal water level dropped.

Much of farmers' overirrigation at Project sites was caused by unlevel fields.

Characteristics of the Water Delivery System

The River Nile is the main source of irrigation water in Egypt. This water is delivered to farms through an extensive system of channels. The delivery system, which contains some large canals discharging up to 1000 m^3/sec, has a combined length of 30,300 km. Canals are classified according to size and functions as follows:

- Principal canals receive water directly from the River Nile for conveyance to main canals. No direct irrigation from these canals is permitted.

- Main canals receive water from principal canals for conveyance to branch canals. (Some main canals may take water directly from the River Nile). No direct irrigation from main canals is permitted.

- Branch canals receive water from the main canals for conveyance to distributary canals. Direct irrigation is permitted along the lower reaches of these canals, where they are comparable in size to a distributary canal.

- Distributary canals receive water from branch canals for distribution to *mesqas*. Direct irrigation along all distributary canal banks is permitted through legal farm outlets. Rotations are normally applied at this level.

- Private ditches *(mesqas)* receive water from distributary canals for distribution to *marwas* or directly to basins and/or furrows on private farms.

To control the proportional distribution of water to the canals, seven main barrages have been built in the River Nile. These main control structures are at Aswan, Esna, Nagga Hammadi, Asyut, Delta, Zifta and Edfina. Additional structures in the delivery system include:

Type of Structure	Number
Intake regulators	5623
Head regulators	2887
Weirs	162
Tail Escapes	1761
Spillways	153
Bridges	9955
Crossing works	567

EWUP activities were confined to areas adjacent to distributary canals and *mesqas*, and to on-farm irrigation from these channels.

Condition of Structures

•*Head Regulators and Outlet Check Structures*

In the Project areas, each distributary canal had a head regulator at the inlet and an outlet check structure (tail escape). The Daqalt canal also had two regulators located intermediately along its course. Most of these structures were of durable concrete and masonry construction. Head regulators had heavy steel or timber block gates. Maintenance of the head regulators was minimal but they were in better condition than the intermediate regulators which were difficult to operate and sometimes inoperative. The head regulator for the Beni Magdul canal was replaced in 1977 by a Nyrpic gate which was easy to operate and maintain. Gates on the lower part of some outlet check structures were impossible to operate due to lack of maintenance.

•*Farm Turnout Structures (vents or outlets)*

Most of the farm turnouts to *mesqas* at Project sites were pipe outlets (called Dunuis outlets). Some were illegal masonry arch-type conduits. Most outlets consisted of a pipe extending through the canal bank without any type of a headwall. Usually there were no gates or control features on the outlets. Different conditions at the entrances caused the flow through the outlets to vary. A pipe extending into the canal with the entrance not flush with the bank could have a lower discharge than one with the entrance recessed into the canal bank. Flow rates could vary more than 10% depending on different entrance conditions.

Lack of adequate head and improper outlet size of legal turnouts were the greatest problems that restricted flow rates into *mesqas*. This issue will be discussed in a later section.

Condition of Channels

The channels at each of the Project sites were subject to the usual maintenance problems of unlined canals. The major problems were weeds, seepage and unstable cross sections.

Weed growth was unchecked in El-Hammami canal where the annual irrigation canal flow was less than one-third of that required for El-Hammami area. There was less weed growth in the Abyuha and Daqalt canals, but the problem was still severe. Even after the Beni Magdul canal was lined, weed growth and debris restricted the flow to the downstream reaches of the canal.

Excessive weed growth in *mesqas* (which have traditionally been the responsibility of the farmers to maintain) restricted the flow to farms in different parts of the Project areas.

Seepage or overtopping from some *mesqas* impeded farm operations due to wet or flooded farmlands adjacent to the channels. Table 2 presents results from seepage tests conducted on various channels. The on-farm channels, which had the highest seepage losses, were allowed to dry and crack between irrigations. The *mesqas* and distributary canals were kept wetter with more frequent use.

Inflow-outflow tests were conducted at Abu Raya on 13 unimproved on-farm channels where the average conveyance loss rate was 22 cm/hr from soil seepage

Animal traffic was one cause of unstable and oversized canal cross sections.

Channels at Project sites suffered from the usual maintenance problems--weeds, seepage and unstable cross sections.

and leakage through cracks. Water lost between the *saqia* and the field in Abu Raya averaged 40% (TR 35). After improving one of the channels by shaping with a V-ditcher, the soil intake rate was initially reduced to 2.6 cm/hr. The reduction in losses was mainly due to filling of cracks and plastering the clay during operations of the V-ditcher.

In the *mesqas* and canals, the seepage rate decreased with time after initial readings except in El-Hammami canal where the soil was sandy and the water table was above the canal bottom.

Unstable and oversized cross sections were caused by sedimentation, erosion of canal banks by water scouring and animal traffic, soil removal for brick manufacturing, and enlargement from cleaning operations to remove weeds and sediment. Approximately 1% of the cropping area was lost because of oversized canals.

Operation

•*Allocation of Water*

The flow in any distributary canal should be based on crop needs as determined by (1) the cropping pattern, (2) water requirements, (3) area served (4) soil type and (5) the expected conveyance and on-farm losses. In practice, however, water delivery to distributary canals was primarily based on the water surface elevation on the downstream side of the head regulator inlet control gates. Regulation of the flow to the distributary canals was related to the available head in the district branch or main canal. Usually, there was no determination or allocation of a specific flow rate at any point within the district. The more water a group of farmers used on a canal, the lower the water surface in the canal became. This increased the head differential at the inlet control gate and subsequently the rate of inflow.

The internal distribution within one or more irrigation districts was accomplished by maintaining adopted water levels in the branch and distributary canals. Most of the intake structures of the principal canals and of the main distribution sites

Table 2 : Seepage Rates from Unlined Earth Channels in Project Sites

Area	Type of Channel	Channel Seepage Rate			
		Intake (cm/hr)		Intake (l/sec/100m)	
		Initial (hr)	Final (hr)	Initial (hr)	Final (hr)
Abu Raya	On-farm 1/ conveyance (unimproved)	22 2/		5.99 2/	
Abu Raya	On-farm 1/ conveyance (improved)	2.6	1.0	0.54	0.21
Abyuha	*Mesqa* (unelevated)	1.6	0.2	0.96	0.13
Abyuha	*Mesqa* (elevated)	2.6	1.2	1.50	1.12
Beni Magdul	*Mesqa* (unelevated)	1.2	0.3	0.56	0.13
El-Hammami	Distributary Canal	0.7	0.7	0.95	0.95

1/Conveyance channels from *saqia* to fields.
2/Average of losses from 13 channels by leakage through cracks and seepage throughout entire tests.

between governorates were calibrated. Water flowing through them was measured.

During on-periods, water flowed through canals 24 hours per day. With no gates on the farm outlets, water flowed from canals into the *mesqas* continuously, day and night. Daytime irrigation was preferred by farmers, thus during the night, water flowed through the system to the drains or was stored in the channels. Water budget studies showed high losses to drains -- 30 to 45% of total water delivered for irrigation at Abyuha and 46 to 58% at Abu Raya (TR 47).

Complete water budgets were made for irrigated regions at Abyuha, Beni Magdul, and Abu Raya. An example of a complete water budget is given in Figure 8 which illustrates each water budget component as a fraction of total inflow for the 1981 summer season at Abyuha. Water deliveries during winter seasons ranged from 4419 to 4440 m^3/*feddan* in Abyuha, from 2685 to 3174 m^3/*feddan* in Beni Magdul, and were 4887 m^3/*feddan* in Abu Raya. Summer season values ranged from 7175 to 10419 m^3/*feddan* in Abyuha, from 3601 to 4271 m^3/*feddan* in Beni Magdul, and were 6810 m^3/*feddan* in Abu Raya (TR 47). Comparisons of water delivery and consumptive use are illustrated in Figure 9 (A, B, C). Irrigation efficiency varied from month to month at each site as illustrated in Figure 10. Control and management of canal deliveries to Beni Magdul was the reason for the high efficiency there. The Beni Magdul canal was equipped with an adjustable inlet gate (Nyrpic type) calibrated for flow measurement.

• *Delivery Schedules*

The area served by a distributary canal was divided either into two equal areas with water delivered by a two-turn rotation, or into three areas with water delivered by a three-turn rotation.

Different space and time allocations were applied on this system according to the type of soil, cropping pattern, season and boundary conditions. For example:

Two-turn rotation:	4 days on and 4 days off (rice)
	7 days on and 7 days off (cotton)
Three-turn rotation:	4 days on and 8 days off (general crops/summer)
	5 days on and 10 days off (general crops/winter)
	7 days on and 14 days off (general crops/winter)

Under rotation deliveries, farmers who had sandy soils or grew vegetables occasionally irrigated both at the beginning and end of an on-period to be certain there would be adequate soil moisture until the next on-period (TR 4). Sometimes rotations continued when farmers had little demand for the water and canal water flowed through the system to drains (TR 47, 48).

• *Uniformity of Distribution*

Figure 11 illustrates the lack of uniformity in water distribution to land served by El-Mansuriya canal in 1978. Kafret Nassar canal received almost four times more water per *feddan* than El-Shimi canal and it conveyed 40% more water per *feddan* than El-Mansuriya canal from which it received water (TR 3). Flow into El-Hammami canal was not adequate for more than one-third of the area. Many irrigation wells were installed by farmers because of the water shortage.

Flow from canals to *mesqas* was intended to be delivered 24 hours per day through legal turnouts, 10 m long, with a head loss of 25 cm. The size of turnouts for specified irrigated areas was legally established (and was not supposed to be changed without MOI approval). The allowable water duty per on-day of 24 hours was 50 m^3/*feddan*/day which represented a depth of 11.9 mm/day.

In most cases, pipe lengths of 10 m were found at *mesqa* inlets. However, the operating head loss at the inlets was often less than 25 cm. Also, irrigation water was usually applied during daylight hours. Consequently, many farmers installed larger pipes to deliver adequate flow rates with the smaller available heads. Larger flow rates were also required where night flow and *mesqa* storage did not provide sufficient water to compensate for irrigating only during a portion of the 24 hours available each day.

To provide adequate flow rates, many farmers illegally installed extra pipes or larger outlets (TR 6). Along the Daqalt canal, 72% of the *mesqas* had illegal turnouts. In El-Hammami, there were three times as many illegal turnouts as there were legal sizes. In Beni Magdul, there were 61 outlets rather than the 25 which were legally permitted.

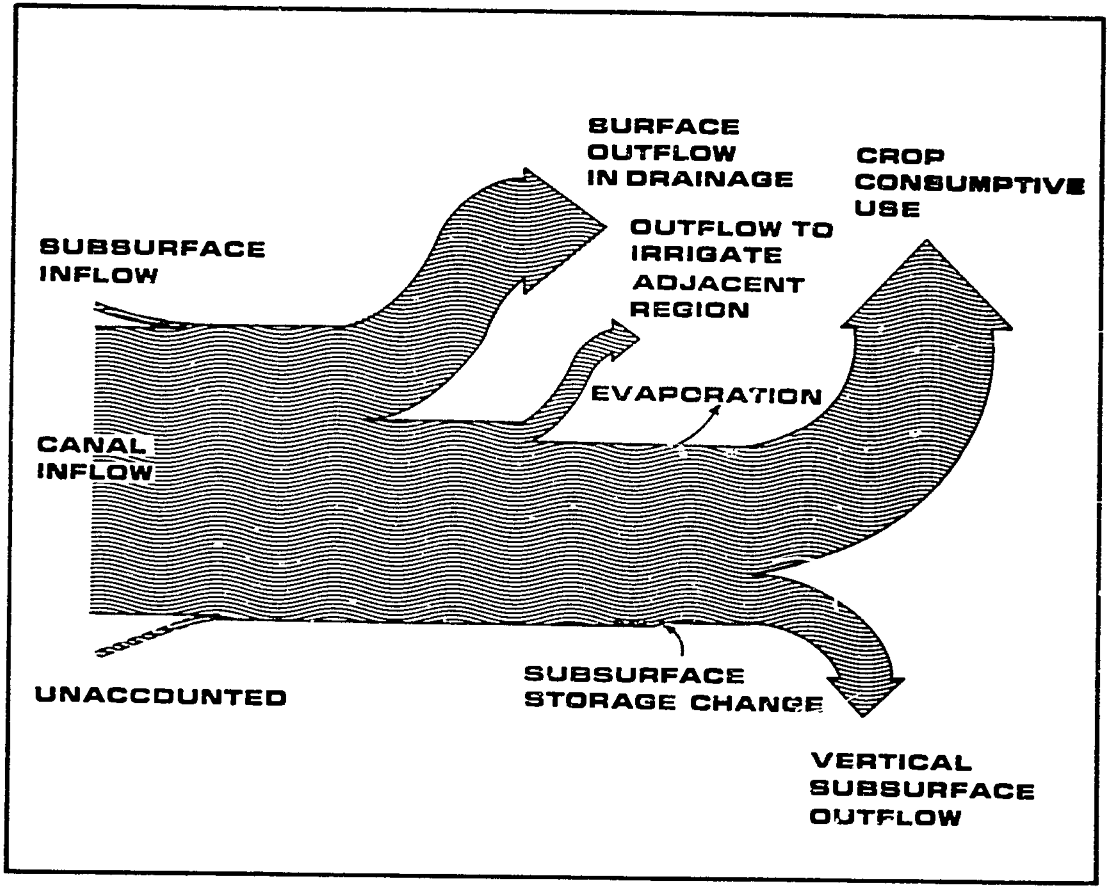
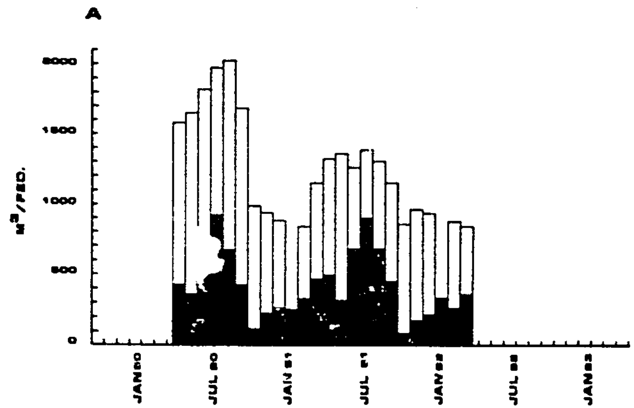
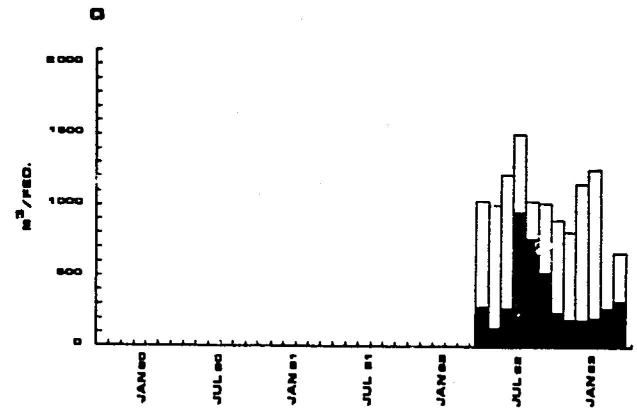


Figure 8. Scaled schematic of the water budget for Abyuha region during summer, 1981.





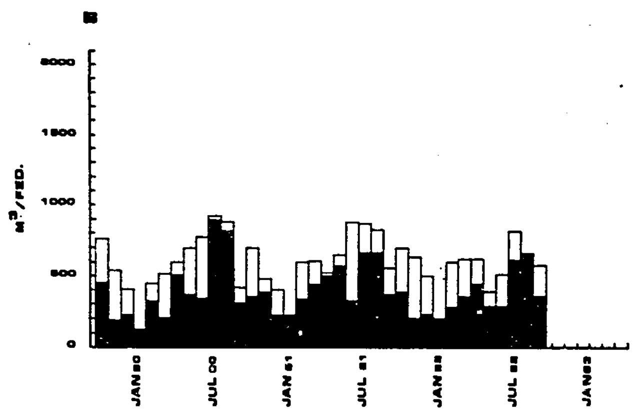


Figure 9.
Monthly total water diverted and crop consumptive use at (A) Abyuha, (B) Beni Magdul, and (C) Abu Raya. The shaded portion of each bar represents consumptive use.

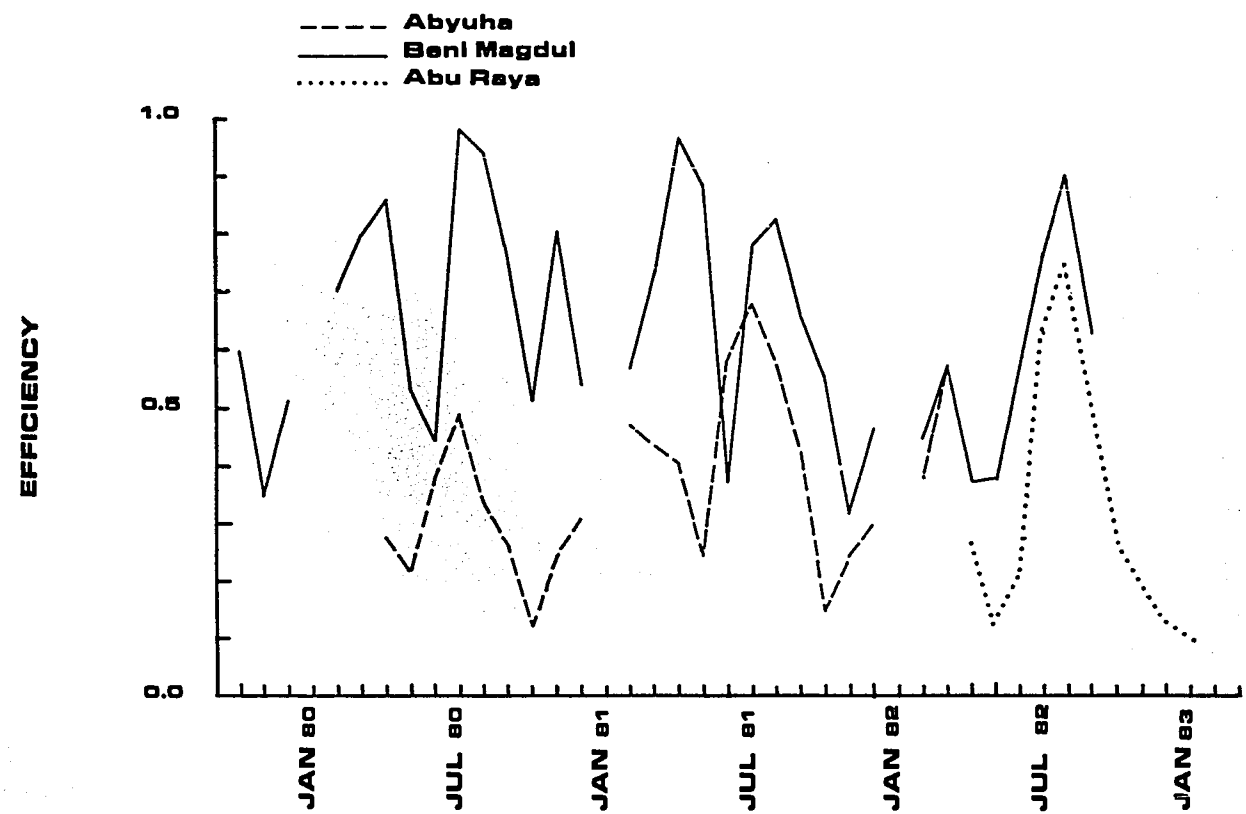


Figure 10. Monthly average irrigation efficiency measured in Abyuha, Beni Magdul and Abu Raya.

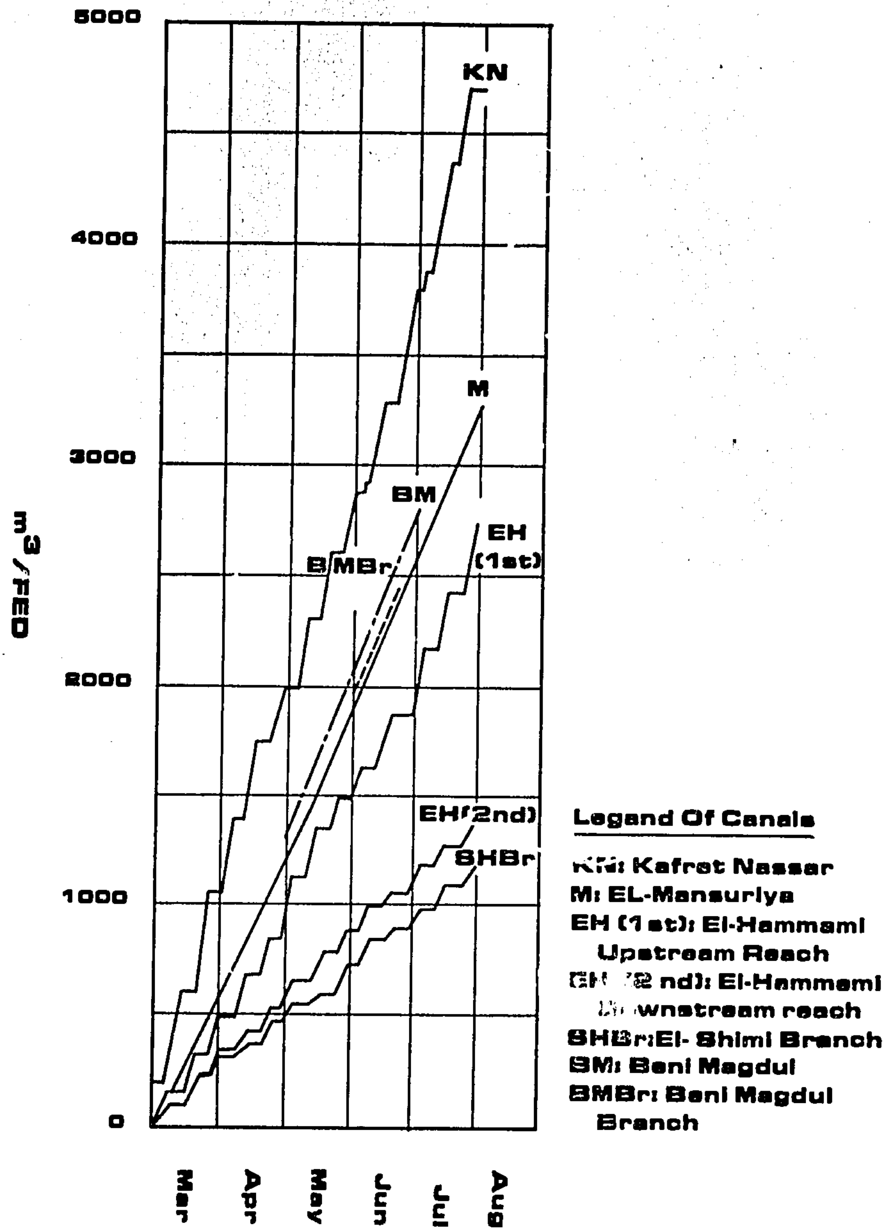


Figure 11. Inequitable water distribution to branches of El-Mansuriya canal during five months in 1978.

Table 3 presents the results of a test measured at the turnout where water was delivered to the Manshiya *mesqa* from the Daqalt canal at Abu Raya. The turnout, which irrigated 246.5 *feddans*, had a pipe diameter of 40 cm which was a legal size for 237 to 316 *feddans*. During the test, the head loss was always less than the 25 cm specified for a legal turnout. The head loss ranged from a low of 4.5 cm on August 6, 1983 to a high of 18.6 cm on August 3. The total inflow volume of 31875 m^3 was equivalent to 11.67 mm/day depth of water on 246.5 *feddans*. The depth was almost equal to the 11.9 mm or 50 m^3/*feddan*/day allowed for a legal turnout, but for any area larger than 246.5 *feddans*, the water delivered would have been considerably less than the legal amount. Water levels were high during the periods between 5:30 - 6:30 a.m., 3:07 - 3:45 p.m. and 7:15 - 7:52 p.m. Irrigations were stopped or reduced during the night, late mornings and late afternoons. This allowed channel storage to recover. There were many reasons for less than legally specified head loss for a turnout including land topography, poor canal maintenance, poor water scheduling among farmers, excess seepage and weeds.

At Abyuha, uneven distribution resulted from variation in land topography. In higher elevation areas, the available head was low and extra pumping lift was required (TR 46). In some lower elevation areas, the head was sufficient for gravity irrigation.

Because of small flow rates through turnouts into *mesqas*, farmers at Abu Raya irrigated extensively from *mesqa* storage. When storage was depleted faster than inflow rates, *mesqa* water levels fell and caused an increase in pumping lift and a decline in *saqia* flow rates. Often, irrigation would end by midday because of insufficient water remaining in *mesqas*. During critical water-use periods, such as rice transplanting or cotton planting, some irrigations occurred at night after inflow refilled *mesqas* with water. Farmers at the downstream end of *mesqas* often had to wait until upstream farmers finished irrigating which made their irrigation schedules more uncertain.

Table 3. Inflow to Manshiya *mesqa* from the Daqalt canal between 3:30 p.m. on August 3 and 6:30 a.m. on August 6, 1983 (Area served by the *mesqa* was 246.5 *feddans*).

Date	Relative Water-Surface Levels, High or Low 1/	Time of Day (hr)	Head loss (H) in Turnout (m) 2/	Rate of Inflow from Canal to *mesqa* (m^3/sec) 3/	Volume of Inflow During Time Periods (m^3)
Aug. 3	High	3:30 p.m.	0.150	0.151	2440
	Low	7:45 p.m.	.186	.168	5037
Aug. 4	High	5:30 a.m.	.093	.119	3574
	Low	2:37 p.m.	.170	.160	1300
	High	3:07 p.m.	.109	.128	2315
	Low	7:52 p.m.	.134	.142	4879
Aug. 5	High	5:37 a.m.	.123	.136	2419
	Low	10:15 a.m.	.157	.154	3059
	High	3:45 p.m.	.158	.155	1972
	Low	7:15 p.m.	.165	.158	4880
Aug. 6	High	6:30 a.m.	.045	.083	

1/ High and low water-surface levels in the canal and *mesqa* occurred almost simultaneously.

2/ Size of turnout: diameter (D) = 40 cm; length (L) = 10 m.

3/ Computed using formula: $H = [(f\,L/D) + 1 + K_e]\,v^2/2g$, where $f = 0.02$, $K_e = 0.50$ (D, L, H = measured dimensions).

• *Water Lifting vs. Gravity Flow*

Most of the existing canals were constructed to provide water surface in *mesqas* at an elevation of 50 to 75 cm below the ground surface which required farmers to lift the water. Lifting was done by traditional *saqias, tambours* and *shadoufs*. *Tambours* and *shadoufs* provided small flow rates which were adequate only for small basin irrigation (TR 41). Initial *saqia* flow rate was usually adequate for long furrows and basins with restricted widths. However, as channel storage was depleted and pumping lift was excessive, flow rates decreased and were adequate only for irrigating small basins.

Government policy has favored lift irrigation on the assumption that gravity flow would result in excessive water applications to the land (TR 4). Work in Project areas has shown that this assumption was not necessarily right under full control and management. Farmers understood that excessive water application to fields containing slowly permeable clay soils would pond on the surface and damage plants. Ponding sometimes prevented seed germination or killed plants. Less caution existed where surface drains were available. Crop damage from excess water applications on sandy soils was not so readily evident to farmers. Water applied to sandy land infiltrated into the soil without undue ponding. The major damage, in this case, would be soil leaching and elevation of the water table which could diminish soil nutrients, rooting depth and crop yields. Sandy soils comprise approximately 10% of the irrigated land along the River Nile.

Wasteful flow through farms with a lift system was observed near the end of the Daqalt canal, but the cause was the delivery system. With closed-end *mesqas* and periodically high water levels in this area, farmers had to release the water to open field drains to prevent flooding of their cropland.

Water Quality

Table 4 shows electrical conductivity (mmhos/cm) and adjusted SAR values measured in canals, shallow groundwater and drains at Project sites during 1982-83. Table 5 presents guidelines for interpreting these water quality data (TR 62).

The quality of canal water at Project sites was "good" during the 11 months of the year and could be used for irrigation with consideration of adequate drainage, good water management and crop selection.

The water quality deteriorated while percolating through the soil. The salinity and sodicity of the shallow groundwater were 3 to 7 times greater than those of the canal water. This increase in concentration occurs under current irrigation management and drainage conditions. According to the guidelines, it is in the increasing to severe problem categories.

Likewise, the drainage water quality in the Project areas was 1 to 5 times more saline and alkaline than the canal water.

Analysis of the monthly samples of drainage water for the Abyuha area showed that the electrical conductivity and adjusted SAR averaged 0.27 mmhos/cm and 1.79, respectively, and this would classify the water as of good quality.

In Beni Magdul, the quality of the drainage water averaged 0.89 mmhos/cm, and the adjusted SAR averaged 5.43. The sodicity, as represented by the adjusted SAR, varied widely throughout the year from a low of 2.46 to a high of 18.69.

The salinity and sodicity of the drainage water in El-Hammami exceeded those in Beni Magdul. The electrical conductivity and adjusted SAR averaged 1.16 mmhos/cm and 7.2, respectively, for the 11-month period. This water would be considered from the salinity and sodicity points of view as moderate.

In Abu Raya, the data showed that the chemical composition of the drainage water deteriorated further compared to the canal water, and varied widely during the 11 months of irrigation. The average electrical conductivity was 1.84 mmhos/cm, but during closure, the salt content as measured by the electrical conductivity increased to 7.15 mmhos/cm. Although there were wide variations in salinity each month, the average value could be classified in the category of increasing problems. Similarly, the sodicity, as measured by the adjusted SAR, varied from month to month and averaged 12.95 for the 11-month period. During winter closure, it increased about 3 times to a value of 37.68. If reused as

Table 4. Electrical Conductivity (EC) and Adjusted Sodium Adsorption Ratio (SAR) of Water in Canals, Shallow Groundwater, and Drains at Project Sites (March 1982 - February 1983) (TR 62)

Area	Type of Channel	Electrical Conductivity (EC) (mmhos/cm)			Adjusted SAR		
		Range	Average	Winter Closure, Average	Range	Average	Winter Closure, Average
Abyuha	Canal	0.22-0.30	0.24		1.42 - 1.84	1.66	
	Shallow groundwater	0.42-2.66	1.28		1.65-24.74	11.46	
	Drains	0.22-0.35	0.27	0.36	1.27-2.57	1.79	1.59
Beni Magdul	Canal	0.30-0.42	0.37		1.98 - 3.00	2.45	
	Shallow groundwater	0.37-6.47	2.44		2.60-40.58	17.02	
	Drains	0.42-2.77	0.89	1.60	2.46-18.69	5.43	10.62
El-Hammami	Canal	0.30-0.76	0.42		2.18 - 5.51	2.88	
	Shallow groundwater	1.16-1.70	1.45		5.94-11.42	8.89	
	Drains	0.50-2.50	1.16	1.24	3.06-16.11	7.20	7.64
Abu Raya	Canal	0.31-0.81	0.41		1.88 - 2.69	2.42	
	Shallow groundwater	0.45-22.67	2.79		2.52-45.57	10.58	
	Drains	0.49-9.30	1.84	7.15	2.80-65.44	12.95	37.68

irrigation water, this drainage water could create increasing salinity and sodicity problems.

Drainage

Public drains in Egypt comprise a system of large open channels having a combined length of 17,497 km. Private drains consisting of small open channels for removal of excess surface water and/or closed tile drains for removal of groundwater, convey water to the larger drains. Drains are classified according to function and size as follows:

- Principal drains receive water from main drains mainly by lift (sometimes by gravity).
- Main drains receive water from branch drains mainly by gravity (sometimes by lift).
- Branch drains receive water from collector drains.
- Collector drains receive water from field drains.
- Field drains are either small open channels, *zawariq*, for drainage of surface water from farms, or subsurface tile drains, sometimes called laterals, for drainage of groundwater.

Principal, main, and branch drains are public drains constructed and maintained by the MOI; collector and field drains are private drains constructed and maintained by farmers.

Field drains and collector drains were found mainly in Abu Raya and Mansuriya areas where they served to drain excess surface water. Their depths were too shallow for drainage of subsurface water. They were generally poorly maintained and weedy. Infiltration studies and measurements of on-farm topography at Abu Raya indicated that due to low infiltration rates and field depressions, surface drainage was required (TR 57).

Public drains were generally in better condition than private drains. Drain No.7, which is a main drain near Abu Rava, was in excellent condition.

Table 5. Guidelines for Interpretation of Water Quality for Irrigation

Irrigation Problem	Degree of Problem		
	No Problem	Increasing Problem	Severe Problem
Salinity: (affects crop water availability) ECw (mmhos/cm)	< 0.75	0.75-3.0	> 3.0
Permeability: (affects infiltration rate into soil) adj. SAR	< 6	6 - 9	> 9

Characteristics of the Groundwater System

The groundwater system of the Nile Valley and Delta is composed of an alluvial clay-silt layer that supports a water table aquifer and forms a semi-confining cap over an underlying aquifer of coarse sand and gravel. The thickness of the clay-silt layer is typically 10 to 15 m in the Nile Valley. Soil profiles from well logs at Abyuha and Beni Magdul indicated a thickness of approximately 12 m and 14 m respectively (TR 60). In the Delta, the thickness increases nonuniformly in the seaward direction.

The water table aquifer in the clay-silt layer is recharged primarily by infiltration of irrigation water. Seepage from irrigation channels is a less significant source of recharge. Although it fluctuates in response to irrigation practices, the water table is consistently very high throughout the Nile Valley and Delta. Monthly average depth to water table from ground surface ranged from 1.20 to 1.91 m at Abyuha, 0.65 to 0.90 m at Beni Magdul, and 0.20 to 0.80 m at Abu Raya as seen in Figure 12 (TR 47).

The hydraulic conductivity of the clay-silt layer is very low. Auger hole tests conducted at the Project sites indicated average values of horizontal saturated hydraulic conductivity of 1.10, 0 20, and 0.10 m/day for Abyuha, Beni Magdul, and Abu Raya respectively. Results from consolidometer and permeameter tests revealed a vertical saturated hydraulic conductivity significantly less than 0.001 m/day (TR 60).

Due to the low hydraulic conductivity and the relatively small hydraulic gradient between the water table aquifer and the lower sand aquifer, the rate of downward vertical leakage is small. Project data indicated leakage rates of 0.0005 to 0.0015 m/day in Abyuha, about 0.0005 m/day in Beni Magdul, and less than 0.0001 m/day in Abu Raya (TR 60). This low natural drainage rate and the practical difficulty of reducing losses to the water table from overirrigation makes it infeasible to lower the water table by improved on-farm irrigation efficiency alone (TR 61).

Comprehensive analyses were made of shallow groundwater quality in the water table aquifer (TR 62). Typically, shallow groundwater at each of the sites was classified as moderately saline (EC of 0.75 - 3.0 mmhos/cm). However, at Beni Magdul and Abu Raya, some wells periodically indicated highly saline conditions (EC>3.0 mmhos/cm). Alkalinity was moderate (adjusted SAR of 6-9) to high (adjusted SAR> 9) at each site.

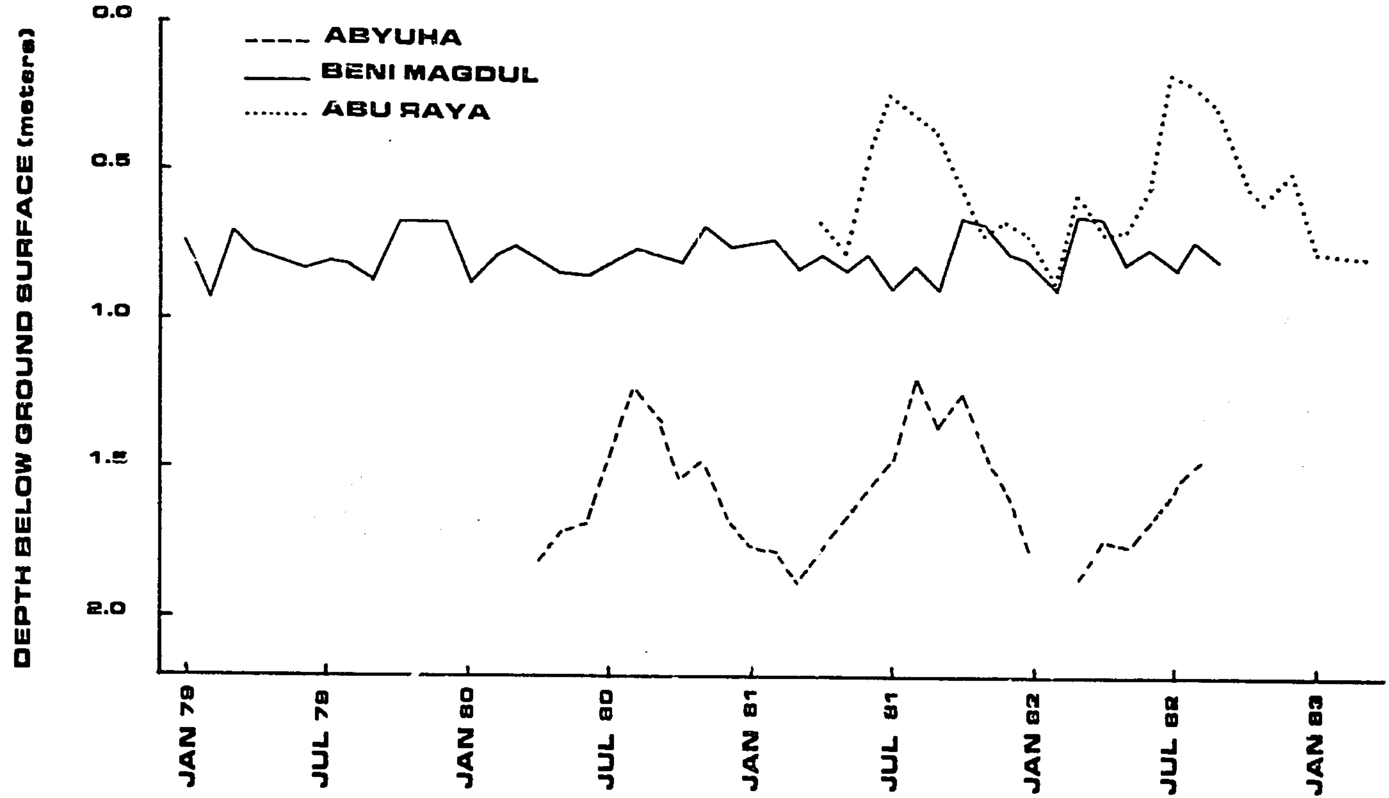
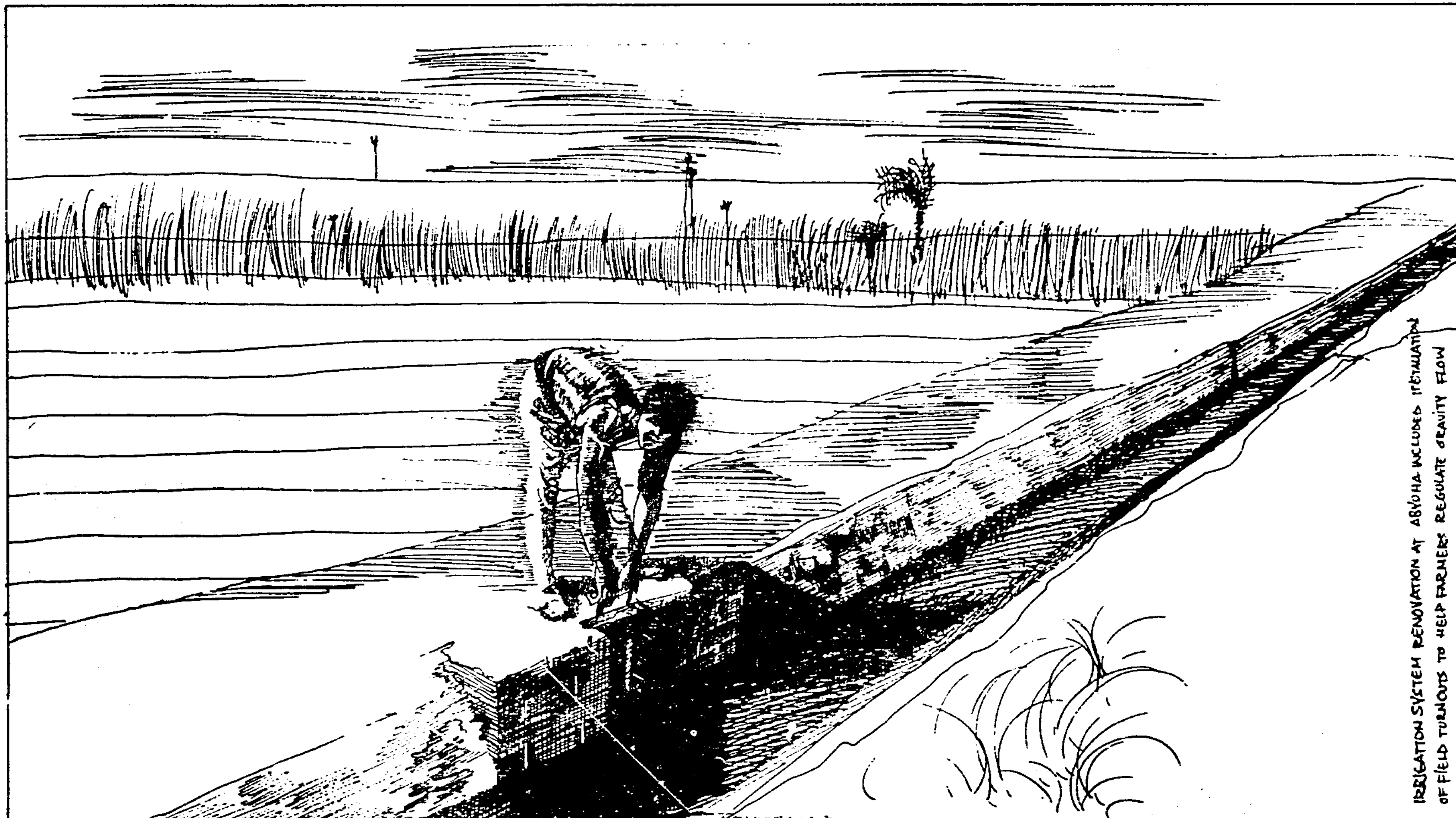


Figure 12. Monthly average depth to water table at Abyuha, Beni Magdul and Abu Raya.


IRRIGATION SYSTEM RENOVATION AT ABYUHA INCLUDED INSTALLATION
OF FIELD TURNOUTS TO HELP FARMERS REGULATE GRAVITY FLOW

INTERVENTIONS TESTED FOR IMPROVING THE SYSTEM

Interventions Tested for Improving On-farm Water Management

Interventions tested by EWUP to improve on-farm water management included precision land leveling, irrigation system design and management, irrigation scheduling, and crop management.

Precision Land Leveling (PLL)

The level basin method of irrigation is used by farmers throughout Egypt. Achieving high water application efficiency with this type of irrigation requires precisely leveled fields. Precision land leveling activities were conducted at each of the Project sites.

- *Earthwork*

The allowable range for variation in elevation within a field was 4 cm (TR 38). Reverse slopes from field head to tail were eliminated in most cases. The land leveling process provided soil for filling poorly maintained field drains and conveyance channels as part of irrigation system renovation (TR 38). Abu Raya farmers very seldom removed open field drains (*zawariq)* which separated crops.

Required cut volumes were small, averaging 60 m^3/*feddan* at Abu Raya. Field sizes ranged from 0.1 *feddan* to 5 *feddans*. The average value for maximum depth of cut within a field was 6.5 cm, although up to 15-20 cm of cut was required in some cases. At Abu Raya, soil cuts were not considered deep enough to adversely affect soil fertility or soil salinity (TR 38).

- *Accessibility and Constraints*

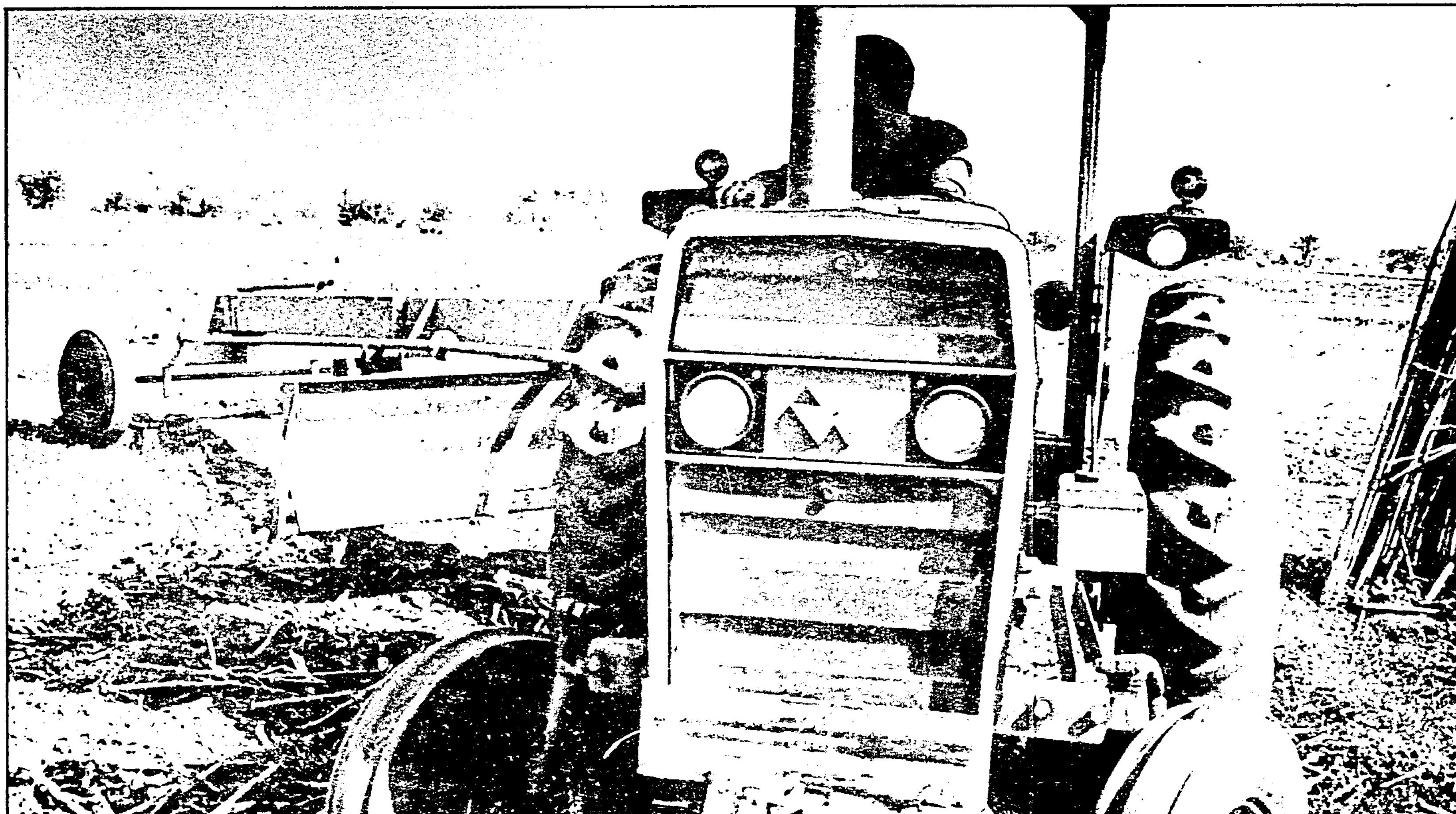
The farmers' ability to perform PLL was constrained by the lack of roads for equipment movement, the small size of individual holdings, and the limited fallow time. Access to agricultural land was obstructed by washed-out inlets to *mesqas* and *saqias*, spoil piles left after canal cleaning, trees, buildings, narrow roads, layout of on-farm channels in fields and wet fields (TR 32). Farm access during PLL intervention was obtained by partial tracking across planted fields, driving through fallow fields, and fording irrigation ditches and drains after filling with crop residues. Tractors and short implements could reach the field in most cases, but the longer field plane often could not be used (TR 38).

Field size was frequently one *feddan* or less. For such field sizes, maneuvering large field planes was difficult. To overcome this in Abyuha, the Project consolidated the fields of several farmers whenever possible. This consolidation was promoted by the work of the sociologists. In Beni Magdul and El-Hammami, the complex vegetable cropping patterns often resulted in fields of only 0.25 *feddan*. These fields were almost impossible to level.

- *Timing*

Precision land leveling could only be conducted during the limited fallow periods, or turnaround times, between successive crops. These turnaround times had to be examined on both an individual field and community-wide basis. The latter provided for better opportunity to move equipment from field to field. The turnaround time on individual fields was generally about one-half that for the community. Typical durations for turnaround are shown in Table 6. The field durations ranged from nearly 50 days to zero. The latter occurred when berseem was sown prior to the harvest of either maize or rice. In Beni Magdul and El-Hammami, the turnaround periods were usually less than 14 days, and more scattered throughout the year. This was the result of more intensive vegetable crop production in the area.

Soil moisture conditions further limited the time period during which PLL activities could be performed. At Abu Raya, PLL was not done after rice cultivation because of very moist soil conditions.



Lack of roads for equipment movement constrained farmers' ability to perform PLL. Movement of long field planes was especially difficult.

Table 6. Turnaround Periods for Abu Raya and Abyuha

Season	Site	Conversion	Average Per Field [a]	Community [b]
			Days	
Winter to summer	Abu Raya	Berseem to Cotton	58	101
		Berseem to Rice	38	92
		Berseem to Maize	29	71
		Wheat to Rice	28	67
		Sugar beets to Rice	21	32
	Abyuha	Broad beans to Soybeans	33	72
		Broad beans to Cotton	14	28
		Wheat to Maize	34	53
		Berseem to Maize	26	82
Summer to winter	Abu Raya	Rice to Berseem [c]	11	37
		Rice to Wheat	36	45
		Cotton to Wheat	31	61
		Cotton to sugar beets	29	62
		Maize to Berseem	24	71
	Abyuha	Maize to Broad beans	24	69
		Soybeans to Broad beans	47	92
		Soybeans to Broad beans	20	46
		Maize to Berseem [c]	8	39
		Cotton to Wheat	47	63

a/ Goes from harvest to planting.
b/ Goes from first harvest to planting.
c/ Includes general fields in which berseem was sown before harvest and turnaround time was zero.

• *Manpower and Equipment*

Manpower requirements for the Abu Raya PLL program included a design engineer, a farm machinery engineer, two technicians and a farm machinery operator. Each member of the PLL team needed to be well-trained.

Required equipment included a tractor, soil scraper, chisel plow and field plane. A furrow-maker, V-ditcher, and border dike implement were also needed for constructing improved irrigation systems. The above personnel and equipment were sufficient to implement PLL on up to 15 *feddans* before planting winter crops and 35 *feddans* before planting summer crops. A PLL program implemented on farmers' fields required machinery and manpower inputs from sources outside the farm community (TR 38).

• *Stability*

Field levelness following PLL activities at Abu Raya was unstable due to prevailing practices such as removing soil for brickmaking, non-uniform spreading of animal bedding material and manure and the removal of soil from rice nurseries during transplanting. Soil settling in fill areas also led to instability of field levelness. Annual smoothing of fields with a field plane following PLL intervention was effective in maintaining a dead level grade (TR 38).

• *Costs and Feasibility*

For the Abu Raya PLL program, costs of L.E. 14 per *feddan* (L.E. 0.26 per cubic meter of earth cut volume) were calculated based on farm machinery and machinery operator costs for soil scraping and smoothing by field plane (costs are based on farm machinery cost tables developed by EWUP during 1979).

Small field sizes and small cut volumes per *feddan* increased PLL costs (TR 38). Technical feasibility of implementing a land leveling program on farmers' fields at Abu Raya and Abyuha was well established.

On-Farm Irrigation Systems

Project activities centered on redesign of the conventional basin irrigation systems. In some cases, this resulted in longer and narrower basin configuration. Length of run from field head to tail ranged from 50 to 150 m. Precision leveled land was necessary for successful irrigation of long runs (TR 41).

• *Design Method*

The United States Department of Agriculture Soil Conservation Service (USDA-SCS) has developed level irrigation system design methods for furrows and borders. These methods proved adequate for farm irrigation system design at Project sites. Appropriate border width or number of furrows irrigated in a set could be determined from design parameters such as available flow rates, infiltration characteristics, design application depth, field length and surface roughness. Minicomputers and hand-held programmable calculators were extremely useful design aids which facilitated consideration of a wide range of design conditions (TR 35).

• *Flow Rates*

Flow rates available at the farm varied considerably at the three Project sites. Small and variable flow rates were often due to deficiencies in the water delivery system serving the farm. Variability of flow rate had a direct effect on irrigation system performance and had to be considered in system design and operation in order to achieve good results (TR 41). For design purposes, average values for discharge were used. For Abu Raya, an average flow rate for a *saqia* ranged from 30 to 35 *l*/sec. For unimproved *saqia* to field conveyance channels, design flow rate at the field ranged from 20 to 25 *l*/sec. In the case of lined channels, losses were considered negligible (TR 35).

The dependence of on-farm irrigation efficiency on flow rate for borders planted to wheat at Abu Raya was analyzed. Desirable results were obtained where flow rates exceeded 2.5 *l*/sec per 100 m^2 of border area.

• *Surface Roughness*

Surface roughness for furrow or border water advance considerations depended on the degree of soil smoothing by farmers prior to irrigation. Estimates for surface roughness in design were based on the prevailing tillage practices in the area. At Abu Raya, for a well-tilled soil condition, values of Manning roughness coefficient estimated to be 0.15 for broadcast small grains grown in borders and 0.04 for furrow irrigation were considered appropriate.

• *Infiltration Characteristics and Design Application Depths*

At Abu Raya, systems were designed for maximum infiltration rates and infiltrated depths, both of which occurred at the first irrigation of the season. USDA-SCS intake families of at least 1.0 and application depths of at least 10 cm were used for designing upland crop systems (TR 35).

For the rice-puddling irrigation which preceded transplanting, ponding of water on the soil surface was necessary. Required water application depths averaged 25 cm.

• *Field Layouts*

Furrow or border length was determined by field dimensions and farmer preference in most cases. Appropriate border width depended on available flow rate at the head of the border, the border length, design application depth, infiltration characteristics and surface roughness. Necessary border dike height was determined by the expected maximum flow depth provided by the SCS border design method, plus freeboard (TR 35). At Abu Raya, typical border strip widths ranged from 10 to 30 meters and a typical border dike height was 0.20 m. Furrows needed to be large and well-shaped. At Abu Raya, a furrow spacing of 1.1 meters was successfully used (TR 35). Field layouts were designed to minimize length of *saqia*-to-field conveyance channels (TR 41). Conveyance channels were reshaped and in some cases lined, in order to reduce or eliminate conveyance losses from *saqia* to field.

• *Management*

For good performance, newly designed system with long runs had to be well maintained. Furrows needed to be cleaned by cultivator prior to irrigation to maintain shape, fill cracks and minimize roughness. Dikes which separated borders and surrounded fields needed repairing before each irrigation to control water advance along the border strip and to prevent undesirable surface drainage (TR 41). Dike maintenance was particularly important during rice cultivation because water was continually ponded on the soil surface (TR 9).

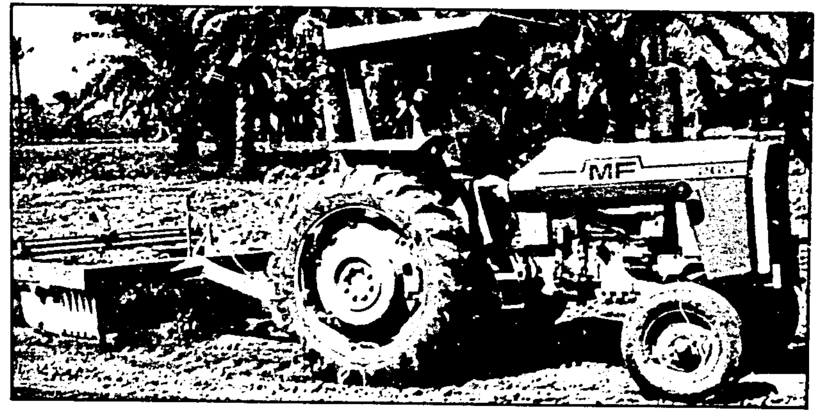
During irrigation of basin crops, the entire flow available at the field was diverted to one border strip. For furrow crops, the number of furrows irrigated at one time was determined at each irrigation depending on the available flow rate. Typical values for furrow flow rate at Abu Raya varied from 2 to 4 l/sec per 100 m^2 of land area (TR 41). Inflow into borders or furrows needed to be stopped when the advancing water front reached the end of the field. This allowed good distribution of water across the field because of low terminal infiltration rates (TR 57).

• *Training*

Project interventions resulted in significant changes in the on-farm irrigation system. Technical assistance was provided to the farmer so he could effectively use the new systems. Training of professionals and technicians in on-farm irrigation system design and management was also a necessary component of the on-farm water management improvement program.

Irrigation Scheduling

Irrigation scheduling addresses two questions: "When to irrigate?" and "How much water to apply?" Project experience involved developing irrigation schedules based on prevailing farmers' practices, measured soil water depletion, and consumptive use estimates. Constraints to implementing an irrigation scheduling program were also assessed (TR 54).



Technical feasibility of on-farm land leveling was well-established at Abu Raya and Abyuha EWUP sites.

Interventions involving long furrows were implemented with trained technical assistance provided to the farmer so he could effectively use the new system.

• *Proposed Schedules*

Proposed irrigation schedules were designed to help farmers follow recommended irrigation intervals based on desired soil water depletion values. Application depths were determined by the soil water deficit, and expected application efficiency (TR 54). Applying less water than the soil water deficit was considered impossible with prevailing surface irrigation application methods and soil infiltration characteristics (TR 57). The heaviest irrigation applied at Project sites occurred at crop planting due to the large irrigation gap between crops. A typical soil water deficit value for initial irrigation was about 12 cm (TR 54). For Abyuha, Beni Magdul and El-Hammami areas, leaching of salts which occurred during the first irrigation was considered sufficient for the entire season. At Abu Raya, where saline groundwater presented a hazard to crop production, the flooding of rice paddies effectively controlled soil salinity. A 40% reduction in soil salinity in the 0-90 cm soil-depth range was measured during each of two seasons of rice cultivation (TR35).

EWUP studies showed that irrigation should take place at a soil water depletion of 40 to 50% of the available water in the effective root depth. This was equivalent to a soil water deficit of about 7 cm, which was accepted as a guideline for when to irrigate. It was observed that many farmers at the Project sites irrigated at this deficit for irrigations following the planting irrigation (TR 54). Water application depth for irrigations following the planting irrigation had to be sufficient to satisfy the 7 cm deficit plus expected losses.

• *Feasibility*

Farmers sometimes deviated in water application from the typical 7 cm deficit value in response to water availability in the distributary canal. Unexpected water shortages caused farmers to irrigate later than desired. Anticipated water shortages, such as before winter closure or before the off-period in a three-turn water delivery rotation caused farmers to irrigate early (TR 54). Farmers integrated irrigation into their total farming activity. For example, irrigations occurred in order to incorporate fertilizer. In many areas, fields were often divided into small basins containing different crops. Sometimes adjacent basins in a field were irrigated at the same time without regard to the soil water deficit in each individual field. Fields of berseem, parsley, and dill were sometimes irrigated early in anticipation of prearranged cutting dates and the need to have the fields dry enough to harvest.

Direct soil moisture measurement by tensiometers or soil sampling on all farms in an area was not practical. Proposed irrigation schedules were developed from average measured values of soil moisture depletion or the estimated consumptive use rate for each crop in an area. Disadvantages of this procedure included questionable reliability of the average values, field variability within an area where an irrigation scheduling program was being implemented and variable climatic conditions (TR 54).

In some cases, proposed irrigation schedules included fewer irrigations than observed under previous farmer practices. Farmers sometimes irrigated to ease removal of cotton stalks. This practice reduced labor requirements but delayed planting of the following crop. Heavy pre-irrigations to aid seedbed preparation also delayed planting. Increased accessibility of farm machinery for appropriate soil preparation decreased the need for heavy pre-irrigations at Abu Raya (TR 35). Elimination of irrigations by increasing irrigation intervals after planting was done with caution to avoid yield reductions from increased soil moisture tension and possible root pruning from soil cracking (TR 54).

Reliable water delivery and appropriate delivery scheduling were essential for implementing an on-farm irrigation schedule. Irrigation water delivery had to be responsive to on-farm irrigation water demand (TR 54).

Crop Management

Project work at the various field sites demonstrated improvement in crop management was required to gain maximum benefit from irrigation system interventions. Yields could be increased by implementing solutions to the prevailing crop management problems.

Improved agronomic practices included timely sowing of improved crop varieties, adequate plant populations, plant protection against insects and disease, and proper rate and timing of fertilizer application. These practices, combined with water management, increased crop production. In general, it was observed that higher yields and greater returns from applied water resulted when farmers followed recommended crop and water management practices (TR 53, 63).

Benefits

Project interventions in on-farm water management resulted in a number of measured and observed benefits. Irrigation of long furrows and basins provided potential for mechanization of field operations (TR 41). Labor requirements for construction and operation of on-farm irrigation systems were reduced on some farms.

Because PLL minimized field elevation variation, farmers were able to achieve good field coverage with smaller application depths. Drainage of excess water was consequently reduced. In Abyuha, land leveling intervention resulted in application efficiencies of 70% and 75% for two long basins of 6.3 m x 133 m and 13 m x 50 m, respectively, while application efficiency on six unleveled farms averaged 61% (TR 41). PLL was only one of a number of factors which influenced application efficiency. Other factors included flow rate, duration of water application, dike and furrow maintenance, and basin size. Similar results were also observed in El-Mansuriya area (TR 41).

In Abyuha, land leveling provided soil for maintaining, aligning, elevating and reconstructing channels. In Abu Raya, construction of long furrows and basins made possible by PLL reduced *saqia*-to-field conveyance channel length and saved water (TR 38).

Water and irrigation time savings were realized through implementation of a package of practices in Abu Raya including PLL, irrigation system design, and management (TR 41). Table 7 is a summary of data from fifty fields during six seasons of Project work. As a general trend, land leveling and conveyance channel improvements led to higher on-farm irrigation efficiencies. Higher efficiencies represent decreased irrigation time and reduced water lifting costs.

In Abu Raya, application of zinc sulphate showed yield increases.

Table 7. Summary of On-Farm Efficiency Results for Six Seasons of EWUP Work.

Season	Crop	Location	Conditions/ Practices			E_{cf} [1/]	E_a [1/]	E_{if} [1/]
			PLL	Conveyance Channels	Basins			
Winter 78-79	Wheat	Field 3-02 Hamad Canal	No	unimproved	conventional	60[2/]	35	21
Winter 78-79	Flax	Field 3-02 Hamad Canal	No	unimproved	conventional	60[2/]	40	24
Winter 79-80	Wheat	5 fields on Manshiya Canal	No	unimproved	conventional	60[2/]	63	38
Winter 79-80	Wheat	5 fields on Manshiya Canal	Yes	unimproved	redesigned	60[2/]	99	61
Summer 80	Cotton	6 fields on Om-Sen and Manshiya Canals	No	unimproved	conventional	60[2/]	87	52
Summer 80	Cotton	6 fields on Om-Sen and Manshiya Canals	Yes	unimproved	redesigned	60[2/]	88	53
Winter 80-81	Wheat	5 fields on Hamad and Manshiya Canals	Yes	reshaped	redesigned	74	69	51
Summer 81	Cotton	6 fields on Hamad and Manshiya Canals	Yes	reshaped	redesigned	84	76	66
Winter 81-82	Wheat	Field 3-10 Manshiya Canal	Yes	unimproved	redesigned	62	85	53
Winter 81-82	Wheat and Barley	4 fields on Hamad and Manshiya Canals	Yes	lined	redesigned	99	76	75
Winter 81-82	Sugar Beets	4 fields on Hamad and Manshiya Canals	Yes	lined	redesigned	98	87	85

1/ E_{cf} = on-farm conveyance efficiency (see Glossary for definition).
E_a = application efficiency (see Glossary for definition).
E_{if} = on-farm irrigation efficiency ($E_{if} = E_{cf} \times E_a$).
2/ Based on inflow-outflow tests

Generally, PLL eliminated low spots or undulations in fields. However, some low spots remained, for example from soil settling over filled areas. Provisions for surface drainage were needed in these shallow depressions to prevent ponding, especially during the winter when evaporation rates were low. Shallow within-field *marwas* were effective in draining these low spots. Water seepage through perimeter bunds was prevalent for rice cultivation in Abu Raya (TR 9). For this reason, rice was separated from upland crops by an effective, well maintained, surface drain. PLL did not completely eliminate the need for surface drainage.

Precision land leveling led indirectly to yield increases. Cropped area was increased through eliminating ineffective, closely spaced, shallow, poorly maintained field drains at Abu Raya (TR 41). Movement of soil from high to low areas in the field and subsequent soil smoothing improved seedbed quality at least for the next crop.

At Abyuha, delivery system improvement was coordinated with on-farm interventions. PLL activities facilitated replacing *mesqas* with farm-access roads and reshaping fields to provide adequate irrigation from remaining *mesqas* (TR 41).

Farmers felt a need for improved irrigation methods. At each of the three EWUP field sites, they showed a willingness to cooperate and allowed Project personnel to work on their farms and test various irrigation practices (TR 41). At Abu Raya, the implementation package discussed above was shown to be possible and replicable for application on farmers' fields. Participating farmers were interviewed following Project work on their farms. A number of improvement package benefits were acknowledged by farmers (TR 35) including:

- Elimination of high and low spots in the fields
- Increased yields
- Good advance of the inflow stream
- Good water distribution
- Decreased water application
- Reduced water lifting time which reduced work for animals
- Decreased labor requirements
- Decreased need for surface drainage, and
- Improved soil conditions.

On-farm interaction between professionals and farmers was an important step in integrating change at EWUP sites.

Interventions Tested for Improving the Water Delivery System

Good on-farm water management requires that a dependable water supply be available to irrigators at the appropriate times and in adequate quantity.

Thus, a major Project effort has been to investigate alternative means of improving the design and management of water delivery systems at the distributary canal and *mesqa* level. Channels were reconstructed using both lined and unlined sections. *Mesqas* were elevated and an adequate head of water supplied to farms by a common point of lift at the upstream end. An entire distributary canal system was renovated to supply water to farms by force of gravity. Various types of water measurement structures and structures for controlling flows were installed and field tested. Farmers were organized and with their cooperation new approaches to operation and maintenance were attempted and found successful. To assist planners in extending similar improvements throughout Egypt, general procedures and computer programs were developed and tested for designing and evaluating alternative schemes for system renovation.

Watercourses

• *Lining*

The benefits of channel lining are numerous and well known. However, the most appropriate methods for Egyptian field conditions must be determined.

Whether the benefits gained from lining justify the relatively high costs must also be decided. EWUP conducted studies to address these considerations.

Several types of lining materials were installed in the field: ordinary concrete cast-in-place, concrete pre-cast units, butyl rubber membrane, plastic membrane,plastic membrane covered with cement tiles, and asphalt. A summary of the observed advantages and disadvantages of each type is given in Table 8.

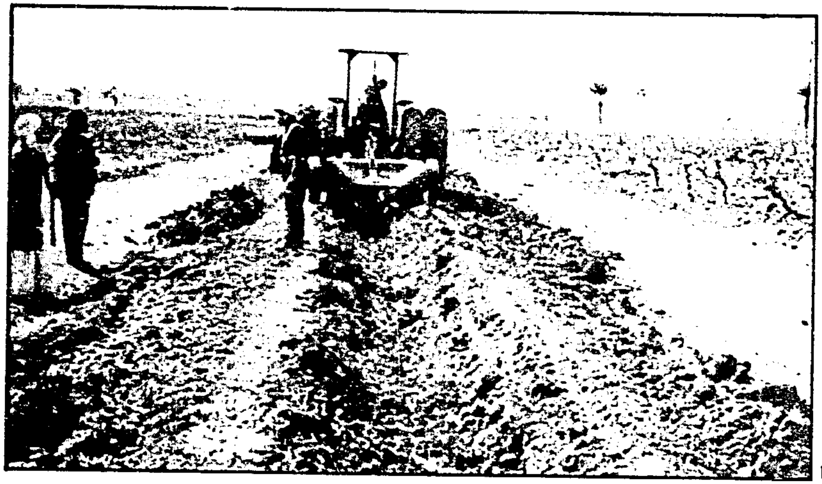
A comprehensive analysis of the economic feasibility of lining channels in Egypt was conducted (TR 56). Three typical channel sizes were specified and the lining costs associated with each size were estimated. For each size, total annual cost summaries were determined for different channel lengths.

The total annual cost (June, 1983 values) for 2,500 meters of size 1 (structural top width of 0.30 to 1.00 meters) varied from L.E. 1.05/m^2 for bricks with concrete lining to L.E. 4.44/m^2 for 35 mil (1 mil = 0.025 mm) butyl rubber membrane. For size 2 (structural top width of 1.00 to 3.00 meters), total annual cost for 10,000 meters of channels varied from L.E. 0.93/m^2 for cast-in-place concrete to L.E. 3.53 /m^2 for 35 mil butyl rubber membrane. For size 3 (structural top width of 3.00 to 10.00 meters), total annual cost for 5,000 meters of channel varied from L.E. 1.02/m^2 for soil cement to L.E. 3.41/m^2 for 35 mil butyl rubber membrane.

Benefits of channel lining that were considered included land area savings, reduced maintenance costs, reduced system management costs, increased irrigation efficiency, and quantitative water savings. Land saved by lining of *mesqas* may be cultivated or may be used to construct farm access roads (as observed at Beni Magdul).

• *Elevated Mesqas*

Two *mesqas* were elevated and provided with pumps to supply the required head and flow rate for efficient irrigation and to eliminate the need for each farmer to lift water. On *Mesqa* 26 at Abyuha, an earth channel was reconstructed with raised and compacted banks. On *Mesqa* 10 at Beni Magdul, an earth channel was replaced with a channel constructed of concrete blocks on a concrete base. In both cases, the increased head supplied at the field turnouts resulted in significant reductions in the irrigation time and farmers were pleased with not having to lift the water. In fact, economic analyses showed that the primary benefit of *Mesqa* 26 was lower labor costs due to reduced irrigation time (TR 63). Also, water was conserved by controlled inflow and elimination of flow to the drain. Leakage from the elevated *mesqas* did occasionally occur, but was not a significant problem. Measurements of irrigation applications on *Mesqa* 26 indicated that



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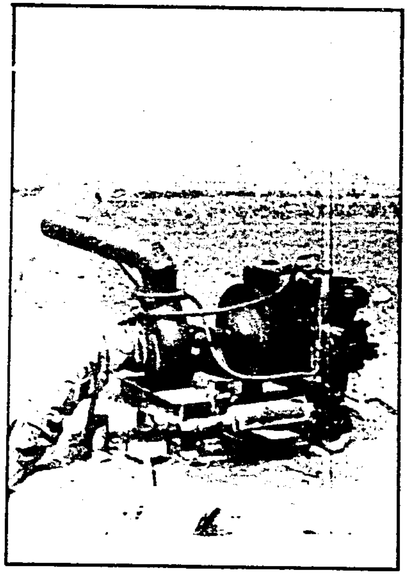

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1. Renovation to raise a *mesqa* for gravity flow at Abyuha.
2. Single-point lift into an elevated *mesqa* at Abyuha.
3. Elevation of *Mesqa* 10 at Beni Magdul for gravity flow resulted in significant reduction in irrigation time for farmers.

Table 8. Channel Linings Studied by EWUP

Type of Lining	Advantages	Disadvantages
Ordinary concrete cast-in-place	Reduces seepage losses; reduces size of channel; long life; requires little maintenance	High initial cost; long construction time with problems of irrigation during construction
Concrete pre-cast units (U-shaped)	Reduces seepage losses; reduces size of channel; long life; requires little maintenance; low initial cost; well accepted by farmers	Units easily broken during transportation from factory to site along small farm roads; higher roughness coefficient due to cement mortar in joints
Butyl rubber membrane	Eliminates seepage losses; very low roughness coefficient; easy to install	Very high initial cost; short life since easily damaged by animals, children, farm equipment; penetrable by weeds; affected by high water table
Plastic membrane (uncovered)	Eliminates seepage losses; very low roughness coefficient; suitable for small cross-sections	High initial cost; very short life since easily damaged mechanically, by heat, and by ultraviolet radiation
Plastic membrane covered with cement tiles	Eliminates seepage losses: relatively easy to install	High initial cost; short life (but longer than uncovered plastic)
Asphalt	Eliminates seepage losses; easy to install; low initial cost	Very short life (only six months); penetrated by weeds; not accepted by farmers

farmers initially had problems adjusting to the larger flow rates, however, after time, they adapted well to gravity flow.

The high cost of operating and maintaining the pumps was a limitation of the elevated *mesqas* with single-point lift (TR 63). Also, experience on *Mesqa* 10 indicated farmers were hesitant to assume mutual responsibility for the pump's management.

A major problem which prevented the *Mesqa* 10 objectives from being fully realized was an inadequate water supply in the distributary canal at the *mesqa* inlet. The lack of control and scheduling among *mesqas* served by the distributary canal resulted in some *mesqas* receiving adequate water while others, such as *Mesqa* 10 at the tail end, suffered from shortages. The accumulation of trash and aquatic weeds in the distributary canal also contributed to the problem of insufficient supply to *Mesqa* 10. An effort was made to solve the problem by improved control, scheduling and maintenance. This experience underscored the importance of carefully studying the entire delivery system from the distributary canal to the farm before attempting to alter any part of the system.

• *Gravity System*

Studies at Abyuha indicated it was feasible and desirable to renovate the water delivery system to provide gravity flow to the 1200-*feddan* area. In addition to installing appropriate hydraulic control structures, the distributary canal was reconstructed and *mesqas* are under reconstruction. Reduced channel cross sections and overall widths should result in a net saving of 10 to 15 *feddans* of farmland (TR 51). Channel banks were raised and compacted allowing high water levels for good gravity flow. Farmers in the area cooperated with the Project to provide right-of-ways for construction equipment and allowed soil to be taken from their fields for reconstruction of *mesqas*. Also, perimeter and farm roads were constructed in coordination with watercourse renovation. These roads, two of which replaced previously existing *mesqas*, were designed to facilitate farm mechanization and land leveling by providing internal access. The contract for the system renovation at Abyuha resulted in a cost of about L.E. 190/*feddan* (TR 51).

The major obstacle to the watercourse renovation effort at Abyuha was the inability of contractors to follow design specifications and to work according to schedule. Apparently, the contractors at Abyuha did not have the equipment and experience required for reconstructing watercourses within irrigated lands; rather, they were accustomed to standardized maintenance work on large canals located within government right-of -ways. Construction problems occurred when work had to be coordinated with the breaks between crop and irrigation rotations. Also, the contractors at Abyuha had difficulty in compacting channel banks, a critical requirement for gravity flow systems. Farmers were particularly disturbed when contractors did not follow agreed-upon construction schedules. They were also concerned about seepage from channel banks caused by improper compaction. With additional experience, contractors should be able to operate in closer cooperation with the farmers.

The Abyuha system has not yet been completed. However, observations to date indicate significant benefits will result. Some *mesqas* have been served by good gravity flow. Farmers have benefited from higher flow rates, reduced irrigation labor requirements, and reduced irrigation time.

• *Buried Pipeline*

In addition to renovation of open-channel systems, the Project prepared a thorough design of a buried low-pressure pipeline system to be constructed at El-Hammami (TR 21). The system was researched to improve the equity and adequacy of water distribution in the region. The company contracted for the job had demonstrated proficiency in desert pipeline construction. However, it was later discovered they lacked the competence for constructing the pipeline system at El-Hammami because of high water table conditions and their lack of experience with reinforced concrete construction. Consequently, construction has been discontinued. Efforts are being made to resolve the problems and satisfactorily complete construction.

Hydraulic Structures

• *Canal Headgates*

Water budget studies at Abyuha showed that inadequate hydraulic control resulted in high water losses to drains (30 to 45% of inflow). On the other hand, at Beni Magdul, careful regulation of canal headgates to control inflow resulted in a relatively high seasonal irrigation efficiency (70%) and only a small amount of water (10% of inflow) was released as surface drainage (TR 47). Thus, the system renovation at Abyuha included the installation of canal and *mesqa* headgates for flow regulation and outlet check structures for downstream control (TR 51). Heavy-duty *mesqa* headgates were manufactured by a private company but after field installation some problems in materials and workmanship were detected. Resolution of this problem was pursued.

• *Field Turnouts*

Several types of turnouts were tested by the Project for use on elevated *mesqas:* sheet metal slide gates with sealing cam locks, iron slide gates, circular concrete turnouts, and siphon tubes. These devices allowed controlled and scheduled distribution of large irrigation streams from the *mesqa* to the farm. Project findings on the advantages and disadvantages of each type are summarized in Table 9. Also, detailed laboratory hydraulic analyses were completed on a combined field turnout and measuring device designed for Egyptian conditions which will soon be tested under field conditions.

• *Measurement Structures*

EWUP water budget studies included experimentation with several types of structures for measuring water in distributary canals (TR 47). Research indicated that Egyptian conditions typically require a structure to operate under high submergence conditions (often greater than 90%). Consequently, measuring flumes such as the cutthroat or trapezoidal flume appeared most

Table 9. Field Turnouts Studied by EWUP

Type of Field Turnout	Advantages	Disadvantages
Pipe with sheet metal slide gate and sealing cam lock	Easy to open and close; easy to adjust for flow regulation; little leakage	High initial cost; relatively short life in the field due to numerous moving and wearing parts; more difficult to manufacture and thus not easily replaced
Pipe with iron slide gate	Easy to open and close	Heavy and thus not easy to adjust for flow regulation; leaks badly due to rigid and poorly sealing paddle
Circular concrete turnouts (Pakistani type)	Easy to install; easy to open and close	Cannot be adjusted to regulate flow; cover can be easily lost or stolen
Siphon tube	Low cost; portable and thus can be situated at exact location for desired water application; will not obstruct mechanical cleaning of channel	Cumbersome to operate and thus not readily accepted by farmers; require relatively large operating heads; can be easily lost or stolen; fluctuating head causes loss of suction which requires frequent resetting

appropriate. A manual describing manufacturing specifications and instructions for installation of the trapezoidal flume was prepared (M 1). Special care was required for field installation and operation of flumes. Experience at Project sites showed that conflicts arose with farmers when they perceived that flumes restricted flow during periods of low upstream head.

Management

The Project expended considerable effort studying how water delivery systems could be better managed to improve their efficiency and effectiveness. Studies concentrated on improving system operation by altering plans of water delivery and organizing farmers to cooperate in irrigation scheduling. Other research investigated maintenance of distributary canals and *mesqas* (TR 35, 43 and 65).

• *Operation*

Most distributary canals in Egypt receive water on a rotation schedule. A Project study at Abu Raya used records of water levels, flow rates, and on-farm irrigation demands to evaluate the adequacy of these schedules on the Daqalt canal. The result was a proposed revision in the rotation schedule (Table 10). This would reduce the number of on-days by 20 and could result in a significant reduction in the water delivered to the area (TR 43).

Field observations indicated fixed rotations of water delivery could contribute to overirrigation since farmers tended to irrigate during an on-period when there was no immediate crop need, but an irrigation would be needed before another on-period. Also, rotation schedules required higher flow rates and, therefore, larger conveyance and control structures than schedules for continuous flow. Hence, the Project tried a water delivery schedule of continuous flow in the distributary canal at Beni Magdul. With a well-controlled inflow, the irrigation efficiency for the region was quite high (TR 47). However, the need was observed for adequate canal maintenance with improved control and scheduling among *mesqas* to insure equitable distribution and adequately high flow rates along the canal. In Abyuha, a comprehensive plan was developed to operate the system as continuous flow at the distributary canal level with a rotation schedule among *mesqas* (TR 46, 59). This reduced the required size of the system and allowed for a flexible schedule that better served crop water needs.

• *Water Users' Association*

One critical aspect of EWUP's work regarding the improved operation of water delivery systems was the development of Water Users' Associations. A Water Users' Association (WUA) is a group of farmers served by a common source of water, who join together to allocate, distribute, and manage water in an efficient and equitable manner. While EWUP organized farmers in each of the Project field sites, it was in Abyuha where the development of a WUA progressed the most.

The need for a WUA was based on the following observations made by the Project while working at the three field sites (TR 65):

- In order for an irrigation system to become most effective in its operation, it had to be properly managed; and that management had to extend down to the distributary canal and *mesqa* levels of operation.
- The lack of experienced and trained personnel affected the management and control of the system below the distributary canal level.
- The organization of farmers could be used as a means to improve the management of the irrigation system at the distributary canal and *mesqa* levels of operation.

Based on these observations, EWUP sought to involve farmers in its system renovation work and found them willing and able to cooperate with each other in scheduling irrigation times and in maintaining improved *mesqas*. Organizing the farmers followed a prescribed set of procedures and the work resulted in the following findings (TR 65):

. It was very important to establish the legitimacy of any system improvement with the farmers. Without this legitimacy, no improvement was long-lasting.

. The use of local leaders in developing the organization was necessary. Procedures were developed by EWUP to select the actual leaders in an area. Efforts were made to see that all the farmers in the area became involved in the work through the local leadership.

. Farmers had to be involved in the work from the planning stage of the activity. Failure to follow this principle led to many problems as the work progressed.

. The structure of the WUA organization was kept as simple as possible. At the *mesqa* level, the organization was fairly informal while at the distributary canal level the organization took on more formal traits; i. e. stated rules of operation, developed lines of authority, etc.

. The WUA at the distributary canal level needed to be formally and legally linked to the MOI in some effective manner. This proved difficult to accomplish.

. Modes of operation and responsibility were developed for the leadership of the WUA. Authority relations were developed and sustained. Change in leadership was taken into consideration and accountability of the leaders needed to be established.

. Communication networks within the organization were initiated and developed. Such a network between the WUA and the MOI appeared necessary.

. Decision-making patterns were created and sustained.

. Specific tasks were assigned for the organization to carry out. Without a clear purpose, the organization would dissolve.

. Coordination of activities within the organization and between the WUA and the MOI was a necessity.

The organization of farmers into a new pattern of working relationships took time, effort and resources. EWUP found that this process incorporated numerous activities designed to solve problems, influence people, and manage

Farmer members of a Water Users' Association and their families. Cooperative activities involved in a WUA include interaction within and among families.

Farmers needed to be involved in EWUP activities from initial planning to final implementation.

Table 10. Current Rotation Schedule and EWUP Proposed Rotation Schedule for Daqalt Canal

Current			Proposed		
Time Period	Ratio On-Days/Off-Days	Total On Days	Time Period	Ratio On-Days/Off Days	Total On-Days
Oct. 16 to Closure	4/8	31	Oct. 1 to Nov. 20	4/12	13
Closure		0	Nov. 20 to closure	5/10	19
			Closure		0
Closure to March 15	5/10	10	Closure to May 15	5/10	30
March 16 to May 25	7/7	35	May 16 to June 14	2/4	11
May 26 to Oct. 15	4/4	71	June 15 to Sept. 30	4/4	54
Total		147	Total		127

situations. The WUA demonstrated that it could become an effective management tool only if it was effectively integrated into the MOI's administrative network. EWUP provided a model for working with Water Users' Associations, but the complete integration of the associations with the MOI needs further development.

- *Maintenance*

Water delivery systems must be adequately maintained if they are to operate as designed. Project activities related to the maintenance of watercourses resulted in the following findings:

. Poor maintenance of channels in a delivery system could result in an increase in required operating head that significantly exceeds that available in the branch canal (TR 46).

. Herbicides were used for effective control of aquatic weeds in distributary canals. However, they were costly and required close technical supervision to avoid the usual dangers associated with chemicals.

. The use of backhoes to clean distributary canals and *mesqas* resulted in unstable and oversized cross sections.

. Farmers had specific reasons for the way they maintained the *mesqas*. Those farmers who did clean their portion of the *mesqas* stated that, with the cleaning, the water moved easily through the *mesqa*, the tail-end farmers received more water, and irrigations were easier to perform. Farmers who did not clean refused to do so because there was already a sufficient amount of water to use, too much labor would be involved and other local problems were present. Other identified issues affecting farmers' decisions in *mesqa* maintenance which need further study were (1) the use of machines versus labor, and (2) the possible effect of downstream weeds raising the head of upstream inlets.

. When it was demonstrated that regular cleaning of *mesqas* was beneficial, farmers, in general, kept their portions of the *mesqas* clean. However, regular cleaning of *mesqas* had to be linked to some other beneficial activity which necessitated a well-maintained channel (TR 66).

EWUP organized farmers to clean large *mesqas* at Abu Raya and Abyuha during the closure period. On *mesqas* populated by a few families, thus having easier organizational requirements, the participation of the farmers was highly successful. On *mesqas* not having a concentrated leadership pattern, the results of participation were mixed (TR 65).

Design

A set of effective procedures was developed and described by the Project to guide interdisciplinary teams in designing and evaluating alternatives for improving water delivery systems (TR 55). These procedures grew out of experience with system renovation at Abyuha and Abu Raya. Several computer programs were developed to facilitate implementation of the procedures. One of the most notable of these programs was a mathematical system model for hydraulic design and analysis of a gravity flow network (TR 46).

Mesqa maintenance following renovation was one of the major cooperative activities carried out by voluntary Water Users' Association.

Irrigation Advisory Service

The introduction of new techniques designed to improve irrigation from the *mesqa* level to the on-farm operation requires a support program which integrates these new techniques with the farmers' present irrigation practices. A mechanism through which such improved techniques can be diffused to farmers is called an irrigation advisory service (IAS). An advisory service generally performs two major activities: (1) advises farmers about ways to improve their irrigation practices and (2) organizes farmers to operate and maintain their watercourses. EWUP served as a prototype of an advisory service by helping farmers implement a precision land leveling program (PLL), construct on-farm irrigation systems, and operate these new irrigation systems. Farmers were also organized into Water Users' Associations (WUA).

The results of EWUP's work as an advisory service demonstrated not only the value of establishing such an organization in Egypt, but also provided insights into how new irrigation techniques may be diffused at the on-farm and *mesqa* levels of operation. Work with the WUA organization has already been discussed. The findings presented here focus on the activities which directly assisted farmers in new irrigation techniques. These findings are presented in terms of the components of the extension process for introducing innovations: (1) the new practices; (2) the farmers who received the new practices; (3) the method by which the practices were introduced, and (4) the advisory service as an organization to introduce the new practices.

New Practices

The new practices described above were introduced as "packages" of ideas to the farmers (TR 67). Farmers' responses to the new practices are summarized below:

- The farmers were able to discriminate among the various effects of the different items in the total "package" introduced to them, and viewed some of those items more positively than others.
- Farmers saw the major advantages of the on-farm practices as savings of time, effort, and money.
- Practices which placed undue financial burdens on the farmers were rejected. Farmers looked for cost-effective solutions to their irrigation problems.
- Land leveling was seen as extremely beneficial by the farmers. EWUP, however, did much of the leveling work in cooperation with the farmers. The farmers stated that they would continue the practice if the equipment were available and the cost was reasonable.
- Farmers appreciated the reduced irrigation time provided by the plastic lining of on-farm channels. However, they did not like the fact that the lining was easily damaged.
- The farmers saw that the elimination of unnecessary open field drains increased their crop area. However, they continued to use open field drains to separate crops and maintain boundaries.
- The introduction of new agronomic inputs was made more difficult because many of these items were unavailable at the cooperative. EWUP helped obtain some items. This EWUP service led to the question: "What is the proper role of an advisory service in such matters?"

The Farmer as a Receiver

EWUP's work with the farmers identified the following receiver characteristics (TR 66):

- The farmers were rational decision-makers who were knowledgeable about their lands and had reasons for their decisions.
- The farmers were willing to use the new practices if the circumstances surrounding them demonstrated that such changes were appropriate.
- Generally, the farmers were willing to cooperate with EWUP and performed the new practices requested.

. The farmers asked for advice to improve their practices. Farmers outside the Project sites inquired to EWUP about working with them.

. The farmers sought to understand the new practices introduced.

. The farmers were willing to use their own resources to make the necessary modifications to improve their situation.

. The farmers understood the concept of water control and how the various practices introduced to them affected that control.

The Method of Introducing Ideas

EWUP's advisory service required care about how a new idea or practice was introduced. Proper introduction of an idea can facilitate the change process. EWUP research indicated the following findings about introduction of new practices (TR 66):

. There were effective procedures used to contact farmers and to work with them. These procedures included how to contact the farmers, what to say to them and how to work with them. Deviation from these procedures usually resulted in problems.

. EWUP had to explain to the farmers the purpose of each practice, how the practices were to be implemented, and the expected results of those practices.

. There was a negotiation process which occurred between EWUP and the farmers in order to effectively introduce a new idea. No practice was introduced unilaterally by EWUP.

. The farmers preferred demonstration, but they also valued "expert" opinion in deciding whether or not they would accept a new practice. EWUP persuaded many farmers to try a new idea without those farmers being able to see the anticipated results.

. The farmers watched the results of a new practice as it was being demonstrated. This outweighed, in many instances, what EWUP had told them, especially if the results were contrary to the expectations generated by EWUP.

. The need for coordinating EWUP's work with the farmers' practices was crucial in the introduction of any new activity.

. The most difficult problems which occurred between EWUP and the farmers were due to circumstances which prohibited EWUP to fulfill its obligations. Basically, these problems were caused by contractors not meeting their schedules and performing unsatisfactory work.

. The infrequent use of coercion as a strategy to effect change had mixed results. Threat of coercion usually failed in working with the farmers.

An Advisory Service

Much of the debate concerning the institutionalization of an advisory service in Egypt will focus on how such a service might be integrated into the government. There are two levels of discussion for such a debate: (1) the assumptions guiding the development of an advisory service, and (2) the administration of such an organization.

While the topic of administration was addressed (TR 66), a detailed study of the institution-building aspect of this organization was beyond the scope of the Project. The assumptions which were studied focused on some general patterns of thinking present in the MOI and the MOA concerning necessary organizational responses to solve irrigation problems. These patterns of thinking are important to understand because they serve as one type of indicator of the environment into which an advisory service will be integrated.

A survey was conducted with MOI and MOA officials in Kafr El-Sheikh and Minya Governorates (TR 66). While the survey examined many organizational issues, one summary issue will be presented here: the officials' evaluation of different procedural approaches to solving irrigation problems. This issue was selected because it expressed what the various officials viewed as priority items in the government's response to solve irrigation problems.

Two points were examined by EWUP: (1) the officials' perceptions of the approach which was most important, and (2) the constraints within Egypt in extending any approach. Regarding the most important approach to solve irrigation problems, the officials labeled the alternatives presented to them as "essential" or "extremely important," and ranked them as follows:

Most Important Approach ↓ *Least Important Approach*	*(1) Establishing local demonstration plots* *(2) Better coordination and planning for extension work* *(3) Better communication of findings and research to farmers* *(4) Stricter enforcement of MOI regulations* *(5) Improving relations with farmers* *(6) Performing research on new practices*

Solutions to the various problems have to be implemented effectively before the problems can be alleviated. Extension of these solutions to the farmers is necessary and so the officials were presented with possible constraints to effective extension work. The officials labeled the alternative constraints as being "a very serious problem" to being a "slight problem," and ranked the constraints as follows:

Most Serious Constraint To Extension ↓ *Least Serious Constraint*	*(1) Conservative nature of farmer and his indifference to national interests* *(2) Limited knowledge of farmers* *(3) Inadequate resources for extension* *(4) Administrative problems within extension* *(5) Farmers' disinclination to cooperate*

The above set of findings point out what issues the two Ministries see as important in solving irrigation problems, and some of the perceived major constraints in implementing various solutions. Starting from this basic knowledge, the MOI needs to examine the administrative requirements to implement such solutions. EWUP represented one mode of operation, and how this organizational entity worked should be examined in light of the possibility of establishing an irrigation advisory service in Egypt.


ELHAMY.N.
TECHNOLOGY
PROFESSIONALS
FARMERS

RECOMMENDATIONS

The goals of the National Irrigation Improvement Program aim at increased crop production. Irrigation is a major component of this vital national function. Other components include labor, developed land, agricultural technology and governmental support. No single component is necessarily more important than the others. Each must be applied to the production process in a timely manner with adequate quality. National policy should take a balanced approach to ensure that all components of agricultural production are effectively supplied and well coordinated.

Enlightened national policy requires implementation of research to learn of additional procedures and practices which should be used to benefit Egyptian irrigated agriculture. Irrigated agriculture is a dynamic system which continues to change in time and space. These dynamics require continuing research in the social, economic, engineering and crop management aspects of irrigated agriculture.

EWUP has worked to improve several important components of agricultural production, giving special attention to water delivery and on-farm water management. Recommendations have been developed based on this experience. Implementation of these recommendations can strengthen and build the various components so they will make appropriate contribution to future agricultural production.

The following recommendations have grown out of six years of EWUP's experience and research. They are not listed in order of priority, recognizing that each can make an important contribution to improving the nation's system of irrigated agriculture. The recommendations are grouped into categories.

Research Process

1. Each water delivery system has site-specific problems and opportunities which should be subjected to appraisal, feasibility analysis and planning before implementing any remedial measures. This should be carried out by trained interdisciplinary irrigation improvement teams of engineers, sociologists, agronomists and economists.

   Various interventions for improving water delivery systems have been planned and tested at Project sites. Determining the interventions most appropriate for a given site is a complex process requiring a broad systems approach. A system renovation scheme that is very beneficial at one site may be less effective when transferred to another. Many physical and socio-economic factors must be considered in the analysis.

   A systematic set of procedures has been developed by the Project to provide guidance to professionals responsible for developing plans for water delivery system renovation. These procedures can facilitate design and evaluate alternative plans for system improvement at the distributary canal system level. Several computer programs were developed as tools to expedite the implementation of the procedures. These procedures should be applied by interdisciplinary teams working throughout Egypt.

2. Although adequate knowledge is available now to begin a National Irrigation Improvement Program, the future viability of such a program will require adequately funded applied research. It will be necessary to monitor and evaluate on-going programs and develop solutions to new problems as they arise. For example, research is needed to determine the quantity of water supplied to meet crop demands under high water table conditions and potential salinity problems. The impacts of irrigation improvements are complex, continued research is important and improvement alternatives are numerous. Socially responsible analyses, under such circumstances, require an on-going program of in-service training for research personnel. The present EWUP organization serves as a model.

3. Continued training of irrigation improvement teams should include project management, team-building and integrated planning as well as technical subject matter. Training should be given very high priority.

Irrigation Parameters

4. Package programs, including improvement of the water delivery system, on-farm water management and associated agronomic practices are essential and should be encouraged. EWUP experience indicates that farmers are enthusiastic about such approaches because they improve irrigation, save labor, increase yields, accomodate mechanization and generate higher net incomes.

5. The development and maintenance of proper drainage systems should continue where it is desired to lower the water table. At EWUP field sites, it has been learned that very little vertical drainage occurs from the water table aquifer. It is not practical with the traditional surface irrigation methods to achieve high enough irrigation efficiencies to avoid contributing to the water table. Consequently, good irrigation management alone cannot be expected to eliminate excessively high water tables.

6. Water allocations should be based on the total needs of the farming system. Water demand diminishes during the time between shifts to different crops and it increases at special times, such as for the first irrigation after harvest and when rice paddy-land is puddled. EWUP experience has demonstrated opportunities for saving substantial quantities of water by coordinating delivery with the total farming system needs.

7. The water table contribution to consumptive use should be considered when determining the total quantity of water to allocate to delivery canals. The reduction of periods of excessive flow through the system would save water and reduce the pressure on drains. Although this issue is complex and needs further study, EWUP experience indicates that the water table, especially where it is near the ground surface, makes a significant contribution to consumptive use.

8. Well managed, gravity water delivery systems should be encouraged at the distributary canal and *mesqa* level. EWUP has demonstrated that farmers can manage such systems without wasting water. The saving in energy and farm labor is significant. This development should proceed slowly in areas where upstream head is adequate to serve the distributary canals and *mesqas*. Farmers must be involved to ensure that gravity systems are well maintained and managed.

9. Conjunctive use of water from canals and drains should be given consideration in the future development of the nation's irrigation system. EWUP studies indicate that water from drains at field sites is of adequate quality, at certain times of the year, to extend irrigation opportunities when mixed with canal water. This alternative should be studied in each water delivery system selected for improvement.

10. Precision land leveling and appropriately designed long level furrow and basin irrigation should be encouraged in order to increase on-farm irrigation efficiency, save irrigation time and labor, and accommodate increased agricultural mechanization. Controlled application of water, under such methods of irrigation, requires proper balancing of advance and recession times with an appropriate rate of flow onto the land. This balance must consider field slopes and soil infiltration characteristics. As in all irrigated areas of the world, farmers in Egypt need technical help to effectively achieve this balance.

Farmer Involvement

11. Farmers should be involved whenever any proposed water delivery system improvement is considered. The legitimacy of such improvements must be established with local farmers to help ensure efficient operation, routine maintenance, and long life.

12 Farmers should be encouraged to become involved in the management of water delivery at the *mesqa* level. This will require active professional assistance to help farmers organize and to help MOI officials identify leaders and utilize these valuable resources. Farmer involvement is necessary for efficient PLL, distributary canal and *mesqa* renovation, water scheduling, *mesqa* maintenance and implementing recommended changes to long level basin or furrow irrigation.

Management

13. Contractors, who are expected to implement improvements of water delivery systems, should be provided training. EWUP has experienced repeated failures on the part of contractors to assemble necessary resources, follow specifications and complete work according to schedule. Improvement of contractor capability is vital to programs on national irrigation improvement.

14. Consideration should be given to modifying the present rules regarding the specified turnout sizes at the heads of *mesqas*. This is a complex issue. As a general rule, the specified turnout sizes deliver an adequate total amount of water if irrigation is practiced 24 hours per day. One problem is that most farmers irrigate during daylight hours only. This overtaxes the capacity of the delivery system during daylight hours and many farmers are unable to consistently get sufficiently large stream flow rates to achieve high water application efficiency. Unless night irrigation is enforced, it may be better to use larger turnouts with turnout control gates and a system of delivery scheduling. However, implementation would require coordination with or modification of water rotation schedules.

15. An irrigation advisory service should be established. EWUP experience has shown that farmers will adopt new irrigation technology. This could save water. It could also help coordinate water delivery with the actual needs of crops which would increase crop production.

16. Cooperation and planning among agencies and authorities concerned with cropping sequences should take place on a timely basis to match crop water needs with water deliveries. Water scheduling for Egyptian agriculture originates at the High Aswan Dam and cannot be altered without allowing for time lags. It is therefore necessary that agricultural and irrigation systems should be carefully coordinated for efficient use of water in achieving high levels of production.

Agronomic and Structural Changes

17. Crop management and soil technology should be emphasized in order to maximize returns from irrigation improvement programs. Soil surveys permit mapping of soil types which have special irrigation requirements and limitations. Soil fertility improvement will permit better crop management and higher returns.

18. Cost studies indicate that cast-in-place concrete lining, for all potential canal sizes, has a lower annual cost than other forms of lining. However, other lining types should be considered where rigid-boundary canal linings are not physically or economically justified due to special conditions. For example, areas with highly expansive clays may prove to be too unstable, thereby causing rapid deterioration of rigid-boundary linings.

19. Gates, calibrated for water measurement, should be installed and carefully regulated at the head of distributary canals. It has been clearly demonstrated at Beni Magdul canal that this permits regulation of water according to crop needs and the irrigation practices of farmers, thereby saving water.

20. The relocation and construction of farm roads should be considered at the time water delivery systems are improved and modified. Where it is possible to close *mesqas* they can be replaced with roads if farmers agree.

Farm roads are popular with farmers because roads improve marketing efficiency and access for machines.

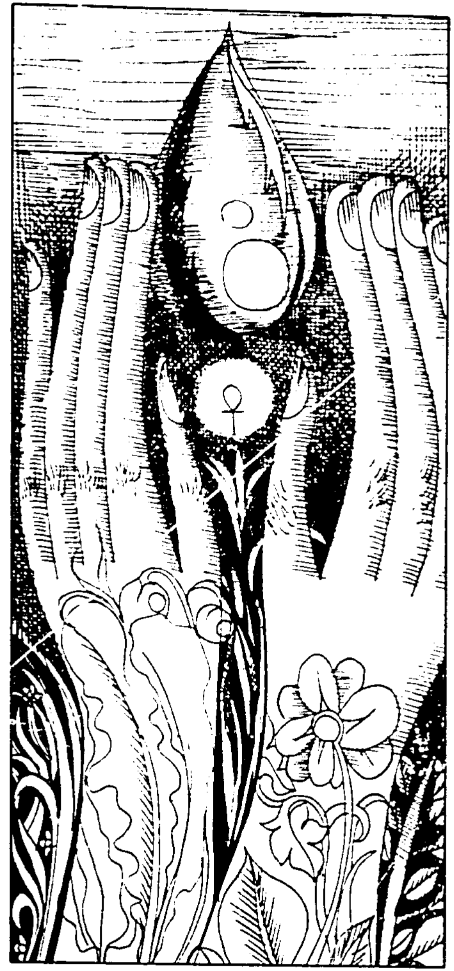
21. Given the present plans to mechanize agriculture in Egypt, action should be taken to further introduce long furrow and long basin systems of on-farm irrigation. This will require precision land leveling. Attention must be given to the development of appropriate technology for precision land leveling which is compatable with small holdings and limited periods of fallow land. Also, training is needed for technicians and machine operators and capital is needed to finance machines and equipment.

22. Adequate sized inlets (vents) to *mesqas* should be installed in areas where mechanization with long furrow and long basin irrigation will be introduced. This is due to the fact that flow rates from existing designed vents are often too small to permit practical scheduling and efficient application for long furrow and long basin irrigation.

23. Single-point lift systems should be considered, especially for areas with reliable sources of water. Farmers along a *mesqa* can join together to lift from one point at the head of a *mesqa* with an appropriate pump size. Lifting water with *tambours*, *saqias* and small pumps is expensive and wastes labor and energy. Single-point lift systems on *mesqas* can conserve these valuable resources and at the same time contribute to strengthening social ties among farmers.

Training

24. Training for MOI professionals, technicians, and farmers, should be provided in water management, soil-water-plant relationships, water control, water measurement, on-farm irrigation methods, interpersonal relations and communications, PLL, water scheduling, crop management practices, construction management, computer-assisted design and record keeping. This training could be provided by special short courses, on-the-job training, demonstrations, academic courses and field days.



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APPENDICES

APPENDIX A: GLOSSARY OF TERMS

Adjusted Sodium Adsorption Ratio (adj. SAR) - A parameter based on the standard Sodium Adsorption Ratio (SAR) [see definition below] but modified to include the added effects of precipitation or dissolution of calcium in soils and related to CO_3 + HCO_3 concentrations.

Application Efficiency (E_a) - The ratio of the water stored in the crop root zone of a field during irrigation to the water applied to the field.

Aquifer - A groundwater-bearing formation sufficiently permeable to transmit and yield water.

Available Water - The amount of water released by a soil between field capacity and permanent wilting point. It is an estimate of the maximum amount of water available in the soil root zone for use by the crop.

Confining Layer - A layer of low hydraulic conductivity that forms a boundary of an aquifer or separates various aquifers.

Consolidometer - A laboratory device used to measure the consolidation, or deformation, of soil sample under an applied load. The consolidation of a saturated soil sample is related to its hydraulic conductivity.

Consumptive Use (CU) - The quantity of water transpired by plants, retained in plant tissues, and evaporated from the adjacent soil surface in a specified time period. Usually expressed in depth of water. As used herein, consumptive use is synonymous with evapotranspiration.

Conveyance Efficiency - The ratio between the water delivered by a watercourse to its branches or outlets and the water delivered to the inlet of the watercourse.

Crop Calendars - The graphic plotting of the crop sequence on a specific area for a crop year.

Electrical Conductivity (EC) - A measure of water salinity, commonly expressed in units of mmhos/cm.

Evapotranspiration (ET) - The combined process by which water is transferred from the earth's surface to the atmosphere. It includes evaporation of water from soil and plant surfaces plus transpiration of water through plant tissues. As used herein, evapotranspiration is synonymous with consumptive use.

Farm or Field Turnout - A pipe, conduit, or bank cut allowing water to flow from *mesqas* into farms or fields for irrigation.

Farm Records- An accounting of income, expenditures, investments, and irrigation and farming activities for a farm for one year.

Field Capacity - The water content in a field soil after gravity drainage has effectively ceased (generally considered to be three days after irrigation).

Hydraulic Conductivity - The property of a material that defines its ability to transmit water, commonly expressed in meters per day.

Hydraulic Gradient - The ratio of the difference in total energy head between two points in a flow path to the distance between the points.

Intake Families - A series of curves developed by the Soil Conservation Service relating cumulative infiltrated depth of water to elapsed time. The curves are used in designing farm surface irrigation systems. The appropriate intake family for a given design problem depends on soil type, soil conditions and irrigation method.

Irrigation Demand - The demand placed on an irrigation system by the actual irrigation practices of farmers.

Irrigation Efficiency - The ratio of water consumed by the crops (ET) of an irrigated region to the water diverted to the region for irrigation.

Irrigation Gaps - The period from the last irrigation of one crop to the first irrigation of the next crop planted on the land.

***Mesqa* Legal Turnout** - A pipe of 10 m length which extends through the distributary canal to deliver water to a *mesqa*. The pipe is sized to deliver a duty of water per on-day of 50 m^3 per *feddan* per day (11.9 mm per day) under an assumed operating head of 25 cm.

Off-Farm Income - The income generated from non-farm activities or additional jobs such as policeman, taxi-driver, factory worker, cooperative manager, etc.

Income generated from farm work performed by the farmer for another farmer is considered as other farm income (i.e., the farmer sells his labor and/or services for field work).

On-Farm Conveyance Efficiency (E_{cf}) - The ratio of the water delivered by an on-farm conveyance channel to the field during irrigation to the water entering the farm from the delivery system.

On-Farm Irrigation Efficiency (E_{if}) - The ratio of the water stored in the crop root zone of a field during irrigation to the water entering the farm from the delivery system. It is equivalent to the product of the on-farm conveyance efficiency and the application efficiency.

On-Farm Water Management - Management of water after it flows from *mesqas* or canals and enters farms where it is under the farmers' control.

Permanent Wilting Point - The soil water content below which plants remain wilted even when transpiration is nearly eliminated.

Permeameter - A laboratory device used to measure the permeability, or hydraulic conductivity, of a material. Flow is maintained through a small sample of material while measurements of flow rate and head loss are made.

Potential Evapotranspiration - The rate of evapotranspiration from an extended surface of short green crop that completely shades the ground and actively grows with a condition of non-limiting soil moisture content.

Semi-Confined Aquifer - An aquifer bound by one or two layers of much lower hydraulic conductivity than itself.

Sodium Adsorption Ratio (SAR) - A parameter used to predict the long-term potential of the water to cause a soil permeability problem. It is a calculated ratio using the concentrations of Na and (Ca + Mg).

APPENDIX B: TRAINING

One of the major EWUP goals was to *"develop and/or train qualified scientists and technicians for the conduct of Project activities."* EWUP provided training opportunities for its staff through a three-point program: (1) developing a special on-farm water management course, (2) sending selected professionals to the United States, and (3) upgrading the English language skills of the Project staff.

EWUP developed a seven-week field-oriented training program which emphasized the two major working principles of the Project: (1) examining on-farm irrigation systems through the research-development process, and (2) working with on-farm irrigation problems in an interdisciplinary manner. The administration of the training program evolved from an American-operated course to an Egyptian managed program over the six years of its development. This course has not only trained all of the EWUP staff, but it also included many officials from both the MOI and MOA who now work throughout the country. In 1983, the administration of On-Farm Water Management Training Program was transferred from EWUP to the Irrigation Management Systems Project.

Many of the EWUP professionals received advanced technical training in the United States. Two programs were developed for sending personnel to the U.S.A. First, 21 professionals spent one academic year (nine months) at Colorado State University to upgrade their respective academic discipline knowledge. Twenty-four other individuals enrolled in specific courses at various universities for a period of one to three months. In order for these individuals to work in the U.S.A., many of them had to upgrade their knowledge and ability in English. The Project provided the means for many of the EWUP staff members to enter the AID-sponsored English program. Through the training opportunities in the U.S.A. ten individuals were supported in their pursuance of graduate degrees.

EWUP felt that training its professional staff was an important and necessary aspect of the Project work. Many individuals improved their skills by participating in the various training activities. EWUP hoped these individuals could effectively use these improved skills to benefit Egypt in terms of improved irrigation management.

APPENDIX C: AMERICAN EQUIVALENTS OF EGYPTIAN ARABIC TERMS AND MEASURES COMMONLY USED IN IRRIGATION WORK

Land Area	in *sq meters*	in *acres*	in *feddans*	in *hectares*
1 acre	4,046.856	1.000	0.963	0.405
1 *feddan*	4,200.833	1.038	1.000	0.420
1 hectare (ha)	10,000.000	2.471	2.380	1.000
1 sq kilometer	100 x 104	247.105	238.048	100.000
1 sq mile	259 x 106	640.000	616.400	259.000

Water Measures	*feddan*-cm	*acre*-feet	*acre*-inches
1 billion m^3	23,809,000.000	810,710.000	
1,000 m^3	23.809	0.811	9.728
1,000 m^3/*feddan* (= 238 mm of rainfall)	23.809	0.781	9.372
420 m^3/*feddan* (=100 mm of rainfall)	10.00	0.328	3.936

Other Conversions

1 *ardeb* =198 liters =5.62 bushels (U.S)
1 *ardeb*/*feddan* = 5.41 bushels/acre
1 kg/*feddan* = 2.12 lb/acre
1 donkey load = 100 kg
1 camel load = 250 kg
1 donkey load of manure = 0.1 m^3
1 camel load of manure = 0.25 m^3

Egyptian Units for Field Crops

Crop	Eg. Unit	in kg	in lbs	in bushels
Lentils	*ardeb*	160.0	352.42	5.87
Clover	*ardeb*	157.0	345.81	5.76
Broad beans	*ardeb*	155.0	341.41	6.10
Wheat	*ardeb*	150.0	330.40	5.51
Maize, Sorghum	*ardeb*	140.0	308.37	5.51
Barley	*ardeb*	120.0	264.32	5.51
Cottonseed	*ardeb*	120.0	264.32	8.26
Sesame	*ardeb*	120.0	264.32	
Groundnut	*ardeb*	75.0	165.20	7.51
Rice	*dariba*	945.0	2081.50	46.26
Chick-peas	*ardeb*	150.0	330.40	
Lupine	*ardeb*	150.0	330.40	
Linseed	*ardeb*	122.0	268.72	
Fenugreek	*ardeb*	155.0	341.41	
Cotton (unginned)	*metric qintar*	157.5	346.92	
Cotton (lint or ginned)	*metric qintar*	50.0	110.13	

Egyptian Farming and Irrigation Terms

fara = branch
marwa = small distributer, irrigation ditch
zawariq = small open field drain
mesqa = small canal feeding from 10 to 40 farms
qirat = cf. English "karat," A land measure of 1/24 *feddan*, 175.03 m^2
qaria = village
sahm = 1/24th of a *qirat*, 7.29 m^2
saqia = animal-powered waterwheel
tambour = auger type water lifting device powered by hand crank
sarf = drain (vb.), or drainage.

APPENDIX D : EWUP PERSONNEL

Main Office

Hassan Wahby	Project Director
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Azza Nasr	Engineer
Mahmoud Ibrahim	Engineer
Ahmed Bayoumi	Engineer
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Talaat Abdel Al	Agronomist
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