PN-AAP-342

ISN 33528

PAPER NO. 83-2580

FARM IRRIGATION SYSTEM IMPROVEMENT, ABU RAYA, EGYPT

by

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For presentation at the 1983 Winter Meeting
AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

Hyatt Regency, Chicago, Illinois
December 13-16, 1983

SUMMARY:
An on-farm water management improvement project which identified problems with farm irrigation methods and practices is described. Suggested problem solutions were field tested, from which a demonstration program for improving surface irrigation evolved. Precision land leveling and level basin design were major components of the program. Improved efficiencies and water, labor and time savings were consistently demonstrated.

American Society of Agricultural Engineers
St. Joseph, Michigan 49085

Farm Irrigation System Improvement, Abu Raya, Egypt[1/]

by

Thomas W. Ley, Kenneth E. Litwiller and Abdel Fattah Metawie[2/]

INTRODUCTION

A major objective of the Egypt Water Use and Management Project[1/] (EWUP) was to assist Egyptian farmers by improving their understanding, resources and abilities for good on-farm water management (Egyptian and American Team, 1980). To do this, EWUP scientists (both Egyptian and American) studied the delivery and on-farm components of the irrigation system using an interdisciplinary approach that utilized the expertise of irrigation engineers, rural sociologists, agronomists and agricultural economists (Clyma, et al., 1981).

Three areas were selected for intensive study (see Figure 1). The crops, soils, and climate, as well as institutional and socio-economic conditions found at these sites were considered representative of each surrounding area. This report focuses on the Abu Raya area of Kafr El Sheikh Governorate in the north central part of the Nile Delta. Conventional methods of farm irrigation used by farmers in Abu Raya were studied and evaluated by the EWUP Kafr El Sheikh Team from early 1978 to 1983. These studies are the basis of this report.

The objectives of this paper are as follows:

1) describe the findings and results of a farm irrigation system improvement process implemented by EWUP in Abu Raya, including problems identified and solutions tested and documented,

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[1/] Paper presented to ASAE Winter Meeting, Dec. 13-16, 1983, Hyatt Regency, Chicago, Il. Submitted by Egypt Water Use and Management Project, GOE Ministry of Irrigation and Colorado State University. Work was prepared under support of the Egypt Ministry of Irrigation and the U.S. Agency for International Development, Contract AID/NE-C-1351. All reported opinions, conclusions or recommendations are those of the authors and not those of the GOE Ministry of Irrigation, Colorado State University or the funding agency of the United States Government.

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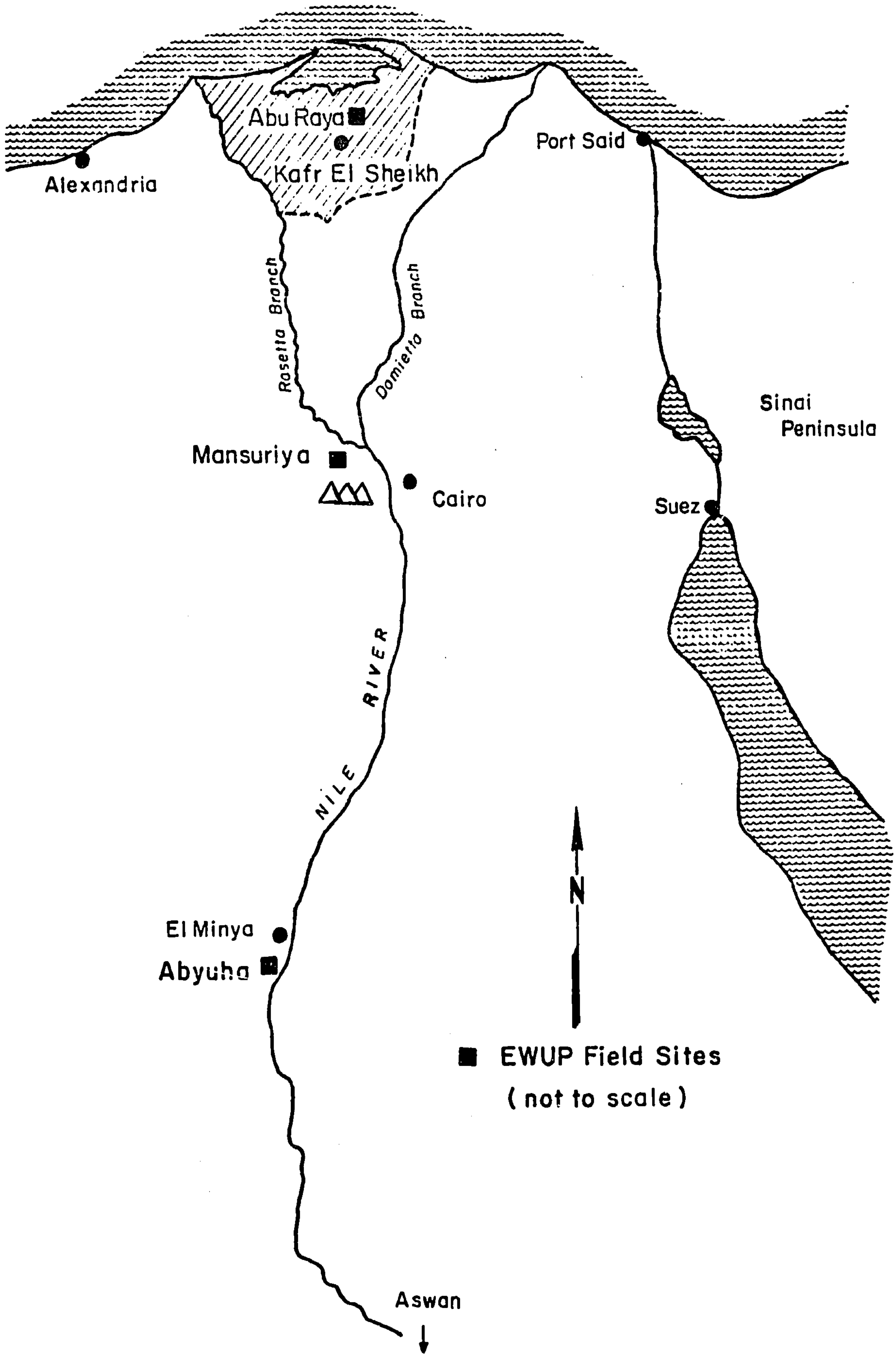

Figure 1. Map of Egypt showing the location of Abu Raya in Kafr El Sheikh Governorate.

2) discuss the application and modification of the USDA-SCS level border design model (USDA, 1974) as a design aid in improving surface irrigation in Abu Raya.

AREA AND SYSTEM DESCRIPTION

The area studied, Abu Raya District, is comprised of nearly 700 ha and lies at the end of a distributary canal which serves nearly 2500 ha. Most of this area is composed of land reclaimed since 1900. Water is delivered on a rotational basis, free of charge, but at a level below the surrounding agricultural land, requiring farmers to lift the water for application to their fields. The lift system was designed to discourage overapplication of water. Water is lifted from private canals called mesqas primarily by using the animal-driven waterwheel (saqia), although small, diesel engine centrifugal pumps are becoming more available. Farmers are responsible for maintaining and cleaning the mesqas. Water delivery levels in the mesqa are variable due to the rotational delivery basis, poor maintenance, and the characteristics of this system which allow greater discharge downstream with declining downstream water levels. This causes short term water shortages in some areas and contributes to highly variable saqia discharge rates on the farm.

Crops are grown year round in the area. Winter season (mid-November to mid-May) crops are wheat, flax, broadbeans, Egyptian clover and sugar beets. Summer season (late May to late October) crops are rice and corn, plus cotton which is generally planted in late March. The time period between crops, from just after harvest to planting of the next crop can extend from two weeks to two months. The time period between irrigations spanning this gap can extend up to three months.

The row crops, such as cotton and corn, are planted on ridges in small irrigation basins, while the broadcast seed crops are grown in small basins with a flat surface. An extensive system of farm distribution ditches, called marwas, delivers water to the basins after it has been lifted. A typical farm layout is depicted in Figure 2. Irrigation basins are of all shapes and sizes and are generally separated by dikes, distribution ditches or shallow surface drains. The majority of farms are less than 2 ha, with the average size being about 1.2 ha. Since farmers prefer to grow a variety of crops during the season, basin sizes on a given farm can vary between 15 to 40 m widths and 40 to 220 m lengths. The small basins with furrows are generally the smallest

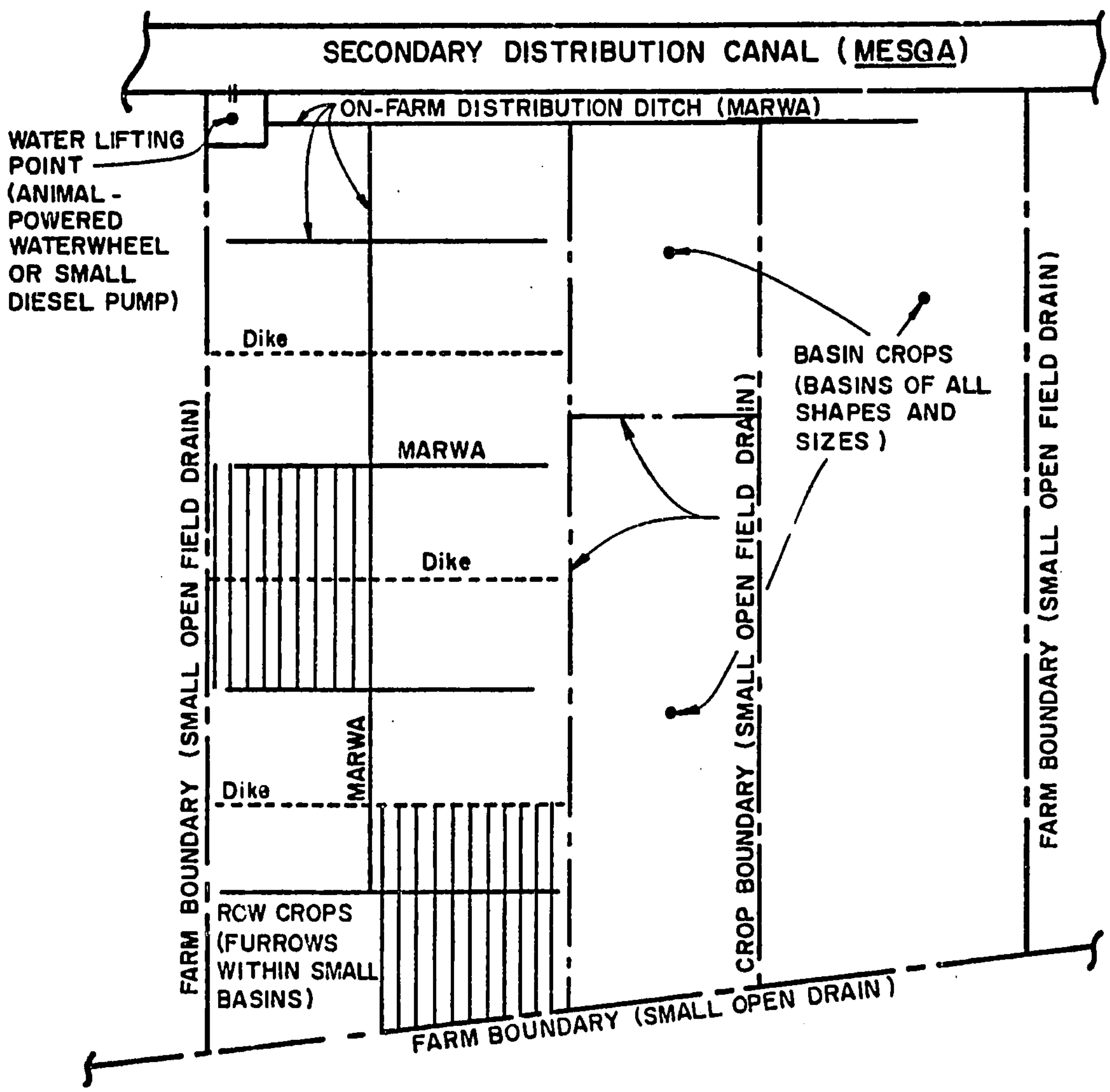

Figure 2. Generalized example of traditional on-farm irrigation system, Kafr el Sheikh, Egypt.

(i.e., 15 to 20 m square) while the wheat, clover and rice crops occupy larger basins. The method of water application could be classified as level basin irrigation due to the fact that farmers grow rice in flooded paddies and attempt to level these areas on nearly a biennial basis.

Soils in the area are heavy clays which are prone to shrinking (severe cracking) and swelling due to a high montmorillonite clay content. The long period between irrigations, which occurs from the end of one crop season to the beginning of the next, when during hot dry weather, can result in heavily cracked soil which is very difficult to till. Soils are generally uniform to a 3 to 5 m depth, at which point a relatively heavier and nearly impermeable layer exists followed by a rapid transition to very sandy soil. Water table levels fluctuate during the season from 20-30 cm below the surface immediately after irrigation to 100-150 cm below the surface between irrigations.

Further details are given by Egyptian and American Field Team (1980) and Ley, (ed.), (1983a,b).

SYSTEM STUDIES AND PROBLEMS IDENTIFIED

On-farm irrigation systems and farmers irrigation practices were studied during several successive winter/summer cropping seasons. These studies included evaluation of on-farm water delivery, water application, crop water use and on-farm drainage. The on-farm water delivery system was studied to determine typical available flow rates, losses in conveyance, ditch cross-sections and lengths. The factors affecting water application including infiltration, field topography, basin sizes and configurations, and stream size at the field inlet were analyzed. Advance/recession data, depths applied and application efficiencies were evaluated. Crop water use was monitored by soil moisture budgeting. Water table levels were monitored and drainage in on-farm surface drains was also evaluated.

Briefly, the problems identified with the conventional farm irrigation systems and farmer irrigation practices were identified as follows.

1) Field topography is unlevel making water distribution difficult and making excess application necessary to wet the high areas. Summary data in Table 1 show the average basin has an elevation difference within it of 0.13 m (± 6.5 cm). This is more than four times the SCS criterion, 0.03 m (± 1.5 cm), for levelness in level basin irrigation

Table 1. Summary of Elevation Variation on six Individual Fields [a] in Abu Raya, Kafr El Sheikh (adapted from Ley, (ed.), 1983c).

Farm	Mean Field Elevation(m) [b]	Elevation (m) [b] Max.	Min.	Range (m)	Standard Deviation (m)
1	1.56	1.59	1.53	0.06	0.02
2	1.51	1.57	1.48	0.09	0.02
3	1.66	1.83	1.59	0.24	0.04
4	1.00	1.11	0.92	0.19	0.05
5	1.64	1.72	1.55	0.17	0.03
6	1.03	1.08	0.98	0.10	0.02
		Mean (of 25 Fields)		0.13	

a/ Selected from data set of twenty-five fields. Elevation data were collected on a 10 m square grid in each field. Mean and standard deviation were determined from the individual grid point elevations.

b/ Elevations given are relative to local benchmarks.

(USDA, 1974). Farmers do not have adequate equipment or technical assistance for performing precision land leveling, although they do understand the need for leveling (for rice) and attempt to level using limited tools. Furthermore, inadequate equipment (methods) for seed bed preparation result in a very rough soil surface causing slow water advance.

2) On-farm conveyance losses can be excessive, up to 40% of the initial flow, causing the average flow rate available at field inlets to be in the 20-25 L/s range (for farm ditches in typical condition). Flow rates made available by the waterwheel (saqia) show a high degree of variability ranging from less than 10 L/s to nearly 60 L/s. The average flow rate is 30-35 L/s for the typical saqia in Abu Raya.

3) Basin size and layout is inappropriate for the existing infiltration, available stream size and surface roughness conditions. The available stream is small and variable due to conveyance losses and the characteristics of the saqia. This small, variable stream results in a unit width stream size which is not large enough to ensure rapid advance to the tail of the field.

4) The small, variable stream size; the basin width and length; and the unlevel topography of the field combine to result in poor water management ability on the farmer's part. There is little or no control over the advancing water front. The farmer simply floods each basin until high spots are covered, and perceives, by visual observation of the ponded depth, that enough water has been applied. Often excess surface water must be removed, reducing application efficiency to very low levels. Farm irrigation efficiency which includes both on-farm conveyance and application losses was typically 20-40%.

5) Open surface drains which are shallow and often choked with weeds serve as crop, basin and farm boundaries and as channels for removal of any excess applied water. Measurements have shown these drains occupy up to 15% of the farm area. These drains do not effectively assist subsurface water removal.

TRIALS OF SUGGESTED SOLUTIONS

The conventional methods of farm irrigation used by Abu Raya farmers are similar to level basin irrigation. Optimal performance of the systems is not achieved due to the problems discussed above. Suggested solutions to the problems identified were as follows:

1) precision land leveling using the techniques described in USDA (1961),
2) renovation of on-farm conveyance channels,
3) level basin design using the USDA-SCS (USDA, 1974) model to size basins in relation to available stream sizes, infiltration, surface roughness and desired depth of application,
4) assist farmers to improve their understanding and abilities for good on-farm water management. This encompassed working closely with the farmer and teaching him how to irrigate with the new system.
5) field drains were removed to increase farm area and on the hypothesis that with the new systems and improved on-farm water management there would be minimal need for excess surface water removal.

Field trials of these suggested improvements were conducted for several seasons on farmer's fields adjacent to fields where the conventional systems were operated. This allowed the farmer visual assessment of the improvement practices.

The irrigation improvements tested during field trials showed that water savings, irrigation time savings, higher irrigation efficiencies and reduced labor resulted when the improved basins were compared with the conventional methods (Ley, (ed.), 1983b). Yields were improved, but cannot be attributed to irrigation improvements alone, as improved varieties, fertilizers, etc. were also tested. In the process of testing the improved level basins, numerous in-field surface drains were removed increasing productive area on the farm. No adverse affects were observed due to drain removal. Precision land leveling and proper operation of the improved systems reduced or eliminated the need for surface drainage from irrigated basins.

ON-FARM WATER MANAGEMENT DEMONSTRATION PROGRAM

Based on the results of problem identification studies and field trials of suggested solutions, an on-farm water management improvement demonstration program was designed and implemented (see Ley, (ed.), 1983b; Gates, et al., 1981). The program was farm-system oriented and addressed the entire layout of each farm including farm distribution ditch improvement, field drain removal, precision land leveling, level irrigation system design and continuing collaboration with the cooperating farmer(s) on system use and management. Farm crop production was also addressed through a package of recommendations designed for improved agronomic and cultural practices. This program was implemented on more than 20 farms over five seasons. Results were evaluated each season to identify areas of required program refinements. Farmer reaction to the program in terms of acceptance of the new practices, interest in them, and ability to understand and implement the new practices was evaluated. Stability of the physical improvements over time was also studied. Generally, the major physical improvements were made at the first season of EWUP work on a given farm. During successive seasons minor adjustments were made to assist the farmers. These included touch-up leveling/smoothing, construction of basin dikes, construction of ditches and construction of long furrows.

Results obtained were very promising. Farm water losses were reduced and farm irrigation efficiencies were increased through the total on-farm system improvement approach. Water, irrigation time, and labor savings were repeatedly demonstrated and documented (Ley, (ed.), 1983b,c). Table 2 presents briefly a comparison of the results of the conventional methods with those obtained on three selected farms on which the program was implemented for several seasons. These results generally support the above conclusions.

Table 3 is a summary of the irrigation studies conducted by EWUP in Abu Raya in terms of irrigation practices and measured efficiencies. As the work evolved from problem identification studies to field trials to the demonstration program the efficiency figures given are seen to generally increase. These distinct increases are the result of the on-farm irrigation improvements discussed above.

Three interdependent components of the irrigation system improvement program were instrumental in bringing about successful results: 1) precision land leveling to dead level, 2) level irrigation system design, and 3) improved water management on the farmer's part in the use of the new systems. The three components needed to be implemented as a package of practices in order to achieve optimal results and improvement over conventional methods.

USING THE SCS LEVEL BASIN DESIGN MODEL

The SCS level basin design model (USDA, 1974) was utilized as a design aid in modifying the surface irrigation systems in Abu Raya. The remainder of this paper focuses on the use of the model in Abu Raya, the problems encountered and the adjustments made. A trial-and-error solution procedure of the given equations (Gates and Clyma, 1980) was used. This procedure was encoded for use on HP-67 handheld calculators as well as the HP9825 desktop

Table 2. Comparison of typical results of conventional methods with results obtained on three selected farms for the initial and succeeding seasons of EWUP's demonstration program in Abu Raya (adapted from Ley, (ed.), 1983c).

Season	Crop	Irrigation Efficiency(%)	Depth Lifted(mm)	Total Irrigation Time (hr/ha)
		TYPICAL RESULTS OF CONVENTIONAL METHODS		
79-80W	Wheat	38	870	13.4
80S	Cotton	52	1020	16.2
80S	Rice	n.a.	1950	n.a.
81-82W	Sugarbeet	n.a.	410	7.9
		RESULTS ON DEMONSTRATION FARMS (Initial and Succeeding Seasons)		
Site A				
79-80W	Wheat	67	560	10.2
80S	Rice	n.a.	1740	n.a.
81S	Cotton	50	1070	18.2
81-82W	Wheat	65	368	10.5
Site B				
80S	Cotton	78	780	11.0
80-81W	Wheat	54	610	12.6
81S	Rice	n.a.	1790	22.3
Site C				
81S	Cotton	80	700	9.8
81-82W	Wheat	83	342	7.8
81-82W	Sugarbeet	75	505	12.7

n.a. means not available

Table 3. Summary of 1978-1982 Seasonal Irrigation Studies at Abu Raya, Kafr El Sheikh (adapted from Ley, et al., 1983d).

Season	Crop	No. of Farms	Conditions: PLL[a]	Conditions: On-farm Ditches	Conditions: Irrigation System[b]	E_c[c] (%)	E_a[c] (%)	E_i[c] (%)
Winter 78-79	wheat	1	No	unimproved	conventional	60-75	28-35	21
Winter 78-79	flax	1	No	unimproved	conventional	60-75	32-42	24
Winter 79-80	wheat	5	No	unimproved	conventional	60-75	51-63	38
Winter 79-80	wheat	5	Yes	unimproved	level basins	60-75	81-100	61
Summer 80	cotton	6	No	unimproved	conventional	60-75	69-87	52
Summer 80	cotton	6	Yes	unimproved	long level furrows	60-75	71-88	53
Winter 80-81	wheat	5	Yes	reshaped; unlined	level basins	74	69	51
Summer 81	cotton	6	Yes	reshaped; unlined	long level furrows	84	76	66
Winter 81-82	wheat	1	Yes	unimproved	level basins	62	85	53
Winter 81-82	wheat, barley	4	Yes	reshaped and lined	level basins	100	75	75
Winter 81-82	sugar beets	4	Yes	reshaped and lined	long level furrows	98	87	85

a/ PLL is precision land leveling

b/ long level furrows and level basins were designed using SCS methods.

c/ E_c = farm conveyance efficiency = ratio of water delivered to field to water lifted x 100%.
E_a = water application efficiency = ratio of water stored in root zone to water delivered to field x 100%.
E_i = farm irrigation efficiency = E_c x E_a x 100%.

calculator (Ley, (ed.), 1983b.

Constraints imposed by the physical system and limitations of the model itself prevented the SCS design procedure from being used as a "cookbook" method. Modification of the model to fit existing conditions was required for design, construction and operation of improved farm irrigation systems. Model modifications concerning infiltration characteristics, inflow rates, surface roughness and time of inflow are presented below.

Infiltration Characteristics

Detailed knowledge about soil infiltration characteristics is essential for designing farm irrigation systems. At Abu Raya the heavy clay soils, which crack severely on drying, exhibit complex infiltration characteristics which varied considerably through the season (Ley, (ed.), 1983b). Litwiller et al. (1983) presented results and analyses of twenty-one infiltration tests conducted during irrigation of wheat at Abu Raya. Infiltration rates proceeded from high initial rates to low long term rates. Infiltration data were shown to be highly dependent on antecedent soil moisture conditions. Macroporosity in upper soil layers which increased with decreasing soil moisture, was shown to greatly effect initial infiltration rates. High water table conditions caused wetter soil moisture conditions in lower soil layers and led to low long term infiltration rates. Macroporosity effects were greatest for the initial irrigation of the season and had less effect for subsequent irrigations.

The SCS level basin design model uses the SCS intake family functions. Average infiltration functions were derived based on measurements made in Abu Raya for the conditions of the first irrigation when the soil is very dry and severely cracked, and for mid-season conditions when the soil profile is moister and less cracked (Litwiller, et al., 1983). These functions tend to intersect several of the SCS curves when plotted on the same graph as the SCS intake family curves (Fig. 3) due to the characteristic high initial infiltration rate which rapidly reduced to low long term infiltration rates. It was especially difficult to match the first irrigation conditions at Abu Raya with the SCS curves.

Initially, level basin designs for Abu Raya were formulated based on the expected mid-season infiltration conditions. Generally this resulted in selection of a basin width, for a given length, available flow rate and depth required,

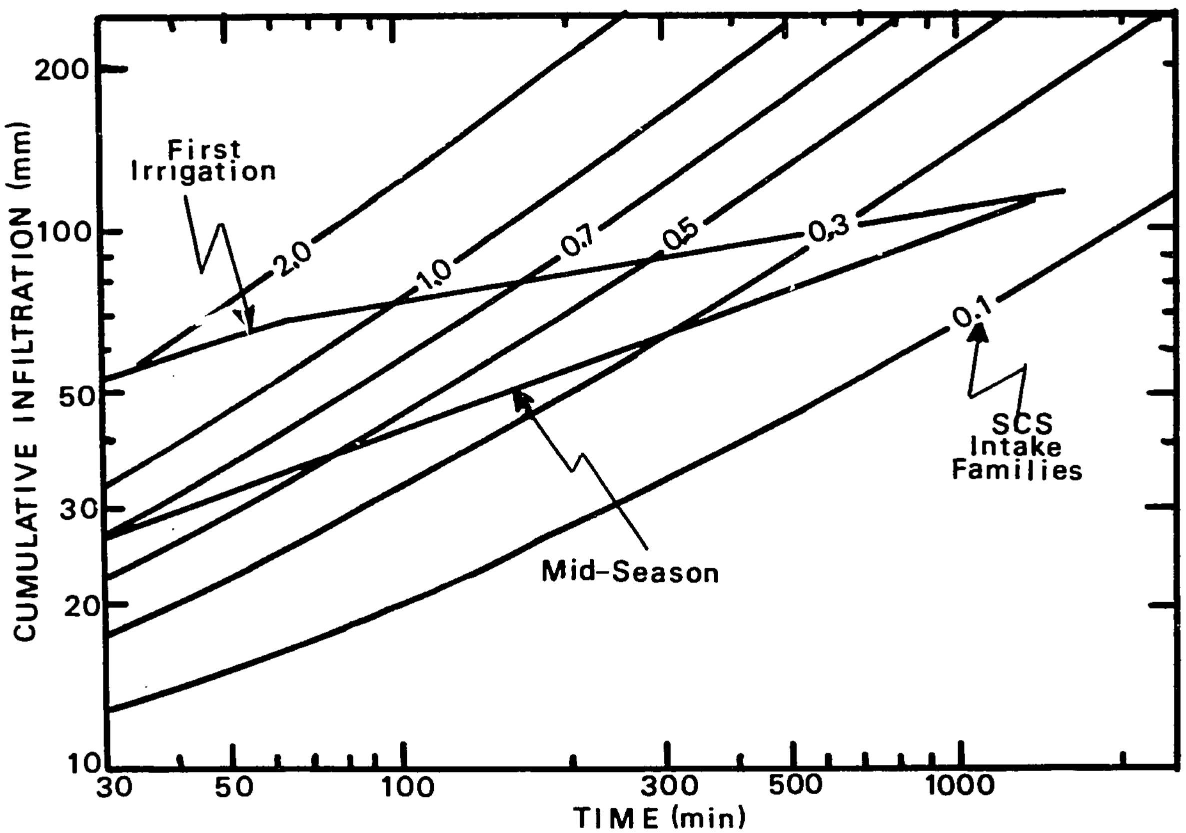

Figure 3. Comparison of average measured infiltration functions, first irrigation and mid-season conditions, with SCS Intake Families. Average measured functions are two-phase infiltration relations described by Litwiller, et al. (1983):

First irrigation		Mid-season	
$z(\text{mm}) = 14.5\ t(\text{min})^{0.37}$	$(t \leq 61)$	$z(\text{mm}) = 6.4\ t(\text{min})^{0.44}$	$(t \leq 8)$
$z(\text{mm}) = 32.2\ t(\text{min})^{0.18}$	$(t > 61)$	$z(\text{mm}) = 7.2\ t(\text{min})^{0.38}$	$(t > 8)$

which was too wide for the conditions existing at the first irrigation. The result was very slow water advance and potentially less than maximum uniformity of irrigation during the first irrigation.

Designs formulated for the conditions of the first irrigation (largest soil water deficit, highest infiltration rate, greatest surface roughness) generally specified basin widths which proved to yield good irrigation results in the field. During successive irrigations, results were very acceptable since strips were narrower and unit streams greater than required for conditions existing at those irrigations. Some compromise between the above two conditions would also yield favorable results through the entire season.

To further illustrate the marked differences in results which occur when using the measured infiltration or the SCS functions, uniformity of irrigation, based on measured advance-recession data of the first irrigation of several level basins, was calculated using each infiltration function. In this analysis, uniformity of irrigation was described using the coefficient UCH (Hart, 1961). The SCS intake family for each field was chosen based on measured data at the first irrigation. The intake family was chosen as the closest curve to the plotted point: measured application depth (there was no runoff) and average opportunity time. The results are compared in Table 4. The effect of the rapid reduction in measured infiltration rates on uniformity is apparent. The low long term infiltration rates assist in obtaining high uniformity.

Variable Inflow Rates

Due to the characteristics of the water lifting device and losses from farm ditches, available flow rates at the field inlet were quite variable. The improvement of on-farm ditches helped decrease conveyance losses. The appropriate design flow rate which could be expected to be available at the field inlet needed to be identified, however. Reddy and Clyma (1982) showed, that under variable flow conditions, designs formulated for the expected average flow rate result in good efficiency and uniformity, as long as the actual average flow rate is not less than 50% of the flow rate used in the design process.

In Abu Raya, the average saqia flow rate of 30-35 L/s was used for design purposes, and good results were obtained. Depending on farm ditch conditions and length, however, this value was at times reduced to account for on-farm conveyance losses.

Table 4. Comparison of calculated irrigation uniformity (UCH)[1/] for two infiltration functions for first irrigation of level basins during 1980-81 Winter Season, Abu Raya, Kafr El Sheikh (adapted from Ley, (ed.), 1983b).

Site	SCS Intake Family [2/]	UCH for SCS Function	UCH for Measured Infiltration Function [3/]
1	0.7	0.83	0.95
2	0.7	0.88	0.97
3	0.6	0.84	0.95
4	0.7	0.88	0.97
5	1.0	0.64	0.88
6	4.0	0.82	0.94
7	2.0	0.78	0.94
mean	---	0.81	0.94

[1/] UCH calculation for each infiltration function based on advance/recession tests at each site.

[2/] SCS Intake Family chosen as that function closest to the data point: total depth applied for the irrigation (there were no runoff losses) and average infiltration opportunity time as determined from advance/recession data.

[3/] Average measured infiltration function for first irrigation conditions as presented by Litwiller, et al. (1983):

$$z(\text{mm}) = 14.5\ t\ (\text{min})^{0.37} \qquad (t \leq 61)$$

$$z(\text{mm}) = 32.2\ t\ (\text{min})^{0.18} \qquad (t > 61)$$

Surface Roughness

Surface roughness at the first irrigation was qualitatively judged to be very high due to the difficulty the farmer had in working the dry, hard soil and preparing a smooth seedbed. In these cases, surface roughness values for the SCS model were set at a Manning roughness factor of 0.25 (even for bare soil surface). Smoother seed beds were prepared with the use of precision land leveling equipment. Under these conditions SCS recommendations were followed in selecting a value of surface roughness.

Time of Inflow

Given an available stream size, infiltration characteristics, net application depth and border dimensions, the SCS model specifies a time of inflow for the unit stream. When the elapsed time following initiation of inflow to the border reaches the specified inflow time, the inflow stream is cut off. Due to the variable inputs of stream size, infiltration characteristics, and surface roughness, the time of inflow specified in the design was not used in operation of the new systems. Rather through experience, best results were obtained when the inflow stream was cut off at the time that the advancing stream front was within 5 to 10 meters from the field tail. Litwiller, et al. (1983) used an average advance curve and average infiltration characteristics to show that good distribution uniformity and adequate infiltrated depth at all field stations could be obtained under the above conditions. Given the measured infiltration characteristics of Abu Raya soils discussed earlier, overirrigation and excessive inundation times were avoided by following this practice. The low long term infiltration rates are not accounted for by the SCS intake families and thus the design model yields an inflow time greater than necessary to apply the desired depth.

SUMMARY AND CONCLUSIONS

The on-farm irrigation improvement work of the Egypt Water Use and Management Project in Abu Raya, Kafr El Sheikh Governorate, Egypt has been described and summarized. Problem identification studies revealed major problems with the on-farm irrigation systems, methods and practices. These problems included poor layout and design of the farm irrigation system with extensive and inefficient water conveyance channels, inappropriately sized basins, and ineffective field drains. Basins were found to be unlevel causing poor water distribution and overirrigation. Farmers tended to overirrigate and then drain excess surface water. The similarity of the conventional irrigation methods used to level basin irrigation prompted a solution package approach which included precision land leveling, level basin design, and educating and assisting farmers to improve on-farm water management. Implementation of the above package on farmer's fields resulted in improved farm irrigation efficiency and water, labor and irrigation time savings.

The USDA-SCS level basin design model (USDA, 1974) was used to assist in designing the new farm systems. Variability in available discharge, infiltration characteristics and surface roughness required careful evaluation before successful irrigation designs were formulated using the model. These physical conditions were observed to vary considerably between the initial irrigation of the season and successive irrigations. Initial irrigation conditions included the largest soil water deficits, highest infiltration rates and high surface roughness. Best results through the season were obtained by designing for these initial irrigation conditions. The measured soil infiltration characteristics, which differed greatly from the SCS intake families had the greatest impact on design. In particular, the infiltration functions derived from measurements were found to intersect several SCS intake families as the high initial rates reduced to low long term infiltration rates. Also, infiltration rates at mid-season were substantially lower.

System operation was modified as compared to the SCS design recommendations. Best results were obtained by shutting off the inflow stream when advance had reached within 5 to 10 m of the tail end of the strip. The low long term infiltration characteristics of the soil assisted in maintaining high uniformity of irrigation under this practice.

The level basin designs constructed and evaluated in Abu Raya contributed substantially to the improved on-farm irrigation systems demonstrated. The SCS model was found to yield adequate results once the design parameters, especially infiltration, were appropriately assessed. Irrigations using the new systems required careful monitoring to avoid overapplication caused by reduction in infiltration rates. EWUP worked closely with farmers to help them understand improved on-farm water management using the new farm systems.

ACKNOWLEDGEMENT

The authors wish to thank the entire staff of the EWUP project in Kafr El Sheikh, Cairo and Ft. Collins without whose assistance and support this work would not have been accomplished.

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