PROJECT TECHNICAL REPORT NO. 41

THE INFLUENCE OF FARM IRRIGATION SYSTEM DESIGN AND PRECISION LAND LEVELING ON IRRIGATION EFFICIENCY AND IRRIGATION WATER MANAGEMENT

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EGYPT WATER USE AND MANAGEMENT PROJECT

22 El Galaa St., Bulak, Cairo, Egypt

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ABSTRACT

The results of EWUP studies at each of three locations in Egypt: El-Mansuriya, Kafr El-Sheikh and El-Minya, to characterize the conventional farm irrigation systems used by farmers in each area are summarized. Typically, the method used is surface gravity flooding of small, flat basins or small basins with short furrows. Basin size is a function of field levelness, farm size, crop pattern/rotation and water supply as well as individual farmer needs and plans. The small basins require high labor inputs for a) construction of the feeder ditches and boundary dikes, and b) the irrigation operation. Careful water management is necessary, but not always present, to obtain efficient and uniform water applications.

Numerous irrigation field trials on farms at the three EWUP study areas have been conducted. The practices tested have included precision land leveling to dead level; level border strip or level long furrow irrigation system design; and teaching and advising farmers concerning improved on-farm water management practices in the use of the improved systems. Objectives of the trials were to increase on-farm irrigation efficiency, improve water control on the farm, save water, save irrigation time and labor, improve water table and soil salinity conditions, and contribute to overall increased crop production along with recommended improved agronomic and cultural practices. The results of the trials are reviewed with a focus on why they were or were not successful, what conditions are necessary for successful implementation and what further improvements or adaptations are suggested.

Generally, results were found to be highly successful when the spatial and temporal variations in farm irrigation system design factors were properly accounted for. A major factor in the success of on-farm improvements is improved water delivery. The water delivery system, in El Minya and El-Mansuriya in particular, needs to be reliable and well-maintained so that a consistent and regular stream size on the order of 25-30 lps at each farm gate is available for the efficient and uniform water applications which can be achieved using level long basins and level long furrows of the dimensions tested.

Another significant factor is the need to continue working with the farmer after system construction, teaching and advising him of improved management practices with the new systems. This is a factor which must be developed over time and will require supporting agencies and trained personnel. EWUP experience has shown that if this factor is lacking, then results can be much less than optimal and possibly worse than under the conventional methods. EWUP experience has also shown that when farmers are well advised in using the new systems improved results are significant.

87 Pages 18 Figures 12 Tables

ملخص

لقد تم تلخيص نتائج دراسات مشروع تطوير الرى فى المناطق الثلاثة بمصر وهى المنصورية وكفر الشيخ والمنيا وذلك لوصف نظم الرى التقليدية المستخدمة بواسطة الفلاحين فى كل من هذه المناطق . وطريقة الرى المستخدمة هى الرى السطحى بواسطة الجاذبية وذلك عن طريق غمر الأحواض الصغيرة والخطوط القصيرة داخل الأحواض . وحجم الحوض يعتبر دالة لعملية تسوية الحقل ، حجم المزرعة : الخريطة المحصولية ، الدوره الزراعية وايضا الامداد بالماء بالاضافة الى احتياجات وخطط المزارع . الأحواض الصغيرة تحتاج الى ايدى عاملة وذلك لشق المراوى والمصارف بالاضافة الى عمليات الرى الأخرى . ونجد ان عملية ادارة المياه المضبوطة تعتبر ضرورية وذلك للحصول على كفاءة عالية لنظام توزيع المياه .

ولقد قام مشروع تطوير الرى باجراء تجارب حقلية فى مناطق المشروع الثلاثة . وتم اختبار عمليات التسوية الدقيقة الى الاحواض المستوية والخطوط الطويلة فى نظم الرى بالاضافة الى تعليم وارشاد المزارعين بنظام ادارة المياه المحسن واثر ذلك على نظام الرى. وكان الهدف من الدارسات هو زيادة كفاءة الرى والتحكم فى وصول المياه الى المزرعة والاقتصاد فى استخدام المياه وتوفير الوقت واليد العاملة وتحسين مستوى الماء الأرضى وظروف ملوحة التربة ومساهمة كل ذلك فى زيادة انتاجية المحصول باستخدام التوصيات الزراعية . ولقد تناولت كل هذه الدراسات وجهة النظر فى نجاحها أو عدم نجاحها وماهى الظروف لنجاح مثل هذه الدراسات عند تطبيقها وما هى التحسينات الواجب ادخالها لتحسين نظام الرى.

وعامة كانت النتائج ناجحة عندما كانت التغيرات الدائمة والمؤقتة فى عوامل نظام الرى مأخوذة فى الاعتبار والعامل الاساس فى نجاح هذه التعديلات التى ادخلت على مستوى المزرعة هو تحسين نظام توزيع المياه.فنجد ان نظام توزيع المياه فى المنيا والمنصورية خاصة يحتاج ان يكون تحت صيانه تامة بحيث يمكن الحصول على تيار مائى منتظم يعطى من ٢٠ - ٣٠ لتر فى الثانية عند كل بوابة وذلك للحصول على كفاءة توزيع منتظم باستخدام نظام الاحواض الكبيرة أو الخطوط الطويلة .

وعامل اخر هام وهو ضروره التعاون والعمل مع المزارع بعد انشاء النظام وذلك لتعليمه وارشاده الى عمليات الادارة المحسنه باستخدام النظم الجديدة ويعتبر هذا العامل هام ولكن تنميته تحتاج الى وقت بالاضافة لبعض الهيئات المعاونة والافراد المدربون. وخبرة مشروع تطوير الرى تشير الى انه اذا كان هذا العامل غير متوفر فنجد ان النتائج المتحصل عليها اقل من الحالة تحت النظم التقليدية بالاضافة ايضا ان خبرة مشروع تطوير الرى ان عملية ارشاد الفلاحين فى استخدام الانظمة الجديدة هامة فى تطوير نظام الرى .

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Administrative Credits

The Egypt Water Use and Management Project 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.

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DEFINITIONS

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.

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.

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 delivery to the inlet of the watercourse.

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.

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

Infiltration Rate
The quantity of water absorbed by the soil per time; dependent on soil type, texture, structure, chemical properties, moisture content, soil tillage, porosity, etc.

Intake Families
A series of curves developed by the United States Department of Agriculture 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.

Machinery Field Use Efficiency
The ratio of the time that machinery is effectively used in the field to the total machinery operating time. Time wasted in stopping, starting, turning and backing reduces machinery field use efficiency.

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 farmer's control.

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

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.

Precision Land Leveling

The movement of soil in a field to change the original slope of the land surface to a desired uniform slope across the field. In EWUP work, the desired slope was dead level or zero land slope and the levelness tolerance criteria used was $\pm$ 2 centimeter from the mean field elevation.

Uniformity of Distribution of Applied Water

An evaluation parameter which compares the variation in depth of water infiltrated at various points in the field with the mean depth of water infiltrated in the field.

I. INTRODUCTION

The Egypt Water Use and Management Project (EWUP) was designed for the study of irrigated agriculture in Egypt to formulate and demonstrate viable on-farm and watercourse improvement alternatives. Emphasis has been placed on on-farm water use and management, although the management of other resources used on irrigated farms in Egypt are also considered, in order that proposed improvements are both acceptable and feasible. The central goal of EWUP is to develop alternatives for improving irrigated agriculture to the benefit of the socio-economic well-being of the Egyptian farmer.

EWUP operates in an interdisciplinary mode, utilizing the expertise of agronomists, economists, engineers and sociologists to accomplish its goals. These interdisciplinary teams have worked with Egyptian farmers at the field level studying the existing situation, documenting physical and institutional constraints, and developing and testing the feasibility of various alternatives for improving farm management practices. A four phase research-development process (Clyma, et al., 1977) was implemented. The first phase involved reconnaissance and problem identification. The second phase consisted of testing various interventions in search of solutions to the problems identified in the first phase. The third phase was evaluation and assessment of solutions tested to determine a package of feasible practices which will have the greatest impact on improving irrigated agriculture in a given area. The fourth phase was implementation of demonstration programs on a larger basis. EWUP experience with this process has found that problem identification and search for solutions through field trials are overlapping and continual phases necessary for developing the most acceptable and/or feasible improvements.

In order to account for the possible wide variation of conditions for irrigated agriculture in Egypt, EWUP has selected and carried out intensive studies and trials at three work locations (see Figure 1). These locations are: Kafr El-Sheikh in the North Central Delta, representing the conditions of lower Nile Delta; El-Mansuriya near Giza, representing the conditions of Middle Egypt; and El-Minya in Middle Upper Egypt, representing the conditions of the Nile Valley.

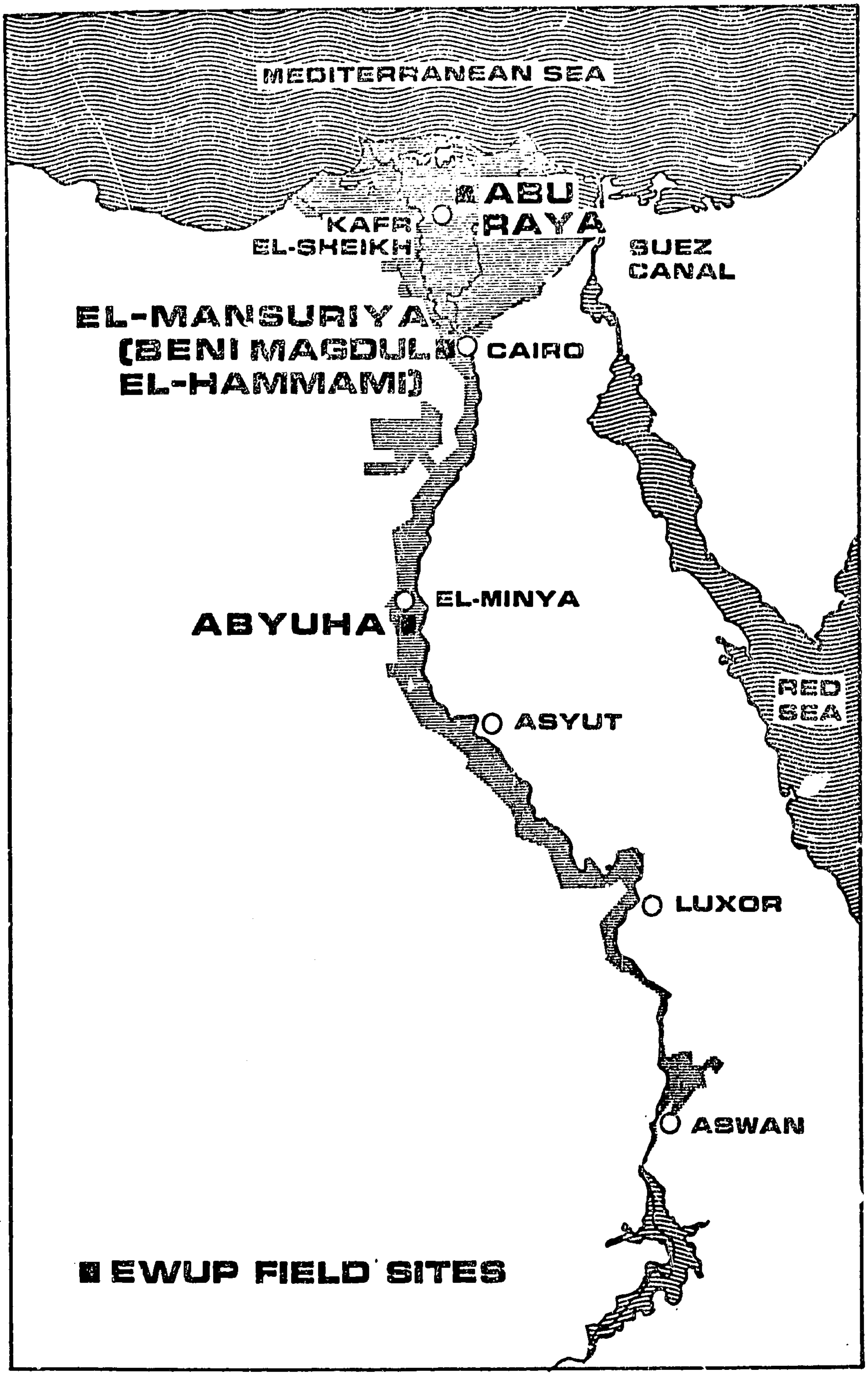


Figure 1. Location of project studies on improving on-farm water management.

Representative study sites in the three locations were selected as a result of reconnaissance surveys of irrigation districts in each area. In Kafr El-Sheikh, the study site was Abu Raya, approximately 1700 *feddans* at the end of the Daqalt Distributary Canal. In El-Mansuriya, the study sites were those fed by the Beni Magdul and El-Hammami distributary canals, approximately 1650 *feddans*. In El-Minya, the Project site was most of the area fed by Abyuha distributary canal, approximately 1200 *feddans*. Criteria for selecting these sites included cropping patterns, relative water table depths and salinity hazards, gravity vs. lift irrigation systems, etc. (Egyptian and American Field Team, 1979; 1980; and 1982). Maps of the irrigation and drainage systems for each area are provided in Appendix A. Studies were initiated successively beginning with El-Mansuriya, then Kafr El-Sheikh, and finally El-Minya, during 1978.

On-farm water management practices of Egyptian farmers have been the focus of intensive studies at the three sites since work began. Objectives were to characterize a) the water supply and delivery, b) methods used for diverting and conveying water from the supply canals to the field, c) methods used for applying irrigation water, d) crop water use and soil-water-plant relations for Egyptian field crops, and e) water removal from the farm by surface or subsurface means. In this way, typical farm water management practices and farm irrigation system performance could be analyzed for potential impacts on crop production and farm management in general. The base of information so developed was used to formulate possible solutions or alternatives for field testing to determine the feasibility and extent of proposed improvements.

Purpose and Scope

The studies and trials which have been accomplished at the three EWUP work sites have revealed many important characteristics of the conventional farm irrigation system and practices in Egypt, and given insight into potential for improvement. The purposes of this report are as follows:

1. To present and summarize the results of the studies performed at the three work locations to characterize the conventional farm irrigation practices of farmers in those areas.

2. To identify what problems and/or constraints exist as a result of these practices, with particular emphasis on the water application methods used.

3. To review the impact of the identified problems and constraints on on-farm water management and on-farm irrigation efficiency.[1/].

4. To review and summarize the irrigation trials performed at the three areas, provide technical analyses as to why these trials were or were not successful in improving water management and suggest modifications which would have caused less successful trials to have had more favourable results.

The scope of this study includes the problem identification and field trials studies of EWUP at these work sites over the period 1978-1982. It is emphasized that these studies represent a wide range of the irrigated agriculture conditions in Egypt in terms of crops, climate, soils and irrigation water delivery characteristics as well as different social and economic characteristics of the farmers involved.

Objectives

The objectives of this report are as follows:

1. To document how the current farm irrigation practices of Egyptian farmers may or may not need improvement with an emphasis on defining the potential for:

a) improving on-farm irrigation efficiency,[1/]

b) reducing over-irrigation where it occurs,

c) reducing farm irrigation labor and irrigation time requirements,

d) modifying farm layouts to increase productive land area and ability for farm mechanization,

e) improved crop production.

2. To document the results of the irrigation trials performed, and illustrate why they were or were not successful; and if not successful, what modifications are indicated to improve the success ratio . Emphasis here will be on-farm irrigation system design modifications and precision land leveling.

1/ See Definitions.

To fulfill the stated purposes and objectives, this report is organized as follows. First, the conventional farm irrigation practices at the three work sites will be presented in summary form with a statement of the potential problems. The effects of these problems on irrigation water management will then be discussed in terms of how the different factors and variables of farm irrigation system design can affect irrigation performance and crop production. The following sections then summarize the irrigation trials of proposed water management improvements which were carried out at the three areas, with technical analyses of the farm irrigation system design variables and analysis of other factors (such as management, conditions of the area, etc.) to show why results were or were not successful. This will provide a basis for stating what modifications or adaptations should be tested in future trials. Finally, a summary and sets of conclusions and recommendations resulting from this study are presented, which represent EWUP's effort to identify, test, and demonstrate the potential for improving the on-farm irrigation systems in Egypt.

II. CONVENTIONAL FARM IRRIGATION PRACTICES AND POTENTIAL PROBLEMS

The following subsections provide brief summary information on the farm irrigation practices of each of the three work sites and what potential problems exist. EWUP references which provide detailed documentation will be given so the reader may find more detail as desired. Reference will be made in the following subsections to several parameters and factors which are used to describe irrigation system performance. A list of definitions for these terms is provided at the beginning of this report to facilitate the reader's understanding.

Beni Magdul and El-Hammami, El-Mansuriya

Egyptian and American Field Team (1979) describes in detail the results of problem identification studies for the El-Mansuriya project location. Studies were conducted on two distributary canals served by El-Mansuriya canal: Beni Magdul and El-Hammami canals. Cropping patterns and irrigation methods were similar for the two canals but there were significant differences in soil type as described below. El-Kady, et al. (1979) gives a detailed analysis of on-farm irrigation practices in El-Mansuriya area. The following summary is abstracted from the above reports.

Water is delivered to farms in El-Mansuriya area at a level below the surrounding agricultural land which requires the farmer to lift water for application to his fields. Lifting is accomplished by the human-operated *tambour* (Archimedes' screw), animal-operated *saqia* (water-wheel) or small diesel-powered centrifugal pumps. Donkeys, cows, and water buffalos are usually used on the *saqias*, which generally are 2-3 m in diameter and have four to seven scoops. Water is generally delivered in the distributary canals on a rotation basis from El-Mansuriya canal. Beni Magdul distributary canal, however, is on a continuous flow basis. Water delivery to Beni Magdul canal is controlled by a Nyrpic headgate. *Mesqas* receive water from the Beni Magdul canal according to the availability of water in the canal. There is no fixed rotation among the *mesqas*. The water level in the *mesqas* can fluctuate widely depending on the number of farmers irrigating at once. Therefore, flow rates available (stream size out of *tambour* or *saqia*) for applying water to a field also vary widely. Measurements show *tambours* can deliver water from 5 to 18 lps and *saqias* from 3 to 61 lps (El-Kady, et al., 1979). Water table level is high averaging between 65 and 90 cm below the ground surface.

The method of applying irrigation water is by surface gravity flooding of small basins. The conventional farm layout is illustrated in Figure 2. The basins are typically very small ranging in size from 2 m x 4 m up to 5 m x 45 m. Basin crops such as wheat and berseem are grown on a flat surface, while row crops such as maize and vegetables are grown on furrow ridges within the small basins. In general, furrows and ridges do not have exact spacings nor dimensions since they generally are formed by hand. Two types of furrows are prevalent with the following spacings.

1. Narrow furrows with top width ranging from 10 to 40 cm, usually used for crops such as corn with one row of plants per ridge.

2. Wide furrows with top width ranging from 60 to 150 cm usually used for vegetables and sometimes having two or more rows of plants per bed.

The ridge height above furrows usually ranges between 12 and 15 cm.

Figure 3 shows typical dimensions of furrow systems for various crops. The ranges for the different dimensions were taken from measurements on farmers' fields. Ridges of borders which surround each irrigation unit are usually not much, if any, higher than the interior ridges

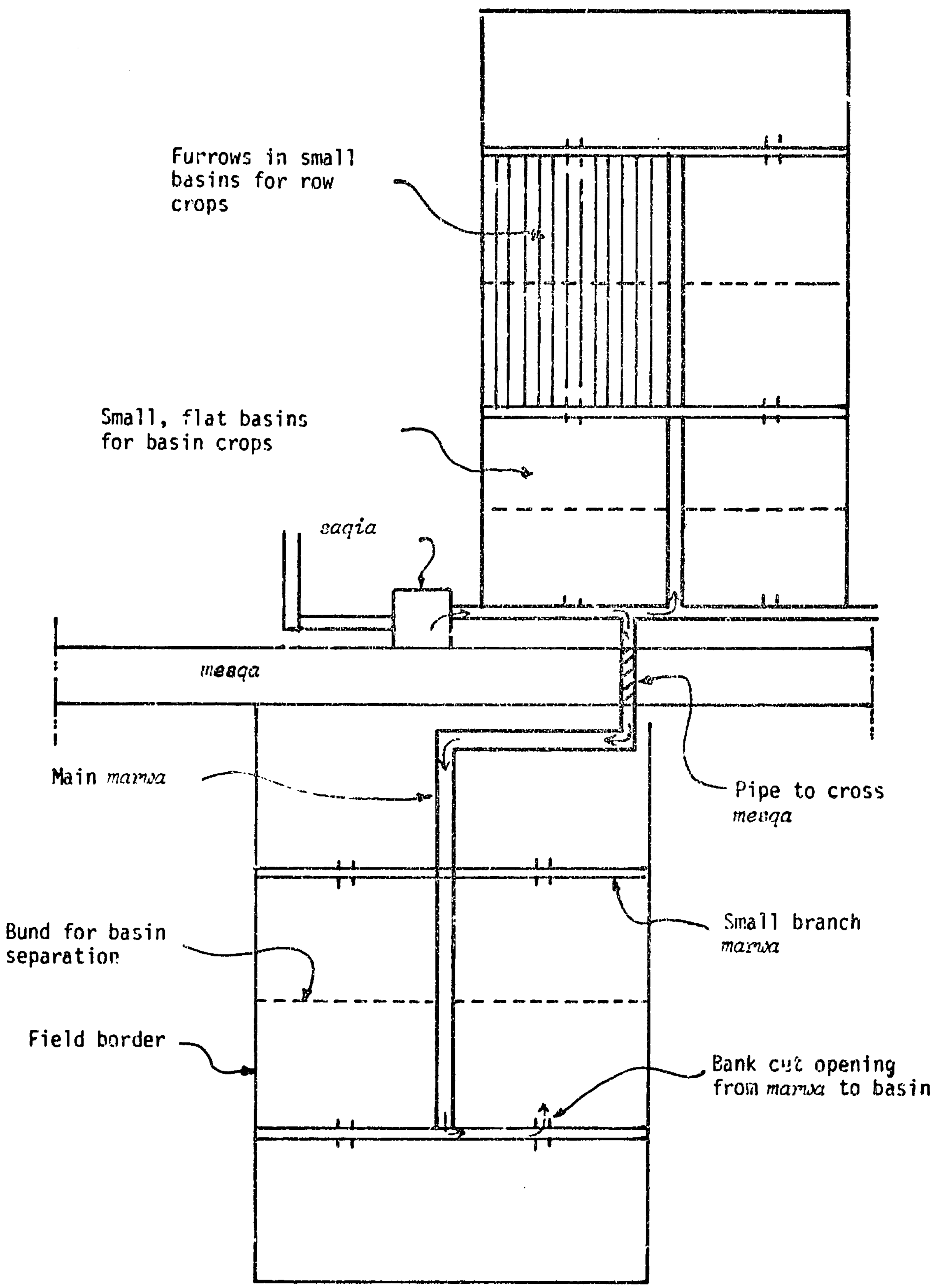
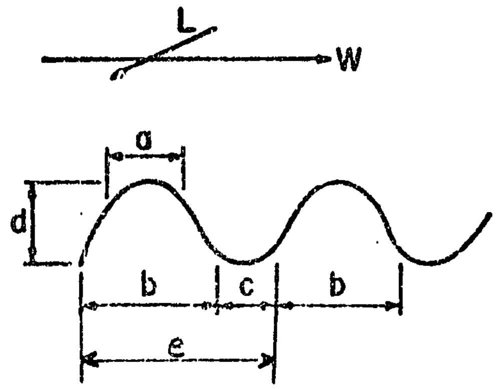


Figure 2. Typical on-farm irrigation system layout in Mansuriya



Crop	Top Width	Base Width	Channel Width	Ridge Height	Furrow Spacing	Basin Length	Basin Width
	a (cm)	b (cm)	c (cm)	d (cm)	e = b+c (cm)	L (m)	W (m)
Squash	70– 85	85–100	18–25	15–20	103–125	8 –20	3– 8
Tomatoes	60– 90	70–100	20–40	12–18	90–140	8 –20	3– 8
Cabbage	10– 20	38– 40	30–42	12–22	68– 82	8 –20	3– 8
Eggplant	10– 20	35– 40	18–25	10–20	53– 65	8 –20	3– 8
Watermelon	140–200	200–250	20–25	20–25	220–275	15–30	10–20
Corn	12– 20	35– 40	15–25	10–15	50– 65	5–15	3–12

Figure 3. Typical Dimensions of Furrows for Various Crops in El-Mansuriya (after El-Kady, et al., 1979).

between the furrows. The boundary ridges are frequently overtopped by irrigation water for irrigations on wheat and berseem. This may cause some damage to crops in nearby bunded units when irrigation water is not needed. A very large variety of vegetables is grown in the area and typically the fallow time between crops will be staggered around the area, i.e., not the same for all farms at a fixed time.

The size of farm (typically 1 *feddan* or less), the type of crops grown and the farmers' need to grow a variety of crops on his land may all contribute to the small basin sizes. El-Mansuriya is an intensive vegetable producing area and farmers use smaller basins to achieve better water control for these higher value crops. Unlevel fields is another factor that accounts for the smaller basins. Farmers would have less within-basin elevation variations in smaller basins. El-Kady, et al. (1979) present data which show that basins and fields on Beni Magdul and El-Hammami canals in El-Mansuriya are typically not very level with variation in field elevation ranging from 0.09 m to 0.21 m for a given field and averaging about 0.16 m (see Table 1). Elevation variation within bunded units for both basin and furrow crops was less, averaging about 0.09 m. Other grid survey data taken on *Mesqa* 10 on Beni Magdul canal show fields are tolerably level there[1/]. Small stream sizes that occur also indicate why farmers use the smaller basins. There would possibly be greater control over the small stream with the small basins and greater flexibility in water management from irrigation to irrigation and within an irrigation as the stream size varies. Major drawbacks to the small basin system are perceived to be the large labor requirements, first, in system construction and second, in irrigating; and also the large amount of land used in ditches and dikes which may not always be planted effectively.

Soils in Beni Magdul area are clay/clay loam which have a tendency to crack upon drying and swell upon wetting. Infiltration rates[2/] have been qualitatively observed to be very high on the dry, cracked soil until it swells enough to close the cracks (usually within 15-30 minutes). The infiltration rate on moist soil is much less and the possibility of surface sealing is present. In terms of irrigation

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1/ Unpublished data. Tahoun, et al., 1982.

2/ See Definitions.

Table 1. Range in elevation within fields and within bunded units, El-Mansuriya (adapted from El-Kady, et al., 1979).

Location[1/]	Mean Elevation (m)		Range Between Maximum and Minimum Elevations (cm)		Standard Deviation (cm)	
Variation within fields - Level basins without furrows						
B. M. Site 2, Field 2	16.59		9		0.02	
Field 4	16.58		20		0.07	
Field 5	16.58		21		0.07	
B. M. Site 6	16.40		13		0.03	
B. M. Site 7	16.64		13		0.03	
B. M. Site 1	16.70		17.5		0.05	
B. M. Site 4	16.49		20		0.07	
B. M. Site 5	16.43		12.5		0.03	
Mean, 8 fields			15.75			
Variation within bunded units - Level basins without furrows						
B. M. Site 3 (3 units)	16.43		11.0		0.03	
B. M. Site 2, Field 2 (2 units)	16.59		7.5		0.02	
B. M. Site 2, Field 4 (6 units)	16.58		7.5		0.02	
B. M. Site 2, Field 5 (2 units)	16.61		8.5		0.02	
B. M. Site 6, (4 units)	16.40		7.75		0.02	
B. M. Site 7, (3 units)	16.64		6.33		0.015	
B. M. Site 1, (6 units)	16.70		8.42		0.025	
E. H. Site 8, (2 units)	16.98		15.50		0.05	
Mean, 8 sites, 30 units			8.55			
Variation within bunded units - Level basins with furrows						
	Ridge	Furrow	R	F	R	F
E. H. Site 6 A	17.70	17.62	8	7	0.03	0.02
B	17.72	17.63	4	5	0.02	0.02
E. H. Site 8 A	16.96	16.86	9	6	0.03	0.02
B	16.92	16.78	8	23	0.02	0.07
C	17.66	17.54	10	8	0.02	0.02
Mean, 2 sites, 5 units			7.8	9.8		

1/ B. M. means Beni Magdul; E. H. means El-Hammami.

water management, it has been observed that due to these factors, heavy irrigations (>120 mm) are typical at the first irrigation of the season. Later in the season, farmers apply 60-80 mm as infiltration rates are less and the soil water deficits are lower.

El-Hammami area is characterized by very sandy soils which create significant problems in water delivery to farms and water application on-farm. Conveyance losses in El-Hammami canal, in the *mesqas* served by the canal, and in on-farm *marwas* may be very high. Deep percolation losses on-farm are excessive. The area has a high and fluctuating water table. Due to water delivery problems and the need to irrigate frequently (a result of the low water holding capacity of the sandy soil), many farmers experience water shortages. Shortages are particularly acute at the tail ends of the canal and *mesqas*. Water application methods and crops grown in El-Hammami area are similar to Beni Magdul.

On-farm irrigation efficiency[1/] in Beni Magdul area for the conventional systems has been measured to be very poor (30-40%) in some cases and very good (80-90%) in others. On-farm conveyance losses are considered negligible because typical distribution ditches are short (when outside of the cropped area) and ditch water losses inside the cropped area would be considered the same as irrigation. Seepage in the clay soils of Beni Magdul is low. Low water application efficiencies[1/] are common with a crop like berseem. However, where the farmer may perceive a greater return, such as with vegetable crops, water management is more careful and the efficiency typically higher.

In summary, the major perceived problems for the farm irrigation system on Beni Magdul and El-Hammami canals in El-Mansuriya were unlevel fields, small stream sizes for irrigating and large labor requirements for building the many small basins and in turn, irrigating them. Also, more land than necessary was occupied by bunds and ditches. Basins could possibly be made larger, depending on design factors. All of these factors contribute to less than optimal farm water management in terms of farmer ability to apply water uniformly and efficiently in known quantities. The water table along both Beni Magdul and El-Hammami canals was high. Secondary drains in the area are

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1/ See Definitions.

often in poor condition being neglected by the farmer. The focus here and in following sections has been on Beni Magdul area, because most of the irrigation trials to test suggested improvements were performed there.

Abu Raya, Kafr El-Sheikh

Egyptian and American Field Team (1980) and EWUP Kafr El-Sheikh Team (1983a) provide detailed information on the results of problem identification and farm irrigation studies in Kafr El-Sheikh. Details of farm irrigation system design considerations for the Abu Raya study area have been compiled in EWUP Kafr El-Sheikh Team (1983b). The following summary is abstracted from the above reports.

Water delivery in Abu Raya is also at a level below the surrounding gricultural land which requires farmers to lift. This is accomplished using 3 m diameter *saqias* with 6 scoops and powered by cow or buffalo, or to a lesser extent by using small diesel-powered centrifugal pumps. Water is delivered to the distributary canal and *mesqas* on a rotation basis. The level can fluctuate greatly causing corresponding variation in the flow rate produced by the *saqia*. This flow rate can vary from 15 lps to 60 lps with an average near 30-35 lps. Slack et al. (1983) present further information and data on the discharge and efficiency of the *saqia*.

Farm size in Abu Raya is relatively larger than that at the other two work sites. Eighty-three percent of the farms are in the 1-5 *feddan* range. Crops are mainly rice and cotton in summer, and wheat and berseem in winter. Large flat basins (from 10 m to 40 m wide by 50 m to 200 m long) are used for rice, wheat and berseem and are of all shapes and sizes. Cotton is grown on furrows or bedded furrows in small basins usually from 15 m x 15 m to 20 m x 20 m in size. The typical farm layout for Abu Raya is given in Figure 4. The conventional basins used at Abu Raya are significantly larger than at the other two sites. The crop rotation and pattern is generally orderly with most farms being fallow at the same time between crops during 2 or 3 periods of the year. Rice and cotton are major summer crops in the area and typically farmers prefer to plant and harvest within two to three weeks of each other due to such factors as insect control and reducing losses to birds. A tendency on the part of the farmers to prefer to cultivate more rice th n that allocated in the official crop pattern affects the water delivery system. Critical water shortages occur when farmers are puddling their rice paddies for transplanting of the seedlings.

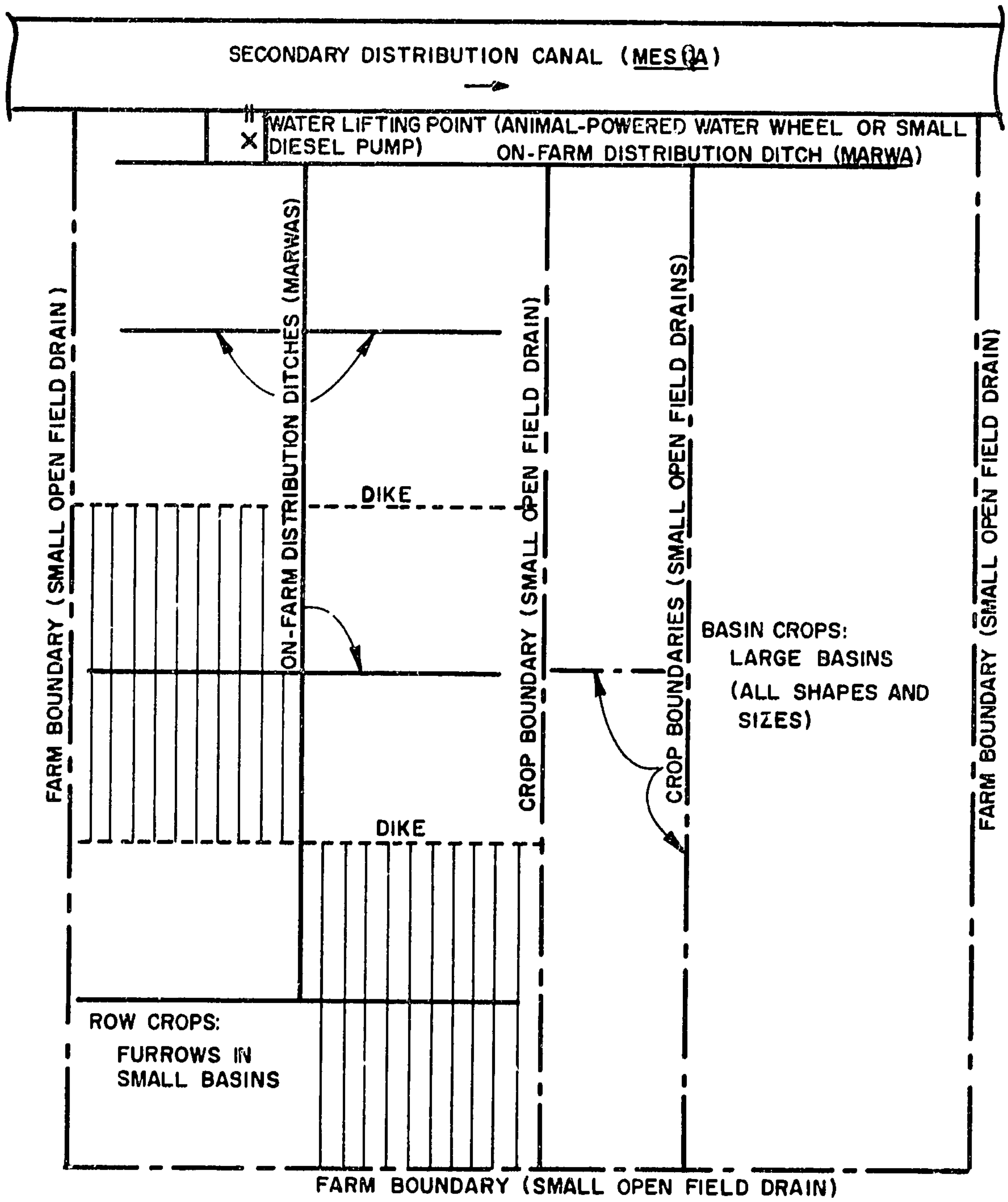

Figure 4. Typical on-farm irrigation system layout at Abu Raya, Kafr El-Sheikh.

Fields in Abu Raya have been surveyed to determine levelness. An average field elevation variation of ± 6.5 cm from the mean was measured (see Table 2), even though rice is grown as a paddy crop and farmers understand the need to level. The type of leveling performed, however, is not precision leveling but actually only a smoothing operation. Further information has been compiled in EWUP Kafr El-Sheikh Team (1983c).

Soils in Abu Raya are heavy clay vertisols which crack severely when dry and expand when wet. Infiltration rates[1/] are very high on the cracked dry soil until expansion closes the cracks, at which point the rate reduces rapidly. This condition causes heavy water applications (150-170 mm) to occur at the initial irrigation of the season. Applications in the middle of the season when soils are wetter are less (80-100 mm). Soil tests showed that for over 50% of samples taken soil salinity ranged from moderately saline to strongly saline (Egyptian and American Team, 1980).

Because of the relatively large farm size and farmer preference to grow more than one type of crop each season, the farm water distribution system of ditches (*maruas*) is extensive. Permanent ditches are often very long and in poor condition (excessive cross-sections, choked with weeds, etc.). Because of the cracking soils, water conveyance losses due to leakage are very high on the farm (25-40% of water lifted at the *saqia*). This significantly reduces the on-farm irrigation efficiency[1/] in Abu Raya which is generally in the 20%-40% range. Due to the large basins, the unlevel fields and the reduced stream size at the field inlet (often only 20 lps after *marwa* losses are accounted for), the water application efficiency[1/] is low. Over irrigation often occurs and the excess water is either lost as runoff or deep percolation. Depth to the water table from the soil surface ranges from 20 cm to 80 cm. Farmers are unable to control water in the large basins during application. Water control is improved for the row crops grown in the small basins, although overirrigation occurs in these also. Removal of excess surface water applied is accomplished by cutting outlets from the field into shallow within field open surface drains. These field drains have been measured and found to occupy from 10 -15% of the farm area. They do not facilitate subsurface water removal and are non-productive, usually being choked with weeds.

1/ See Definitions.

Table 2. Summary of single field elevation variation data for selected fields in Abu Raya, Kafr El-Sheikh, Egypt.

Farm and Strip ID	Mean Strip Elevation (m)1/	Elevation (m)1/ Max.	Min.	Range (m)	Standard Deviation (m)	Time of Year
3-01 (1)	1.36	1.40	1.32	0.08	0.03	Nov '79 (after rice)
3-01 (2)	1.33	1.39	1.30	0.09	0.02	Nov '79 (after rice)
3-02 (2)	1.55	1.61	1.49	0.11	0.03	Oct '79 (after cotton)
3-02 (3)	1.57	1.62	1.52	0.10	0.02	Oct '79 (after cotton)
3-02 (4)	1.56	1.59	1.53	0.06	0.02	Oct '79 (after cotton)
3-02 (5)	1.51	1.57	1.48	0.09	0.02	Oct '79 (after cotton)
3-02 (6)	1.49	1.56	1.45	0.11	0.03	Oct '79 (after cotton)
3-08	1.31	1.35	1.25	0.10	0.02	Nov '79 (after rice)
3-09	1.03	1.08	0.98	0.10	0.02	Nov '79 (after rice)
3-10	1.58	1.64	1.55	0.09	0.02	Nov '79 (after rice)
3-12	1.50	1.58	1.47	0.11	0.03	Nov '79 (after rice)
3-02 (10)	1.47	1.52	1.32	0.20	0.04	Nov '80 (after cotton)
3-02 (11)	1.48	1.56	1.41	0.15	0.03	Nov '80 (after cotton)
3-21 (5)	1.66	1.83	1.59	0.24	0.04	Nov '80 (after cotton)
3-23 (1)	1.43	1.49	1.37	0.12	0.03	Mar '81 (after berseem)
3-25 (5)	1.60	1.64	1.57	0.07	0.02	Jun '81 (after wheat)
3-25 (4)	1.63	1.68	1.59	0.09	0.03	Jun '81 (after wheat)
3-01 (B)	1.64	1.72	1.55	0.17	0.03	Jun '81 (after wheat)
3-27 (1)	1.00	1.11	0.92	0.19	0.05	Nov '81 (after cotton)
3-27 (2)	1.00	1.07	0.91	0.16	0.03	Nov '81 (after cotton)
3-26 (1)	1.00	1.09	0.95	0.14	0.03	Nov '81 (after cotton)
3-26 (2)	1.00	1.07	0.91	0.16	0.03	Nov '81 (after cotton)
3-01 (D)	1.00	1.07	0.88	0.19	0.04	Mar '82 (after berseem)
3-28 (A)	1.00	1.07	0.93	0.14	0.04	Mar '82 (after berseem)
3-29 (A)	1.00	1.07	0.94	0.13	0.03	Mar '82 (after berseem)
	Mean (± Std. dev.)			0.13 (± 0.05)		

1/ Elevations given are relative to local benchmarks.

Source: Compiled from unpublished data collected by S. El Din, A. F. Metawie, A. El Kayal, K. E. El Din A. Dardir, M. Awad, S. Zaki, S. Fahmy.

Water lost to drains in the Abu Raya area (north central delta) is water lost to the entire system because it is pumped from the main drains into the sea. Water lost to drains in El-Minya and El Mansuriya eventually enters the river/canal system and is available for reuse. At Abu Raya, improving canal water management and irrigation efficiency will reduce water lost and drainage requirements, and consequently will reduce drainage pumping costs.

In summary, the major problems in Kafr El-Sheikh are unlevel fields, poor design for the farm irrigation basins (i.e., dimensions not based on design factors), overirrigation, high water conveyance losses due to leakage in poorly maintained *marwas* and excessive land area wasted with open field drains. The area also generally has a high water table and saline soils. Careful water management is necessary for such conditions to avoid potential waterlogging/drainage problems.

Abyuha, El-Minya

Egyptian and American Field Team (1982) contains the problem identification report for the Abyuha site. The following summary is abstracted from that report.

The inlet gate to the Abyuha canal was in poor condition and provided poor water control. Water was available in the canal at all times with the flow rate reduced during scheduled off periods. Because of this lack of control and poor water management, large quantities of water flowed through the system to the drains serving the area. Poor canal and *mesqa* maintenance resulted in poor overall water distribution. Shortages occurred when many farmers tried to irrigate at the same time. Poor control and water management led to excessive drain flows, high water table, channel erosion, and water losses due to evapotranspiration by weeds in drains. Energy was wasted in pumping water from the drains back into the river.

Water delivery in the Abyuha area was generally considered to be by gravity flow distribution, i.e., the water surface level was above the surrounding agricultural land. However, due to many factors, such as poor *mesqa* maintenance, open-ended *mesqas* (allowing water to go to drains), obstructions in the *mesqas*, etc., the flow of water available was usually small with very low head (5-15 lps has been a commonly measured range in irrigation stream size). In many places farmers were required to lift water by pumping or using *tambours*. Water lifting was particularly common at the tail ends of *mesqas* where available head and stream size were reduced by poor *mesqa* maintenance upstream. Irrigation was generally directly from *mesqa* to basins or to a distribution ditch within basins, so on-farm conveyance losses were not considered a problem as in Kafr El-Sheikh. The Abyuha distribution system has been analyzed and redesigned using a hydraulic computer model (Gates, et al., 1984). System renovation is currently underway.

Major crops grown in Abyuha are cotton and maize (on furrow ridges in small basins) in summer and *berseem*, wheat (in small flat basins) and broadbeans (small basins with furrows) in winter. The fallow time between crops appears to occur on a routine schedule with the majority of farms being fallow at the same time.

The typical farm layout is illustrated in Figure 5. Basin sizes are very small as in El-Mansuriya and generally are 5 m x 7 m. Farm size is also small with about 80% of all rented or owned farms being less than two *feddans*.

Field grid surveys show that fields are not level. Grid surveys on two typical farms in Abyuha show the elevation variation in single fields has a range of 0.16 m and 0.19 m. These represent deviations of $\pm$ 8 cm and $\pm$ 9.5 cm, respectively, from mean field elevations (Egyptian and American Field Team, 1982). The use of small basins tends to compensate for this field unlevelness. Soils in Abyuha are clay/clay loam similar to Beni Magdul. The characteristic cracking when dry and expanding when wet is present. Thus, high initial infiltration rates[1/] (during 0-15 min) exist when the soil is dry. As the cracks swell closed, the rate reduces rapidly.

Cases of both low application efficiency (50-60%) and good application efficiencies (85%-90%) have been measured in Abyuha. Interrelated factors at the time of irrigation such as the stream size available, the soil water deficit, and the soil infiltration rate will often determine whether application efficiency will be high or low. Generally farmers control the water fairly well and can manage it well with the small basins. The major drawbacks are seen to be the large labor requirements for constructing the systems of small basins and for the irrigation operation itself. The small stream sizes that are common often compound the irrigation process and cause excessive time for irrigations.

1/ See Definitions.

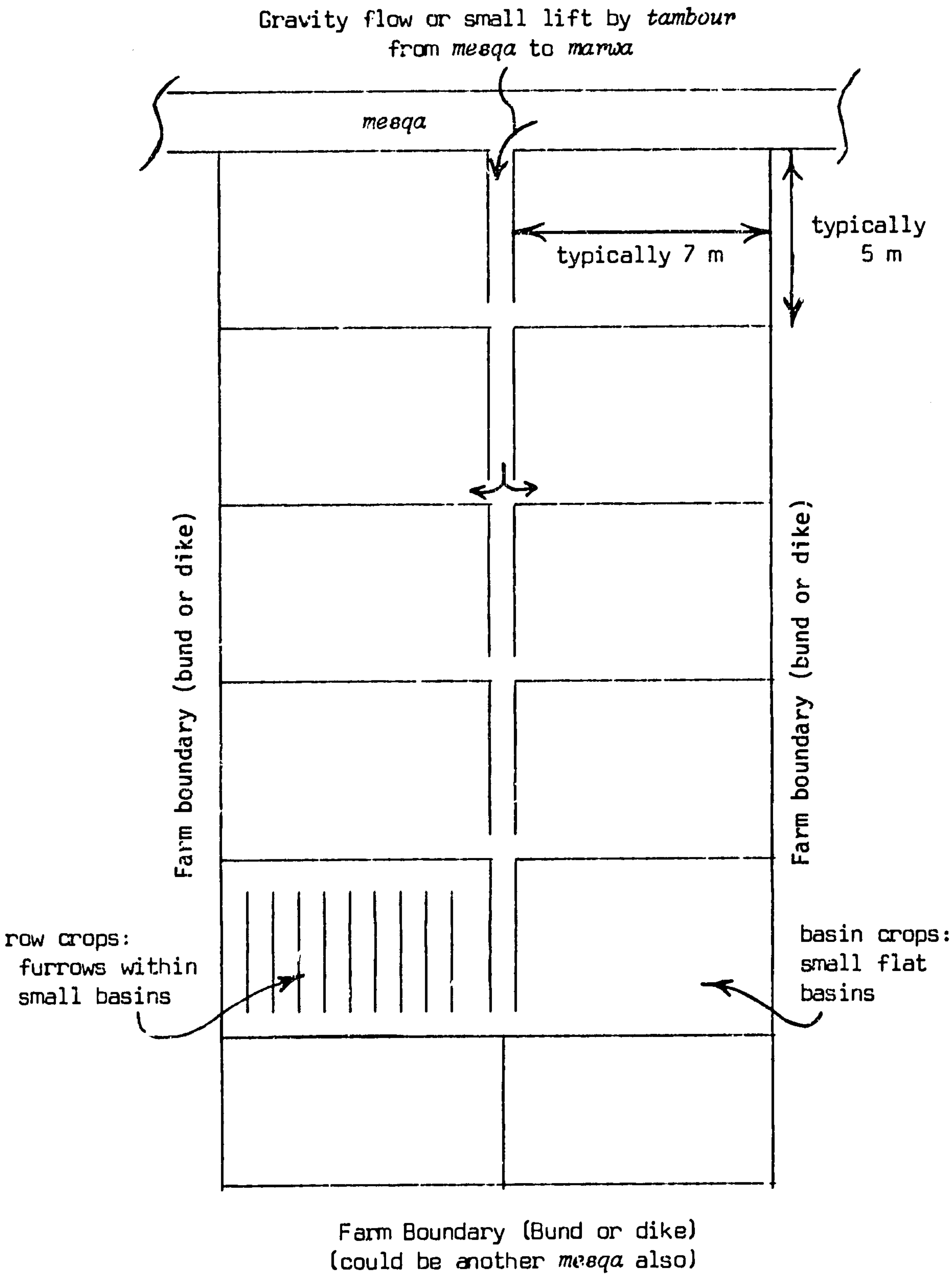

Figure 5. Typical layout of the on-farm irrigation system, Abyuha area, El-Minya.

In summary, the problems identified for the farm irrigation system at Abyuha are similar to the other areas in terms of unlevel fields and the effect this may have on causing overirrigation and poor distribution of applied water. Poor water control in the delivery system led to excessive drain flows, periodic water shortages and inequitable distribution of delivered water including low head and stream flow available to farms at *mesqa* tails. A redesigned system is currently being constructed at Abyuha to improve water distribution.

Small stream size in turn causes excessive water applications and application times on farm. Farmers compensate for unlevel fields and small available stream flows by dividing their fields into small basins requiring high labor inputs.

III. IMPACT OF POTENTIAL PROBLEMS ON IRRIGATION WATER MANAGEMENT AND EFFICIENCY

The small basin irrigation system currently used in Egypt has served the more efficient farmers effectively in the past by utilizing the small streams from *saqias*, *tambours* and poor gravity systems to sometimes irrigate with favorably high water application efficiency [1/]. However, the high water application efficiency in small basins may be somewhat offset by low water-conveyance efficiency in the extra lengths of *maruas* that are required to deliver water to small basins. Long basins may be irrigated directly from *mesqas* without *maruas*.

The small basin irrigation system is labor intensive requiring long hours to form the borders and to irrigate. The large labor requirement for irrigation is due to the large number of basins and the small streams used. With a decrease in the amount of available labor, resulting in increasing labor costs, the use of labor saving irrigation systems and labor saving machinery will be required for efficient farming operations in the future. Currently, the use of machinery with small basin irrigation systems is not operationally feasible due to frequent stopping, starting, backing and turning of tractors, etc., which results in low machinery field use efficiency [1/].

Unless machinery, similar to the two wheel hand tractors used extensively in Asia, becomes widespread in Egypt, future farming practices

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1/ See Definitions

will require redesigning the field irrigation systems to relatively long border strips and/or furrows that will permit the use of conventional machinery to increase the productive capacity of the farmer. According to Israelsen (1950), a healthy man can generate about 1/8 horsepower. With a 50 horsepower tractor he can theoretically do 400 times more work per hour. If this concept is applied in Egypt, the necessary adjustments can be made in farming practices with machinery to reduce the labor requirement for food and fiber production.

Since different soils may require different system designs in changing from small basin irrigation systems to long furrow and/or border strip irrigation systems, the performance of these alternative systems on the different Egyptian soils needs to be measured and analyzed. Any adjustments in the irrigation practices and/or delivery systems related to the different soils should be included when redesigning the field irrigation systems.

Level and Graded Farm Irrigation Systems

The emphasis in this report is on dead level rather than graded basin and furrow farm irrigation systems. There are conditions where a slope in furrows or basins is desirable. A comparison of level and graded systems is included here to explain the reasons that level systems were used in Project work.

In areas where rainfall may periodically flood land a small slope is needed to drain away excess water especially where longer lengths of run prevail. Danger of flooding from excessive rainfall is insignificant at all three EWUP work sites. Also with soils with swelling and shrinkage characteristics which cause settlement, and tillage practices which may cause low and high spots from season to season after land leveling, some slope may be desirable. This applies more to slowly permeable soils where low areas will retain ponded water unduly long. Once land is leveled, however, seasonal maintenance by using a field plane or surface float to smooth surface irregularities is a necessary tillage practice.

The use of maximum non-erosive streams on land graded with a slope may cause excessive depths of water to accumulate at the lower ends of basins and furrows. Cuts in borders would be necessary to allow excess water to flow to drains. To avoid excessive applications (as well as inadequate applications) methods have been developed to compute stream size, time of application, and depth of application for soils with different slopes and infiltration rates. Some of the methods are described by USCA (1974) and USDA (1979).

When a decision is made to level land, it must apply to all crops which may be included in future rotations. It is not feasible to flat level land for a crop such as rice and then to form the land with a slope for row crops the next season for which some land slope on longer runs may be advantageous to help increase the rate of advance. It is therefore not practicable to level for a grade when paddy rice is in the rotation. For longer furrows with lengths exceeding 220 meters on heavy textured soil, FAO (1977) recommends land slopes between 0.05 and 2.0 percent depending on furrow stream size according to data presented in Table 3. For smaller streams, steeper slopes are recommended as shown in the table. Longer runs may require some land slope to obtain efficient irrigation.

Most of the long runs in the Project that have been tested with zero slope have been only 100 to 150 m long on heavy textured soil. One run at Abyuha, El-Minya was 171 m long, and trials at Abu Raya, Kafr El-Sheikh during the 1982-83 winter season were on strips 200 m long.

In many ways, it is less complicated to distribute water efficiently in a level basin than in a graded basin providing the level basin is not unduly long and the non-erosive inflow stream used is sufficiently large for rapid advance to the tail of the basin. Large streams and rapid advance lead to uniform water distribution on level basins. This relationship of stream size to water distribution uniformity is not as simple with graded basins since large streams flowing too long may accumulate water at the lower end of the field and "drown out" plants. For open ended sloping basins, excessive applications may result in large runoff losses to the drain and consequently low application efficiencies. For closed end sloping basins, if too much water is applied because of an error in timing or water measurement, the excess water will accumulate in the lower end of the basin to a depth greater than that under similar circumstances in a dead level basin where the excess water is distributed over the entire basin.

In summary, level farm irrigation systems were used in EWUP work because:

Table 3. Length of furrows and stream size for different soil type, land slope and depth of water application under conditions of perfect land grading (after FAO, 1977).

Land Slope (%)	Length of Furrow (m)												Furrow Stream Size (l/sec)
	Heavy Texture				Medium Texture				Light Texture				
0.05	300	400	400	400	120	270	400	400	60	90	150	190	12
0.1	340	440	470	500	160	340	440	470	90	120	190	220	6
0.2	370	470	530	620	220	370	470	530	120	190	250	300	3
0.3	400	500	620	800	280	400	500	600	150	220	280	400	2
0.5	400	500	560	750	280	370	470	530	120	190	250	300	1.25
1.0	280	400	500	600	250	300	370	470	90	150	220	250	0.6
1.5	250	340	430	500	220	280	340	400	80	120	190	220	0.4
2.0	220	270	340	400	100	250	300	340	60	90	150	190	0.3
Application depth (mm)	75	150	225	300	50	100	150	200	50	75	100	125	

(1) there was little danger of flooding from rainfall,
(2) rice was in the crop rotation at Abu Raya,
(3) length of run did not exceed 200 meters,
(4) level systems are easier to manage than graded systems.

The Egypt Water Use and Management Project has included precision land leveling and the design of level long furrows and/or level border strips in irrigation trials at the three Project sites to assess the impacts which these modifications to the farm irrigation system might have in terms of improved efficiencies, water savings and reduced labor requirements. This section and following subsections provides, in simplified terms, a technical and/or theoretical background to the potential problems identified earlier for level irrigation systems at the three sites.

Irrigation on Unleveled Land

The laws of nature require that precision land leveling[1/] must be adequately accomplished before laying out an irrigation system with long furrows and border strips or basins if reasonably high water application and conveyance efficiencies are to be attained. Even in small basins with or without short furrows, irrigation efficiencies may be adversely affected where large variations in the ground surface elevations exist. A desirable limit for variation in ground surface elevation for flat planted land is three centimeters (± 1.5 cm) and for furrowed land, six centimeters (± 3 cm) (USDA, 1974 and USDA, 1979).

Figure 6 shows the effect of high and low areas of unleveled land on the distribution of water in the soil after an irrigation.

Under the high area where the depth of ponded water is shallow, the figure shows that the moisture penetration may be too little to fill the root zone. The high areas may be subject to salinity problems from upward flow of saline groundwater. Also much water would be lost to deep percolation in the low area where the figure shows excessive water penetration below the root zone. Crops in the low areas would be damaged by prolonged ponding of water which would restrict soil aeration. Leaching of fertilizer and soil nutrients would also occur with excessive deep percolation of water after each irrigation.

1/ See Definitions.

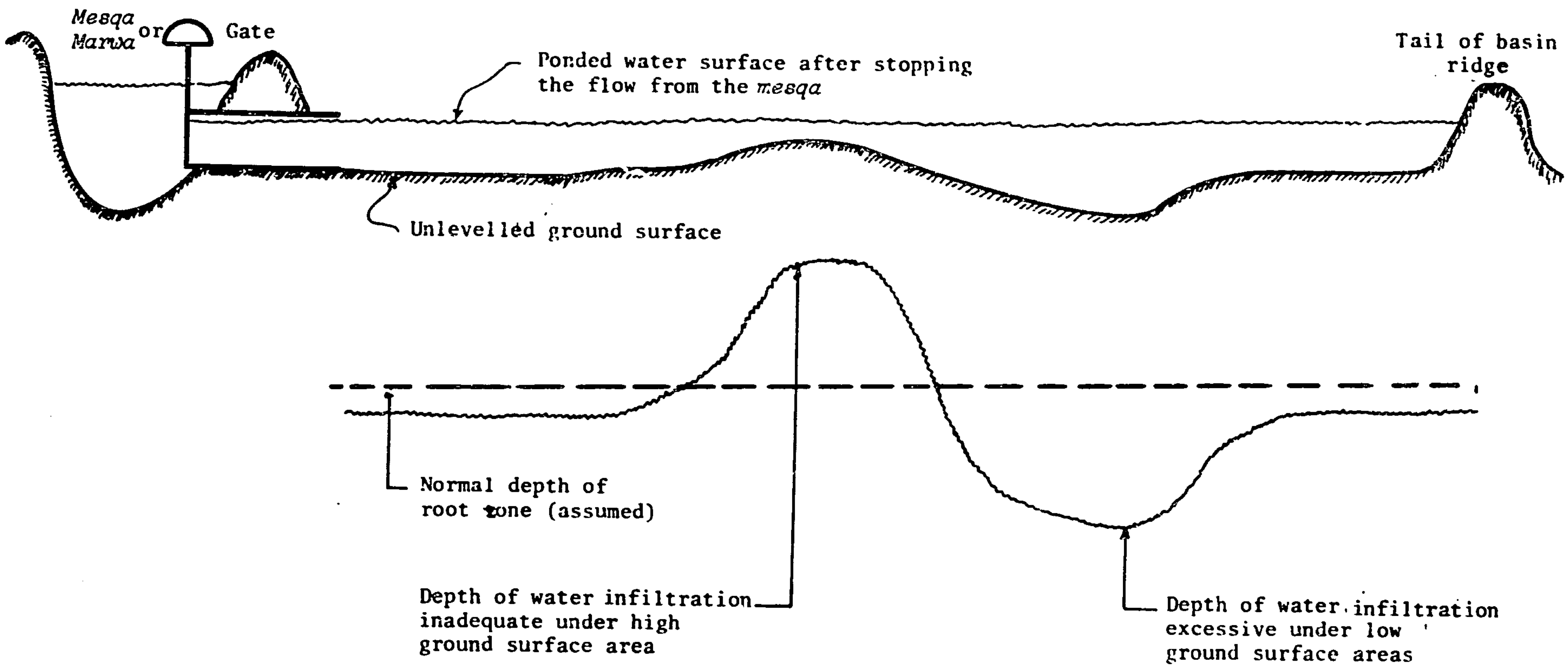

Figure 6. **Profile showing depths of infiltration of irrigation water in a basin having low and high areas of ground surface. (Does not include infiltration during the time of water advance from the *mesqa* to the basin tail).**

An area in the field that is five centimeters lower than the surrounding land would hold five centimeters depth of water after each irrigation. Water recession from the field depression would occur due to the combined effects of infiltration and evaporation. Long-term infiltration rates for clay soils vary from 0.01 cm/hr to 0.1 cm/hr (Hansen, et al., 1980). A typical value for evaporation would be 0.72 cm/day or 0.03 cm/hr. Combining the two components of water recession, rates of water recession from the field depression would vary between 0.04 cm/hr and 0.13 cm/hr. Five centimeters depth of extra ponded water in low areas with clay soils will theoretically require from 38 to 125 hours to recede from the soil surface as the following computations show:

5 cm / 0.04 cm/hr = 125 hours; 5 cm / 0.13 cm/hr = 38 hours.

Water covering the land surface for more than 24 hours after each irrigation will retard growth of many types of crops and kill others. Proper precision land leveling will eliminate high and low areas.

Figure 7 shows that the shorter the basins on sloping land the more level the basins become in that a smaller depth of ponded water will be required to cover the sloping land surface as basins become smaller. Egyptian farmers have compensated for field unlevelness throughout the centuries by irrigating with the small basins even though small basins require much time and energy on the farmers' part for construction and irrigation. Even today with modern methods of precision land leveling with machinery, it is difficult on some soils to irrigate long level border-strips or furrows with higher water application efficiencies than those that are attained by good Egyptian farmers using small basins that are reasonably level. However, for small basins, the farmer has relatively little control over the amount applied to each basin, other than letting water into each basin for a given length of time or until a certain ponded depth is reached. The uniformity of distribution of applied water[1/] over the entire field, from basin to basin can be very poor. A properly designed and managed "long-basin" system will have both high efficiency and good distribution. With the more permeable soils, the favorable water-application efficiency of small-basin irrigation will be offset considerably by larger seepage losses from the more complex network and extra lengths of farm distribution ditches (*marwa*) which are required with small

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1/ See Definitions.

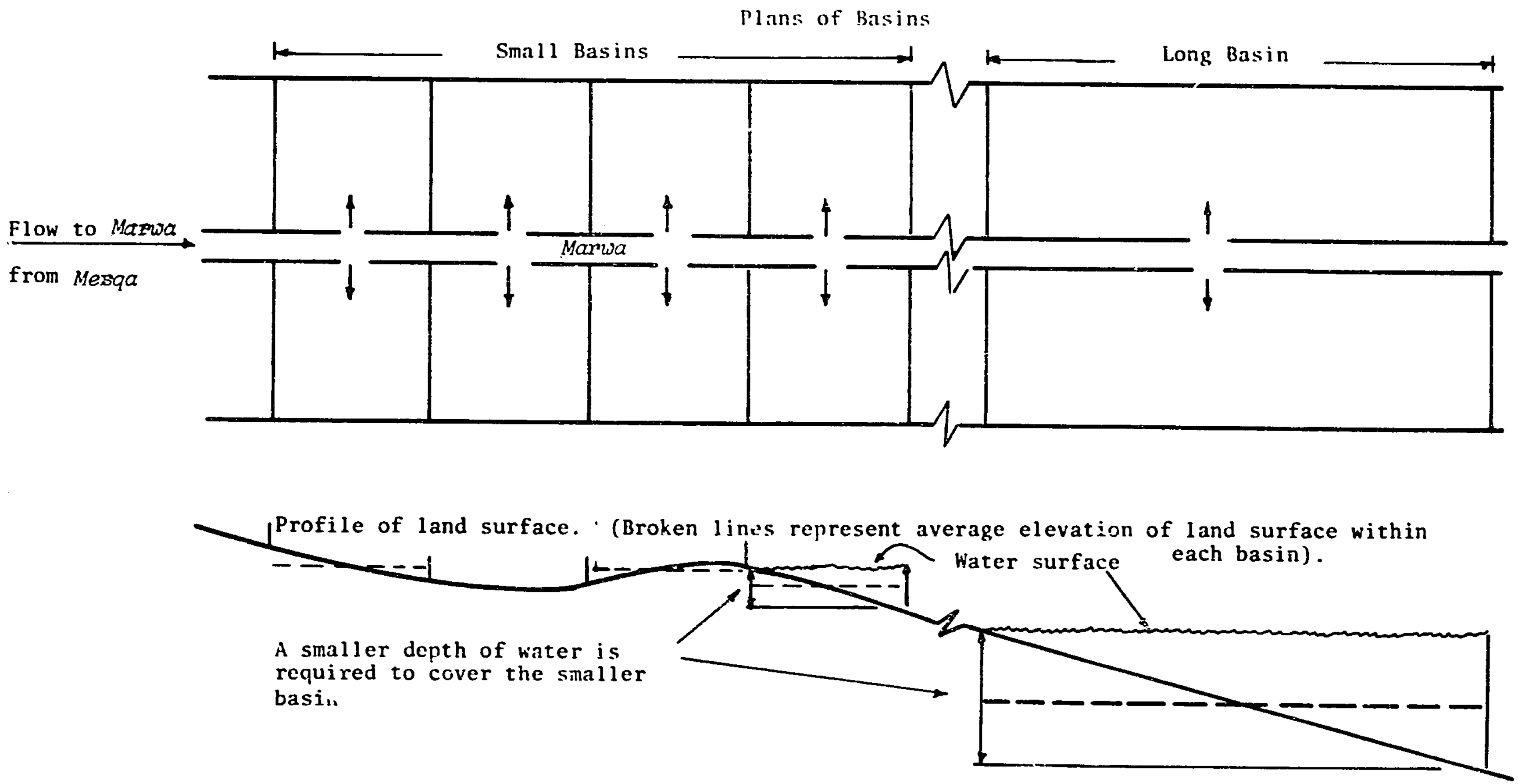

Figure 7. **Plan and profile of irrigated basins on a sloping land surface showing the effect of basin size on elevation variation within a basin and depth of ponded water required to cover the entire basin.**

basins. Excessive *marwa* lengths also remove land from production. Long basins may be irrigated directly from *mesqas* or main *marwas* thus eliminating smaller *marwas*.

Irrigation on Leveled Land With Level Border Strips or Level Long Furrows

Correct water management decisions based on available flow rate, soil infiltration characteristics, surface roughness, and desired net application are required to achieve high application efficiency for long runs on leveled land. Figure 8 shows different stages of wetting fronts, as water infiltrates into a sandy soil, when irrigation water advances on leveled land from the *mesqa* or *marwa* to the boundary at the downstream end of the field. The water table is assumed to lie far below the root zone and does not influence infiltration. After the surface stream reaches C in the figure, the gate must remain open if sufficient water has not been applied to have enough flowing to the point C to penetrate downward to D. This assumes that the entire root zone at all places is to be supplied with soil moisture. With large non-erosive streams on flat-level land with long runs, it is more usual with relatively frequent irrigations that the gate must be closed before the advancing stream reaches the downstream boundary. With long runs and large streams the design time of application may be shorter than the time of advance to the end of the border. After the gate closure the surface water will spread the rest of the way to the end of the strip resulting in a high water application efficiency if flow rate is appropriate for the soil conditions (soil infiltration rate, surface roughness, soil moisture, etc.) and area to be irrigated.

The wetting fronts below the root zone ending at B', C', and D', in Figure 8, represent deep percolation losses. The following example of assumed conditions will show how deep percolation losses influence water application efficiency. Losses to runoff are considered negligible.

Assumptions:

W_a = 12 centimeter depth of water diverted from the *mesqa* and applied to the land surface of the farm,

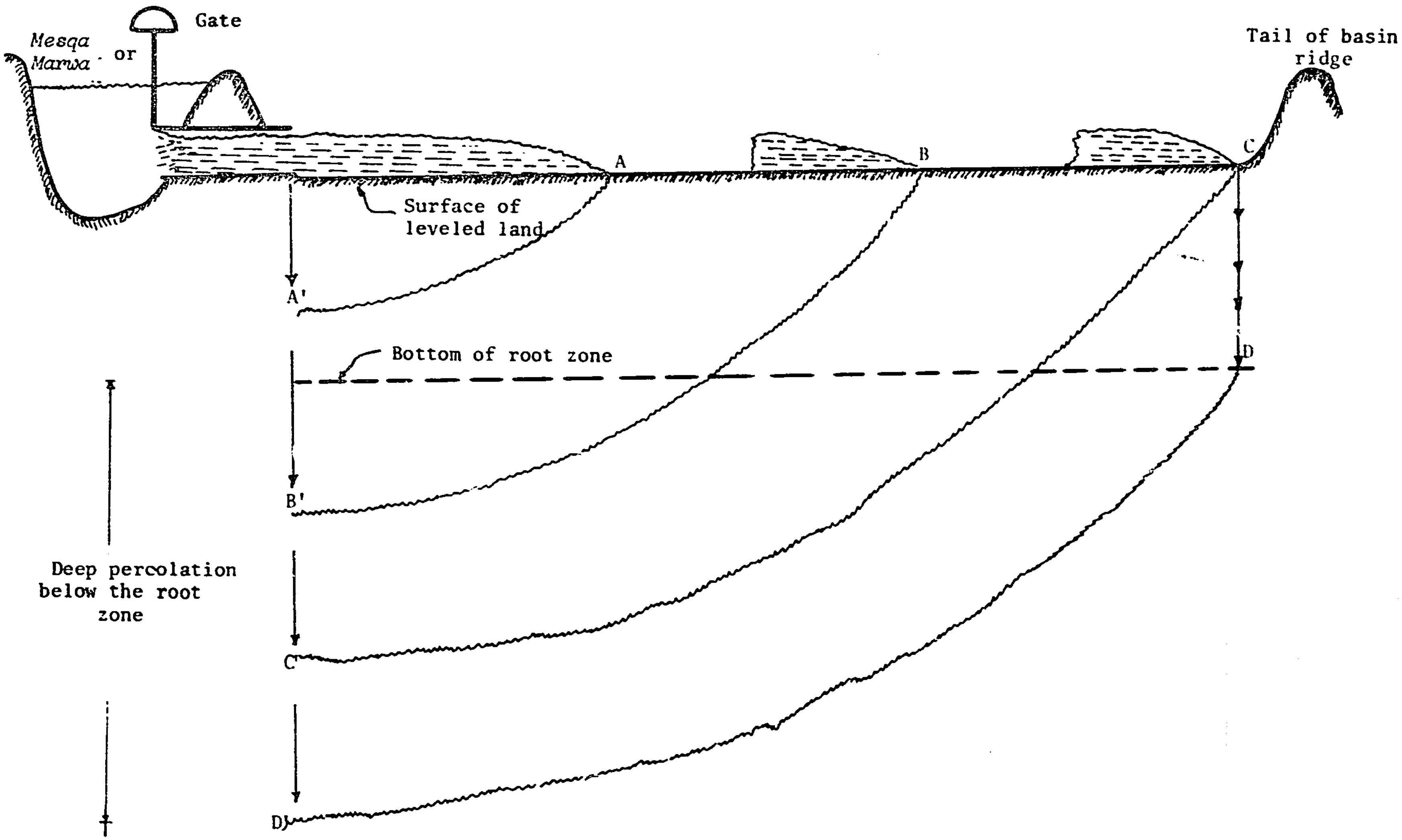

Figure 8. Profiles of water infiltration showing deep percolation on highly permeable soils during the advance of water on leveled land at selected points from the head to the tail of an irrigated basin.

W_s = 6 centimeters stored in the root zone,
(6 centimeters of water lost below the root zone as deep percolation).

E_a = Water application efficiency equals 50 percent since half of the water was lost, e.g.,

$$E_a = \frac{100\ W_s}{W_a} = \frac{100\ (6)}{12} = 50\%\ .$$

Figure 9 shows a similar analysis to that of Figure 8 except that the soil is a vertisol clay soil such as found at the Abu Raya EWUP site. The water table is high, less than one meter below the ground surface. These conditions lead to high initial infiltration rates, low long-term infiltration rates and profiles of infiltration with water advance as shown in Figure 9. Losses to deep percolation are not likely to be as great under these conditions as for sandy soils without a high water table. However, some deep percolation will occur at the upper end of the field.

Figure 10 shows how deep percolation losses may be minimized on flat leveled land (sandy soil, no water table effect) by applying higher non-erosive rates of flow of irrigation water to the land. A maximum non-erosive stream will advance relatively fast from the *mesqa* to the downstream end of the strip as compared to a small stream as shown in the figure. The quicker the time of advance to the end of the strip, the less difference there will be in the infiltration opportunity times at all points along the basin, and the more uniform will be the storage of moisture in the soil. With the relatively flat wetting front shown as A - A' and B - B', there is relatively small deep-percolation loss in the upstream portion of the field as compared to the loss indicated by the small-stream wetting front, C - C'. For a given discharge, increased surface roughness will slow water advance and increase deep percolation losses. This analysis shows that the proper design of a farm irrigation system using long level borders or furrows requires a proper accounting and balance between such factors as stream size, infiltration rate, and surface roughness in order to determine the appropriate dimensions for the strips.

The use of furrows with large streams requires that furrows must be relatively large if they are to contain the high rates of flowing water without overtopping or flooding the beds too severely. Figure

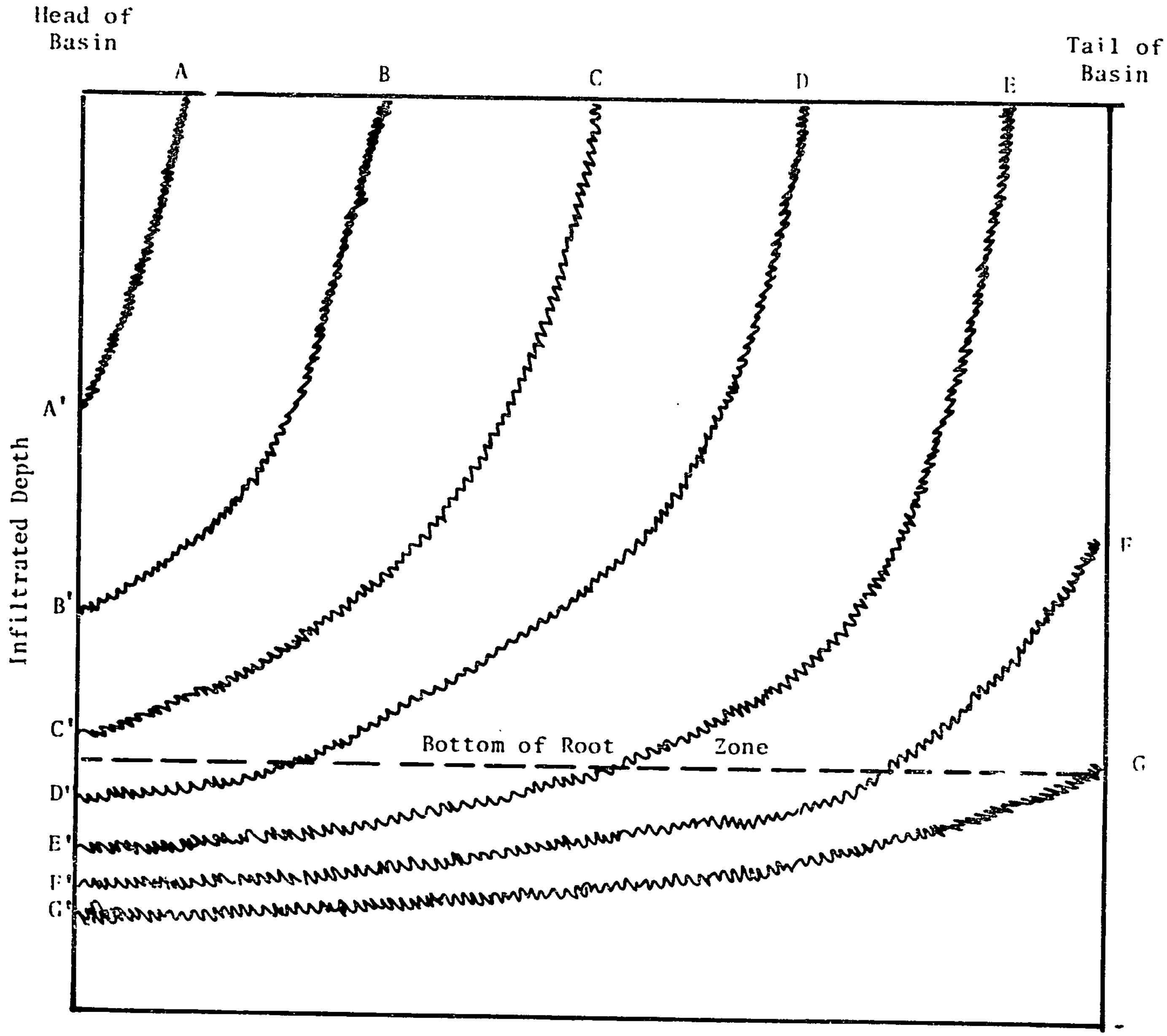

Figure 9. Infiltrated profiles for clay soil with high water table conditions at Abu Raya.

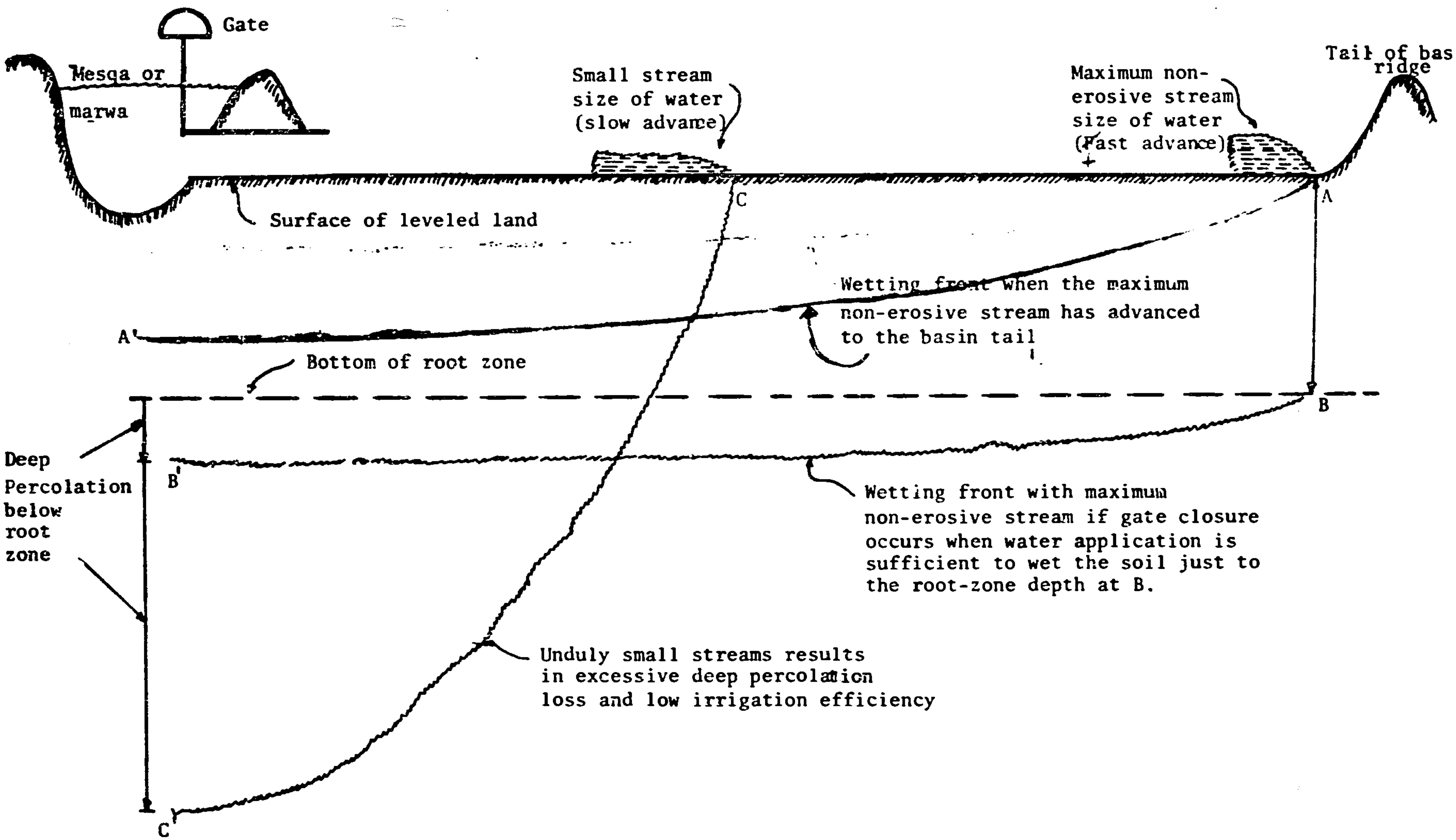

Figure 10. Effect of stream size on deep percolation losses below the root zone during irrigation of a leveled basin on highly permeable soils.

11 shows the relative size of large furrows with 90-100 cm spacing in comparison to small furrows used conventionally in Egypt with 50 to 70 cm spacing. The large furrows are used with large streams to increase the application efficiency and to reduce the time required to irrigate. The use of large non-erosive streams is limited by the height of furrow ridges which may be over-topped if the water flows too deep. Some soils develop a hard surface crust after submergence which will prevent emergence of seedling plants unless the crust is broken. Also, some types of seeds will not germinate if the seed bed is submerged after planting; and some types of crops will be damaged if the plants are allowed to stand in water. In these cases the depth of flow in the furrows must be limited and held low sufficiently long to allow water to wet the beds by capillary rise. The goal of achieving high water application efficiency must be balanced with that of getting a good crop stand and good crop yield.

It must also be kept in mind that numerous constraints may exist which can significantly reduce ability to perform land leveling. In Egypt (at the three Project sites) such constraints are: limited access to fields because of poor or no roads and crop patterns and/or fallow times between crops being irregular (as in El-Mansuriya). Also the farm and field size (particularly the small fragmented ownership patterns at El-Minya and El-Mansuriya) limit the ability to efficiently do land leveling with the conventional equipment. The cost of performing precision land leveling may also be prohibitive to farmers with smaller land holdings. Farmer interest in land leveling has been very strong. Farmers in Abyuha and Abu Raya have cooperated to arrange for fallow fields to facilitate leveling.

Water Application Efficiency and Stream Size

According to Figure 10, the larger the stream size on level basins the higher the water application efficiency becomes if the time of flow is just sufficient for moisture to penetrate to the bottom of the root zone at B in the figure. This concept agrees in general with findings by Bos and Nugteren (1974) that are presented in Figure 12 for stream sizes from 2 to 40 lps per hectare. In this range of stream sizes, the efficiency increased from 38 to 67 percent. However, there was a decrease in efficiency for stream flows above 40 lps per ha. Reasons for the decrease are not presented. One may speculate that the streams above 40 lps were too large for the farmers to adjust to from their habitual practices. Also, it has been observed throughout

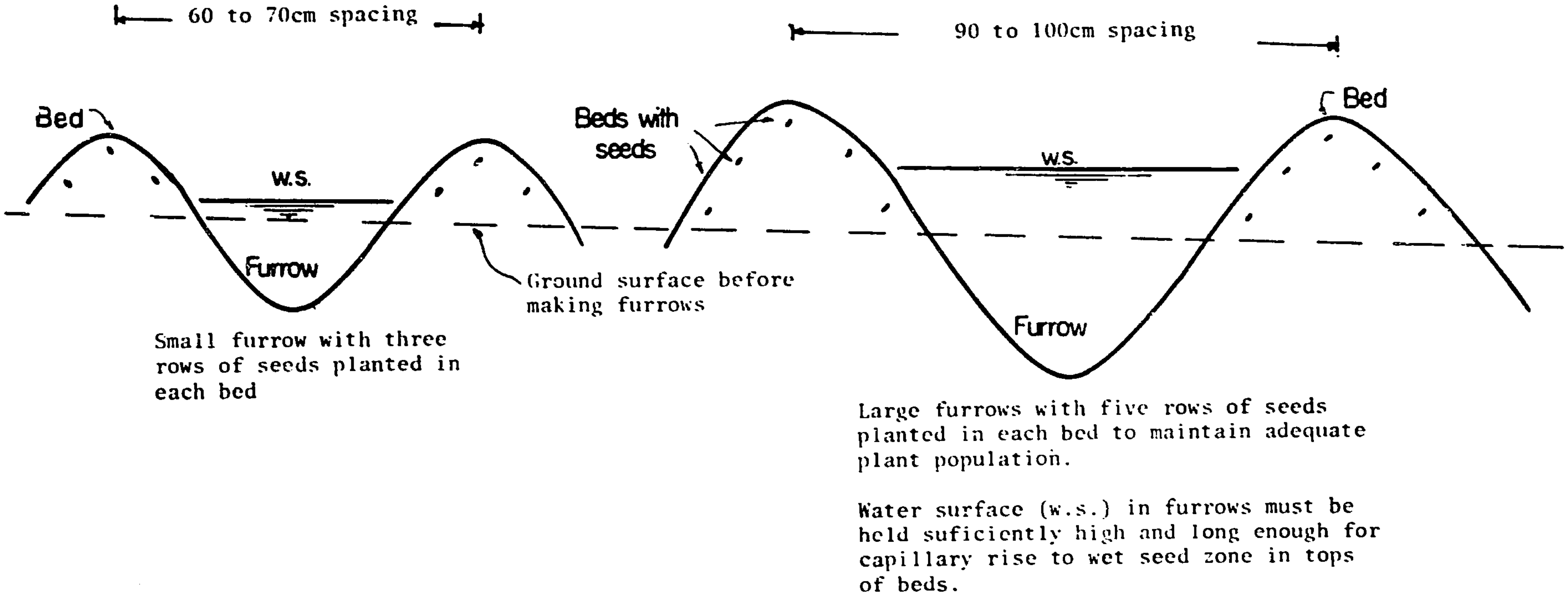

Figure 11. Relative size of large furrows used with large streams for rapid irrigation on leveled land as compared to small furrows with conventional streams.

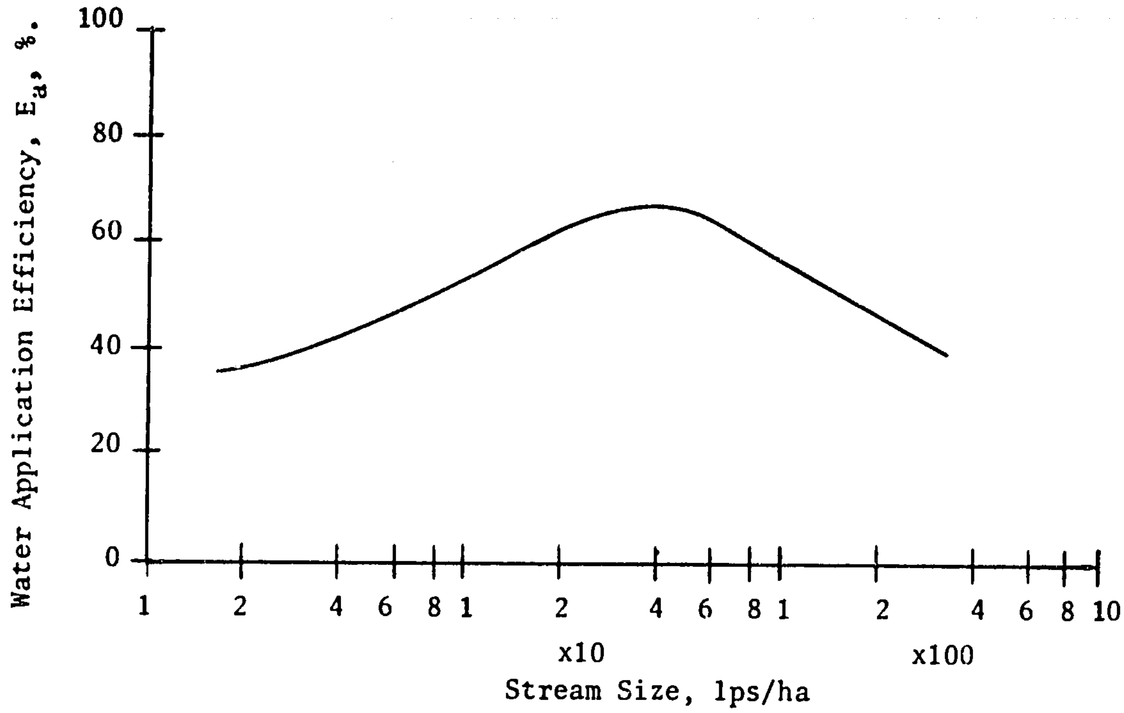

Figure 12. Influence of stream size per farm area on water-application efficiency (after Bos and Nugteren, 1974).

irrigated areas that farmers "worry less" about being careful during irrigation when there is an abundant supply of water. It is a natural trait of all people to be more careless with any type of resource if the supply is abundant.

One main reason is apparent: The larger the area of land and length of run the more the need there is for programming the hydraulic variables to calculate the appropriate time period required to apply the correct volume of water. A farmer can irrigate a small basin reasonably well by intuition easier than a large or long basin. He can easily see when the ground surface of a small basin becomes covered with water to give him an idea of how soon to shut off the water. But with a large stream entering a wide and long basin, the proper shut-off time is not so obvious. It may occur when the stream has advanced only two-thirds of the way to the end to the basin. Delaying the shut-off until the stream reaches the end of the border could in this case, result in a low water-application efficiency.

Effects of Soil Characteristics

The previous section indicated that the three work sites had very similar soil characteristics in terms of type and texture (clay to heavy clays), cracking upon drying, swelling upon wetting, infiltration rate trends for dry and moist soil conditions, etc. It is also important to point out the difficulty of soil tillage at the three areas when the soil is dry and cracked. Chisel plowing, in this case, causes large surface aggregates to be pulled loose creating a rough soil surface. The possible effects of these characteristics on irrigation performance must be accounted for in designing new systems and basin dimensions.

Due to the wide variation in soil infiltration rates measured (from very rapid when the soil is dry and cracked to slow and very slow when the soil is wet), it is possible that a design for one condition may not work well at all for the other. This is particularly true for the case when infiltration rates are greater than expected. When this happens, the advancing water stream is slowed down significantly and the potential for high deep percolation losses and low application efficiency is great. A proper design accounting for the higher intake rate would have given a narrower or shorter strip (or essentially have indicated that a larger non-erosive unit stream must be used to get the faster coverage of the basin). For the opposite case when infiltration rates are lower than expected, it is quite possible that too much water can be applied resulting in a ponded condition. In this case drainage of surface water would be necessary to prevent crop damage, also meaning the efficiency would be low. Careful management is necessary so the stream can be turned off before water reaches the end of the strip and too much is applied.

Surface roughness in basins caused by large aggregates of soil and by plant stems retards the flow of water down the strip. Flow depth is increased and water advance is retarded but to a lesser degree than by using too small of an inflow stream. The boundaries of the strips (border dikes or bunds) must be well-made and well-maintained (especially at the first irrigation) to allow effective water control and no leakage outside the intended control boundaries.

It is apparent, from the previous review of how different factors affect irrigat' ' design and performance, that the need for flexibility in irrigation management for a given system is necessary. For instance, factors beyond the irrigator's control (dry soil, high infiltration rates) cause heavy wetting applications at the first irrigation, while lighter, more efficient applications are obtained during the season. The use of very small basins in El- Mansuriya and El-Minya tend to compensate for this variability with the tradeoff being the large labor requirements described above and possible lost land area to ditches. In Kafr El-Sheikh, farmers use much larger basins, but are unaware of how to design water control boundaries to account for changes in design conditions, and thus they have low efficiencies. The effects of unlevel land complicate these problems in all three sites, as well as the small, highly variable available stream sizes in El-Mansuriya and El-Minya.

Irrigation activities on precision leveled land (to dead level) in the three Project areas will be considered in the next part of this report to find out how well actual measured results on trial fields agree with theoretical/technical concepts presented in this section. Also, the designs used on the leveled basins will be evaluated for appropriateness (i.e., correct basin dimensions, etc.) given the measured values of factors affecting the design. Where water-application efficiencies measured for irrigations on leveled land were lower than desired, possible reasons for the lack of improvement will be determined and remedies for obtaining improved results will be recommended.

IV. IRRIGATION TRIALS: RESULTS AND DISCUSSION

Beni Magdul, El-Mansuriya

Irrigation field trials have been conducted on several farms in Beni Magdul and El-Hammami. Numerous irrigation trials have been conducted on *Mesqa* 6 served by Beni Magdul canal and are the focus of this section. These trials were for comparison of long furrow or border strips on leveled land with the conventional small basins used in El-Mansuriya. Trials began with 1980/81 winter season wheat, then corn in the 1981 summer season, *berseem* in the 1981/82 winter and then corn again in the 1982 summer season (see Tables 4 to 7).

Summaries of these trials are provided in the following paragraphs. Design analyses of the long furrow or level border strips used are also made to evaluate why certain results were obtained. Definite conclusions cannot be drawn, because tests were not replicated. The data and design analyses do indicate possible trends, however.

Table 6 shows summary irrigation data collected for wheat in 1980/81 (test nos. 1-4). Small basins and large basin irrigation systems were studied. The large basins were leveled to zero slope before planting. The two cases with the small unleveled flooded basin irrigation system which is traditionally used in the area required 1351 and 1435 minute per *feddan* for irrigation during the crop season. One case with long level basins (5 m width by 139 m length) required more time, 2547 min/*fed*. The average depth applied per irrigation and total seasonal application depths for small basins were in the range of 4.9 to 6.0 cm and 24.6 to 30 cm, respectively. The average application per irrigation for the large basin system was higher, 9.3 cm. The total seasonal depth applied was correspondingly higher, 46.4 cm. As would be expected with the figures given above, the on-farm irrigation efficiency [1/] (E_{if}) was higher for the small basins. The 85 to 93% E_{if} found for the small unlevel basins was higher than the 77% E_{if} of the large level basins. However, an E_{if} above 75% in a surface irrigation system, especially where there are variable flow conditions, is quite satisfactory.

[1/] See Definitions

Note: On-farm conveyance losses were considered to be negligible for irrigation trials on *Mesqa* 6. The application efficiency and on-farm irrigation efficiency have the same value.

Table 4. Description of various treatments for irrigation trials on basin crops on *Mesqa* 6, Beni Magdul, 1980-1982.

Test Number	Season	Crop	Conditions/Practices	
			Land Leveling	Basin Configuration
1	Winter 80/81	Wheat	Yes, dead level	6 long basins (5 m x 139 m)
2	Winter 80/81	Wheat	Yes, 0.083% slope	1 long basin (5 m x 119 m) 3 long basins (13.5 m x 41.6 m)
3	Winter 80/81	Wheat	No	Conventional small basins (11.2 m x 11.5 m); bedded furrows prepared at 1.28 m spacing
4	Winter 80/81	Wheat	No	Conventional small basins (13 m x 15.6 m); bedded furrows prepared at 1.1 m spacing
9	Winter 81/82	Berseem	Yes, dead level	4 small basins (9.8 m x 31 m); 2 long basins (4.9 m x 123 m)
10	Winter 81/82	Berseem	Yes, dead level	6 small basins (5.5 m x 45 m) 4 long basins (5 m x 135 m)
11	Winter 81/82	Berseem	Yes, dead level	long basins (5 m x 135 m)

1/ Unpublished data, Mahmoud, et al., 1982a; W. S. Braunworth, 1983 (personal communication).

Table 5. Description of various treatments for irrigation trials on corn crop (furrows) on *Mesqa* 6, Beni Magdul, 1981-1982.[1/]

Test Number	Season	Conditions/Practices	
		Land Leveling	Basin Configuration
5	Summer 1981	No	Conentional small basins (12 m x 10 m); furrows at 0.75 m spacing
6	Summer 1981	No	Conventional small basins (12 m x 9 m); furrows at 0.75 m spacing
7	Summer 1981	Yes, dead level	Long furrows in basin (9 m x 127 m); furrows at 0.75 m spacing
8	Summer 1981	Yes, dead level	Long furrows in basin (17.5 m x 128 m); furrows at 0.75 m spacing
12	Summer 1982	No	Conventional small basins (16.5 m x 27.8 m); furrows at 0.75 m spacing
13	Summer 1982	Yes, dead level	Long furrows (137.3 m); spacing of 0.75 m
14	Summer 1982	Yes, dead level	Long furrows (82 m); spacing of 1.30 m
15	Summer 1982	Yes, dead level	Long furrows (120 m); spacing of 1.30 m
16	Summer 1982	No	Conventional small basins (4.4 m x 30 m); furrows at 0.75 m spacing

1/ Unpublished data, Mahmoud, et al., 1982b; W. S. Braunworth, 1983 (personal communication).

Table 6. Summary of results from irrigation trials on basin crops, Beni Magdul, 1980-1982.

Test Number	Treatment[2/]	Number of Irrigations	Total Irrigation Time (min/fed)	Depth of Water Applied: Average per Irrigation (cm)	Depth of Water Applied: Total (cm)	Average Stream Size Available at Field Inlet (lps)	Range in Basin Width[3/] (m)	Range in Unit Stream[3/] (lps/m)	Average E_a[4/] or E_{if}
	Wheat Crop, Winter 80/81								
1	level long basins	5	2547	9.3	46.4	13.6	5-15 m	0.91-2.72	75
2	level long basins	5	1797	5.9	29.4	9.0	5-10 m	0.90-1.8	100
3	Unlevel small basins	5	1351	6.0	30.0	16.1	-	-	85
4	Unlevel small basins	5	1435	4.9	24.6	13.4	-	-	93
	Berseem crop, Winter 81/82								
9	Level small and long basins	9	2795	7.9	71.9	19.38	-	-	73
10	Level small and long basins	8	2625	9.6	76.5	20.42	-	-	77
11	Level long basins	3 (1)	N/A	12.5		-	-	5.8	100
		(2)	N/A	8.3		-	-	4.0	87
		(3)	N/A	7.2		-	-	2.5	78
				$\bar{x}$ = 9.33					

1/ Unpublished data, Mahmoud, et al., 1982a; W. S. Braunworth, 1983.
2/ Complete treatment description given in Table 4.
3/ Not always known since a varying number of basins were irrigated as a set.
4/ Ratio of depth stored to depth applied (see Definitions). For these trials water-conveyance losses were considered negligible and application efficiency, E_a, was numerically equal to on-farm irrigation efficiency, E_{if}.

Table 7. Summary of results from irrigation trials on corn crop (furrows), Beni Magdul, 1980-1982.[1/]

Test Number	Treatment[2/]	Number of Irrigations	Total Irrigation Time (min/fed)	Depth of Water Applied: Average per Irrigation (cm)	Depth of Water Applied: Total (cm)	Average Stream Size Available at Field Inlet (lps)	Maximum Number of Furrows in One Set[3/]	Minimum Furrow Stream[3/] (lps)	Average E_a[4/] or E_{if} (%)
	Corn Crop, Summer 81								
5	Unleveled small basins	8	2280	5.5	43.7	14.0	14	1.00	59
6	Unleveled small basins	8	2387	7.5	60.2	17.6	16	1.10	93
7	Level long furrows	8	3106	10.3	82.4	18.3	12	1.53	82
8	Level long furrows	8	3984	7.3	58.4	10.5	23	0.46	86
	Corn Crop, Summer 82								
12	Unleveled small basins	7	2949	10.9	76.1	18.77	-	-	70
13	Level long furrows	7	2878	9.4	66.1	19.36	9	2.12	85
14	Level long furrows	7	4011	8.9	62.6	11.95	21	0.57	69
15	Level long furrows	5	2964	11.9	59.7	16.43	11	1.53	77
16	Unleveled small basins	7	3801	9.9	69.5	15.22	-	-	84

1/ Unpublished data, Mahmoud, et al., 1982b; W. S. Braunworth, 1983.
2/ Complete treatment description given in Table 5.
3/ Not always known since a varying number of furrows were irrigated as a set.
4/ Determined from ratio of depth stored as determined from evapotranspiration estimates and depth applied (See Definitions). Conveyance losses were considered negligible so that application efficiency, E_a, was numerically equal to on-farm irrigation efficiency, E_{if}.

The results show that a substantially greater amount of water was applied on the long, large basins. A review of the probable range of design parameter values for level border design in Beni Magdul and comparison with the trial case indicates why these results were obtained. Level border design analyses were performed using the USDA-SCS design model (USDA, 1974; Gates and Clyma, 1980; EWUP Kafr El-Sheikh Team, 1983b). A summary of irrigation conditions for El-Mansuriya area was given earlier in this report. Of particular importance to design are the available discharge, the soil infiltration rate, the net depth of water to apply, the surface roughness, and the field dimensions.

Two sets of design conditions were evaluated: a) those at the first irrigation when intake rate is high (SCS Intake Family 1/ of 1.0), soil is dry (net depth of 120 mm) and roughness greater (Manning's n of 0.20), and b) those of the mid-season when intake rate is lower (SCS Intake Family of 0.5), wetter soil conditions (net depth of 70 mm) and roughness is less (Manning's n of 0.15). For the 139-m length, design analysis indicated that to obtain 90% efficiency, a unit inflow stream of about 6 lps/m is necessary (for both conditions). Given the average total stream size at this farm of 13.6 lps, then the strip width should have been 2 m to 2.2 m and not the 5 m width used. These required widths are excessively narrow and would require a large percentage of land to be used for dikes. Alternatively, given the same conditions but using the 5 m width and designing for length, design analysis indicates that a length of about 70 m is appropriate to obtain 90% efficiency. Further analysis indicated that a total stream size of 25 - 30 lps should have been used for the 5 m x 139 m strips. Had this been the case, then the applications would have been faster and lighter. It appears the actual measured stream was the major limiting factor for the long basins tested (13 lps actual vs. 25 - 30 lps required). It is doubtful that the small *saqias* used in Beni Magdul area can deliver the larger flow rates under the normal operating conditions in the area. Other complications of the test were the poorly constructed border dikes (bunds) which leaked and were not high enough to contain the flow. These dikes must be well-constructed and well-maintained for proper irrigation water control.

1/ See Definitions

Note: On-farm conveyance losses were considered to be negligible for irrigation trials on *Mesqa* 6. The application efficiency and farm irrigation efficiency have the same value.

Table 7 shows results from several fields of corn during the 1981 summer season. The conventional small basins with furrows are compared with trials of long furrows (128 m) on leveled land. The major difference was found to be the time required for irrigation , averaging 2330 minutes/*feddan* for the small basins and 3545 minutes/ *feddan* for the long furrows. The on-farm irrigation efficiency was an average of 95% for the small basins and 86% for the long furrows. In one set of the long furrows, the total application of 82 cm of ater was excessive, as compared to the others.

Design analysis of the long level furrows was performed using the level furrow design model (USDA, 1979; EWUP Kafr El-Sheikh Team, 1983b). Similar to the analysis for wheat, two sets of conditions were investigated: a) at the first irrigation when the infiltration rate1/ is higher (SCS Intake Family1/ of 0.7), and soil is drier (net depth of 100 mm), b) mid-season when infiltration rate is lower (SCS Intake family of 0.3) and wetter soil conditions (net depth of 70 mm). For both sets of conditions, the length of 125-130 m and furrow spacing of 0.75 m were studied. The design analysis indicated that best performance (efficiency over 90% with irrigation time constrained to a maximum of 90-120 min) is obtained when the stream size for each furrow is greater than 2.0 lps. Furrow capacity evaluation suggests that for this spacing the maximum flow rate should be constrained to 3.0 lps per furrow to prevent overtopping of furrow ridges (assuming a trapezoidal furrow shape with side slopes of 0.5 and bottom width of 15 cm; flow depth is estimated at about 13.0 cm and top width near 30 cm).

It is doubtful, based on qualitative observations at the site (and on data presented by El-Kady, et al., 1979), whether the furrows were constructed this large at the beginning of the season and whether the cross-section was maintained through the season.

The data for long furrows in Table 7 indicate the average furrow stream size was too small. This plus the actual furrow shape conditions constrained the performance of the long furrows resulting in the excessive total irrigation times and greater average total depth applied. Long level furrow irrigation requires deep, well-constructed furrows with large well-defined cross-section and good maintenance through the season as discussed in a previous section. Such conditions allow larger stream sizes per furrow (in this case, at least 2

1/ See Definitions

lps per furrow would be recommended) for rapid advance and coverage. For the given trials, adjustments that would have given better performance would be as follows:

a) improved furrow cross-section (size, shape, maintenance by tillage).

b) irrigate fewer furrows per set to result in 2 lps/furrow, i.e., for test no. 7, irrigate 9 furrows per set (based on average available flow rate); for test no. 8 irrigate 5 furrows per set.

Alternatively, the length of run can be shortened as was illustrated for wheat. Decreasing the length of run, in successive increments, from the long 125-130 m runs to the short 15 m runs of the conventional system has the effect of allowing greater management flexibility in terms of the stream size (both total and per furrow) that can be utilized for efficient (E_a > 90%) irrigation. In other words, for longer runs, the farmer must exercise more care in the number of furrows to irrigate at once (i.e., for the case in hand, the total stream size divided by the number of furrows per set should be at least 2.0 lps). For the shorter runs, this value decreases to the point where, for the conventional basin lengths, stream size per furrow can be as low as 0.5 lps. This effectively gives the farmer a wide range of choices for irrigating, depending on what the *saqia* may deliver, what the soil conditions may be, etc.

Continuing with the analysis, from Table 7 under the column "minimum furrow stream", the average condition is seen to be 1.0 lps/furrow for these trials. With this stream size and using the same two sets of conditions described earlier for design, analysis indicates a maximum run length of 75 m is appropriate (when the arbitrary condition of constraining irrigation time to 90-120 min is used).

Table 6 presents summary data and results for irrigation trials of long level basins vs. the conventional small basins on *berseem*, 1981-82 winter season, on *Mesqa* 6 in Beni Magdul. Two fields were tested (test nos. 9 and 10), each with portions for each system type. Unfortunately, measurements were somewhat mixed together after the first few irrigations, so it is not possible to determine the separate results for each system. Essentially the same overall results were obtained for each field, although the field with more long basins showed a slightly higher average depth per irrigation.

Also in Table 6, some summary results (for the first three irrigations) are listed for one of the fields with level long basins only (test no. 11). It is noted that design conditions for the *berseem* (81/82 winter) are very similar to those presented for the 80/81 winter wheat (test No. 1). It is recalled from that discussion that a unit inflow stream of about 5 - 6 lps/m is needed for efficient (E_a > 90%) irrigation (and could be less as conditions change through the season). From Table 6, the data for the first irrigation on berseem (test No. 11) show that because the unit stream size was high (near the indicated design value) that good results were obtained. Figure 13 is an illustration of advance data measured on wheat (1980/81) and *berseem* (1981/82) level border strips. Conditions for each, being at the first irrigation, were very similar. However, the effect of stream size, which was different, is well illustrated. Although the unit stream size for the wheat trial (test no. 1, first irrigation) of 3.25 lps/m was higher than the seasonal average (0.91-2.72 lps/m) it was still far below the 6.0 lps/m recommended. Coverage of the strips was accomplished in about 25% less time for the *berseem* (where the stream size is closer to the design as based on the given conditions, whereas the wheat had a stream size near 50% of the design value). In both of the above cases, factors such as leakage through the dikes were ignored to simplify the discussion and for comparison with design indications.

For the second and third irrigations, the unit stream used was seen to decrease. Because the design conditions are changing this is tolerable, and the second irrigation shows that a drop to 4 lps/m still gave reasonable results. However, for the third irrigation, the unit stream size of 2.5 lps/m used was too small and the efficiency dropped.

The final set of trials from El-Mansuriya studied in this report are from 1982 summer season when long level furrows were compared with the conventional system. The crop was again corn. Table 7 presents summary data and results. Long furrows were for run lengths of 82 m, 120 m and 137 m with furrow spacings of 1.30 m, 1.30 m and 0.75 m, respectively.

In general, the long furrows had a slightly smaller total irrigation time while the total average depth was about 63 cm vs. 73 cm for the small basins. Average irrigation efficiency for the long furrows was 84% vs. 77% for the small basin systems.

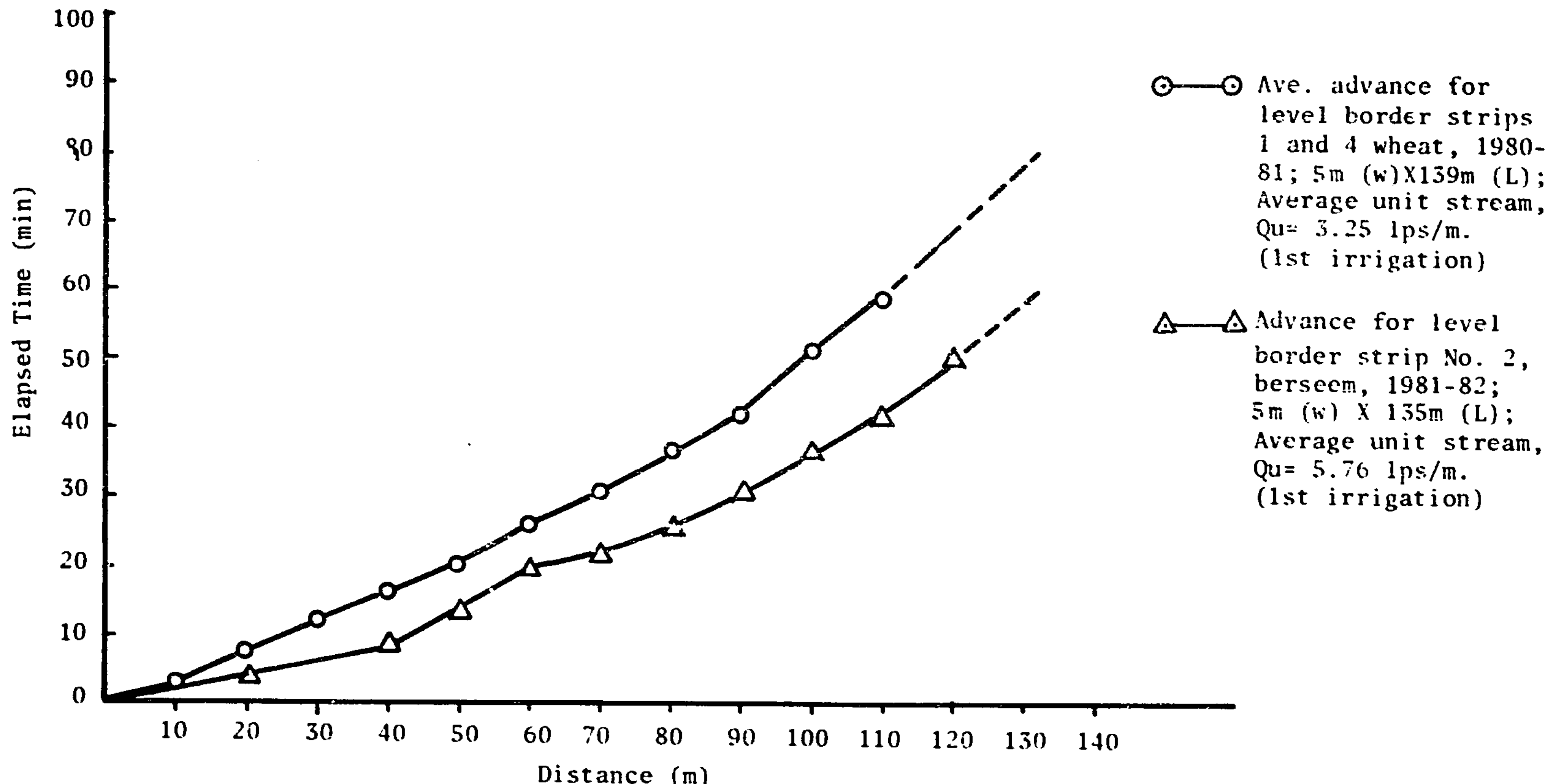

Figure 13. Comparison of rate-of-advance data for level border strips under approximately the same conditions showing the effect of stream size. Wheat, 1980-81 winter season, and Berseem, 1981-82 winter season, Mahmoud Basha Farm, Mesqa 6, Beni Magdul, Mansuriya.

There are several factors which may have contributed to the better results for the long furrows during this season's (1982) trials. First, consider test no. 13 where the long furrows used are similar to the case study from 1981 summer season (in terms of length and furrow spacing). Note that the average minimum stream per furrow was about 2.1 lps. This corresponds with the design indication discussed earlier. It is seen that good results were obtained on this field. Second, consider test no. 14 where the furrow length was 82 m with spacing of 1.30 m. An excessive total irrigation time is noted because of the relatively small furrow stream size. Design analysis for this site indicates a furrow stream of at least 1.5 lps would give the best results through the season. Had this been the case, the total time would have been less on this field. Finally, for test no. 15 (L=120 m, spacing=1.30 m), design analysis indicates a larger average furrow stream size (i.e. in the range of 2.0-2.5 lps per furrow) would have given better results than the 1.53 lps average furrow stream. Total time would be less and efficiency higher. With the larger furrow spacing, it is very possible that the furrows used in tests 14 and 15 were in better condition, yielding better water control and thus the fairly good results, even though the stream sizes were less than desired.

The experience gained through the irrigation trials on *Mesqa* 6 indicate that many factors must be considered before recommendations can be made. The data presented are a limited sample and by no means should be considered as representative of the wide variation in crops, crop patterns, farmer land holdings, etc. The results presented do indicate the following:

(1) the long level basins and level furrows tested performed at less than potential levels because predicated values of available stream size and other design factors used in design of the tested systems were inaccurate;

(2) design analysis indicated the dimensions of the "new" systems were inappropriate (too long or too wide) for the given available stream sizes;

(3) *saqias* in Beni Magdul are small and characteristically produce limited, highly variable streams;

(4) improvement to water delivery rates to the field inlet would be one way of being able to utilize the longer runs (length > 100 m) tested on widths of 5 m or more; a minimum stream of 25 lps at each long basin would have to be consistently available. More realistically, an approach may be to simply design level basins and long furrows for the existing conditions. Recall that run lengths of 75 m appeared appropriate with widths of 5 m for level basins and furrow streams of 1.0 lps (spacing = 0.75 m). Further design analysis is necessary, but these values are presented for discussion purposes.

The ultimate analysis of these farm irrigation system designs will be economic. The conventional small basins appear to be efficient (as represented by data presented here). An important question to consider is whether precision land leveling can be performed economically on the small land holdings (and when cropping patterns allow), and whether the benefits of the level basins and long furrows (potential water, labor, time and land savings) are enough to offset the cost of leveling.

Abu Raya, Kafr El-Sheikh

Irrigation field trials were conducted during the 1979/80 winter season (wheat crop) and during the 1980 summer season (cotton, rice and corn crops) in Abu Raya. Suggested improvements to the farm irrigation system were tested side-by-side with conventional systems. The suggested irrigation system improvements included precision land leveling to dead level, level border strip or level long furrow irrigation design and assistance to farmers on managing these new systems. Starting with the 1980/81 winter season a package of on-farm irrigation system improvement practices was implemented each season as a demonstration program. This package included on-farm water distribution improvement through improved *marwas*, field drain removal where possible, and crop production advisory assistance to farmers as well as the above-mentioned irrigation improvements.

Table 8 shows results of efficiency measurements [1/] (irrigation, conveyance and application) on farms during 7 seasons of EWUP work in Abu Raya. These results extend from problem identification studies to recent demonstration trials. Discussion in the following paragraphs (of seasonal results) will refer to this table repeatedly, but it is

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1/ See Definitions

TABLE 8. Summary of On-Farm Efficiency Results for Seven Seasons of EWUP Work at Abu Raya.

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
Summer 82	Cotton	9 fields on Hamad and Manshiya Canals	Yes	lined	redesigned	99	69	69
	Cotton	1 fields on Hamad Canal	Yes	unimproved	redesigned	66	85	57
	Corn	4 fields on Hamad and Manshiya Canals	Yes	lined	redesigned	100	68	68

1/ E_{cf} = on-farm conveyance efficiency (see Definitions).

E_a = application efficiency (see Definitions).

E_{if} = on-farm irrigation efficiency ($E_{if} = E_{cf} \times E_a$).

2/ Based on inflow-outflow tests

important here to make a few explanations. First, the efficiency values measured are average seasonal values. Second, water losses between the *saqia* and the field were not measured during the problem identification and field trial work preventing the direct calculation of values for on-farm conveyance efficiency, E_{cf}, and water application efficiency, E_a. On-farm irrigation efficiency, E_{if}, was directly measured. Water depths lifted, applied, and stored were measured during later on-farm work and all three efficiency values could be obtained. On-farm conveyance loss measurements taken during the 1980/81 and 1981/82 winter seasons indicated that on the average as much as 40% of the water may be lost from unimproved *marwas* between the *saqia* and the field. The seasonal E_{cf} average for 5 sites with reshaped *marwas* on the Hamad and Manshiya canals during the 1980/81 winter season was 74% as shown in Table 8. During the 1981/82 winter season the average E_{cf} value for an unimproved *marwa* at site 3-10 was 62%. Using these data, an estimate for E_{cf} for the problem identification and field trials stages is then taken to be in the area of 60%. From this estimate, application efficiencies for the same period are also estimated.

During the 1979/80 winter season, irrigation trials were conducted on 5 farms growing wheat. The conventional basins used were compared with level border strips (leveled to dead level) on each farm. In general, the results obtained, which can be attributed to precision land leveling, farm irrigation design and irrigation water management advisory assistance, were:

1) increased on-farm irrigation efficiency, see Table 8, from 38% for the conventional methods, to 61% for the improved systems;

2) Water savings of 34%: water lifted by the conventional systems averaged 87 cm while it was 65 cm for the improved systems,

3) 33% irrigation time savings: total time averaged 1907 min/*fed* for the conventional while it was 1304 min/*feddan* for the improved systems.

4) the water and time savings produce these benefits: less labor by the farmer during irrigation, less labor by the animal to lift water; these translate to reduced costs for irrigating [1].

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[1] Unpublished data (EWUP Kafr El-Sheikh Team, 1981a)

Level border designs used in Abu Raya for these trials were formulated using the USDA (1974) design model. Generally the designed strips were for widths of 9 m to 10 m and lengths from 50 m to 105 m. The farmer's conventional basins ranged from 14 m to 20 m width with lengths from 60 m to 105 m. One basin was 48 m x 89 m. Generally, these design dimensions are not largely different, so the benefits of precision land leveling in terms of water savings and improved efficiencies are apparent. An analysis of flow rate data for these trials also provides insight to the success of the improved systems. The seasonal average stream size produced at the *saqia* (for all sites) was about 31.5 lps (range was 24-39 lps). After reducing this by the average estimated conveyance losses, the average stream size at the field inlet was 22 lps (for all sites, range was 16-31 lps). The values of stream size at the field inlet were analyzed to determine the stream size per unit width of basin and stream size per unit area of basin. These were then compared with the on-farm irrigation efficiencies measured. The results are plotted in Figure 14 (results from the 1980/81 winter season are also included and will be discussed later). A general but strong trend for on-farm irrigation efficiency to increase with increasing unit width stream size <u>and</u> unit area stream sizes is observed. This agrees with theoretical discussions in a previous section. Note that the designed level border strips of the 1979-80 trials consistently had higher unit width and unit area streams and corresponding higher on-farm irrigation efficiencies. This indicates the design dimensions used are an improvement over the conventional and also that the design model was appropriately applied, i.e., the design factors were appropriately evaluated. Generally, this can be translated to the concept that the improved water control with rapid basin coverage was a result of designing the border strip dimensions based on the site conditions.

Overall, the on-farm irrigation efficiency could have been even higher had the *marwa* losses not been so high (estimated *marwa* conveyance efficiency of 60%). Improving this value directly improves on-farm irrigation efficiency and indirectly improves water application efficiency, because a larger stream is then available at the field.

During the 1980 summer season, similar irrigation trials were conducted on 6 farms growing cotton.[1/] On each farm, long furrows on

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1/ Unpublished data (EWUP Kafr El-Sheikh Team, 1981b)

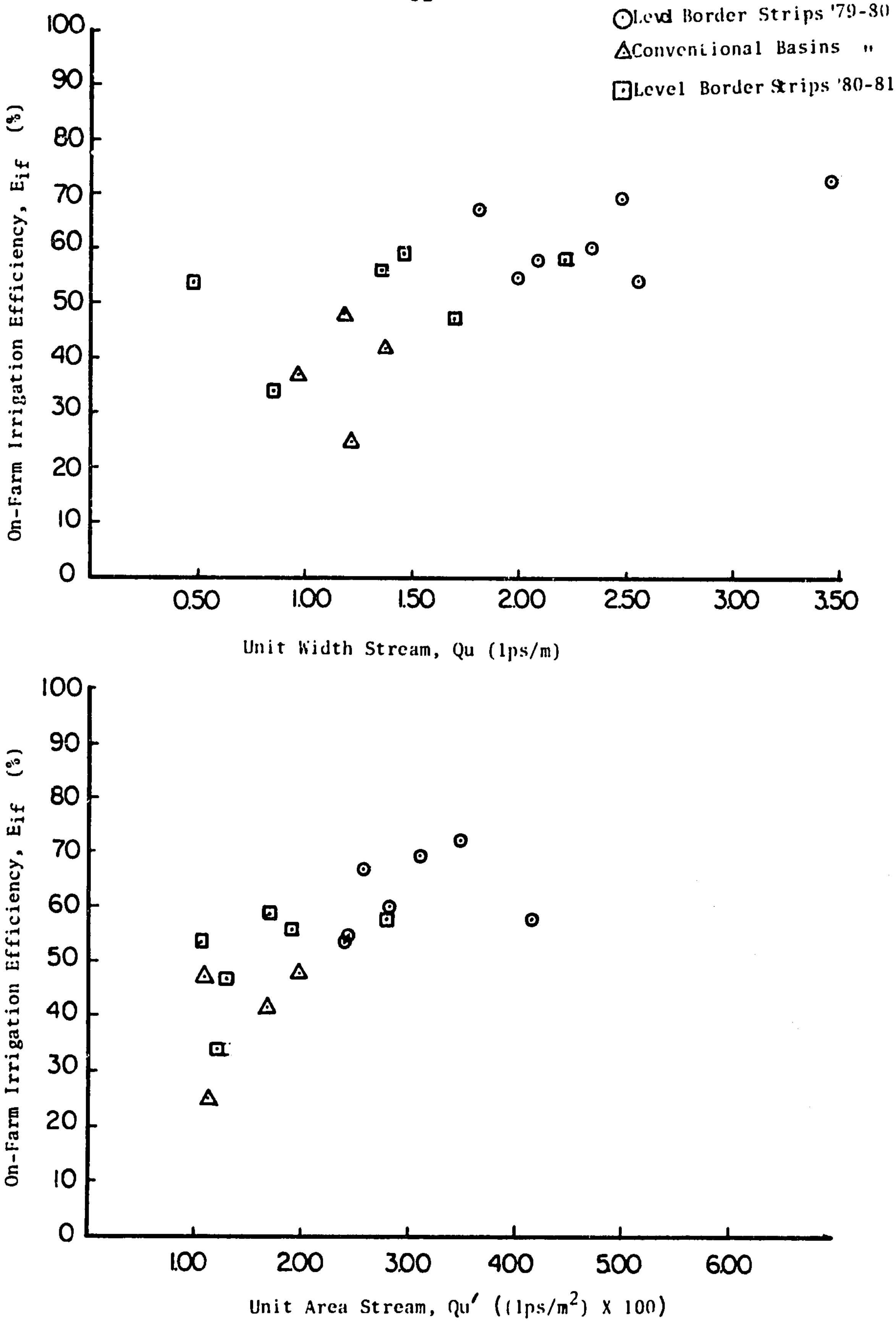


Figure 14. Unit width stream and unit area stream vs. irrigation efficiency for designed level borders and conventional basins, 1979-80 Winter season wheat field trials; and 1980-81 winter season demonstration trials on wheat, Abu Raya, Kafr El Sheikh.

leveled land were compared with adjacent strips where the conventional furrows in small basins were used. Note from Table 8 that the on-farm conveyance efficiency was estimated to again be low (60%), causing low on-farm irrigation efficiencies. *Marwas* on all of the farms but one were in excess of 100 m. Generally, the same results were obtained for the long furrows as for the conventional system:

(1) On-farm irrigation efficiencies for each case were 52-53%.

(2) total depth lifted at the *saqia* averaged from 102 to 107 cm for each.

(3) the improved systems did exhibit about 7% time savings: 2148 min/*feddan* vs. 2309 min/*feddan* (average for the 6 farms).

4) the time savings translates to irrigation labor savings (animal and human), and possibly of equal importance, the farm labor required to construct the numerous small basins and extensive distribution ditches is saved when the long furrow system is used.

Many problems were observed during the irrigation season which contributed to the long furrow system performance being less than desired. The major factor was the furrow size, shape and spacing. The furrow spacing was 55 cm to 65 cm. This narrow spacing made it difficult to construct the large, deep, well-defined furrows necessary for level long furrow irrigation. Furrow shape was not maintained through the season. Tillage occurred up to about the second irrigation. By mid-season the shape of the long furrows was very shallow and wide. This condition resulted in a loss of water control and ultimately, the reduced performance level of the long furrows.

An analysis of the flow rate data for the cotton furrow trials similar to that presented for wheat was made. Estimates of the unit width and unit area stream are plotted vs. on-farm irrigation efficiency in Figure 15. It is most important to note from these data that the long furrows were achieving the same levels of performance (range in E_{if}) as the small basin furrows but with a higher range in unit area stream. It is felt that the on-farm irrigation efficiencies on the long furrows would have been consistently higher had the loss of water control, discussed above, not occurred. Note that a wide range of

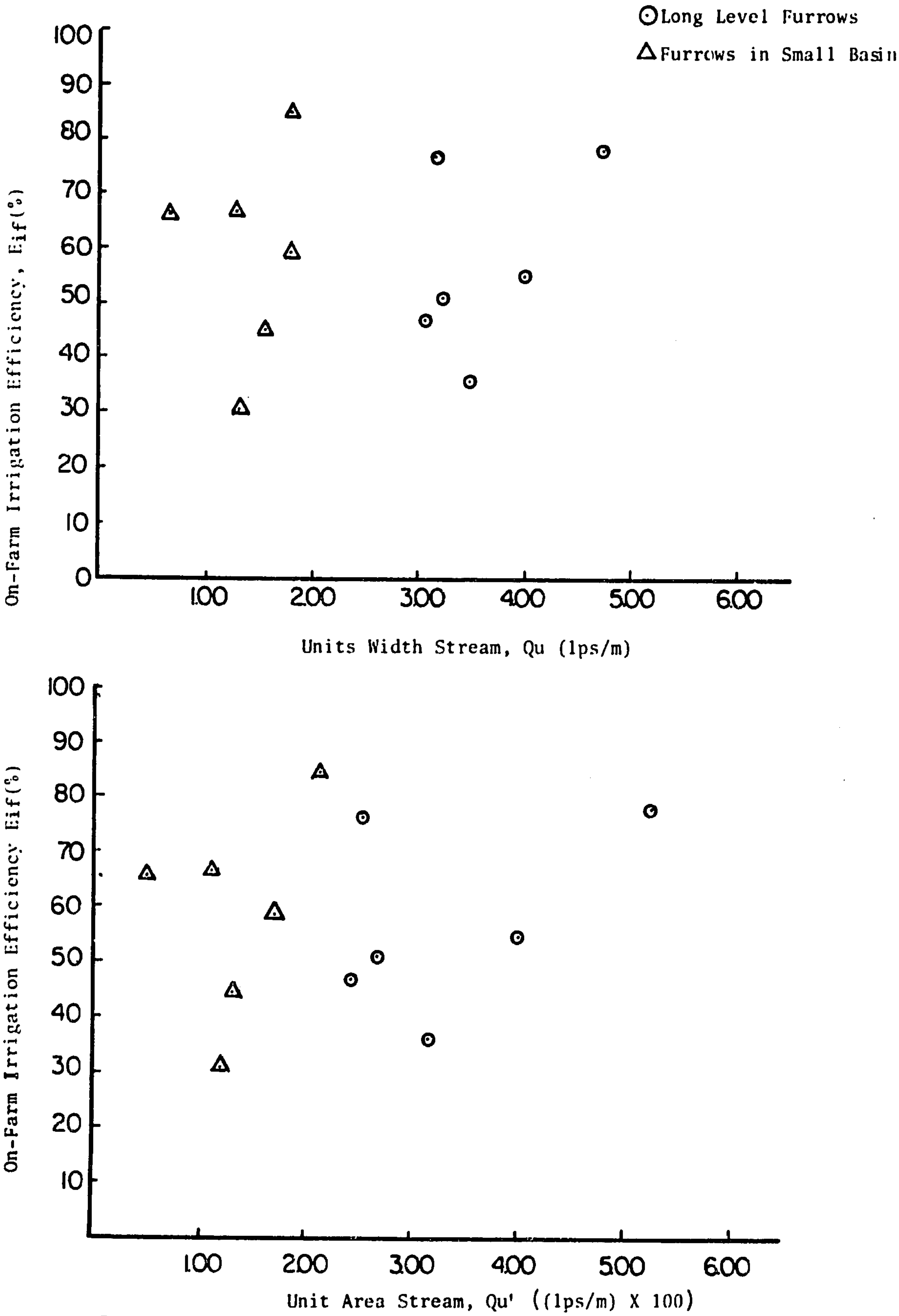


Figure15. Unit width and unit area stream vs. irrigation efficiency for long level furrows and conventional furrows in small basins, 1980 Summer season cotton field trials, Abu Raya, Kafr El Sheikh.

efficiencies were found for the conventional methods over a relatively narrower range of flow rates. This tends to indicate that some farmers manage water well, while others do not, using the small basins.

Summary results of field trials on rice during summer 1980 on three farms are reported in EWUP Kafr El-Sheikh Team (1983a). Generally the same irrigation improvements were tested. The major result found was an average water savings of about 14% for the improved systems (160-165 cm water applied for the designed level border strips vs. 185-190 cm of water applied for the conventional, unlevel, large basins).

Trials on the corn crop during summer 1980 were similar to those for cotton, however, only two farms were involved. With limited data it is difficult to draw conclusions. Of importance, however, is the fact that the corn was planted on 70-75 cm spacings allowing better, larger furrows to be made. The general irrigation results show this may have been a major factor in that the long furrows averaged 39% less water lifted at the *saqia* compared to the small basins with furrows.

The irrigation improvement practices of precision land leveling, farm irrigation system design and water management advice were combined with crop production advice, farm water distribution and conveyance improvement and field drain removal to be implemented as a demonstration package beginning with the 1980/81 winter season. The demonstration trials were conducted on five farms. Water losses in *marwas* were directly measured and the summary of efficiency values in Table 8 was obtained. The 74% average E_{cf} value represents conditions of both improved but unlined *marwas* and unimproved *marwas*. *Marwa* improvement consisted of renovation and shaping of the cross-section by hand labor.

The level border systems designed were for a wide range of basin dimensions in an attempt to assess the effects of rectangular vs. square configurations. In general, the results showed relatively equal levels of performance regardless of the length to width ratio, indicating the other factors, most importantly stream size, were appropriate. Qualitatively, the longer, narrower strips seemed to irrigate better because of seemingly more rapid advance. Detailed analysis has been presented in a report on farm irrigation system design considerations for Abu Raya (compiled in EWUP Kafr El-Sheikh Team, 1983b).

Stream size per unit width and per unit area vs. efficiency are presented for the 1980/81 farms in Figure 14 along with data from the previous year of field trials. It is seen that these results fit the trends discussed earlier.

Results from the 1981 summer season [1/] and 1981/82 winter season[2/] showed high application efficiencies of 75-87% for cotton, wheat, barley, and sugar beet crops on leveled land (see Table 8). *Marwa* improvements made possible by land leveling work resulted in very high on-farm water conveyance efficiencies of 84% to 100%. *Marwa* improvement work was done by lining with plastic sheets and use of lay-flat tubing during the 1981/82 winter season [2/]. On field 3-10 where *marwa* improvement was not done conveyance efficiency remained low (62%).

Long level furrows constructed during the 1981 summer season achieved better results with the bedded furrow method of cultivation. Two rows of cotton at 55 cm spacing were planted on each bed. Irrigated furrows were then at 1.10 m spacing. This allowed construction of deeper, better shaped furrows. The efficiency results from 1981 compared to 1980 illustrate the effect of this modification (E_{if} increased from 53% to 66% for the long furrows).

The major improvements demonstrated in 1981/82 winter season in reduction of *marwa* conveyance losses resulted in the highest irrigation efficiencies measured in Abu Raya. Because *marwa* losses were reduced to practically zero, larger stream sizes were thus available at the field inlet. Consistent with the previously discussed trends, the larger streams produced higher application efficiencies (75-87%) on properly-sized fields. *Marwa* improvements also led to high application and on-farm irrigation efficiencies during the 1982 summer season.

As described in EWUP Kafr El-Sheikh Team (1983b), improved irrigation systems on EWUP sites in Abu Raya have depended on precision land leveling, farm irrigation system design and improved management practices. Management is a key factor needing improvement. Farmers must learn how to use larger streams effectively, plus better understand irrigation timing and frequency. Basic management questions to be answered are:

1/ Unpublished data (EWUP Kafr El-Sheikh Team, 1982)

2/ Unpublished data (EWUP Kafr El-Sheikh Team, 1983d)

1) When to irrigate?
2) How to irrigate?
3) How much water to apply?
4) When to stop irrigating?

Kafr El-Sheikh experience has shown that correct management of the new irrigation systems made possible by precision land leveling is essential to obtain efficient irrigations. Precision land leveling and long runs can save water, labor and irrigation time and reduce water lifting costs only if the irrigator is familiar with how to use his system. For example, under Abu Raya conditions the irrigator must adjust his management practices in response to changes in flow rate between irrigations and during an irrigation. For efficient furrow irrigation, the number of furrows irrigated at one time must be balanced with the available discharge to provide a furrow stream within an appropriate range (2-3 lps, e.g.). Changes in the infiltration rate of the soil and roughness of the furrow or border through the season have an effect on the farmer's decision concerning when to stop irrigating. For example, when irrigating a border of length 200 meters, the farmer may have many choices concerning when to stop inflow into the border:

a) When the water advances to the end of the field,
b) When the water advances to within 30 meters of the end of the field,
c) When the water advances to within 50 meters of the end of the field.

The correct management decision may depend on which irrigation during the season is in process. Alternative "a" might be correct for the first irrigation, "b" for the second irrigation, and "c" for the third irrigation, for example. Changes in flow rate may further complicate the irrigator's management decisions. As the farmer's knowledge about his system and experience in manipulating the part of system over which he has control increase, the potential for more efficient irrigation also increases. With precision land leveling, irrigation system design, and further on-farm water management experience, on-farm irrigation efficiencies even higher than those resulting from EWUP field trials and demonstration program work are possible at Abu Raya.

On-farm irrigation system improvements carried out by EWUP Kafr El-Sheikh Team depend on precision land leveling. The following benefits, realized during several seasons of demonstration program work were made possible by precision land leveling:

1) Reduced *marwa* length with the related benefits of reduced *marwa* losses or reduced cost of *marwa* lining.

2) Improved *marwa* condition with or without lining which reduces *marwa* losses due to leakage, seepage and dead storage.

3) Fields with variations in elevation brought within a tolerance of ± 2 cm with associated improvements in water application efficiency.

4) Construction of long level border and level furrow systems which provide potential for reduced labor requirements, increased mechanization of field operations and better seed bed preparation.

5) Water savings through elimination of surface runoff and reduction in deep percolation. Due to high water table conditions not all deep percolation is lost since it may return to the root zone through upward flow from the high water table. Surface drainage water is lost to the system since it enters main drains and is pumped into the sea.

6) Reduced irrigation time due to the improvements in on-farm irrigation efficiency. Reduced irrigation time represents decreased water lifting costs and reduced labor requirements.

7) Possible yield increases due to improved water management, soil salinity and seed bed preparation; but it was difficult to separate yield increases due to improved agronomic practices from those resulting from irrigation improvements. Yield increases from improved agronomic practices and yield increases from irrigation improvements are interdependent.

Kafr El Sheikh EWUP demonstration program work at site 3-19 during the 1980/81 winter season illustrates the benefits of precision land leveling. Figure 16 shows maps of field layouts at the site before and after demonstration program implementation. An area of 4.8 *feddans* was leveled to dead level. Three internal field drains were eliminated. A *marwa* was constructed which was less than half the length of the previous one. Level border strips were designed for high application efficiency in relation to the available flow rate from the *saqia*. Without the initial step of land leveling the other changes would not have been possible.

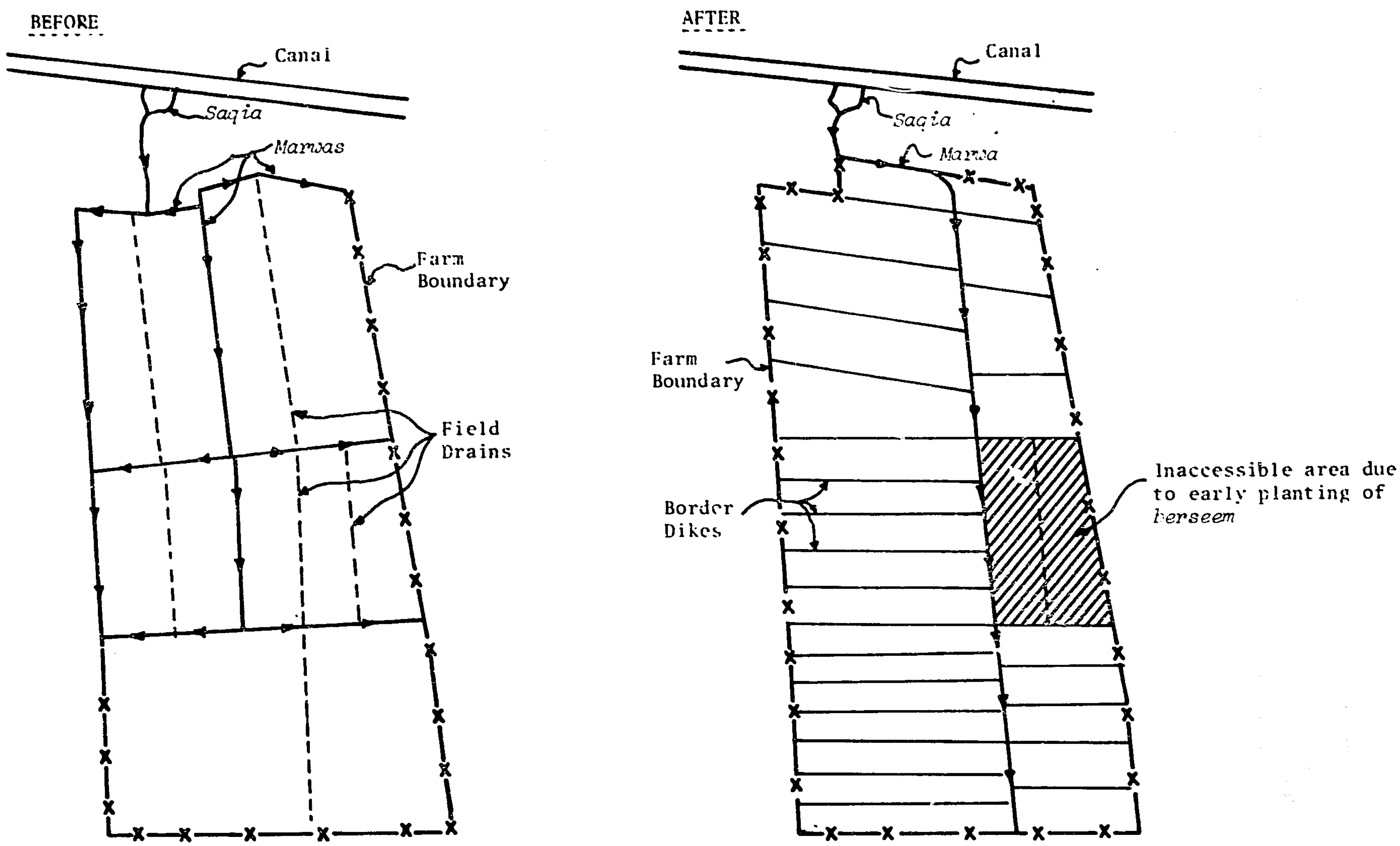


Figure 16. On-farm irrigation system layout at site 3-19 during winter season 1980-1981, before and after implementation of Project improvements, Abu Raya, Kafr El-Sheikh.

Results of the work at site 3-19 were positive. The elimination of field drains and *maruas* represented an increase in cropped area (about 6% of total farm area). A high seasonal on-farm conveyance efficiency of 80% was obtained through shortening (from 545 m to 285 m) and shaping of the *marwa*. A seasonal water application efficiency of 72% was obtained although the farmer irrigated too soon on several occasions. Total irrigation time for the season was 1412 min/*fed*.[1/]

It is important to note that precision land leveling does not guarantee the above benefits. However, precision land leveling is necessary for achieving these benefits. Associated modifications to improve the farm irrigation system design and to improve the farmer's understanding of the water management for the new systems are also necessary.

Monitoring of water table levels and chemical analysis of soil samples and water samples revealed that the on-farm improvements did not lead to increased salinity levels or water table level. Rice cultivation led to salinity decreases in the 0-90 cm soil profile of about 40 percent from beginning to end of the season. Rice cultivation provides effective soil salinity control at Abu Raya (EWUP Kafr El-Sheikh Team, 1983a).

Following the demonstration program implementation during winter 1980/81, summer 1981 and winter 1981/82, a sociological evaluation was carried out to test farmer perceptions of EWUP recommended practices. Included in the evaluation questionnaire were items concerning land leveling. The following goals for land leveling were presented to the farmer:

1) To eliminate high and low spots in the field,
2) To establish an easy advance for the water,
3) To allow farmers to use less water for irrigating,
4) To create good water distribution.
5) To improve the quality of the land.
6) To remove the need for surface drainage.
7) To decrease irrigation time.
8) To decrease labor necessary to irrigate.

1/ Unpublished data (EWUP Kafr El-Sheikh Team, 1981c)

Farmers were asked which benefits they observed during the season. The results are summarized here.

Many farmers stated that land leveling eliminates high and low spots in the field. Several farmers emphasized that yield was increased due to land leveling since inundation in low spots decreases yield. In some cases farmers, while agreeing with the concept of land leveling, complained that the land leveling work itself was not carried out satisfactorily. The related benefits of easy advance and good water distribution were also mentioned by the majority of farmers as results of land leveling.

Most of the farmers stated that land leveling decreases the water required for irrigating. They suggested that they needed to use the *saqia* for less time and this eased the work of their animals. In a few cases farmers said that the labor requirement for irrigation was reduced. Several farmers also stated that land leveling decreased the need for surface drainage.

Many farmers stated that land leveling improved the quality of their land. Soil texture was improved as large soil chunks were broken down by the grinding action of earth moving and smoothing. Filling in of the cracks caused by the vertisol soil type also was cited as a benefit of land leveling work.

In general, such site conditions as larger farms and relatively fixed crop patterns and fallow times facilitated the ability of the Kafr El-Sheikh Team to do land leveling. Abu Raya farmers are also more aware of the benefits and need for leveling since paddy rice is part of the rotation. Such factors such as relatively larger available stream sizes and accurate assessment of infiltration changes through the irrigation season facilitated the ability to construct improved farm irrigation systems in which the designed systems outperformed the conventional system.

<u>Abyuha, El Minya</u>

On-farm water management measurements have been taken and irrigation trials of long runs on leveled land have been conducted at the EWUP Abyuha site [1/]. Data concerning these trials are shown in Tables 9

1/ Unpublished data (Wafik, et al., 1982 and Awad, et al., 1982) and 10. Table 9 presents a detailed description of the various trials including field dimensions, land leveling and basin configuration. Results from the trials are shown in Table 10. Applied water depth and average stream size were measured by cutthroat flume. Soil sampling was used to determine water stored. Minimum stream size was determined from the total available stream and the width of the field irrigated as a unit when known. The unit area stream was estimated by dividing the total stream by the total field area. Actual unit area stream would be based on the area of the field irrigated as a unit. The following paragraphs provide a summary and analysis of results from irrigation trials at Abyuha.

During the 1980/81 winter season in Abyuha, two farms on *Mesqa 7* were leveled to dead level. On Farm 1, wheat was planted in the conventional small basins (but leveled land) and in one level long border strip (6.3 m x 133 m). On Farm 2, broad beans were planted in the conventional small basins with furrows spaced at 60 cm (on leveled land) and in two strips of long level furrows. One strip was 6.5 m x 100 m with furrow spacing of 60 cm. The second strip was 6.5 m x 100 m with furrow spacing of 90 cm. Several farms growing wheat in the conventional small basins on unleveled land were measured for documentation of the results obtained by these methods (farms on *Mesqas* 13, 22, 26). Summary results of these measurements are presented in Tables 9 and 10.

The most striking result to be noted in Table 10 when comparing the wheat crop results (tests 1-3) is the significant reduction in irrigation time on the leveled land, regardless of whether small basins or long runs were used. The conventional small basins showed an average stream size of about 65-70% of the average stream size used for the basins on leveled land, but at the same time required (on average) more than twice the amount of time to irrigate one *feddan*. It is noted also that the application efficiency was higher on the leveled land (70-75% vs. 61%).

The single long level basin performed almost as well as the small basins on leveled land. The small basins showed slightly better efficiency and less total water applied. Figure 17 shows application efficiency vs. stream size for individual irrigations on the long basins and small basins (both on leveled land). There is a large amount of variability; however, a general trend of lower application efficiency for the higher stream sizes is indicated. Several physical

Table 9. Description of various treatments for irrigation trials at Abyuha, 1980-1981.

Test Number	Season	Crop	Location	Field Dimensions[1/]			Conditions/Practices	
				Width (m)	Length (m)	Area (m^2)	Land Leveling	Basin Configuration
1	Winter 1980/81	Wheat	Farm 1, *Mesqa* 7	6.3	133	838	Yes	Long basin (6.3 m x 133 m)
2	Winter 1980/81	Wheat	Farm 1, *Mesqa* 7	13	50	645	Yes	Small basins
3	Winter 1980/81	Wheat	6 Farms, *Mesqas* 13,22,26	-	-	130-1230	No	Small basins
4	Winter 1980/81	Beans	Farm 2, *Mesqa* 7	6.5	100	650	Yes	Long furrows (60 cm spacing, 100 m length)
5	Winter 1980/81	Beans	Farm 2, *Mesqa* 7	6.5	100	650	Yes	Long furrows (90 cm spacing, 100 m length)
6	Winter 1980/81	Beans	Farm 2, *Mesqa* 7	12.5	100	1250	Yes	Short furrows in small basins
7	Summer 1980	Cotton	5 Farms, *Mesqas* 5,9,13,30	-	-	227-1414	No	Short furrows in small basins
8	Summer 1980	Corn	Farm 6, *Mesqa* 13	11-13	37-66	412- 794	No	Short furrows in small basins
9	Summer 1981	Cotton	Farms 7 & 8, *Mesqa* 26	-	-	715-2976	Yes	Short furrows in small basins
10	Summer 1981	Cotton	Farms 7 & 8, *Mesqa* 26	7-15	120	860-1740	Yes	Long furrows (60 cm spacing)
11	Summer 1981	Corn	2 Farms on *Mesqas* 7,26	-	-	638-3137	Yes	Short furrows in small basins
12	Summer 1981	Corn	Farm 1, *Mesqa* 7	5.5	171	940	Yes	Long furrows (120 & 140 cm spacing, 171 m length)
13	Summer 1981	Corn	Farm 9, *Mesqa* 26	14	124	1736	Yes	Long furrows (60 cm spacing, 124 m length)

1/ Area irrigated varied from irrigation to irrigation due to water movement to and from adjoining fields.

Table 10. Summary of results from irrigation trials at Abyuha, 1980-1981.

Test Number	Treatment[1]	Number of Irrigations	Total Irrigation Time (min/fed)	Total Depth Applied (cm)	Total Depth Stored (cm)	Average Stream Size Available at Field Inlet, Q (lps)	Minimum Unit Stream Size,[2] Q_u (lps/m) or (lps/furrow)	Unit Area Stream Size[3] Q_u [(lps/m^2)x100]	Efficiency E_a[4] or E_{if} (%)
1	Long level basin	6	2359	57.3	40.1	18.6	2.95	2.22	70
2	Small level basin	6	2094	49.6	36.9	17.0	-	3.15	75
3	Conventional small unleveled basin	6-7	4308	62.2	37.9	12.0	-	2.132	61
4	Long level furrows	5	2240	49.0	34.8	17.3	1.7	2.61	71
5	Long level furrows	5	1738	39.4	30.3	20.3	2.8	3.11	77
6	Short level furrows	5	2399	45.9	28.7	15.9	-	2.12	62
7	Short unlevel furrows	9-10	6277	82.6	56.2	10.7	-	1.82	68
8	Short unlevel furrows	10	7158	87	52.5	9.1	-	1.67	60
9	Short level furrows	11	2602	102	61.2	29.0	-	1.52	60
10	Long level furrows	11	3790	129	61.9	26.4	1.9-2.0	2.44	48
11	Short level furrows	8	3122	90.3	43.3	23.1	-	1.54	46
12	Long level furrows	7	2344	63.5	40.0	18.9	4.0	2.01	63
13	Long level furrows	8	1979	67.9	38.7	25.2	1.1	1.45	57

1/ Complete description in Table 11.
2/ Not always known since a varying number of basins were irrigated at one time.
3/ Based on total field area.
4/ See Definitions. Conveyance losses are negligible at Abyuha and application efficiency, E_a, is numerically equal to on-farm irrigation efficiency, E_{if}.

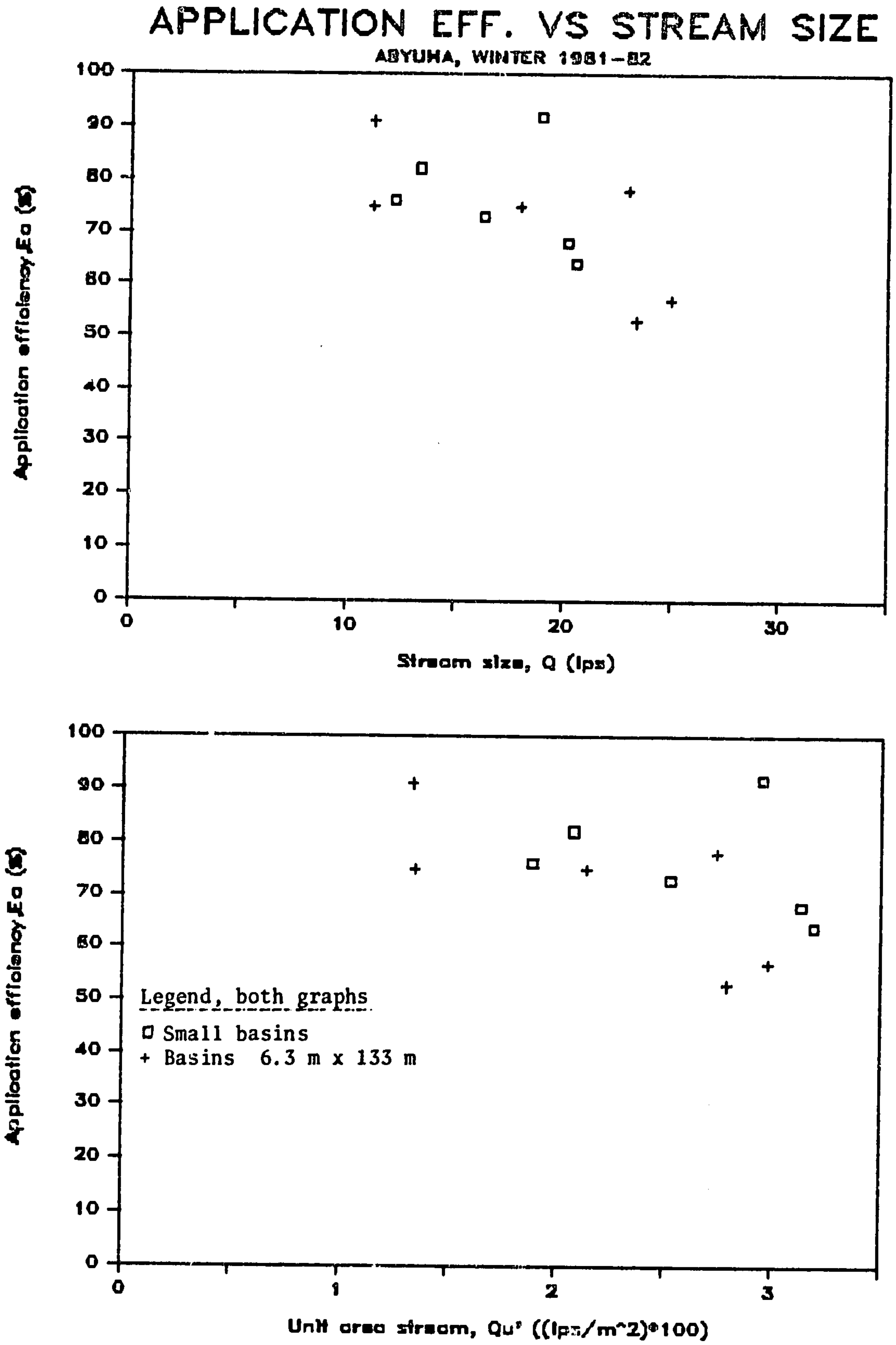


Figure 17. Stream size vs. application efficiency for basins, wheat, Abyuha, winter season, 1980-1981. Data points represent individual irrigations.

factors contribute to this, plus there is a management factor (when to irrigate and how much to apply?) which appears to affect the results obtained. Numerous observations at Abyuha indicate that the available stream size is widely variable. This coupled with the observation that soils at the site exhibit a high, rapid infiltration rate when dry and cracked and a much lower infiltration rate when soils are wetter can tend to cause results to occur which are contrary to established thinking. Management of farm irrigation systems under such conditions must be very careful in order that irrigation timing and application rates are appropriate for the conditions which may exist at the time of irrigation. Design dimensions of level basins must also be appropriate for the wide range of expected conditions.

Analysis of design conditions for level border strip irrigation in Abyuha (test no. 1) aids in understanding the results obtained in Table 10 and Figure 17. Using the USDA-SCS design model for level border irrigation (Cates and Clyma, 1980; USDA, 1974), several designs to simulate results for various conditions were formulated. Two cases were studied: 1) initial season conditions when infiltration rate is high (SCS Intake Family[1/] of 1.0) and soil is dry (100 mm design depth) and 2) mid-season conditions when intake rates are less (SCS Intake Family of 0.5) and soils are wetter (design depth of 70 mm). These sets of conditions are based on soil moisture conditions at the area with variation through the season, on qualitative observations of soil conditions (intake rates, cracking and swelling, etc.) and on the similarity to soils in Abu Raya and Beni Magdul.

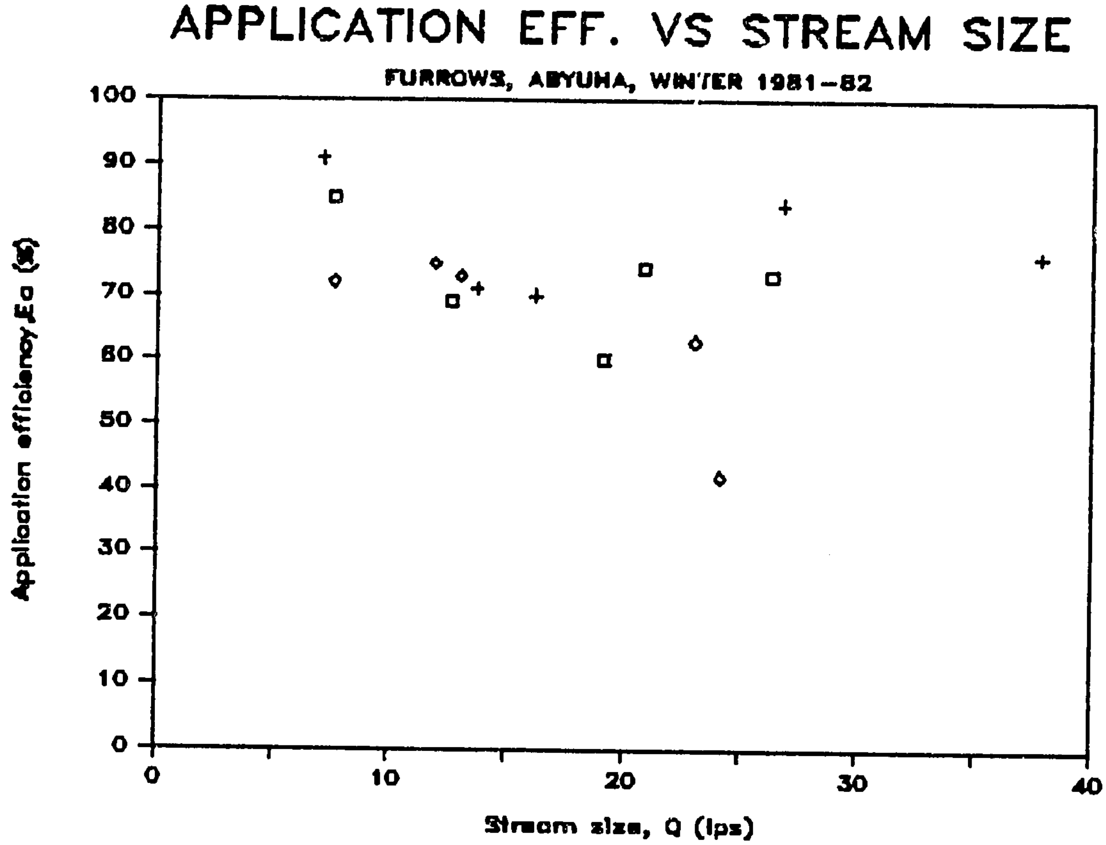
For the initial season conditions for test no. 1, the design model indicates a unit width stream of 6-7 lps/m is necessary for rapid coverage and an application efficiency of 90%, while for the mid-season conditions a unit stream of 3-4 lps/m is desirable for maintaining 90% efficiency. In Table 10 it is noted the average seasonal unit stream for test no. 1 was about 3 lps/m. Complications were noted with border dikes/bunds being of insufficient size to contain the water flow during irrigation, and leakage through the dikes was also present. These two conditions further reduced the effectiveness of the average 3 lps/m stream. For the first irrigation of the long strip, the available stream was large (25 lps) but the resulting efficiency low (57%). In this case, the unit stream was only about 4

1/ See Definitions.

lps/m. This is only about 60-65% of the stream size indicated by design. So in this case, even though the available stream was large, it was not large enough. For the measured stream the border strips should have been narrower or shorter. During the season, there was also an irrigation on the long strip when the available stream was high (23 lps) but the efficiency low (53%). For this case, the unit stream was in the proper range (being about 3.6 lps/m), but a light application was needed (less than 70 mm in this case). The farmer irrigated too long applying too much water. The stream should have been shut off earlier. This indicates that farmers will need to learn to manage long runs by gaining experience with use of the larger stream size and by irrigating the proper amount of time for the conditions at any given irrigation. If strip dimensions for level long runs appear to be on the order of 6-7 m width by 130 m length, then delivery of water must be improved to consistently supply 30-35 lps at the farm inlet. This assumes some compromise between intial and mid-season conditions, but with proper management overall seasonal average results should be very acceptable.

Results from the 1980/81 wheat trials (test nos. 1-3) showed that the long level runs performed just as well as the small basins (when both are on leveled land). The long level runs performed much better than the small basins on unlevel land. The long level strip dimensions were not entirely appropriate for the given design conditions. It is projected that if the long runs are designed according to the present conditions or if the available stream is provided at a consistent magnitude of about 30-35 lps, then long level runs such as those tested would be an improvement over the small basins. This would be in terms of water savings, improved efficiency and labor savings (both irrigation time and system construction). Along with further area development, mechanization of the farm systems could be facilitated in Abyuha.

A review of the results for long level furrows vs. small basin furrows on level land for broad beans during the winter 80/81 season is shown in Table 10 (tests nos. 4-6). Overall, the long level furrows performed better (higher efficiency, reduced time). Figure 18 is a plot of the application efficiencies vs. stream sizes for the individual irrigations on the three plots of land having differenct furrow systems (see Table 10). A high degree of variability is seen, although a possible general trend for efficiency to be less for the higher stream sizes is again indicated. Design analyses using the USDA-SCS design model for level furrow irrigation (USDA, 1979) for two



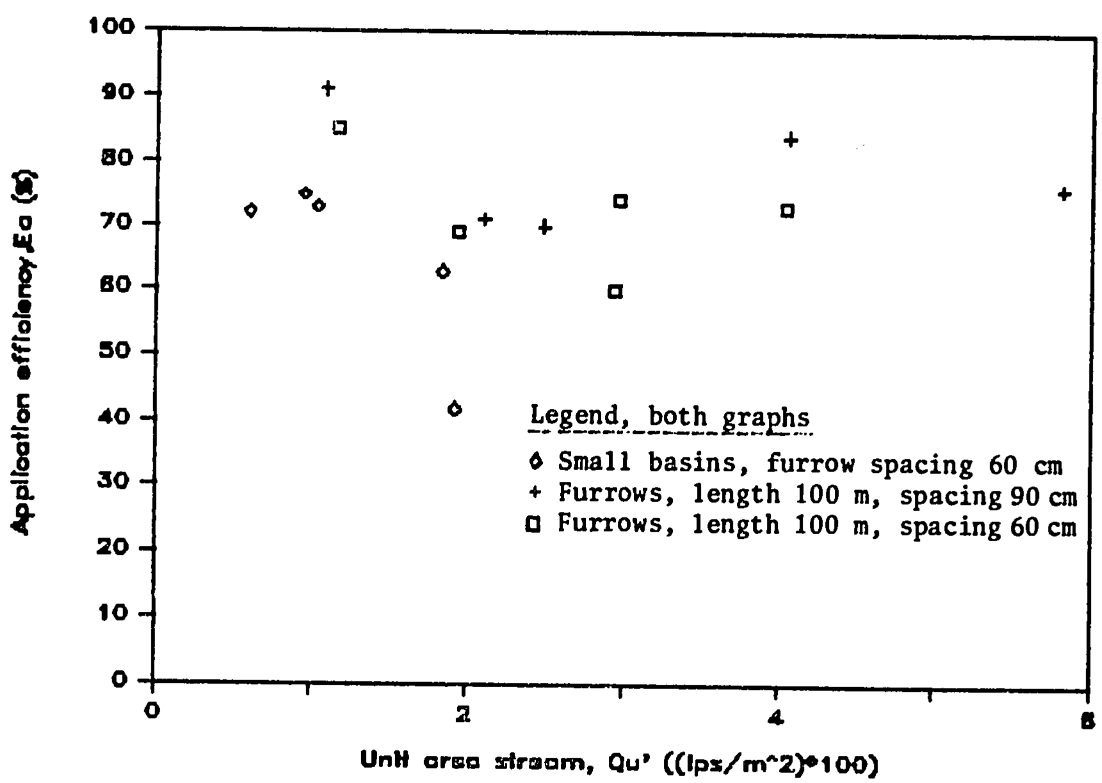


Figure 18. Stream size vs. application efficiency for long furrows and short furrows in basins, broadbeans, Abyuha, winter 1980-1981. Data points represent individual irrigations.

sets of conditions similar to those discussed for level border systems for wheat were performed. In general, these analyses show that furrow stream sizes (for the 100 m run length, test nos. 4 and 5) should be at least 2.0 lps/furrow for both 60 cm and 90 cm spacings for the initial season condition and as low as 1.50 lps/furrow for the mid-season conditions.

Data in Table 10 show that these furrow flow rates were, on average, available. For the individual irrigations, the high variability in stream size, infiltration rates, soil water deficits, etc. caused a large fluctuation in resulting efficiencies (as discussed for the level border trial), indicating a need for development of management expertise on the part of the farmer to learn how to effectively use the large streams on long level furrows. It is noted for this trial that the long level furrows performed better at the wider spacing. This agrees with concepts discussed previously which dictate that large, well-constructed and maintained furrows are necessary for efficient level furrow irrigation. This condition is easier to achieve with the wider furrow spacing. Some of the lower efficiencies resulting when the higher flow rates were available are due to leakage and overtopping of inappropriately sized furrows.

Results of measurements made to determine irrigation practices on cotton and corn during summer 1980, and results of irrigation trials on cotton and corn during summer 1981 and also presented in Tables 9 and 10 (test nos. 7-13). The irrigation trials on cotton were of long level furrows (L = 120 m at 60 cm spacing) vs. the conventional small basin furrows on level land. Trials on corn were of long level furrows (L = 171 m at spacings of 120 cm and 140 cm; L = 124 m at spacing of 60 cm) vs. the conventional small basin furrows on leveled land. The 1980 results for both cotton and corn (test nos. 7 and 8) show very long irrigation times with relatively small average stream size for the conventional methods. The conventional small basins on leveled land in 1981 (test nos. 9 and 11) show much smaller average total irrigation times, but the average stream sizes were higher. The trials on unlevel conventional basins in 1980 showed higher average efficiency than the 1981 trials on leveled fields. The explanation for this unexpected result is not known. The long level furrows for cotton (test no. 10) showed an average efficiency of only 48%. This is most likely due to problems with furrow size and poor maintenance through the season. Spacing was 60 cm. Observations during irrigation indicated that the furrows were ineffective for controlling the streams due to leakage and overtopping.

The long level furrows for corn show similar results, although the average efficiency was higher. For one set of long furrows on *Mesqa* 26 (test no. 13), the average stream size per furrow was 1.1 lps. This was too small based on previous discussion of design considerations and indications for level furrow irrigation in Abyuha. The major problems with level furrows in Abyuha seem to stem from the poorly constructed and poorly maintained furrows used for the long runs and insufficient furrow stream.

In Figure 19a, average seasonal water application efficiency is plotted with average seasonal stream size available at the field for the various conditions of irrigation trials conducted at Abyuha. Three categories can be defined in which the plotted results are grouped:

1) Results from unlevel farms using the conventional small basins, where average efficiencies are from 60-68% for average streams from 9-15 lps.

2) Results from leveled farms, where 4 of the 5 data points are for long runs, where average efficiency is from 63-77% for average streams from 17-20 lps.

3) Results from leveled farms on *Mesqa* 26, both conventional small basins and long runs, where improvements to the *mesqa* were made to provide consistently large streams for gravity irrigation; here average efficiencies ranged from 47-60%, while average streams ranged from 23-29 lps.

Excluding the results from *Mesqa* 26, it can generally be said that precision land leveling and use of long runs has resulted in slightly higher efficiencies utilizing slightly greater average stream sizes. Due to the limited amount of data, however, this is only an indication, not a conclusion. These data results tend to support the theoretical discussions presented earlier for the need for land leveling, etc. The long runs (long furrows and long level basins) were not entirely successful due to design problems. Given that design dimensions are adjusted for the actual design parameters or that the available stream size is consistently large, then design analyses indicate results would have been better.

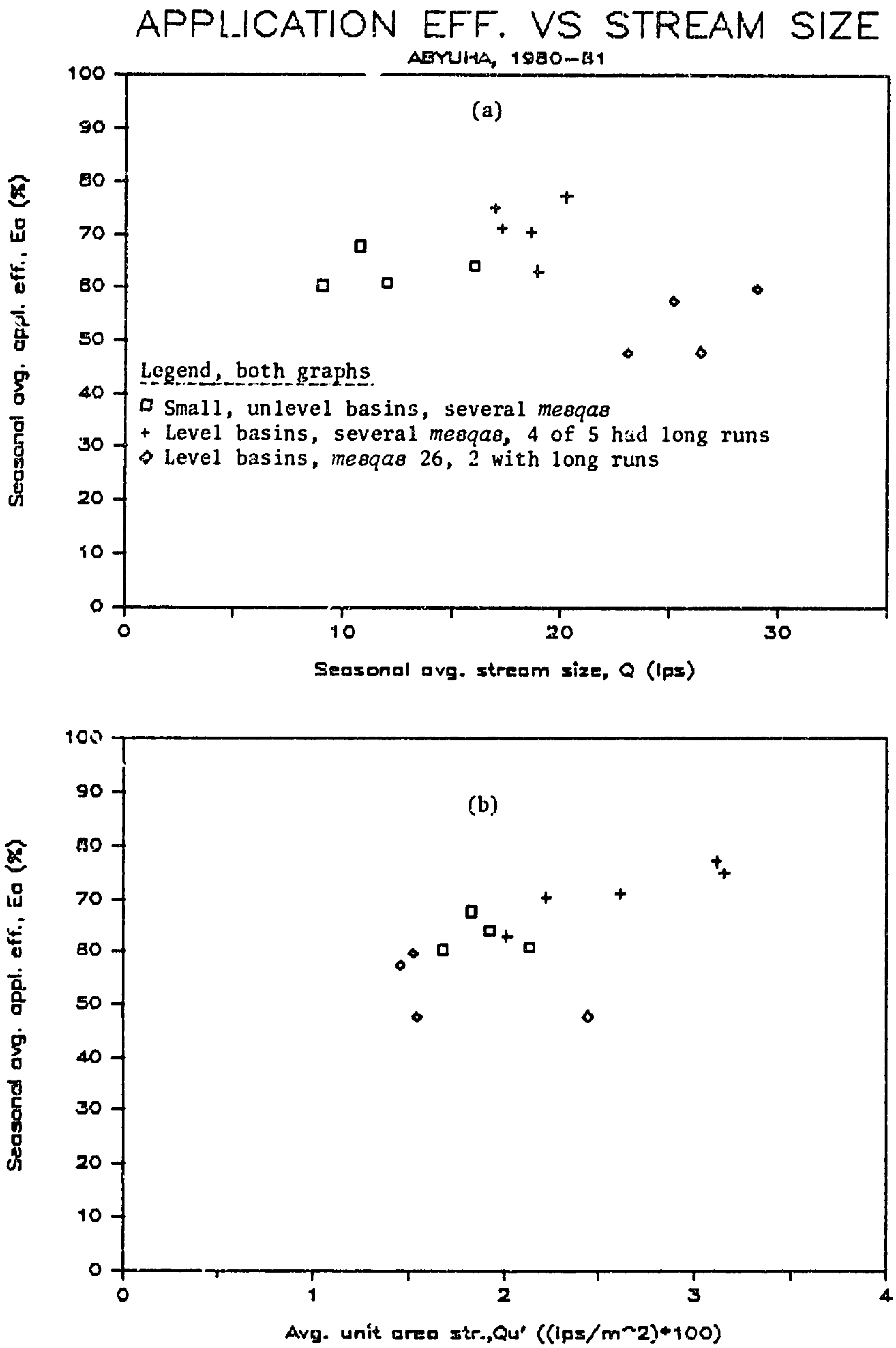


Figure 19. Stream size vs application efficiency for various conditions, Abyuha 1980-1981. Data points represent seasonal averages of stream size and efficiency.

In Figure 19b, average seasonal water application efficiency is plotted vs. unit area stream size based on total field area. A general trend for application efficiency to increase with unit stream size is observed. Since the area irrigated as a unit was not measured, results are not conclusive. However, it can be seen that the discharge per unit area for farms with long runs on *Mesqa* 26 was not adequate for efficient irrigation. A smaller basin size would have led to better results.

Another management problem led to lower efficiencies on *Mesqa* 26. Farmers were inexperienced in utilizing the large stream sizes available at the farm inlet. This is supported by the fact that the low efficiencies were obtained by both the case of the conventional small basins (a system the farmer is used to) as well as the case of long runs. Two trials of the *Mesqa* 26 data were for conventional small basins, while two were for long runs. The management element (particularly in this case: how much to apply and when to stop) is an integral component of the improvements to the farm system. Two other components of farm system improvement, precision land leveling and farm irrigation system design, may represent significant changes to the traditional farmer operation of his system. Learning to operate and manage the new systems and gaining experience with them is necessary in order to obtain improved on-farm irrigation results. Significant input in advising and teaching farmers on the new systems and how to use them will be necessary as changes are made. The development for Abyuha included improvement of the delivery system to provide large stream size with good head for gravity irrigation, as well as improvement of farm access for possible mechanization by eliminating *mesqas* and building roads.

In conjuction with these delivery system developments, precision land leveling, farm irrigation system design and proper system management also needed to be implemented. Fields which lay between *mesqas* were often irrigated from both ends with a low spot in the field midway between the two *mesqas*. Precision land leveling was necessary to ensure that irrigation could be accomplished from the remaining *mesqa* if one was eliminated. Long runs were used to facilitate mechanization. With consistently large stream sizes available, the improved farm system has the potential to operate efficiently if both the water delivery system and the farm irrigation system are properly managed.

V. SUMMARY

This report provides a summary of the farm irrigation system studies conducted by the Egypt Water Use and Management Project at its work sites in the Upper Delta, Middle Egypt and Nile Valley. A brief overview of the potential problems with on-farm water management at the three sites resulting from these studies is provided. The focus of the report is to present results of farm irrigation trials which were designed to test suggested solutions to the problems identified.

Typically, conventional farm irrigation methods used at the three sites are flooding of small flat basins or small basins with furrows. The basin size is a function of many factors such as field levelness, farm size, crop, crop pattern, ownership patterns and water supply. Farms are relatively larger at Abu Raya in the Lower Delta so basins are larger, while at El-Mansuriya (Middle Egypt) and El-Minya (Nile Valley) the farms are smaller and individual basins also smaller. A common problem at all three sites has been shown to be unlevel fields or a large degree of variation of surface elevation within individual irrigated basins. Potential problems with the small basin systems include the high labor inputs necessary for construction and for irrigation. At the same time, to mechanize such farm systems is difficult.

To set the stage for review of the results of irrigation trials, a review of serveral key concepts in farm irrigation systems is presented. This includes discussion of the effects of unlevel fields, stream size, soil characteristics and basin configuration on irrigation water management.

Precision land leveling to dead level and use of long level border strips or level furrows have been central practices in attempting to improve farm irrigation water management at the three sites. The objectives of trials to test suggested solutions were to increase efficiency, save water, save irrigation time and labor, and improve the water table and soil salinity conditions which are affected by overirrigation. The irrigation trials conducted are reviewed for their impact in meeting the above objectives, and if results were not successful, analysis is provided to show why. For trials showing undesirable results, modifications or adaptations to the practices are suggested which should enhance their ability to improve on-farm water management.

The trials conducted at El-Mansuriya (Beni Magdul) site were of limited success. The major constraint to success in the trials was the fact that the design dimensions (of long basins or of long furrows) were inappropriate for the given site conditions, particularly the available stream size. Generally, the stream size available during irrigation for these trials was too small for the given design area to ensure rapid, efficient coverage of the strip or furrow. Farm size is extremely small and varied in the area and farmers prefer to grow a large variety of crops. The ability to perform precision land leveling in the area is limited due to crop patterns and the limited access to farm machinery. Measurements from *Mesqa* 6 in Beni Magdul show that farmers do a relatively good job of irrigating using their small basins. In this case, the effect of unlevel fields is less critical. Thus, it may be that the suggested solutions are inadequate for the area due to the numerous constraints. An economic analysis which compares the costs and benefits would assist the decision.

In Abu Raya, Kafr El-Sheikh, the irrigation trials of precision land leveling and farm irrigation system design improvements have been much more successful. Farms as well as individual basins are relatively large, the crop pattern and rotation is relatively orderly, and farm machinery access is not severely constrained so that precision leveling is more easily accomplished. Implementing level border and level long furrow designs in Abu Raya has provided more control in the application of irrigation water than farmers normally have with the conventional basins of all shapes and sizes. The benefits of improved efficiency, water savings, labor and time savings have consistently been demonstrated over several seasons. Further improvements to the farm systems such as improvement of *maruas* for better on-farm water delivery and distribution (also significant water savings) and the removal of non-productive open field drains (to increase productive land area) have contributed to the benefits demonstrated. All of these practices have had no observed adverse effect on water table conditions; and with paddy rice in the two-year crop rotation, soil salinity can effectively be controlled.

In El-Minya, the irrigation trials met with the same problems as encountered in El-Mansuriya. The lengths and widths of the long runs attempted were generally inappropriate for the existing design conditions, especially the available stream size. Another important factor demonstrated in El-Minya trials has been that precision leveling and farm irrigation design changes are not sufficient in themselves to produce improvements. Management of water on the farm is a key element to also be addressed. This is evident in the fact that on *Mesqa* 26 where improved water delivery provided consistently large available streams, farmers using long runs or small basins did equally poorly in managing the large streams.

The results of the trials at each of the three areas indicate that improvements must be based on the local conditions. Where conditions are similar (from farm size to crops to irrigation water delivery characteristics to soils), then similar solutions could be feasible over the entire area. In general, practices such as precision leveling, farm irrigation design (level border strips or level long furrows) and improved water management can bring about improvements, but only when properly applied.

VI. CONCLUSIONS

Precision land leveling to dead level and farm irrigation system design (long level basins and long level furrows) are practices which can produce improvements to the conventional farm systems used in Egypt. It is necessary that farm water management advisory assistance to farmers be provided with the above, as these practices can result in significant changes to the farm system. Such changes require that the irrigator adapt and learn, and gain experience before the full potential benefits are realized.

EWUP experience with the suggested farm irrigation system improvements has produced mixed results: some successful and some not so successful. Those trials and results which were not so successful were analyzed to identify what modifications are necessary before success is achieved.

In El-Mansuriya on Mesqa 6 served by Beni Magdul canal, irrigation trials of long, dead level basins and furrows indicated that farmers could irrigate just as good or better with the conventional small basin systems. Design analysis showed, however, that the design dimensions used in the tests were not entirely correct for given design conditions in the area. In particular, the effects of a relatively small and highly variable irrigation stream, and of variable infiltration rates through the season were not adequately accounted for. This resulted in less than optimal performance of the long level systems. Altnough results were not so successful, the practices tested should not be abandoned. Modifications and adaptations can and should be made either in the form of increasing the size, dependability, regularity, consistency of delivery, etc. of the irrigation stream by improving the water delivery system. Conversely, the farm systems could be designed for the present available stream (which means shorter runs, narrower strips, fewer furrows irrigated per set, etc. than those tested) The major question to be answered will be one of whether this is feasible for an area such as El-Mansuriya. The large variety of crops, and the small farms and fields tend to heavily constrain the ability to do precision land leveling and redesign of farms except on an individual basis. It is doubtful that such an approach is economically viable, i.e., whether the expected benefits will outweigh the costs.

In El-Minya, irrigation trials of long level basins and furrows were also of limited success. Those trials showed farmers using small basins could do as well or better than by using the systems tested. Again, however, a design analysis shows that the design dimensions tested were inappropriate for the given conditions. Major factors which limited the performance of the long basins and furrows tested in El-Minya were the available stream size, infiltration rates and lack of proper water control at the designed boundaries (i.e., poorly constructed dikes, furrows too small and not well-maintained). The practices of precision land leveling and long level basin or long level furrow design should not be abandoned in this case either. The developments in the Abyuha work plan clearly indicate the need for leveling and long runs (particularly, when *mesqas* are being eliminated). Improved farm access will facilitate the leveling as well as other mechanization; the long runs will also greatly aid mechanization. Given that the planned improved delivery of water in the new system design gives a consistently large stream ([illegible]-30 lps) at each farm inlet, then the long runs as tested should perform well. Further design evaluation is necessary in this case to be sure the appropriate strip widths and/or number of furrows to irrigate per set are utilized. Results from *Mesqa* 26 (after improvements there produced larger stream sizes) show that a key element to success will be teaching farmers how to manage the larger streams as well as the new farm systems. In other works, providing leveling, long runs and a large stream will not yield improved water management unless water management practices are addressed specifically also.

Finally, in Kafr El-Sheikh, trials of precision land leveling, farm irrigation system designs and on-farm water management advisory service yielded important improvements on the farms there in terms of water savings, efficiency improvements, time savings and labor savings. Several key factors common to the farm systems there aided the success of the trials. These included relatively larger farms, large available stream sizes provided by the larger *saqias* and understanding on the part of the farmer of the benefits of leveling to dead level (due to the paddy rice grown in the area).

Farm design improvements (improved *marwas*, improved farm layouts, improved water control boundaries and field dimensions) tested in Kafr El-Sheikh were based on the actual measured conditions which affect design of farm systems significantly (i.e, available flow rates, soil infiltration rates, etc.). This dependence on actual measured conditions was the major contributing factor to the success of the systems tested. As a result of major improvements in on-farm irrigation efficiency demonstrated in Abu Raya, water is saved through decreases in surface drainage and deep percolation. A portion of deep percolation water may be reused on farm through water table contribution to evapotranspiration. Elimination of surface water losses represents water available for use elsewhere in Egypt. As horizontal expansion of agriculture in Egypt is attempted, water saved on farms in the old lands such as Abu Raya is needed to irrigate new lands in the Nile Delta and fringe areas. Delivery system operation and management must be upgraded and improved so that farm water savings can be utilized and not simply allowed to flow to the drains.

The field testing and technical feasibility of precision land leveling, improved farm irrigation design and improved management practices for improving on-farm water management have been established in the results of the trials and the analyses included in this report. In some cases, technical modifications were found to be necessary to achieve success. Economic feasibility of the suggested improvements has not been addressed in this report. Further economic analysis to establish benefits and costs is necessary.

A final conclusion must be drawn. Much of the success of EWUP work reported herein would have not been possible without the willingness and cooperation of farmers involved to allow EWUP personnel to work on their farms and test various irrigation practices. The willingness, cooperation and interest on the farmer's part generally suggest that the farmer's feel a need for improved methods and are the major factors in bringing about improved irrigated agriculture in Egypt.

VII. RECOMMENDATIONS

Recommendations derived from and based on the work and results reported herein have been developed and are aimed specifically at two levels of the irrigation system in Egypt:

1) Water delivery system improvements: From the experience with limited and highly variable stream sizes at El-Minya and El-Mansuriya and with inequitable water distribution in the canals and *mesqas* of all three areas it is recommended that significant effort to improve the physical conditions of canals, *mesqas* and structures on these watercourses and to improve operation and maintenance of these watercourses be expended. It was seen that the significant irrigation improvements at the farm level are in major part due to the size, dependability, consistency of delivery, etc. of the available irrigation stream at each farm inlet. Improvements to the delivery system physically and in operation and maintenance should have the goal of supplying dependably, consistently available stream size of 25-30 lps at each farm inlet. This will allow efficient use of the level farm irrigation systems of the dimensions tested and reported on herein.

2) On-farm irrigation system improvements: Improved farm irrigation system designs and precision land leveling are needed on farms throughout Egypt if the three sites studied are considered a representative cross-section. These factors are effective only when properly applied, i.e., designs which are formulated according to the local or area design factors/conditions; precision land leveling only in areas where it is physically and economically feasible, etc. Teaching and advising farmers on improved water management practices (how to irrigate, when to irrigate, how much to apply) for the new systems is a necessary element to be implemented with the first two practices.

   Farm irrigation system improvements can only be effected through involvement and cooperation of the farmer. Effective organizations patterned after the teams of EWUP's three study sites are means for gaining the farmers' confidence, for close collaboration with farmers in implementation of improvements and for carrying out the necessary teaching and advising on a long-term basis described earlier.

Continued research in water delivery problems and farm irrigation system problems will be necessary to complement the information already collected by EWUP as improvement programs are expanded into other areas of Egypt.

REFERENCES

Blair, Jesse. 1982. "Revamped Irrigation System Increases Yields Over 15 Percent". Irrigation Age, Vol. 17 No. 2, October , Page 34.

Bos, M. G. and J. Nugteren. 1974. "On Irrigation Efficiencies". Publication 19, International Institute for Land Reclamation and Improvement/ILRI, P. O. Box 45, 6700 AA Wageningen (The Netherlands).

Clyma, W., M. K. Lowdermilk and G. L. Corey, 1977. A Research-Development Process for Improvement of On-farm Water Management. Water Management Research, Colorado State University, Ft. Collins, CO.

Egyptian and American Field Team. 1979. Problem Identification Report for Mansuriya Study Area. Technical Report No. 1, Egypt Water Use and Management Project, Cairo, Egypt.[1/]

Egyptian and American Field Team. 1980. Problem Identification Report for Kafr El-Sheikh Study Area. Technical Report No. 6, Egypt Water Use and Management Project, Cairo, Egypt.[1/]

Egyptian and American Field Team. 1982. Draft of Problem Identification Report for El-Minya Study Area. Compiled by R. H. Brooks. Technical Report No. 25, Egypt Water Use and Management Project, Cairo, Egypt.[1/]

EWUP Kafr El-Sheikh Team. 1983a. Irrigation and Production of Rice in Abu Raya, Kafr El-Sheikh Governorate. Complied by T. W. Ley and R. L. Tinsley. Technical Report No. 9, Egypt Water Use and Management Project, Cairo, Egypt.[1/]

EWUP Kafr El-Sheikh Team. 1983b. Irrigation System Design, Kafr El-Sheikh, Egypt. Compiled by T. W. Ley. Technical Report No. 35, Egypt Water Use and Management Project, Cairo, Egypt.[1/]

EWUP Kafr El-Sheikh Team. 1983c. Precision Land Leveling on Abu Raya Farms, Kafr El-Sheikh Governorate, Egypt. Compiled by T. W. Ley. Technical Report No. 38, Egypt Water Use and Management Project, Cairo, Egypt.[1/]

1/ All Egypt Water Use and Management Project Technical Reports were prepared jointly by the Water Distribution and Irrigation Systems Research Institute, Ministry of Irrigation, Cairo, Egypt and Colorado State University, Fort Collins, Colorado.

El-Kady, M., W. Clyma and M. Abu Zeid. 1979. On-farm Irrigation Practices in Mansuriya District, Egypt. Technical Report No. 4, Egypt Water Use and Management Project, Cairo, Egypt.[1]

FAO 1977. "Crop Water Requirements". Irrigation and Drainage Paper 24. Food and Agriculture Organization for the United Nations, Rome. Revised 1977.

Gates, T. K. and W. Clyma. 1980. "Design of Level Border Irrigation Systems". Agricultural and Chemical Engineering Department, Colorado State University, Ft. Collins, Colorado.

Gates, T. K., W. D. Ree, M. Helal, A. Nasr and D. Molden. 1984. Hydraulic Design of a Canal System for Gravity Irrigation. Technical Report No. 46, Egypt Water Use and Management Project, Cairo, Egypt.[1]

Hansen, V. E., O. W. Israelsen and G. E. Stringham. 1980. Irrigation Principles and Practices. Fourth Edition, John Wiley and Sons, New York.

Israelsen, O. W. 1950. Irrigation Principles and Practices. Second Edition, John Wiley and Sons, New York. Page 86.

Slack, R., H. Wahby and W. Clyma. 1983. Discharge and Mechanical Efficiency of Egyptian Water-Lifting Wheels. Technical Report No. 36, Egypt Water Use and Management Project, Cairo, Eygpt.[1]

UNDP, 1981. Consumptive Use of Water by Major Field Crops in Egypt. Water Master Plan Technical Report No. 17, Ministry of Irrigation Cairo, Egypt, March.

U. S. Department of Agriculture. 1974. Border Irrigation. National Engineering Handbook, Chapter 4, Section 15, SCS, U.S. Government Printing Office, Washington, D. C.

U. S. Department of Agriculture. 1979. Furrow Irrigation. National Engineering Handbook, Chapter 5, Section 15, SCS, U.S. Government Printing Office, Washington, D. C.

1/ All Egypt Water Use and Management Project Technical Reports were prepared jointly by the Water Distribution and Irrigation Methods Research Institute, Ministry of Irrigation, Cairo, Egypt and Colorado State University, Fort Collins, Colorado.

UNPUBLISHED DATA CREDITS

In addition to the above references, information used in this report was taken from a number of staff papers and draft working papers as listed below. All opinions, conclusions, and recommendations contained in these papers are those of the authors and not those of the Egypt Water Use and Management Project or of the funding or contracting agencies. Valuable data is included in these papers and has been used in this report.

Awad, M., A. A. Naim, S. Saleh and J. Wolfe. 1982. On-farm Water Management Trials at Abyuha during the Summer Seasons 1980 and 1981. Draft Working Paper No. 83, Egypt Water Use and Management Project, Cairo, Egypt.

EWUP Kafr El-Sheikh Team. 1981a. 1979/80 Winter Season Field Trials, Wheat Crop, Kafr El-Sheikh. Staff Paper No. 57, Egypt Water Use and Management Project, Cairo, Egypt.

EWUP Kafr El-Sheikh Team. 1981b. Cotton Field Trials, Summer 1980, Abu Raya, Kafr El-Sheikh. Draft Working Paper No. 74, Egypt Water Use and Management Project, Cairo, Egypt.

EWUP Kafr El-Sheikh Team. 1981c. Final Report for 1980/81 Winter Season On-farm Pilot Program, Kafr El-Sheikh. Draft Working Paper No. 86, Egypt Water Use and Management Project, Cairo, Egypt.

EWUP Kafr El-Sheikh Team. 1982. Kafr El-Sheikh On-farm Pilot Program, 1981 Summer Season. Draft Working Paper No. 86, Egypt Water Use and Management Project, Cairo, Egypt.

EWUP Kafr El-Sheikh Team. 1983d. Kafr El-Sheikh On-farm Pilot Program, 1981/82 Winter Season. Draft Working Paper No. 110, Egypt Water Use and Management Project, Cairo, Egypt.

Mahmoud, S., M. Khidr, G. Fawzy, W. S. Braunworth and J. Wolfe. 1982a. Wheat Irrigation and Variety Performance on *Mesqa* 6, Beni Magdul Canal, Mansuriya District, Egypt, 1980/81. Draft Working Paper No. 87, Egypt Water Use and Management Project, Cairo, Egypt.

Mahmoud, S., M. Khidr, G. Fawzy and W. S. Braunworth. 1982b. Maize Irrigation and Variety Performance on *Mesqa* 6, Beni Magdul Canal, Mansuriya District, Egypt, 1981. Draft Working Paper No. 91, Egypt Water Use and Management Project, Cairo, Eygpt.

Tahoun, A., F. Abdel Al and W. S. Braunworth. 1982. Summary of the Farmer's Organization and On-farm Water Management Data for *Mesqa* 10, Beni Magdul Canal, Mansuriya District, Egypt. Draft Working Paper No. 96. Egypt Water Use and Management Project, Cairo, Egypt.

Wafik, E., M. Awad, A. A. Naim, S. Saleh and J. Wolfe. 1982. On-farm Water Management Trials at Abyuha, Winter Season, 1980/81. Draft Working Paper No. 81, Egypt Water Use and Management Project, Cairo, Eygpt.

APPENDICES

APPENDIX A

Maps of Irrigation and Drainage
Systems at the Three EWUF Work
Locations

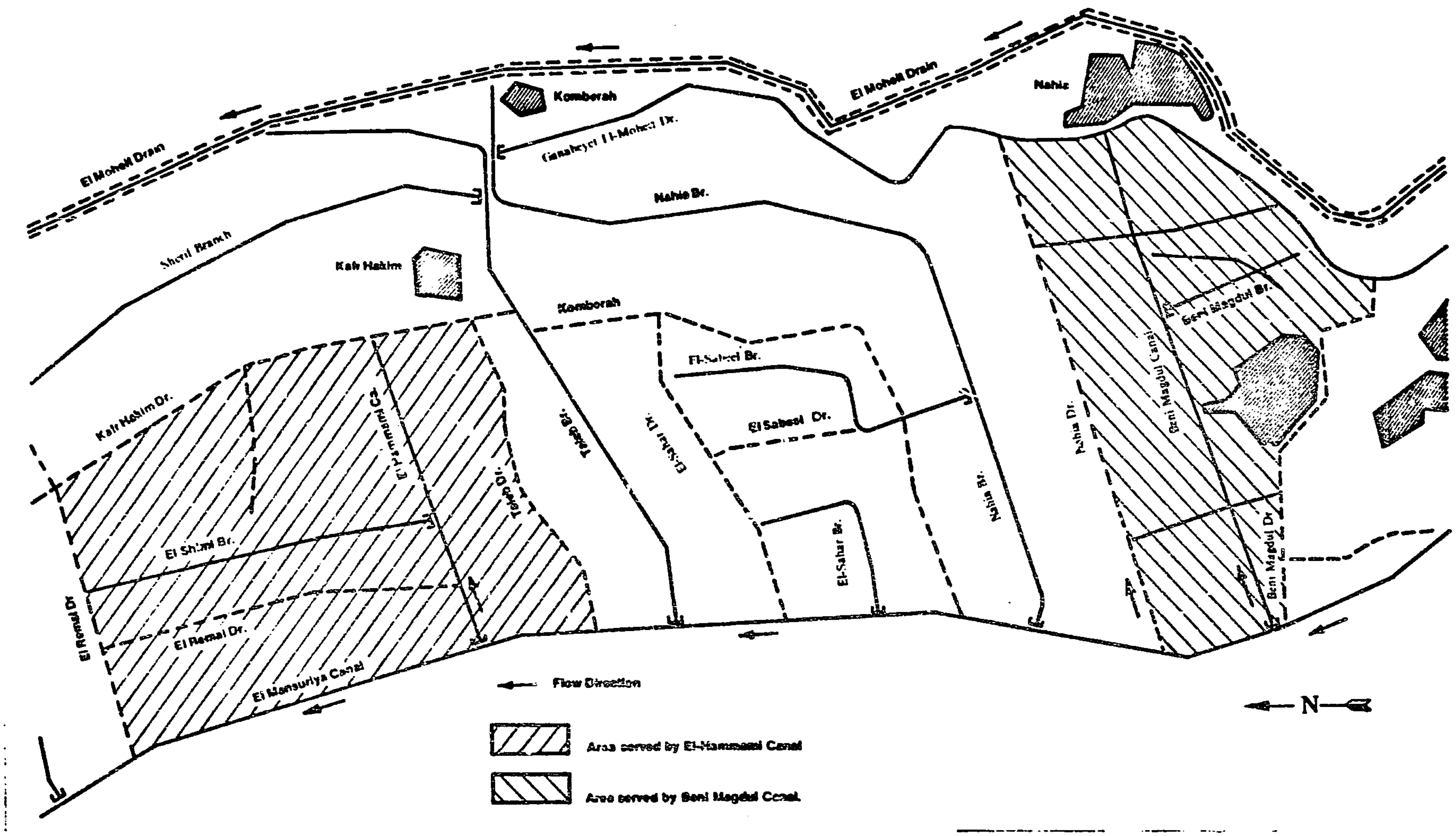


Figure A1. El-Mansuriya Project Location showing areas served by Beni Magdul and El-Hammami distributary canals.

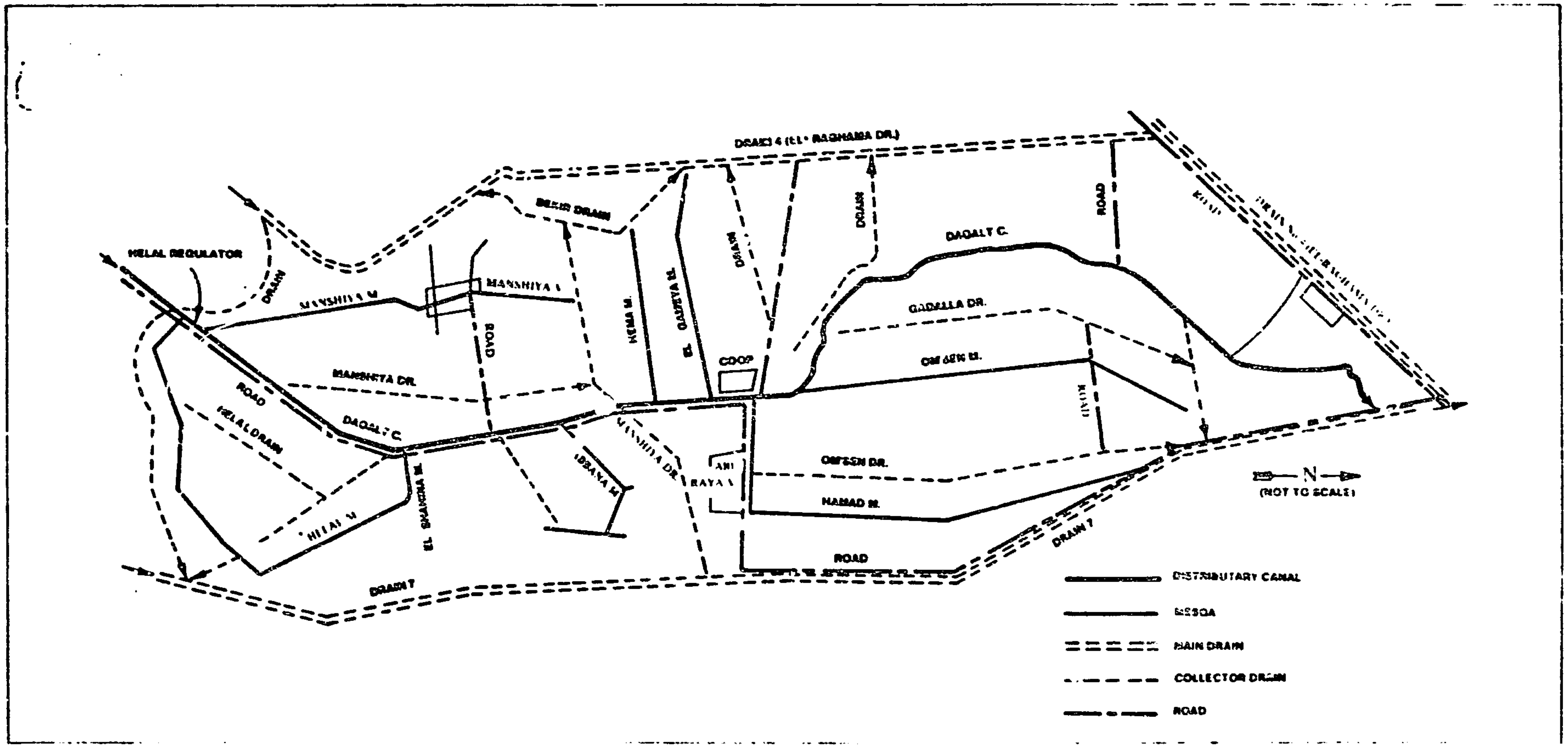


Figure A2. Abu Raya, Kafr El-Sheikh Project Location showing area served by the third reach of Daqalt distributary canal.

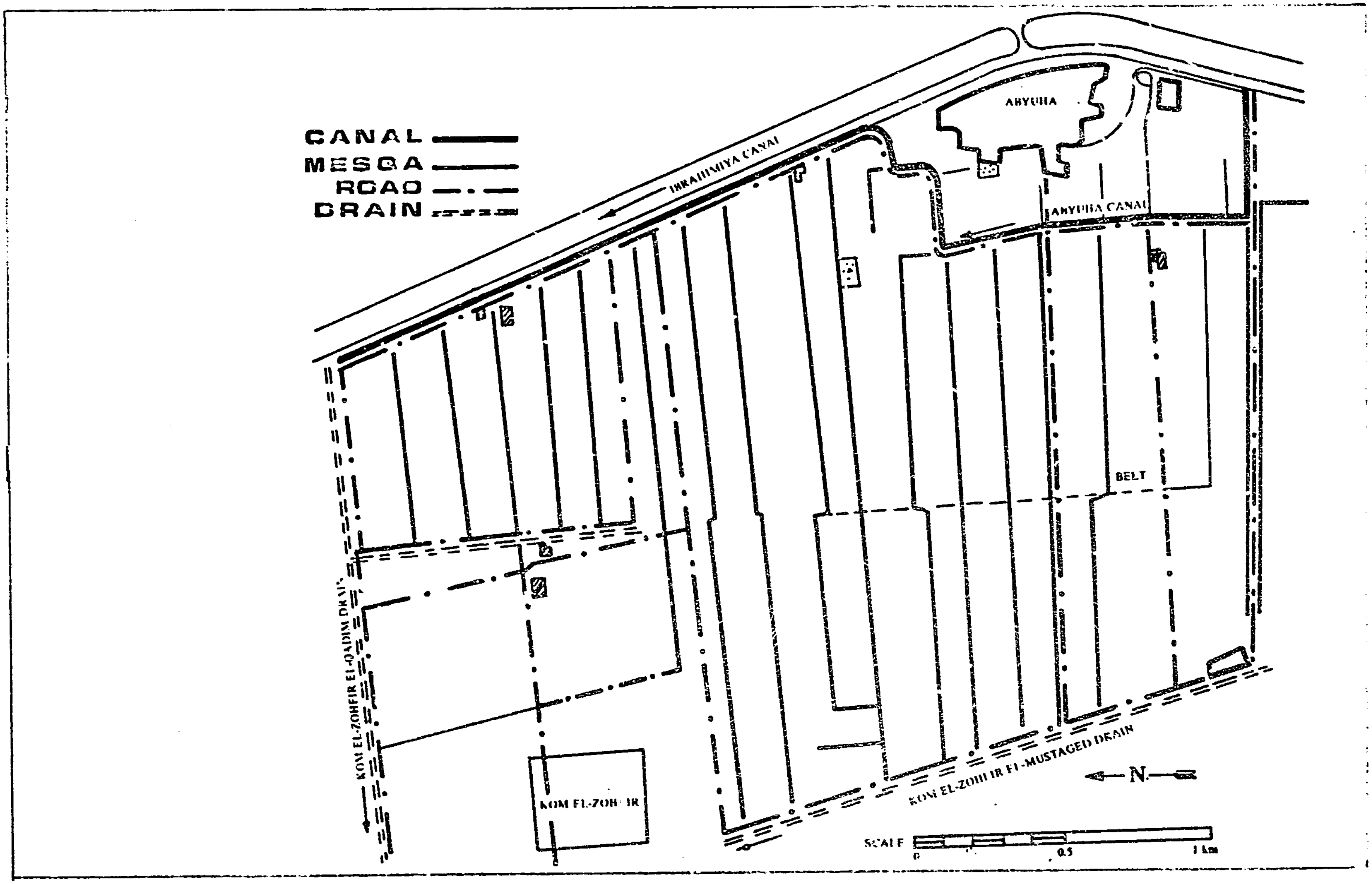


Figure A3. Abyuha, El-Minya Project Location showing area served by Abyuha distributary canal.

APPENDIX B

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	100×10^4	247.105	238.048	100.000
1 sq. mile	259×10^6	640.000	616.400	259.000

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

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

EGYPTIAN UNITS OF FIELD CROPS

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

EGYPTIAN FARMING AND IRRIGATION TERMS

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

EGYPT WATER USE AND MANAGEMENT PROJECT

PROJECT TECHNICAL REPORTS

NO.	TITLE	AUTHOR
PTR#1	Problem Identification Report for Mansuriya Study Area, 10/77 to 10/78.	Egyptian and American Field Teams.
PTR#2	Preliminary Soil Survey Report for the Beni Magdul and El-Hammami Areas.	A. D. Dotzenko, M. Zanati, A. A. Abdel Wahed, & A. M. Keleg.
PTR#3	Preliminary Evaluation of Mansuriya Canal System, Giza Governorate, Egypt.	American and Egyptian Field Teams.
PTR#4	On-farm Irrigation Practices in Mansuriya District, Egypt.	M. El-Kady, W. Clyma & M. Abu-Zeid
PTR#5	Economic Costs of Water Shortage Along Branch Canals.	A. El Shinnawi M. Skold & M. Nasr
PTR#6	Problem Identification Report For Kafr El-Sheikh Study Area.	Egyptian and American Field Teams.
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PTR#8	Farm Record Summary and Analysis for Study Cases at Abu Raya and Mansuriya Sites, 1978/1979.	F. Abdel Al & M. Skold
PTR#9	Irrigation & Production of Rice in Abu Raya, Kafr El-Sheikh Governorate.	Kafr El-Sheikh Team as Compiled by T. W. Ley & R. L. Tinsley
PTR#10	Soil Fertility Survey in Kafr El-Sheikh, El Mansuriya and El-Minya Sites.	M. Zanati, P. N. Soltanpour, A.T.A. Mostafa, & A. Keleg.
PTR#11	Kafr El-Sheikh Farm Management Survey Crop Enterprise Budgets and Profitability Analysis.	M. Haider & F. Abdel Al
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MAN.#2	Programs for the HP Computer Model 9825 for EWUP Operations.	By: M. Helal, D. Sunada, J. Loftis, M. Quenemoen, W. Ree, R. McConnen, R. King, A. Nazr and R. Stalford.
MAN.#5	Precison Land Leveling Data Analysis Program for HP9825 Desktop Calculator	T. W. Ley
MAN.#8	Thirty Steps to Precison Land Leveling	A. Bayoumi, S. Boctor & N. Dimick
MAN.#9	Alphabetical List of Some Crops and Plants with Their English, Egyptian, Botanical & Arabic Names and Vocabulary of Agricultural and other Terms Commonly Used.	G. Ayad
MAN.#10	EWUP Farm Record System	Farouk Abdel Al, David R. Martella, and Gamal Ayad

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