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FARM IRRIGATION SYSTEM DESIGN, KAFR EL SHEIKH, EGYPT

by

Kafr El Sheikh Team
As Compiled By
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EGYPT WATER USE AND MANAGEMENT PROJECT

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FARM IRRIGATION SYSTEM DESIGN

KAFR EL SHEIKH, EGYPT

TECHNICAL REPORT NO. 35

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ABSTRACT

Level farm irrigation design methods, experience and results from the EWUP Kafr El Sheikh study area in Abu Raya District are reviewed. Three major sections of the report provide the review. Part I is a review of the SCS level furrow and level border design methods which have been used, the effects of design parameter changes on irrigation performance and a presentation of HP-9825 and HP-67 computer/calculator programs for design. In Part II, design considerations for the Abu Raya area (and for areas with similar conditions) are reviewed by an analysis of the individual factors and parameters which affect level farm irrigation system design. The methods used in this case study should be applied in developing design recommendations in major areas having similar conditions. Part III of the report is a review of the experience of the K.S. Team in implementing level irrigation designs in Abu Raya. Comparison of the improved methods with the conventional methods shows that consistently water savings, labor savings, time savings and improved efficiency result. The improvement package also gave improved crop yields. Design analysis is included to show how further design improvements should be made.

Level irrigation system design programs and user instructions for the HP-9825 and HP-67 are included in appendixes. Advance-recession data plots from several farms where designs were constructed and evaluated are given in Appendix C.

116 Pages 28 Figures 14 Tables

مستخلـــــــــــص

هذا التقرير هو عرض لطرق الرى المصممة فى الأرض المستوية وللخبـــرات والنتائج التى تم الحصول عليها فى منطقة أبو ريا بمحافظة كفر الشيـــــخ . وينقسم التقرير الى ثلاثة اجزاء رئيسية . يتناول القسم الأول كيفيـــــــة المحافظة على الأرض المصممة (SCS) فى خطوط وأحواض مستوية ومـــــدى تأثير تعيير الطرق المصممة على عمليات الرى . كما يتضمن القســـم الأول عرضا لطريقة استخدام برامج الحاسب الآلى الالكترونى HP - 9825 و HP- 67 فى عمل التصميمات . أما القسم الثانى فيشتمل على العوامل التى تؤخذ فى الاعتبار اثناء التصميم لمنطقة أبو ريا (والمناطق المتشابهة الظروف) وذلك بعمل تحليلات للعوامل الفردية التى تؤثر فى تصميم نظم الرى فى الأراضى المستوية.كذا يجب أن تطبق الطرق المستخدمة فى هذه الدراســـة عند وضع توصيات للتصميم فى المناطق الرئيسية ذات الظروف المتشابهـــــة . والقسم الثالث من التقرير يحتوى على خبرات فريق العمل بكفر الشيخ فـــى تنفيذ تصميمات نظام الرى فى الأرض المستوية فى منطقة أبو ريا . وقد ثبت بمقارنة الطرق المعتادة بالطرق المحسنة ان هناك ادخار فى المياه والعمالة والوقت وتحسين فى الكفاءة . وقد أدت هذه المجموعة من التحسينات ايضا الى زيادة انتاجية المحاصيل . وتتضمن تحليلات التصميم توضيح كيفية عمل أقصـــى تعديل فى التصميم .

ملحق بهذا التقرير برامج لتصميم نظام الرى فى الأراضى المستوية وايضا تعليمات لاستخدام HP - 9825 وايضا HP - 67 . ويحتوى ملحـــق " ج " على بيانات جبهة تقدم وانحصار السياه فى العديد من الحقول التـــى شيدت وقيمت فيها التصميمات .

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PREFACE

This report presents the results and findings of farm irrigation system studies conducted by the EWUP Kafr El Sheikh Team over several phases of the EWUP work plan. Part I of the report is a general review of the level irrigation system design concepts and design processes. The computer and calculator programs, examples and system performance sensitivity to design parameter variation are mainly the work of Kamal Ezz El Din, Thomas Ley and Kenneth Litwiller. Part II of the report represents the work of the entire K.S. Team in characterizing irrigation system design and operation parameters in Abu Raya, Kafr El Sheikh. Part III of the report also represents the experience of the entire Team in level irrigation system design and operation in Abu Raya. The work of the entire K.S. Team, both past and present, listed on the next page, is gratefully acknowledged. The work of the technicians laborers, and office staff in data collection and primary analysis is also acknowledged. Without the inputs of either group, this report would not be possible. The assistance and guidance provided by the EWUP main office staff and directors is also acknowledged. Without their support the work would not have been as successfully conducted.

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*as of March 1983

FARM IRRIGATION SYSTEM DESIGN, KAFR EL SHEIKH, EGYPT

INTRODUCTION

The conventional methods of farm irrigation used by farmers in Abu Raya District, Kafr El Sheikh Governorate, have been studied and evaluated by the Egypt Water Use and Management Project (EWUP) Kafr El Sheikh Team since early 1978. The type of irrigation farmers practice in Abu Raya is surface flooding of small basins. Row crops such as cotton and maize are grown on ridges within the basins (i.e., furrow irrigation in small basins with furrow lengths generally less than 20 m) while other crops are grown on the flat surface in basins ranging from tenths of a Feddan to over one Feddan in size. Rice is a major summer crop in the two-year crop rotation in Abu Raya. From the viewpoint of water management for rice, farmers perceive the need to make the basins to as level as possible. Basins in Abu Raya are of all shapes and sizes due to the land ownership patterns, crop patterns, other boundaries and general limited acquired knowledge of basic surface irrigation hydraulics on the part of the farmer, who also has limited access to engineering support and appropriate equipment. The studies conducted by the Kafr El Sheikh (K.S.) Team have shown that farmer irrigation practices in Abu Raya generally result in inefficient water application and overirrigation, especially near poorly maintained farm distribution ditches. This is due in part to inadequate water management of poorly designed farm irrigation systems. The farmer's inability to adequately level his basins compounds the problem. The cracking nature of the heavy clay soils in the area directly affects the efficiency of water application and conveyance. Furthermore, the farmer perceives no real incentive to conserve water.

The purpose of this report is to present and discuss farm irrigation system design improvements for the Kafr El Sheikh area. These improvements are based on useful and easily applied design techniques, a farm irrigation system data base for the Abu Raya area, and numerous actual case studies conducted on Abu Raya farms. The improvements have three main emphases which are strongly interdependent:

1) precision land leveling to dead level,[1/]

[1/] Level furrows and borders studied in this project have not exceeded 200 m in length which is well within the range required for adequate irrigation of dead-level fields. For lengths of 300-400 m FAO (1977) recommends a slope of 0.05 percent for clay soils similar to soils in the Kafr El Sheikh area.

2) level irrigation system design, and

3) improved water management for the new system.

These three components represent a package for farm irrigation system improvement. Each should be addressed. Ignoring any of the components can lead to failure of the package to bring about desired improvements. The suggested package of improvements is not limited to Abu Raya, but is applicable to many areas in Egypt which have similar conditions. Precision land leveling and the need for it in Kafr El Sheikh are discussed in a separate report (EWUP, 1982g). Improved water management is discussed in both this report and the report on land leveling. This report is subdivided into 3 parts to accomplish the above stated purpose.

Part I provides a basic review of level irrigation system design concepts and of the USDA-SCS design methods for level furrow and level border irrigation. Computer and calculator programs have been written and documented to facilitate the design process. The information presented in Part I is applicable to on-farm surface irrigation system improvement throughout Egypt.

In Part II, the farm irrigation system data base for Abu Raya is summarized and reviewed. The analyses presented for the Abu Raya area are necessary to develop specific design recommendations for design parameters and for water management recommendations. Such analyses can be and should be carried out where surface irrigation system design improvements such as those presented are being considered.

Finally, in Part III of this report, a review of the actual farm irrigation system design improvements implemented as field trials and in the pilot programs in Abu Raya is presented. A qualitative review of the farm irrigation system improvement work illustrates what the K.S. Team did, how the work was carried out and what the results have been. A quantitative evaluation of the implemented designs provides a summary of design effectiveness to produce improvements. It is also an effective means for evaluating how to improve design method applicability. A comparison of the improved farm irrigation systems with the conventional systems farmers have used illustrates the benefits that result. These include: water savings, labor savings, improved irrigation efficiency and improved crop production, all of which combine to meet the goals and objectives of EWUP.

I. LEVEL BORDER AND LEVEL FURROW IRRIGATION SYSTEMS DESIGN

INTRODUCTION

The purpose of this part of the report is four-fold:

1) Provide basic background and characteristic information on the USDA-SCS level irrigation systems design methods.
2) Discuss the general design process to be used in designing level border or level furrow systems using the SCS methods. Delineate the basic data requirements for design.
3) Present computer programs for level border and level furrow design for both the HP-9825 desktop computer and the HP-67 calculator. Include user instructions and examples.
4) Present and discuss the effects of design variable changes on irrigation system performance.

It is not intended that this part of the report provide technical and mathematical details on the design model development and/or formulation. That information has been reported elsewhere (see next section). Rather it is intended that the reader gain an understanding of the general characteristics of level irrigation systems, the underlying design assumptions, the advantages and disadvantages, and general design processes. The computer programs have been prepared as design - computational aids which allow the designer to look at a number of design possibilities with relatively minimum effort. Finally, understanding the effects of variations in design parameters on system performance, as predicted by the computer models, will aid the designers' judgement in selection of proper designs. Pertinent design conditions for the Abu Raya area, Kafr El Sheikh, are used in this analysis

GENERAL CHARACTERISTICS AND DESIGN ASSUMPTIONS

The Soil Conservation Service (SCS) of the United States Department of Agriculture has developed quasi-rational procedures for the design of level irrigation systems which are based on a volume balance approach to modeling of system hydraulics (USDA, 1974; USDA 1979). The development and formulation of the design models for level border and level furrow irrigation is completely described in each of the above publications, respectively. Supporting

information and descriptions are given by Gates and Clyma (1980a), Erie and Dedrick (1979), Jensen (1980), Collins and Koluvek (1981), and Ley and Clyma (1980).

Level system (border or furrow) irrigation is a method in which water is supplied in sufficient quantity over a relatively short time period to level ground areas, such that the entire area is quickly covered by gravity flow distribution. The level areas are surrounded by control barriers (dikes, bunds, etc.). The method is best suited for medium to low intake rate soils and can be used for irrigating all crops. Proper design of level irrigation systems (basin dimensions, number of furrows which can be irrigated, etc.) depends on the water supply flow rate, soil infiltration characteristics and other factors. Surface runoff losses are eliminated. High application efficiencies, 90% or greater, are possible. Deep percolation losses can be held to an acceptable level.

Another advantage of level irrigation systems is the ability to control the application of excess water for leaching of salts without an undesirable buildup of the water table. The correct amount of water to be applied is more easily determined since no runoff losses occur. Light applications are possible with well-designed systems which have the proper balance of flow rate and soil intake rate taken into consideration. Large streams of water can be used, and with precision land leveling, large areas can be irrigated in one set. This reduces labor requirements. Crop production should improve due to improved uniformity of water application; improved seed germination; and with careful management, application of the proper amount of water to meet crop requirements.

As implied by its name, level system irrigation means that the field must be as close to dead level as possible. This means precision land leveling must be performed. If low or high areas exist, uneven application of water results and corresponding water-logging or salinity problems will develop to reduce crop production. Precision land leveling to dead level generally will mean increased land development costs. Consideration to the depth of topsoil must be given before significant earthmoving occurs. A recommended criterion for acceptable field levelness as given by the USDA (1974) for level borders is a range in field elevations within $\pm$ 1.5cm of the mean field elevation. For level furrows, an acceptable levelness standard is up to twice this much, however, there must not be any reverse gradients in the furrow.

Larger streams are desirable for level system irrigation to allow quick, uniform application of water. This also will allow larger-size fields, which would aid mechanization, reduce labor, and save water.

The SCS design methods for level border and level furrow irrigation are based on satisfying the following conditions:

1) The volume of water applied is equal to average total infiltration depth.
2) The infiltration opportunity time at the last point covered is equal to the time required for the design requirement depth to enter the soil.
3) The longest infiltration opportunity time at any point is short enough to prevent excessive deep percolation.
4) The depth of flow is not greater than that which can be contained in the furrow or by the border bunds.

The volume-balance approach used by the SCS is based upon mass continuity while the dynamic relationships (energy and momentum) of the flow phenomena are supplanted with assumptions or are ignored. The SCS uses the results of empirical field studies to simplify the design process. The approach has been found to be quite adequate for a wide range of field conditions.

Proper farm water management is as important as a correct design in operation of the farm irrigation system.. Questions of when to irrigate and how much to apply must be answered. Knowledge of the temporal changes in factors affecting system performance is necessary so that appropriate adjustments in the operation and management of the system can be made through the season (Gates, 1980). The area irrigated and the available flow rate must be measured. Crop water requirements based on soil moisture monitoring and predictions of evapotranspiration should be determined. Other considerations such as crop and seed sensitivity to water inundation will affect management. Field tests and studies can often be used to develop general recommendations, such as applying a known discharge of water for a set period of time. Such tests and studies should be broad-based and encompass the management considerations discussed.

GENERAL DESIGN PROCESS

Use of the SCS level irrigation system design methods requires that the following information and data, based on field observations, be known:

1) Soil intake characteristics and classification into an SCS intake family, I_f. Table 1 is an adapted version (a and c values converted to mm) of the Table of SCS intake family equation parameters given in USDA (1974) for border irrigation. Table 2 and Figure 1 are adapted from USDA (1979) for furrow irrigation. Note that there are slight differences between the parameters, a, and, b, for some of the intake families as given in Tables 1 and 2. The effect on predicted intake depth is not large and use of either is satisfactory. The parameter, c, in the SCS intake equations is an empirical constant based on the general groupings of numerous intake tests into the intake families by the SCS. Soil infiltration characteristics are measured using cylinder or blocked furrow infiltration experiments (Trout, et al., 1982). Such tests may not always adequately describe the soil intake characteristics. It is often necessary to adjust the intake function parameters as measured by these tests using inflow data and advance/recession rate data in a volume balance analysis.
2) An estimate of the expected flow retardance coefficient as characterized by Manning's n, Table 3 provides basic guidelines. The crop, crop density, planting method and surface roughness affect the flow retardance.
3) The field dimensions -- length of run, total field width -- should be measured. Furrow spacing must be known; it is usually dependent on the crop, cultural practices and tradition. Farmer preferences for layout of the system should be considered, as well as a complete redesign of the layout of the farm system. Further discussion and experience is provided on this aspect in Part III of this report.
4) The available discharge at the inlet to the field must be known. Farm conveyance losses must be deducted from any discharge value known upstream of the field inlet.
5) The design requirement depth must be known. It is dependent on the crop, climate, soil, water supply and leaching considerations.

Table 1. Values of Parameters a, b, c for SCS Intake Families (adapted from USDA, 1974, border irrigation).

Intake Family	a(mm)	b	c(mm)
0.1	.6198	0.661	6.985
0.3	.9347	.721	6.985
0.5	1.1862	.756	6.985
1.0	1.7805	.785	6.985
1.5	2.2835	.799	6.985
2.0	2.7534	.808	6.985
3.0	3.6500	.816	6.985
4.0	4.4450	.823	6.985

$z = aT^b + c$, where z (mm) is intake depth, T(min) is intake opportunity time.

Table 2. Values of Parameters a, b and c for SCS Intake Families (adapted from USDA, 1979, furrow irrigation).

Intake Family	a(mm)	b	c(mm)
0.05	0.5334	0.618	6.985
0.10	0.6198	0.661	6.985
0.15	0.7110	0.683	6.985
0.20	0.7772	0.699	6.985
0.25	0.8534	0.711	6.985
0.30	0.9246	0.720	6.985
0.35	0.9957	0.729	6.985
0.40	1.064	0.736	6.985
0.45	1.130	0.742	6.985
0.50	1.196	0.748	6.985
0.60	1.321	0.757	6.985
0.70	1.443	0.766	6.985
0.80	1.560	0.773	6.985
0.90	1.674	0.779	6.985
1.00	1.786	0.785	6.985
1.50	2.284	0.799	6.985
2.00	2.753	0.808	6.985

$F = (a\ T^b + c)\ p/w$, where F (mm) is equivalent intake depth in furrow irrigation, T (min) is intake opportunity time, p/w is ratio of furrow wetted perimeter (m) to furrow spacing (m).

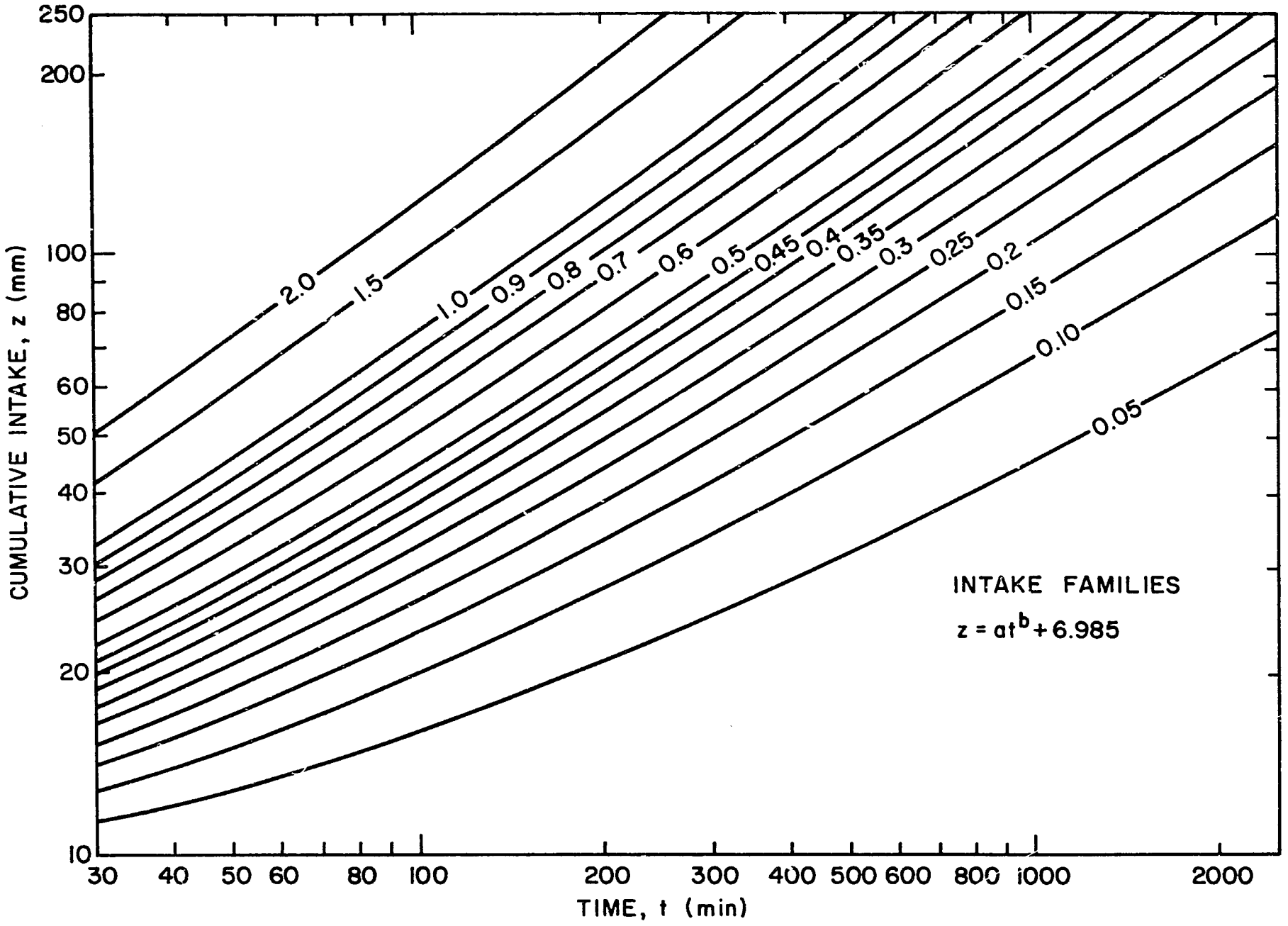

Figure 1. SCS Intake Family Curves (after Collins and Koluvek, 1981)

Table 3. Common Retardance Coefficients (values of Manning's n) Used in Irrigation Design (after USDA, 1974 and USDA, 1979).

Smooth, bare soil surfaces (furrows)	0.04
Small grain, drill rows parallel to border strip	0.10
Alfalfa, mint, broadcast small grain, and similar crops	0.15
Dense sod crops, drill rows of small grain across the border strip	0.25

Typically a design is formulated so that the maximum expected crop water requirements (i.e., during a peak use period) are supplied according to some irrigation schedule. However, local practices and soil water deficits through the season should be studied to determine other possible maxima (see Part II of this report).

6) Other information such as typical farmer irrigation practices, soil physical characteristics, irrigation and drain water quality, soil salinity, water table levels, cropping rotations, etc. should be collected to assist design formulation and management recommendations.

Level Border Design

Typically, level border systems will be designed for a field of given dimensions and the designer seeks to find an appropriate strip width for the basic design parameters discussed above. That is the approach focused on here. However, it is worth noting that the design can be for length of run given a strip width, and available flow rate at the field.

The SCS level border design model calls for the following input design parameters as discussed previously: 1) length of run, 2) SCS intake family and intake function parameters, 3) Manning's n-value, 4) design requirement depth, 5) total available flow at the field inlet. A desired minimum value for water application efficiency is also required. With this information and using the model assumptions, the process determines a suitable unit width inflow stream, i.e., a required minimum inflow rate (lps) per meter of field width. The required application time, gross application depth and estimated

time for water advance to the end of the field are also calculated. A comprehensive description of the sequence followed is given by Gates and Clyma (1980a).

The design process does not end there, however, as there are numerous constraints to check. The resultant unit width inflow rate and the total available field inflow rate are used to determine a strip width. It is recommended that the number of strips for a given field be an integer number. This will often require that the determined strip width be divided into the total field width to see if an integer number of strips results. If this is not the case, then it is recommended that the designer round off to the next higher and lower integer number and work back through the calculations to get a revised strip width, unit width inflow rate, inflow time and advance time. Agricultural machinery may also constrain the appropriate strip width. The strip width should nominally be an even integer muliple of the implement width. Once the revisions have been accomplished, the following constraints are checked:

1) ratio of inflow time to advance time should be $\geq$ 0.5 for clayey soils and $\geq$ 0.75 for sandy soils (Gates & Clyma, 1980a),
2) maximum flow depth for the unit width stream is calculated. The minimum bund height recommended is this maximum flow depth plus a freeboard of 30 mm.
3) a relatively large stream of water is needed for efficient level border strip irrigation, and as such, facilities to allow two or more turnouts per strip must be considered so that the proper stream size is supplied without causing erosion.

If all conditions check, the design is acceptable. Design parameters, desired efficiency, etc. may need to be altered if constraints are not met or if any other unacceptable condition results.

Level border strips are constructed by forming bunds or dikes, which are high enough to contain the maximum expected flow depth with a freeboard of at least 30 mm, at the designed spacing. Often a small ditch or furrow adjacent to the bund, and on either side, is formed (as a result of construction). Irrigation water advance and distribution is facilitated by these furrows and they should not be removed or blocked.

Figure 2 and Table 4 were developed by the SCS, USDA (1974), as design aids in their level border design procedure. This relationship between water

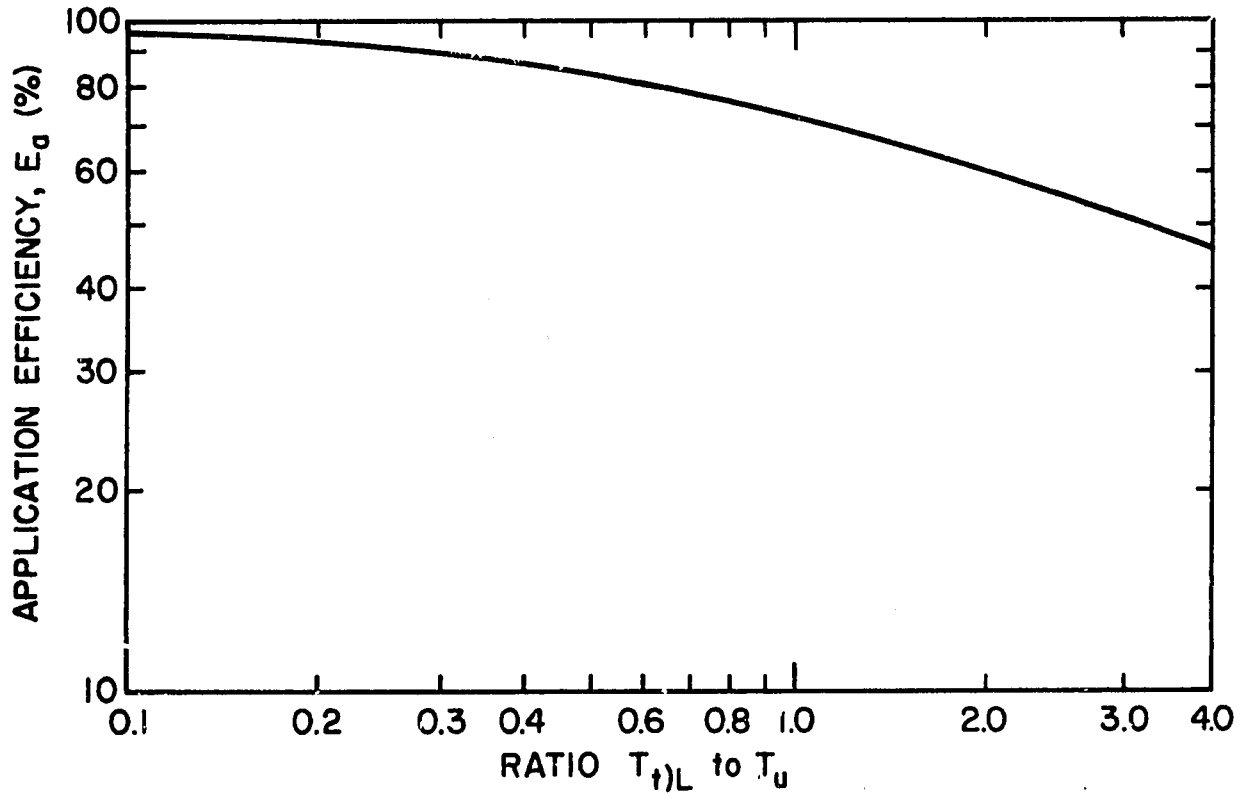

Figure 2: Chart relating application efficiency ,E_a, to the ratio between total advance time ,$T_{t)L}$, and design infiltration opportunity time, T_u, in level-border irrigation (after Gates and Clyma, 1980a).

Table 4. Ratio of $T_{t)L}$ to T_u for Various Values of Application Efficiency (after Gates and Clyma, 1980a).

Application Efficiency	$T_{t)L}$ to T_u
Percent	Ratio
95	0.16
90	.28
85	.40
80	.58
75	.80
70	1.08
65	1.45
60	1.90
55	2.45
50	3.20

$$E_a = 69.98 - 15.39 \ln (T_{t)L}/T_u)$$
$$(r^2 = 0.99)$$

application efficiency and the ratio of advance time (to the end of the field) to the opportunity time required for the design depth to infiltrate has been developed by the SCS as a result of numerous simulation studies (see USDA, 1974 and Gates and Clyma, 1980a).

The SCS level border design model has been encoded for use on the HP-9825 desktop computer and the HP-67 handheld programmable calculator. Program listings, user instructions, discussion and examples are provided in Appendix A for the HP-9825 and Appendix B for the HP-67. These computer programs significantly aid in the computational procedures of the design. The designer is allowed, therefore, to look at numerous design conditions and alternatives in a relatively minimal amount of time. Calculation errors are also miminized. The programs are simple to use given the user follows all the steps carefully and has all the design input data available. An initial, simplified version of the level border design program for the HP-67 was presented in EWUP (1982f).

The HP-9825 program also contains a routine to perform a very simple evaluation of a level border irrigation given the proper input data. No attempt is made to characterize the application uniformity. Only a gross volume balance is performed.

Level Furrow Design

In level furrow design, the designer usually seeks to find the inflow rate for each furrow based on the input design conditions such that an acceptable irrigation time and application efficiency result. Sometimes the irrigation time is also specified, and some compromise between a reduction in losses at the upper end of a field and underirrigation at the lower end is necessary.

The SCS level furrow design model calls for the following input design parameters: 1) furrow length, 2) furrow spacing, 3) SCS intake family and intake function parameters, 4) design requirement depth, 5) Manning's n-value (commonly n = 0.04 for furrow design). A range of possible furrow inflow rates should be tested. Flow rates too low will result in excessive water advance times and poor performance. Flow rates too great will cause erosion in the furrow and overtopping of the furrow ridge. Site specific conditions will generally constrain the range of possible trial flow rates. The larger the stream is, however, the better the performance will be. Also, for a given discharge, the uniformity of application varies inversely with

intake rate; better uniformity with lower intake and vice versa. Thus, for level furrow irrigation the furrows must be large, deep and well-made. Good tillage and maintenance of furrow cross-section through the season is strongly recommended. A cross-furrow(s) should always be constructed at the far end of the furrows so that water in furrows which advances faster is directed back through the slower furrows (from the far end). This facilitates faster coverage of the field and water distribution.

For each trial furrow stream the model will determine the required application time, estimated advance time, furrow wetted perimeter, the depth applied, the deep percolation and the application efficiency or the model assumptions require the design depth to be infiltrated at all points. Thus, the goal is to minimize the deep percolation loss, or conversely maximize application efficiency. The designer chooses the furrow inflow rate which best meets this and is within site specific constraints. With the total flow available at the field inlet known, the designer then determines the number of furrows which can be irrigated in one set.

The SCS level furrow design model has been encoded for use on the HP-9825 and HP-67 computers. Program listings, user instructions and discussion, and examples are given in Appendix A and Appendix B. An initial version of the HP-67 program was presented in EWUP (1982f). Criteria such as limiting the furrow inflow rate to a maximum of 4 lps, the application efficiency to a minimum of 90%, the average intake opportunity time to a maximum of 2880 min, and the length to a maximum of 150 m, all based on Abu Raya conditions, were also recommended to aid the design selection. Such site specific conditions and constraints should be developed and refined at individual areas as experience with this method is developed. The user is cautioned to follow the step-by-step program instructions closely to ensure successful usage.

As for the level border program, the HP-9825 program for level furrows also contains a simple, gross volume balance, evaluation routine. Again, no attempt is made to characterize application uniformity in the routine.

EFFECTS OF DESIGN PARAMETER VARIATION

As implied earlier, an irrigation system is usually designed to supply the crop water requirements during some peak use period., Typically, such a

design may be based on the design conditions (i.e., design parameter values) at the time of the peak use period. The variation over time of the design parameters is an important consideration which is often neglected. The designer must be aware of the effects of design parameter variation on system performance to formulate an effective design and to develop appropriate system management recommendations (Gates, 1980; Gates and Clyma, 1980b).

The design conditions at Abu Raya and the large temporal variations of those conditions provide a good example. These are analyzed individually in Part II of this report. The purpose here is to discuss generally, the effects of design parameter changes and the recommendations for dealing with those changes. For example, in Abu Raya, significant variation in the soil intake characteristics occurs during the season, saqia flow rates can be extremely variable during an irrigation and through the season, surface roughness can change appreciably and is dependent on the local tillage practices, and the required depth of application is not always its maximum during the peak consumptive use period.

An initial analysis of system performance sensitivity to design parameter changes was given in EWUP (1982f). The design models were used to predict system performance when certain variables were changed. The results of such an analysis are the "best" designs for such input conditions, and a comparison with the original design case gives the designer insight to the effects of the changes.

For level border design the analysis was for the effects of changing the available discharge. The results showed that the available discharge must drop to 50% of the original design value before unacceptable results are obtained, i.e. application efficiency less than 80%. This was a case, however, when both the discharge and inflow time were varied, as the design model will do this in formulating the "best" design. If only the discharge is allowed to vary while other design conditions are held constant, the results show a much quicker and more significant response (and the trend is also reversed, i.e., a lower discharge gives a greater application efficiency but there is increasing underirrigation). This is illustrated in Table 5 for the design conditions presented therein (which are typical for Abu Raya). Note that for this case, varying the discharge outside of a range from 75% to 125% of the initial design discharge gives unacceptable system performance. Either

the water requirement efficiency is low (underirrigation) or the application efficiency is low (overirrigation). The same type of analysis can be made for the design requirement depth. If this depth is less than the initial design value, then overirrigation will occur. Underirrigation will occur if the opposite is true. This assumes all other design conditions remain constant.

On level border strip systems installed in Abu Raya, an effort is often made to shut off the water to a given strip when the advancing stream reaches the end of the strip (set application time equal to advance time). Using the design in Table 5 illustrates what happens. If the calculated application time of 112.6 min is reduced to just 74.1 min, then the gross application is reduced to 71.2 mm, the application efficiency goes to 100%, but the water requirement efficiency drops to 71.2%. In general, when the application and advance times are set equal (for a given design in which the application time is greater than the advance time), then the depth applied will decrease, the application efficiency will increase to a maximum of 100% and the water requirement efficiency will decrease (once E_a = 100%). The magnitude of change depends on the difference in design application and advance times. If the design application time is less than the advance time, then when application and advance times are set equal, the gross depth applied will increase, the application efficiency will decrease and deep percolation will increase. In this case, the water requirement efficiency will always be (theoretically) 100%. The magnitude of change again depends on the difference in design application and advance times. For practical purposes it must be noted that the design model does not always accurately predict actual field water advance. Thus, when water reaches the end of the strip, the volume applied may be more or less than the design. A quick, easy calculation of depth applied (knowing strip area, discharge rate and time) compared to an estimate of the required application will indicate if enough water has been applied or if more time is needed.

For the sake of brevity, an analysis for level furrows similar to that in Table 5 for level borders is not included. It is noted, however, that the results and conclusions reached would be essentially the same.

For level furrow design, analyses in EWUP (1982f) were for effects of changes in intake rate, furrow inflow rate, roughness, design depth and length. Once again, the design model was used for simulation. Since "best"

Table 5. Effect of varying discharge on level border system performance when all other parameters are held constant.

Basic Design Data

I_f = 0.5 a = 1.186 mm b = 0.756 c = 6.985 mm
Length = 80.0 m Surface Roughness = 0.15
Design Requirement Depth = 100.0 mm
Desired E_a = 90%
Total flow available at field = 25.6 lps
Total field width = 80.0 m

Design Results

Number of Strips = 4 Strip width = 20.0 m
Unit Inflow Stream = 1.28 lps/m Inflow Time = 112.6 min
Depth Applied = 108.1 mm E_a = 92.5%

Estimated Advance Time = 74.1 min

Parameter	Ratio of Test Inflow Stream to Initial Design Inflow Stream 0.5	0.75	1.00	1.25	1.50
Unit Inflow Stream (lps/m)	0.64	0.96	1.28	1.60	1.92
Inflow Time (min)	112.6	112.6	112.6	112.6	112.6
Depth Applied (mm)	54.0	81.1	108.1	135.1	162.1
Deep Percolation (mm)	0.0	0.0	8.1	35.1	62.1
Application Efficiency (%)	100.0	100.0	92.5	74.0	61.7
Requirement Efficiency (%)	54.0	81.1	100.0	100.0	100.0

designs are formulated, the inflow time usually also varied with the other parameter changes. The general trends determined were:

a) Application efficiency decreases as intake increases.

b) Application efficiency is acceptable for a range of furrow inflow rates from 2.0 to 4.0 lps. For inflow rates less than 2.0 lps, inflow times are excessive and for inflow rates greater than 4.0 lps, furrow scour and overtopping is expected to occur.

c) Greater surface roughness tends to increase the flow depth causing increased intake. This results in larger inflow times being required; advance time is slower. The effect is not large, however.

d) The design model predicts a lower application efficiency will result when design depth is half the original value, i.e., it becomes increasingly difficult to maintain high efficiency, with uniform application, for smaller requirement depths.

e) It is increasingly difficult to maintain high application efficiency with uniform application for increasing furrow lengths.

Assuming only one parameter were varied while the others were held constant, similar results would be obtained as discussed for level borders. However, in some cases the trends may be reversed as was shown.

Given that the designer has information available on the temporal changes of system design parameters, design and management recommendations such as follows should be considered. In this case, it is assumed that an initial design has been formulated, the system constructed, and in operation.

a) If available discharge rate is less than expected, the irrigation time must be longer to ensure adequate coverage of the field. If the discharge rate is greater, reduce the application time to get the appropriate depth applied.

b) If the intake rate is greater than expected, either increase the discharge rate (if possible) or increase the application time to insure adequate coverage of the field. If intake rate is less than expected, the irrigator must be careful not to overirrigate, overtop the boundaries, or inundate the crops for too long a period of time.

c) If the requirement depth is greater than expected increase the application time. Decrease application time for the opposite case.

Most often the prevailing conditions at irrigation time will deviate from the design conditions in some combination rather than individually. The designer

should use the knowledge of the effects of individual parameter variations, in combination with how the conditions at irrigation time deviate from the design conditions, to formulate recommendations for the irrigator on how to manage the system through the season. Site specific conditions must be considered and may indicate trends which can be used for general recommendations.

SUMMARY

This part of the report has focused on an introduction to level irrigation system design as developed by the USDA-SCS. Design model assumptions and development were briefly reviewed. Design programs for the HP-9825 and HP-67 computer/calculators have been presented with user instructions, program listings and examples included in Appendixes A and B. These programs greatly aid design formulation allowing the designer to look at a wide range of design conditions with minimal effort. The general effects of design parameter variation on system performance have been reviewed. The designer uses this information to assist irrigators with irrigation system management recommendations for better water management as conditions indicate.

II. FARM IRRIGATION SYSTEM DESIGN CONSIDERATIONS, ABU RAYA, KAFR EL SHEIKH

INTRODUCTION

To effectively design farm irrigation systems, the designer must collect or obtain specific information about the site or area for which the design is to be made. Such information includes, but is not limited to:

A. Crop data: patterns, growing seasons, rotations, cultural and tillage practices, any available local crop water use information, conventional practices for irrigation timing and frequency, etc.

B. Soils data: type, texture, moisture characteristics, intake characteristics, salinity, drainage, drain water quality, etc.

C. Water supply data: timing, quantity & rate of delivery, water quality, continuous or rotational supply, etc.

D. Physical data: farm sizes and field sizes, boundary conditions, field slopes or general topography of the area, etc.

E. Conventional farmer irrigation and water management practices. Typically, the above types of information have both spatial and temporal variability. The designer should obtain some idea of this variability so that a range of design conditions can be investigated. The designer uses the compiled information to formulate the specific design data used as inputs in the design models discussed in Part I of this report. The expected values of the design parameters and their variability allows the designer to formulate a range of possible designs for field implementation. Engineering judgement and experience gained from trial designs will aid in the selection of the most suitable designs.

The purpose of this section of this report is to present and discuss design data and information to be used in level farm irrigation systems design. These data are specific to the Abu Raya area, Kafr El Sheikh Governorate. Significant amounts of information on local conditions which affect irrigation design have been collected over the several seasons of EWUP work in Abu Raya. These data have been summarized. Individual treatment and discussion of the state variables and management considerations as related to the SCS level system design models is included. The goal is to provide the reader with a process to be used in analyzing site specific design conditions and management factors using an actual case study. Development of recommendations for level systems design using the SCS design models, specific to the conditions at Abu Raya, is the end result. It is noted, the results of this study are applicable to many areas of Egypt having similar conditions, especially the Delta area. Short intensive field investigations covering such items as crop pattern, soil intake characteristics, etc. specific to a given area can be conducted to further extend the applicability of the investigations summarized here.

FACTORS AFFECTING DESIGN

Water Supply and Delivery Characteristics at Abu Raya

Irrigation water is delivered to the farm turnout or lifting point through the private mesqa. Water is delivered to mesqas from branch canals. Branch canals and consequently the watercourses they serve, receive water on a rotation basis. Irrigation rotations for the Abu Raya area have been fully

discussed in EWUP (1982a), but are dependent on crop and season. Water delivery surface elevation at farm turnouts (i.e., at saqia inlets) is below the surrounding agricultural land elevation, usually about 0.5m to 0.7m, during "on" rotations. Farmers are thus required to lift water for application to their fields. This is accomplished most often using saqias (animal-powered waterwheels) and sometimes by small diesel pumps. Mesqas in Abu Raya, being the farmer's responsibility for routine maintenance and cleaning, are often in poor condition, as compared to the rest of the delivery system. Mesqa inlets from branch canals are pipe vents of a specific diameter with no gates or other control. Consequently, during periods of low water demands surplus water in the system can fill up the mesqas. Due to the poor mesqa maintenance (eroded banks, reduced cross-sections) the mesqas at the end of the system may often flood adjacent land or farmers will cut the bank near a ditch which flows directly to a drain. This condition sometimes also allows irrigation by direct gravity flow from the mesqa.

The 3m-diameter saqia is used almost exclusively in Abu Raya. There are 6 kados (or openings) in these saqias. Cows and water buffalo (gamusa) are used for the animal power, although occasionally a camel is used. Water is lifted from a brick-lined well connected to the mesqa. Each of the 6 outside "scoops" picks up water and channels it to the center of the saqia, where it is discharged into a pipe or brick lined channel for conveyance under the animal travel path, after which there is normally an earth channel (marwa) going in two directions. The farmer can divide the flow or channel it all in one direction at this point.

Saqia discharge tends to be a function of the width of the saqia, the lifting head, and animal power management. The age of the saqia, its condition (holes, rusted out patches, etc.) and the condition of the transition from the saqia outlet to the pipe or channel under the animal path (where backflow to the saqia well can occur) also affect the actual delivery of water to the point where measurement of flow rate is made. Slack (1982) has provided detailed descriptions of the history of saqia development, the types of saqias, saqia construction, and measurement of saqia discharge. Three methods were developed and compared for determining the volume discharge per revolution of the saqia.

1) A Cutthroat flume technique suggested as best suited for heavily damaged saqia.
2) A measuring-device technique in which a device is used to measure the shape and size of a kado to determine water volume lifted by the kado.
3) A generalized characteristic curve technique based on field measurements of saqias in which a few easily measured geometric parameters are used to determine the volume discharge.

Slack (1982) suggests the accuracy of all three methods is within ±20-30%; the accuracy being dependent upon the variability of site measurements. Using the general characteristic curve method, Slack (1982) reports an average volume discharge of 600 liters per revolution of a 3m-diameter, 6 kado, 17-cm wide saqia (typical of those in Abu Raya), at a head lift of 75 cm. Slack (1982) indicated that under normal conditions with animal power, the saqia would rotate at about 3 rpm. Using these estimates, an average saqia discharge rate of 30 lps is determined. Wahby, et al. (1980) presents a saqia discharge data analysis which yields about 27.5 lps discharge for the same 75-cm lift, 3 rpm conditions.

Various irrigation measurements which have been made in Abu Raya for several seasons have been summarized to determine saqia flow rate characteristics. The results are presented in Tables 1-3; each will be discussed in the following paragraphs.

Table 1 is a presentation of the "gross" mean seasonal saqia flow rate for several sites over several seasons. The flow rates are determined from the total irrigation depth lifted and the total irrigation time. The results show a range from 21.1 lps to 44.1 lps. The overall mean value is about 32 lps with a standard deviation of 5 to 6 lps. Determining the mean saqia flow rate in this way provides only a gross indication of actual conditions. Saqia flow rates are variable from irrigation to irrigation and can vary considerably during an irrigation.

In Table 2 the variation of the mean saqia flow rate for individual irrigations at several sites is given. These mean values are based upon actual flow rate measurements during irrigation. The variation in mean flow rates from one irrigation to the next can be quite large, i.e., for the two rice sites presented (3-01, 3-25-8) values range from 25.1-63.4 lps and 14.0-50.9 lps, respectively. As discussed earlier, the lower means are probably for irrigations conducted during the off rotations. Using the

TABLE 1. Computed[1/] mean seasonal saqia flow rate, Abu Raya, Kafr El-Sheikh.

Site	Season	Total Depth Lifted (cm)	Total Irrigation Time (min/Fed)	Mean Seasonal saqia Flow Rate (lps)
3-08 a	79-80 (w)	63.8	1439	31.0
b		64.6	1888	23.9
3-09 a	"	62.9	1766	24.9
b		91.3	2185	29.3
3-10 a	"	56.3	1462	27.0
b		92.1	2189	29.5
3-11 a	"	64.6	1186	38.1
b		105.1	2431	30.3
3-12 a	"	77.3	1559	34.7
b		82.3	1921	30.0
3-01 a	"	51.0	914	39.1
b		54.2	1105	34.3
3-02 a	"	44.5	802	38.8
b		74.0	1628	31.8
3-16 A_1	80 (s)	151.0	2775	38.1
A_o		136.0	2904	32.8
3-17 A_1	"	106	2090	35.5
A_o		124	2846	30.5
3-13 A_1	"	114	2379	33.5
A_o		93	1946	33.4
3-14 A_1	"	82	1942	29.6
A_o		96	2633	25.5
3-15 (a) A_1	"	78	1577	34.6
A_o		72	1944	25.9
3-15 (b) A_1	"	114	2123	37.6
A_o		92	1581	40.7
3-10	80-81 (w)	66	1900	24.3
3-22	"	60	1550	27.1
3-21	"	61	1468	29.1
3-02-6	"	80	1340	41.8
3-19	"	56	1412	27.8
3-20	81 (s) Cotton	70	1395	35.1
3-22	"	81	1868	30.4
3-10	"	107	2603	28.8
3-01	81 (s) Rice	163	2588	44.1
3-25	"	195	3790	36.0
3-01	81 (s) Maize	85.1	2311	25.8
3-10	"	62.6	2082	21.1
				Mean: 31.9 ± 5.5

[1/] Mean seasonal saqia flow rate computed from:

$$Q\ (\text{lps}) = \frac{700\ d_{total}\ (\text{cm})}{t_{total}\ (\text{min/Feddan})}$$

TABLE 2. Selected saqia flow rate data, Abu Raya, Kafr El-Sheikh. 1/

Site	Season	Mean saqia flow rate during irrigation (lps)										Seasonal Mean (lps) 2/
		Irrigation Number										
		1	2	3	4	5	6	7	8	9	10	
3-01-4 (01)	78-79 (w)	14.9	26.7	34.1	23.4	-	-	-	-	-	-	24.8 ± 8.0
3-01-6 (01)	"	33.5	39.9	35.0	46.4	-	-	-	-	-	-	38.7 ± 5.8
3-02-1 (07)	"	-	34.9	37.6	13.4	33.8	34.6	23.5	-	-	-	29.6 ± 9.3
3-03-1 (03)	"	-	37.5	19.1	-	-	45.9	-	-	-	-	34.2 ± 13.7
3-01-4 (09)	"	-	32.7	-	12.7	35.6	-	29.5	30.6	-	-	28.2 ± 9.0
3-02-2	"	18.4	24.5	36.8	36.8	50.4	54.6	40.3	29.4	29.4	34.9	35.6 ± 11.1
3-02-8	"	-	-	32.1	43.2	35.6	35.0	33.7	35.0	36.9	35.0	35.8 ± 3.3
3-01-4 (02)	"	-	34.0	37.1	23.2	39.0	-	-	-	-	-	33.3 ± 7.1
3-03-1 (01)	"	-	18.6	18.9	18.9	16.2	23.6	-	-	-	-	19.2 ± 2.7
3-01 (wh)	79-80 (w)	36.8	44.8	-	-	-	-	-	-	-	-	------
3-02 (wh)	79-80 (w)	32.1	39.7	-	-	-	-	-	-	-	-	------
3-02 (2)	80-81 (w)	38.1	38.6	46.5	32.2	-	-	-	-	-	-	38.9 ± 5.9
3-02 (6)	80-81 (w)	45.0	50.6	43.6	31.0	-	-	-	-	-	-	42.6 ± 8.3
3-01	81 (s)		(Rice crop: 25 irrigations; range of values = 25.1 - 63.4)									46.[illegible] ± 10.3
3-25-8	81 (s)		(Rice crop: 25 irrigations; range of values = 14.0 - 50.9)									36.9 ± 7.9
3-10-05	81-82 (w)	-	24.6	20.8	18.2	-	-	-	-	-	-	21.2 ± 3.2
												Mean: 33.3 ± 7.9

1/ Saqia size is 3m diameter with 6 outlets; cows and gamusa are used to operate the saqia. 0.20m x 0.90 m cutthroat flumes were installed within 5 m of saqia outlet to measure flow rate.

2/ Values are means ± the standard deviation. Not all the irrgations during the season may have been measured on some of the sites.

TABLE 3. Selected saqia flow rate and field inflow rate data showing variation and marwas losses during individual irrigations, Abu Raya, Kafr El-Sheikh.

Site	Irrigation Number	Season	Variation in Saqia flow rate (lps) during irrigation 1/				Variation in Field flow rate (lps) during irrigation 1/			
			Min.	Max.	Mean	Std. Dev.	Min.	Max.	Mean	Std. Dev.
3-02-2	1	80-81 (w)	20	48	38	7	19	36	26	4
	2		30	53	39	6	21	31	26	4
	3		33	59	46	7	20	36	28	5
	4		19	47	32	9	17	26	23	3
3-02-6	1	"	39	51	45	4	23	35	29	5
	2		35	70	51	12	15	36	28	7
	3		39	51	44	4	19	30	24	3
	4		23	39	31	5	7	20	14	6
3-02-8	3	"	42	57	48	4	11	29	18	4
	4		40	56	50	5	7	15	12	3
3-02-10	2	"	32	51	42	5	11	30	25	5
	3 2/		26	43	33	6	18	24	20	2
3-21-9	2	"	47	55	54	2	28	38	36	2
3-19-23	4	"	26	51	37	8	20	36	26	5
3-10-5	2	81-82 (w)	22	29	25	2	11	14	13	1
	3		15	26	21	4	7	13	12	2
	4		13	23	18	4	8	13	11	2
Mean (± std.dev.) 3/			29(±10)	48(±12)	38(±11)	--	15(±6)	27(±9)	22(±7)	--

1/ Saqia flow rate measured uning 0.2m x 0.9m cutthroat flume installed within 5m of saqia outlet. Field flow rate measured using 0.2m x 0.9m cutthroat flume installed in marwa near head of field or at field inlet.

2/ Irrigation by small 5-hp diesel pump.

3/ The overall mean saqia flow rate of 38 lps and the overall mean field flow rate of 22 lps illustrate a mean marwa conveyance loss near 40%:

$$\text{Mean Loss} = \frac{38 - 22}{38} \times 100 = 42\%$$

This is consistent with the results found in EWUP Draft Working Paper #89, Progress Report: On-Farm Conveyance Losses on Abu Raya Farms, Kafr El-Sheikh. (EWUP, 1982 d).

information in Table 2, seasonal mean flow rates were determined. A range of 19.2 lps to 46.9 lps is shown, with the overall mean of about 33 lps and standard deviation of about 8 lps. These values are consistent with the results of Table 1, but do indicate a higher degree of variability exists in the irrigation to irrigation flow rates.

The analysis is carried two steps further in Table 3. Saqia flow rate variability during individual irrigations at several sites is presented. Furthermore, marwa conveyance losses were measured for these irrigations and the variability in the flow rate at the field inlet is thus available. A glance at minimum, maximum, mean and standard deviation gives a good idea of the saqia flow rate variability during irrigation. The range in observed flow rates is generally from 80% to 100% of the minimum observation. The mean of minimum observed saqia flow rates is 29 lps, the mean of the maximum is 48 lps and overall mean is 38 lps with a standard deviation of 11 lps. The high degree of variation is most likely due to the variation in animal power and speed vs. the timing of the flume measurements. It is possible the animal may be moving slower or faster than average (or not at all) at the time of measurement.

Field inflow rates have been consistently much less than the saqia flow rates due to marwa losses. The variation in individual observations is dampened somewhat compared to the variations observed at the saqia. The mean of minimum observed values is 15 lps, the mean of the maximum is 27 lps, the overall mean is 22 lps with a standard deviation of 7 lps. It is noted in Table 3 that an average marwa conveyance loss near 40% is shown by these data., Further discussion of farm conveyance losses in Abu Raya is given in EWUP (1982d).

One irrigation included in Table 3 was by a small 5 hp diesel pump (site 3-21-9). A mean flow rate for the pump of 54 lps was determined with a standard deviation of only 2 lps. Such consistent delivery is expected by mechanical methods. More consistency in flow rates can also be achieved through use of a natural gravity delivery, i.e., the agents of variability: the saqia and animal power are eliminated. Natural gravity delivery could be provided through a system, where the mesqas are raised and water is provided to them by diesel pumping or gravity delivery from the branch canal. With a farmers' organization established on such a mesqa to control operation and

water scheduling, farmers would be assured of a more consistent delivery flow rate, which in turn will provide for more efficient farm irrigation.

Site 3-02-6, 1980-81 winter season has been included in each of the three tables. In Table 1, an overall seasonal mean saqia flow rate near 42 lps was calculated. In Table 2, the mean irrigation flow rates varied from 31 to 51 lps for the 4 irrigations for a seasonal mean near 43 lps. In Table 3, the minimum observed value and the maximum observed value of saqia flow rate for the 4 irrigations are 23 lps and 70 lps, respectively. Using the observations of all 4 irrigations, the mean is about 41 lps with a standard deviation of about 10 lps. This particular saqia would be considered one in better condition, resulting in the higher average discharges. It is interesting to note that the means determined in the three cases are relatively equal.

For design purposes, the designer will have to provide a best estimate of the saqia flow rate and the field inflow rate (based on marwa conditions). It was shown in Part I of this report that varying the available discharge (while holding other factors constant) results in changes in irrigation time, advance time, depth applied and water application efficiency. An example was given showing that the unit width inflow rate at the field must decrease by half to drop the application efficiency from 90% to 80%. With this in mind and based on the data presented in this section, a safe assumption for average saqia discharge would be on the order of 30 to 35 lps. Depending on marwa conditions and length, losses in the range of 25% to 40% should be expected. This would yield field inflow rates on the order of 20 to 25 lps. This value is necessary for determing border width or number of furrows to irrigate in one set. If marwa improvements are made: renovation, shaping and compaction, estimated losses of at least 10% should be included. If plastic lining is used then losses could be expected to be zero and the full saqia flow would be available at the head of the field. Redesign of farm irrigation system layouts using level border strips and long level furrows often results in the elimination of marwas, which helps to decrease water losses. Elimination of conveyance losses in this area is very important, as the lost water is also completely lost from the system being discharged to the sea.

Infiltration Characteristics of Abu Raya Soils

A broad-based soil characteristics survey was conducted in 1978 in Abu Raya using a 10-Feddan grid sampling procedure (Abdel-Wahed, et al.,

1982). The survey delineated three basic soil series with several phases for each series. The most common soils were the Typic Torrerts of the Vertisol order, common throughout the alluvial soils of the Nile Valley and Delta. Vertisols are heavy clay soils with a high content of montmorillonite type clay particles. Consequently, the soils of Abu Raya are subject to excessive cracking upon drying and expansion upon wetting. When kept wet, such soils have low infiltration rates.

Several tests have been conducted to determine the range of infiltration characteristics of Abu Raya soils over the period since 1979. Generally, these tests have been made using either a double ring cylinder infiltrometer or a single ring cylinder infiltrometer when the test was conducted during an irrigation. One type of test used called for measurements of the depth of water inside the cylinder to be made at different time intervals as the water level receded. The volume of water required to bring the water level in the ring up to a pre-set level after intervals of time was measured for another type of test in which the water level is maintained at a constant level. Water levels in the cylinders were generally kept at or less than the expected maximum depth during an irrigation.

The data obtained were reduced to the form of accumulated depth infiltrated in (cm) vs. elapsed time in (minutes). These data were then subjected to a curve fitting regression technique on the HP-67 calculator to determine the "best fit" regression coefficients, in a power function of the form:

$$z = k\ t^{a}$$

This is the simple and well-known empirical infiltration function of the Kostiakov (1932) form, where z is the accumulated depth infiltrated (cm), t is elapsed time (minutes), and k (cm/min^{a}) and a (dim.) are empirical regression coefficients.

Available test data from January 1979 (<u>birsim</u> crop), May-June 1980 (cotton crop), May-June 1980 (dry soil before rice crop), December 1980 (dry soil at planting or first irrigation of wheat and bean crops) and January 1981 (at second irrigation of wheat and bean crops) were analyzed using the above method. The results of the individual regressions and averages for the different sites are given in Table 4, parts A through E, respectively.

TABLE 4. Cylinder Infiltration Test Results,

1979 - 1981, Abu Raya, Kafr el-Sheikh

	Site	Test Date	Crop	Infiltration function of form: $z\ (cm)=kt(min)^{a}$ 1/ k	a	r^2 2/
Part A						
O	3-03-2	27 Jan. 79	Berseem	0.2547	0.5303	0.97
O	3-03-2	27 Jan. 79	Berseem	0.0819	0.6723	0.99
	ave.	"	"	0.1625	0.5823	0.99
H	3-02-3	17 Jan. 79	Berseem	0.1513	0.6941	0.99
H	3-02-3	17 Jan. 79	Berseem	0.2514	0.4981	0.96
	ave.	"	"	0.1877	0.6092	0.99
H	3-02-4	21 Jan. 79	Berseem	0.1818	0.5471	0.99
H	3-02-4	21 Jan. 79	Berseem	0.3578	0.3429	0.97
	ave.	"	"	0.2507	0.4511	0.99
O	3-03-12	23 Jan. 79	Flax	0.1032	0.7690	0.99
	Average of 7 tests			0.1746	0.5905	0.99
	This average is equivalent to SCS Intake Family of 0.2					
Part B						
O	3-16 (Head)	27 May 80	Cotton	0.2169	0.2333	0.70
O	(Middle)	27 May 80	Cotton	0.1599	0.4035	0.98
O	(Tail)	27 May 80	Cotton	0.0610	0.5220	0.96
	ave.	"	"	0.1400	0.374	0.97
M	3-15 A	5 Jun. 80	Cotton	0.8466	0.2514	0.98
M	3-15 B	5 Jun. 80	Cotton	0.4417	0.5248	0.97
	ave.	"	"	0.5695	0.4176	1.00
M	3-13	8 Jun. 80	Cotton	1.2419	0.3306	0.98
M	3-14	7 Jun. 80	Cotton	0.7478	0.3109	0.94
	Average of 7 tests			0.4968	0.3690	0.99
	This average is equivalent to the 0.1 to 0.2 SCS Intake Family					

Continued

TABLE 4. Cont'd.

Site	Test Date	Crop	Infiltration function of form: z (cm)=kt(min)^a k	a	r^2
Part C					
M 3-10 A	3 Jun 80	Before Rice	4.4992	0.2418	0.98
3-10 B	3 Jun 80	Before Rice	5.6956	0.139	0.99
ave.	"	"	5.0047	0.195	1.00
M 3-11 A	1 Jun 80	Before Rice	0.5769	0.3558	0.96
3-11 B	31 May 80	Before Rice	0.2111	0.4202	0.97
ave.	"	"	0.3919	0.3763	1.00
H 3-02 (Head)	25 May 80	Before Rice	0.5351	0.3474	0.95
(Middle)	24 May 80	Before Rice	0.0415	0.7616	0.99
(Tail)	25 May 80	Before Rice	0.2062	0.4665	0.95
(Tail)	14 Jun 80	Before Rice	0.1610	0.5106	0.99
average of 4 tests			0.2106	0.4782	0.99
average of 8 tests			1.3290	0.2700	1.00
Equivalent to very high inital intake, SCS I_f=1.0 at t=30 min, changing to low, SCS I_f=0.15 at t=1000 min					
Part D					
M 3-10 B	6 Dec 80	Wheat	4.3157	0.1848	0.97
3-10 B	6 Dec 80	Wheat	1.4502	0.3156	0.98
3-10 B	6 Dec 80	Wheat	1.3613	0.3464	0.97
ave.	"	"	2.3975	0.2584	0.98
H 3-02-2 (Head)	12 Dec 80	Wheat	0.6046	0.2346	0.85
(Middle)	12 Dec 80	Wheat	0.3401	0.3134	0.94
(Tail)	12 Dec 80	Wheat	0.4629	0.3443	0.97
ave.	"	"	0.4190	0.3848	0.99
M 3-21 (Head)	5 Dec 80	Wheat	2.7781	0.2361	0.90
(Mid. & Tail)	5 Dec 80	Wheat	0.900	0.270	0.95
ave.	"	"	1.5034	0.2829	0.99
M 3-22 (Head)	9 Dec 80	Wheat	0.3293	0.6581	0.95
(Middle)	9 Dec 80	Wheat	0.8015	0.5324	0.99
(Tail)	9 Dec 80	Wheat	1.835	0.4624	0.95
ave.	"	"	0.9613	0.5246	0.98

Continued

TABLE 4. Cont'd.

Site	Test Date	Crop	Infiltration function of form: z (cm)=kt (min)^a k	a	r^2
H 3-19-01 (Head)	2 Dec 80	Beans	0.416	0.2687	0.88
(Middle)	2 Dec 80	Beans	2.1198	0.3086	0.99
(Tail)	2 Dec 80	Beans	0.5232	0.3541	0.94
ave.	"	"	1.09	0.299	0.99
H 3-19-10 1	16 Dec 80	Wheat	0.68	0.23	0.97
2	16 Dec 80	Wheat	2.42	0.18	0.96
3	16 Dec 80	Wheat	0.19	0.41	0.95
4	16 Dec 80	Wheat	0.39	0.50	0.94
5	16 Dec 80	Wheat	0.84	0.32	0.85
6	16 Dec 80	Wheat	4.75	0.25	0.98
ave.	"	"	1.532	0.2701	0.98
Average of 20 tests			1.2436	0.3378	1.00
Equivalent to very high initial intake, SCS I_f = 1 to 1.5 at t=30, decreasing rapidly to low intake, I_f= 0.7 to 0.8 at t=100; I_f= 0.25 to 0.3 at t=1000					
Part E					
H 3-19-01	23 Jan 81	Beans	0.47	0.28	0.92
2	23 Jan 81	Beans	0.23	0.62	0.87
3	23 Jan 81	Beans	0.40	0.45	0.99
ave.	"	"	0.3827	0.4303	0.96
3-02-2 (1)	14 Jan 81	Wheat	0.2018	0.5184	1.00
(3)	14 Jan 81	Wheat	0.7677	0.3955	0.98
ave.	"	"	0.45	0.48	0.99
Average of 5 tests			0.3833	0.4611	1.00
SCS I_f = 0.30 at t=100, I_f = 0.15 to 0.20 at t=1000					

1/ This is the simple relationship first proposed by Kostiakov (1932), where k and a are empirically determined constants. When test data (depth infiltrated, cm vs. elapsed time, min) are plotted on log-log paper, k (cm/min^a) is the intercept at t=1 min, and a (dim.) is the slope of the line.

2/ r^2= coefficient of determination which indicates the goodness of fit of a regression of the data to a power function: $y=ax^b$.

Averages for a particular condition or time of year are also given, i.e., the average of all the tests conducted in December 1980 is considered representative of the soil intake conditions for the first irrigation of winter crops. The regression curves for the average intake data of a given site, plus the overall regression curve of the average intake data from several sites when conditions are considered similar, are plotted in Figures 1 to 5.

With reference to the SCS procedures for level border (USDA 1974) and level furrow (USDA, 1979) irrigation designs and the SCS methods for classifying soils into intake families, the following comments are made concerning the results in Table 4 and Figures 1-5:

1) The results for the January 1979 tests (Table 4, part A) are considered representative of the soil infiltration characteristics at mid-season for winter season. Figure 1 illustrates the range of conditions is narrow. Generally, the average condition shows a relatively low initial (t = 1 minute) intake rate, 61.9 mm/hr, decreasing to 9.4 mm/hr at 100 minutes. This would be equivalent to the 0.2 SCS intake family.

2) The May - June 1980 test results on the cotton (Table 4, part B) are considered representative of mid-season conditions for summer season crops (cotton and maize). Figure 2 illustrates that a fairly wide range of conditions existed. This is expected since there is no precipitation during the summer and the soil water depletion rate is higher, allowing the cracking nature of the soil to have a greater effect. Generally, the average initial (t = 1 minute) rate is higher, 110 mm/hr, and decreases to 6 mm/hr at 100 minutes. These conditions are also roughly equivalent to the 0.2 SCS intake family.

3) The May - June 1980 test results on the dry soil before the rice crop was transplanted (Table 4, part C) are considered representative of soil infiltration conditions when the soil is dry, cracked and has undergone some degree of tillage. Figure 3 illustrates a very wide range of conditions were found. The average condition has a very high initial (t = 1 minute) rate: 215 mm/hr. This decreases to 7.5 mm/hr at 100 minutes. In comparison with SCS intake families, it is found that the "average" curve in Figure 3 crosses several intake families. This is due to the cracks in the soil. As the soil

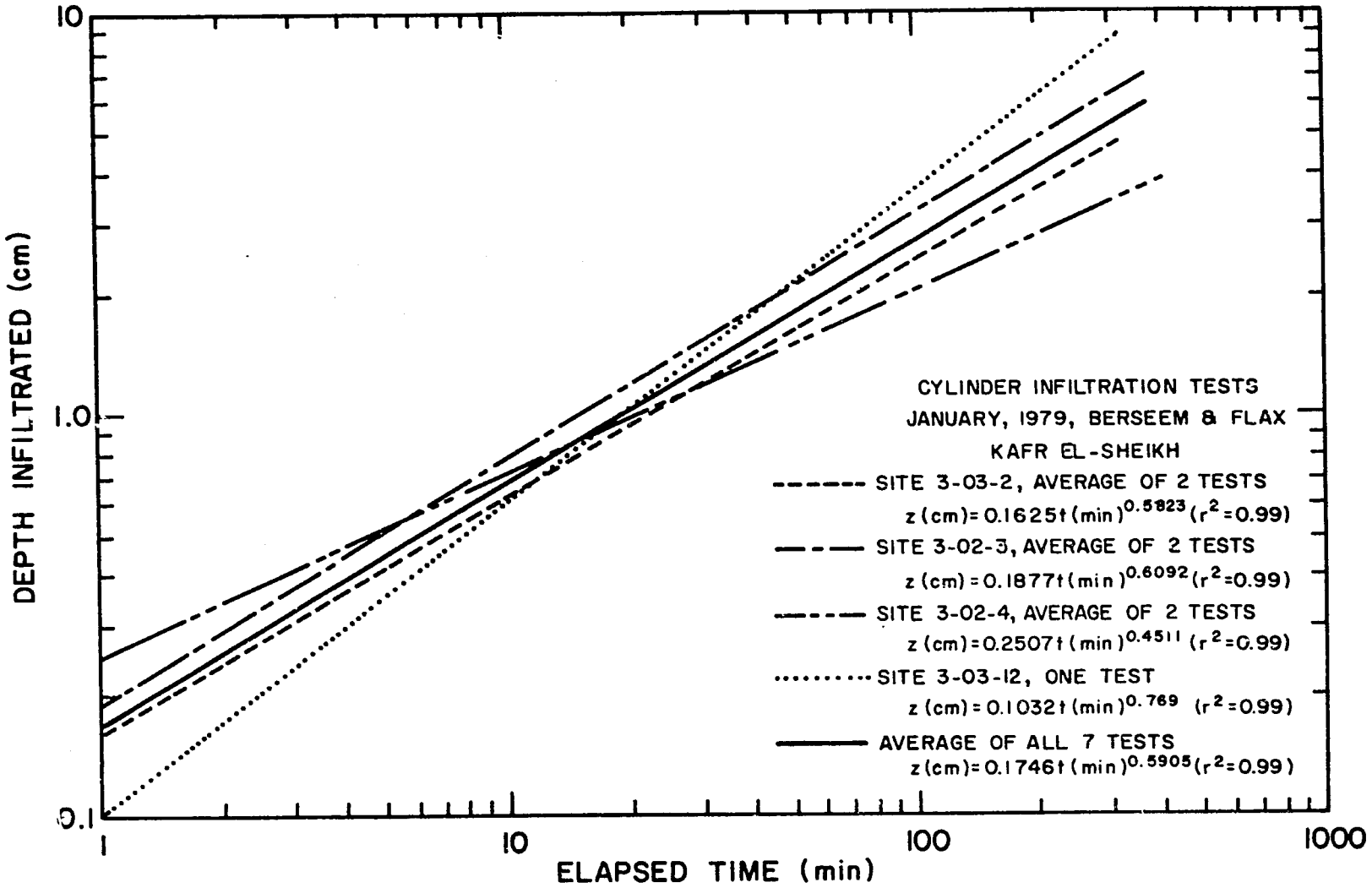

Figure 1. Regression curves for cylinder infiltration tests, January 1979, Berseem and Flax, Kafr El Sheikh.

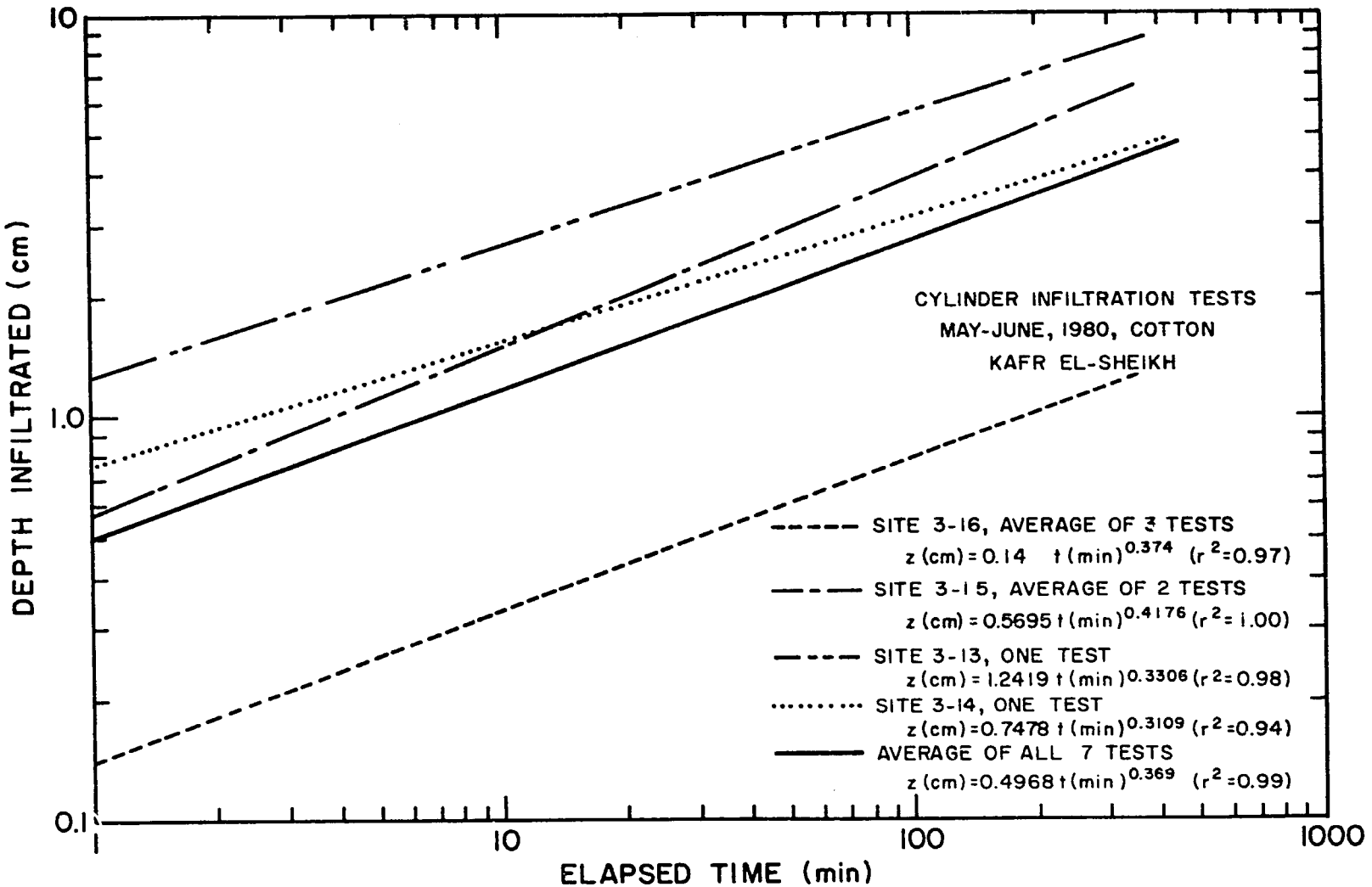

Figure 2. Regression curves for cylinder infiltration tests, May - June 1980, Cotton, Kafr El Sheikh.

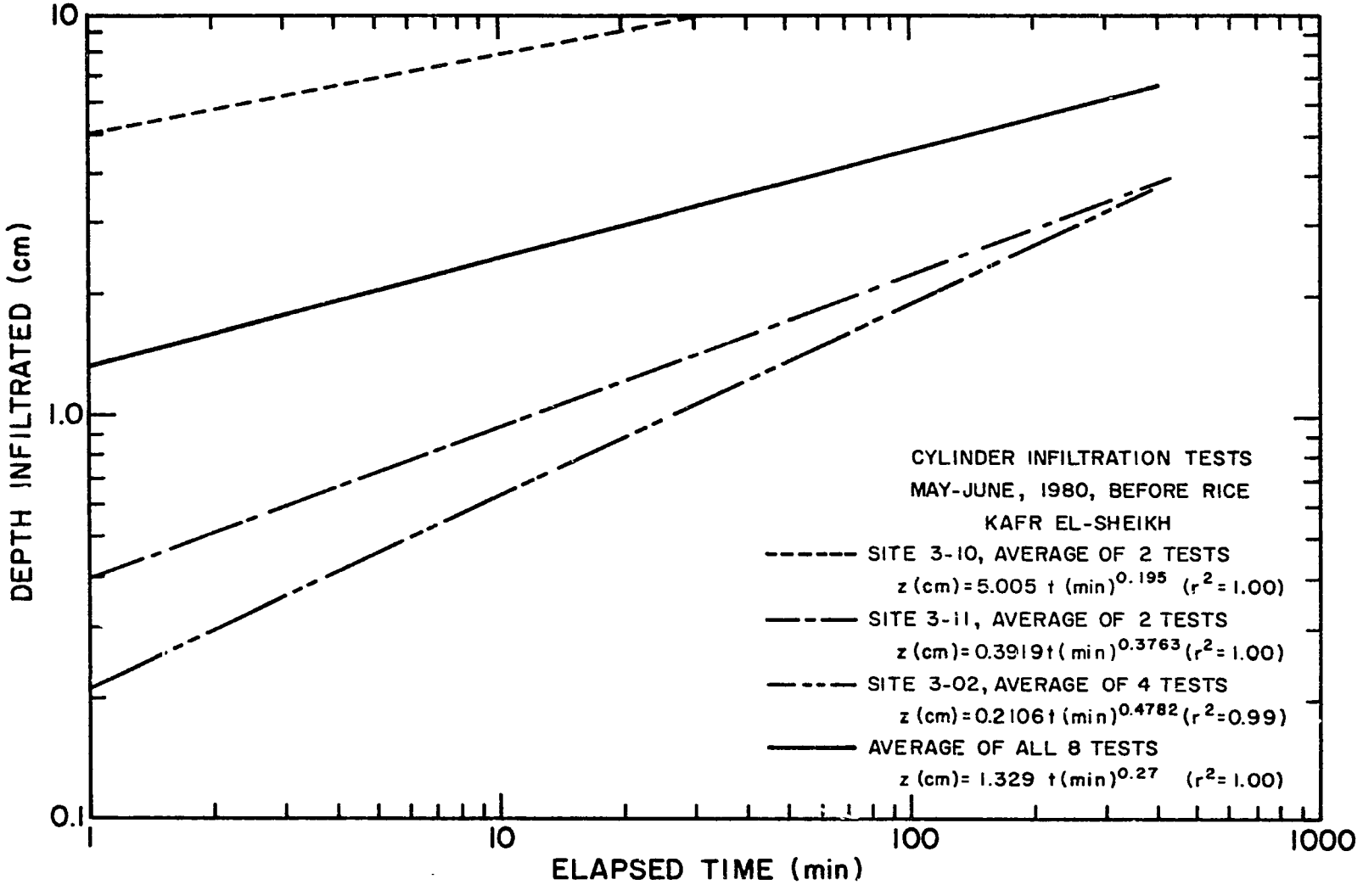

Figure 3. Regression curves for cylinder infiltration tests, May - June 1980, before rice, Kafr El Sheikh.

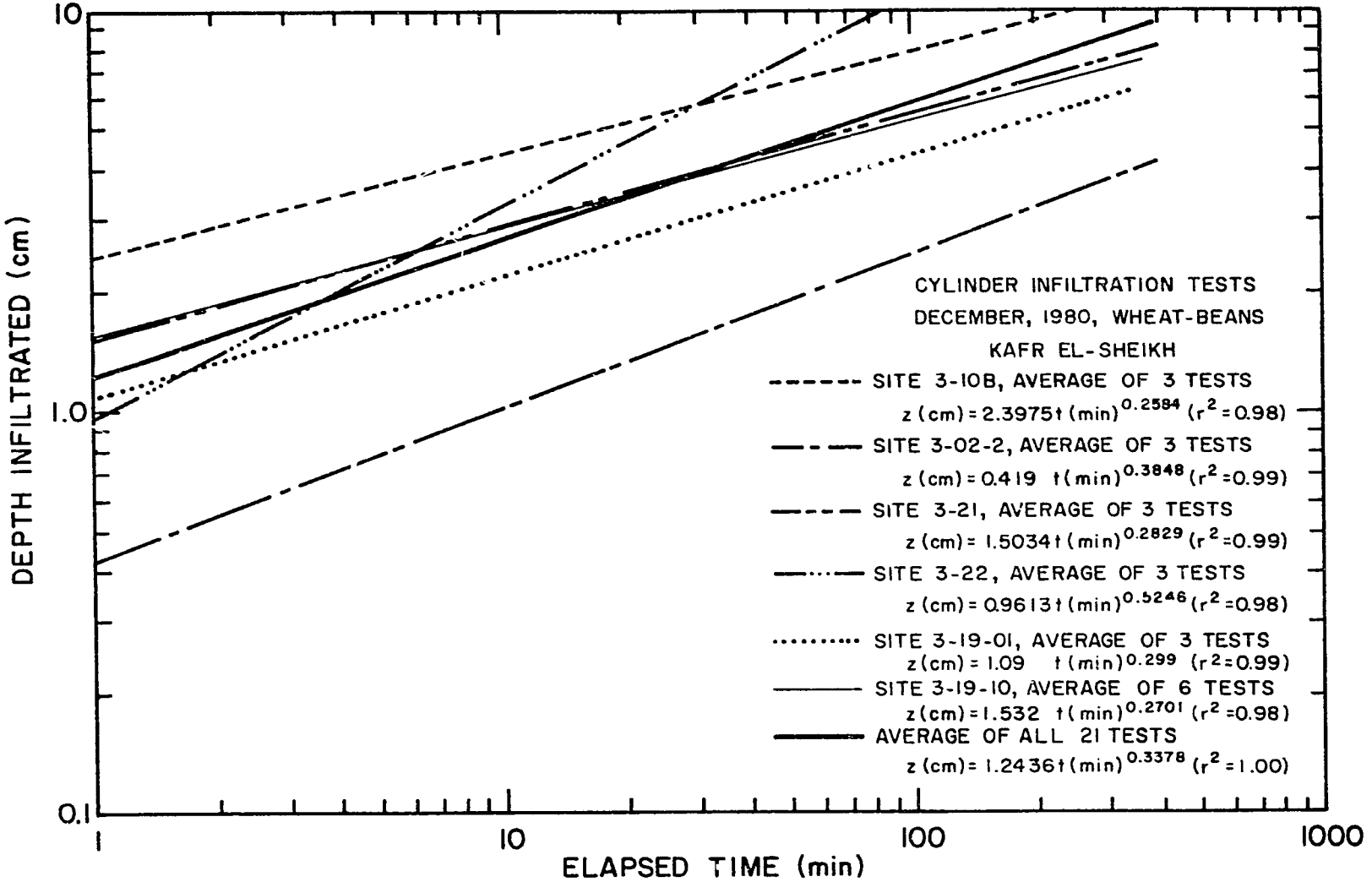

Figure 4. Regression curves for cylinder infiltration tests, December, 1980, Kafr El Sheikh.

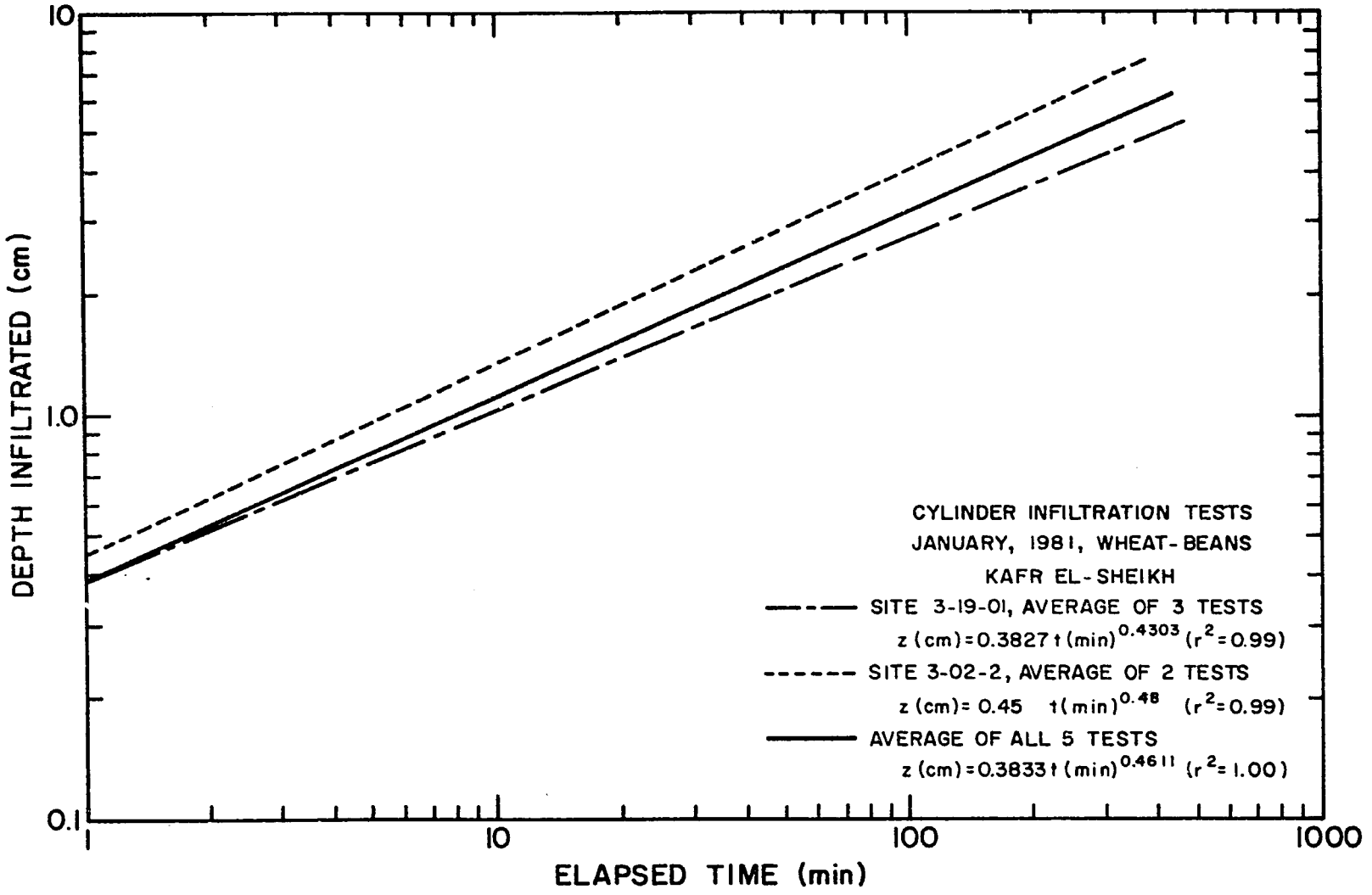

Figure 5. Regression curves for cylinder infiltration tests, January, 1981, Kafr El Sheikh.

expands, the cracks close and the infiltration rate is reduced. For design considerations, an SCS intake family of 1.0 to 2.0 should be considered because of the high initial intake rates, even though the intake family would be in the 0.35 to 0.4 range after an interval of 3 hours.

4) The December 1980 test results on wheat and beans (Table 4, part D) are representative of the soil infiltration conditions prior to the first irrigation of winter crops. The soil is dry, cracked and has undergone some degree of tillage (when the dry method for planting wheat is used). Figure 4 shows that a wide range of conditions were found, similar to those for the dry soil conditions prior to the rice crop. A very high initial (t = 1 minute) rate of 252 mm/hr for the average condition was found. This decreases to 11.9 mm/hr at 100 minutes. The same comments for design considerations as made in (3) above apply here. A very high initial intake means an SCS intake family in the 1.0 to 2.0 range, however, here after a period of 3 hours an intake family of 0.5 to 0.6 was found.

5) The January 1981 test results (Table 4, part E) are for the second irrigation of winter crops. Figure 5 shows a relatively narrow range of conditions. The average condition gives an initial (t = 1 minute) rate of 106 mm/hr and decreases to 8.9 mm /hr at 100 minutes. These conditions are equivalent to an SCS intake family of around 0.3.

6) The mid-season tests of January 1979 (Fig. 1), May - June 1980 (cotton) (Fig. 2), and January 1981 (Fig. 5) are all very similar. Consequently, average mid-season infiltration conditions at Abu Raya could be expected to be equivalent to SCS intake families in the 0.2 to 0.3 range.

7) The dry-soil condition tests of May - June 1980 (rice) (Fig.3) and December 1980 (Fig. 4) are very similar, exhibiting very high initial intake rates which decrease as the soil expands. The initial condition is equivalent to SCS intake families in the 1.0 to 2.0 range.

8) At 100 minutes, all 5 groups have an intake rate of 6 to 12 mm/ hr, with an average of 8.7 mm/hr (0.34 in/hr). If this is considered a basic intake rate, it would be classified as moderately slow.

In concluding this section, it is noted that the trend for decreasing intake rates as the season progresses, as found here, is a characteristic of soils all over the world. It is re-emphasized that for design considerations an SCS intake family at least 1.0 should be considered as representative of the high initial intake rates at the first or planting irrigation. This statement is further qualified by the fact that these tests were normally conducted with the objective of not placing the cylinders over or near cracks in the soil. Therefore, it is possible that actual "field-wide" initial intake rates are higher than the "point measurement" results described here. On the other hand, the reduced intake rates which are characteristic after the cracks are closed or at mid-season must be kept in mind. The problem of excessive ponding or intake times could occur causing crop damage. Thus, for a design based on the initial high intake rates, the irrigator will have to manage the water at succeeding irrigations (when intake rates are lower) with the fact in mind that irrigation time may have to be reduced to achieve a light application. In this light, irrigation frequency may also have to be adjusted.

Surface Roughness

Flow resistance during surface irrigation is affected by the condition of the soil surface and the presence or absence of vegetation. The SCS design procedures for surface irrigation utilize Manning's equation to describe the overland flow conditions. Consequently, Mannings roughness coefficient (n) is used to describe flow retardance. The recommended value for smooth, bare soil surfaces is 0.04. This is the value typically used for furrow irrigation design. For border or basin irrigation, the SCS recommends an n-value of 0.10 for drilled small grains, when the drill rows are in the direction of the advancing water. An n-value of 0.15 is recommended for broadcast small grains, alfalfa, etc. Dense sod crops and drilled small grains when the drill rows are perpendicular to the direction of advancing water are assigned a value of 0.25.

There have been no attempts during these studies to characterize surface roughness in Abu Raya. For design purposes, the recommended values -- n=0.04 for furrows and n=0.15 for broadcast small grains and alfalfa -- are considered representative. For border strip irrigation and furrow irrigation on fields which are poorly tilled (i.e., have large chunks or clods, furrows

not well made or very rough) higher roughness coefficients such as 0.15 for furrows and 0.25 for border strips are appropriate.

If the roughness coefficient is underestimated in the design, the general effects will be:

a) for level border strip irrigation, the unit inflow stream will be less than desired, the advance time will be greater, the flow depth greater, the application efficiency will be reduced with the possibility of greater deep percolation loss and lower uniformity of application,

b) for level furrow irrigation, given the same furrow inflow rate, the advance time and flow depth will be greater and the application efficiency will be reduced. Deep percolation losses will be greater and uniformity will be reduced.

The magnitude of these effects is not large for the general range of design conditions at Abu Raya. However, when designs are being made for conditions at the extreme -- especially for the longer run lengths, lower available flow rates and very high intakes -- the effect of using an n-value too low (see above) will be more pronounced.

If the roughness coefficient is over-estimated in the formulation of a design the general effects will be such that a larger design stream is used, coverage of the field will be quicker, efficiency and uniformity better; this is not considered a problem.

Field Topography

Since rice is a major summer crop in Kafr El Sheikh and farmers perceive a need to produce and irrigate rice on as flat an area as possible (see EWUP 1982a), it was determined that the farm irrigation system in Abu Raya is generally managed as one with zero slope or grade, or level basin irrigation. The problem of unlevel fields exists, however, and has been described in the above report. A detailed report on field levelness and land leveling in Kafr El Sheikh is being formulated (EWUP, 1982g).

For design purposes, it is necessary that fields be level to within a tolerance of $\pm$ 1.5cm of the mean field elevation for level border irrigation (USDA, 1974). For level furrow irrigation, this tolerance may be up to twice as large, however, there must be no reverse gradients at any point in the furrow. A slight, uniform grade where the total fall in the total length does

not exceed the design application depth is acceptable for level furrows. The design procedures cannot be expected to produce good results without proper precision land leveling.

Channel Geometry and Boundary Conditions

With reference to border strip irrigation, channel geometry for the open channel flow condition in surface irrigation is related to field geometry and boundaries. Controlling factors are the strip width and border ridge or bund height. For furrow irrigation, the furrow is the channel and controlling factors are the tool used for making the furrow, furrow spacing, tillage practices and maintenance of the furrow cross-section. The field length in both cases controls the required total volume of application.

Ownership patterns in Abu Raya can be highly variable. Field shapes range from rectangular to triangular to trapezoidal. Boundaries are often open watercourses -- canals, mesqas, drains, marwas, field drains -- and range from straight to meandering. There is normally a small bund along these boundaries to facilitate water impoundment in the basins.

Farmers typically irrigate basin crops in large flat basins, bounded by bunds. The largest basins used are for rice and widths from 15 m to 40 m with lengths from 40 m to 220 m have been observed. The conventional method for irrigating row crops is furrows in small basins which are approximately 15 - 20 m square.

For level irrigation systems design, strip widths and lengths, and furrow lengths and spacings must be based on site specific design conditions. Naturally, lengths of run are constrained to the farm and/or crop boundaries. Total field and/or farm width constrains the number of strips. The number of strips should be an even multiple of the total field width. Furrow spacings depend on cultural practices. There may be an irrigated furrow between each plant row or the plant rows (2 to 4) may be on a bed with furrows between beds. Both situations exist in Abu Raya. For level furrow irrigation, large, well-defined furrows are required to accommodate the large flows without overtopping. The Kafr El Sheikh team has had good results with strip widths up to 45 m, strip or furrow lengths up to 150 m and furrow spacings of 0.55 m (every row irrigation of cotton) and 1.10 m (cotton and maize rows spaced at 0.55 m on beds). Better furrows were constructed and maintained when beds were used. Further discussion is provided in Part III of this report.

Soil Moisture Characteristics for Abu Raya Area

Soils in the Abu Raya area are deep, uniform, alluvial clay soils where the clay fraction averages 60% or more and sands less than 12%. The most common soil types were the Typic Torrents of the Vertisol order (Abdel Wahed, et al., 1982). (EWUP, 1981c) reported the results of several pressure plate moisture extraction tests on soil samples taken in Abu Raya. Samples were taken every 20 cm to a depth of 60 cm. Moisture content at 0.1, 0.33, 3.5 and 15 bars was determined. For the heavy clay soil, field capacity was taken as the moisture content at 0.33 bars. The average was 50.2% moisture by volume. The permanent wilting point was taken as the moisture content at 15 bars and the average was 32.6% moisture by volume. The total available water (TAW) per meter of soil is:

$$TAW = \frac{(50.2 - 32.6)}{100} \times 100 \text{ cm/m}$$

$$= 17.6 \text{ cm/m } (2.1 \text{ in/ft})$$

Further analysis of the data presented in (EWUP, 1981c) shows the field capacity averages 15.0 cm per 30-cm layer with a coefficient of variation of 4% for the 10 samples and the permanent wilting point averages 9.8 cm per 30-cm layer with a coefficient of variation of 8% for the 10 samples.

Soil moisture sampling in Abu Raya has typically been conducted to a 90-cm depth. Field testing to determine field capacity by saturating the profile under a small basin, covering it with plastic and taking soil samples at intervals of time afterwards has shown that gravity movement or drainage typically ceases to occur 3 to 5 days after wetting to saturation. The moisture content at that time is equivalent to field capacity and typical values range from 45 to 52 cm of water in the 90 -cm profile. This checks well with the results just discussed. Hundreds of post-irrigation moisture samples, taken 3 to 5 days after irrigation, also fall in this range. EWUP root sample studies reported in EWUP (1982e, Table 7) show root penetration is anywhere between 20 cm and 60 cm. With 17.6 cm/m total available water, plant roots thus have between 3.5 cm and 10.6 cm of water available in these zones, respectively.

Typical soil apparent specific gravity (bulk density) values determined for Abu Raya soils are:

layer (cm)	γ_s
0-10	0.99
10-20	1.13
20-30	1.23
30-60	1.20
60-90	1.23

These are based on numerous field measurements. Due to the expansive nature of the soil it is possible the 0-10 cm layer will have different bulk densities when dry and when wet. For the typical range of soil moisture conditions during the irrigation season, the difference is not expected to result in significant error.

MANAGEMENT CONSIDERATIONS

How Farmers Irrigate

The Abu Raya area is considered part of the "old lands" of Egypt where the irrigation method has been surface gravity flooding of basins for thousands of years. Perennial irrigation of the Nile Valley and Delta did not start until about 1840. The Abu Raya area is land only relatively recently reclaimed, however, the first irrigation canals and drains being constructed in the area about 1910-15. Farmers irrigate crops such as rice, wheat, birsim and flax in flat basins. Rows crops such as cotton and sugar beets are grown on ridges or beds and irrigated by furrows within small basins. Maize, broadbeans and vegetables are grown and irrigated by either method. Cropping patterns and rotations have been reviewed in EWUP, (1982a) and will not be repeated here.

The dead level irrigation system design methods (level border strip and level furrows) are well-suited for the crops and management practices farmers use in Abu Raya. It has been discussed, that due to rice culture, farmers will attempt to level their land to as flat as possible. With precision land leveling techniques, the dead level border systems will provide farmers with good water control. Dead level border strips are very appropriate for basin crop irrigation in Abu Raya. With precision land leveling, dead level, long furrow irrigation is appropriate for row crops, and farmers would no longer

need to construct the furrows in small basins to achieve some measure of water control. Farmer acceptability of the level basins, long level furrows and land leveling has been good. Some farmers have adopted the long furrows on their own. Many farmers request EWUP input on their farms each season

Border strips should be separated by earthen bunds which are of a height not less than the maximum expected flow depth, plus 3 cm. Furrows must be well constructed -- large, deep and well-defined -- to handle the large furrow flow rates necessary for rapid water advance. Kafr El Sheikh Team experience has found that the "bed" method (one furrow per two crop rows) achieves this requirement better than irrigating with one furrow for every row. Further discussion of farmer irrigation methods are given in Egyptian and American Field Team (1980a), EWUP (1982a).

When Farmers Irrigate

Irrigation water is delivered to the Abu Raya area on a rotational basis. Rotations are based on the season and crops. Generally a 4 day on - 4 day off rotation for most of the summer season for the rice crop and a 5 day on - 10 day off or 7 day on - 7 day off rotation for most of the winter season exist. Further discussion of the rotation system for Abu Raya is given in EWUP (1982a). Farmers generally prefer to irrigate during on periods, but will also irrigate during off periods if conditions necessitate this, and if water is available. There is generally water storage in mesqas during the off periods since the system is closed-end and because the head structures leak. When farmers irrigate during off periods, irrigation times are excessive due to the high lifting head (>1.0 m) at the saqia and the resulting lower saqia flow rate.

Studies have shown that farmers prefer to irrigate in the early morning hours until 11 a.m. or noon and in the evening from 4 p.m. to 7 p.m. (EWUP, 1982h). Night irrigation is not common due to many factors, but does occur during critical water demand periods such as when rice paddies are submerged for the first time. Continuous water level records for mesqa inlets support these observations.

Conventional practice of Abu Raya farmers for irrigation timing and frequency is given in Table 5 for the various crops grown. (Sugar beets is not included since it has only recently been introduced in the area.) For the cotton crop and most of the winter crops a heavy pre-irrigation is often applied. This is done for several reasons, the most important are:

Table 5. CONVENTIONAL IRRIGATION PRACTICES OF ABU RAYA FARMERS, KAFR EL SHEIKH.

CROP	PRE-IRRIGATION	PLANTING IRRIGATION	FREQUENCY OF IRRIGATIONS	NO. OF IRRIGATIONS
Cotton	Usually; but depends on weather Mid-March	Yes; around April 1	1st Irrig. after planting: 4-6 weeks then every 14 to 15 days until Aug 15 - 30	8 to 10
Rice	Yes; puddling irrig. mid-June to 1st week of July	Yes; same as pre-irrigation	averages every 2 to 4.5 days until Sept 15-20	20 to 25
Maize	No	Yes; late May	1st irrig. after planting: 3-4 weeks, then every 7-10 days until Sep 1-10	9 to 11
Wheat	Sometimes late Oct to assist cotton stalk removal & soil tillage	Yes; late Nov	1st irrig. after planting: 4-5 weeks, then every 20-25 days to about Apr 10	6 to 8
Flax, Barley		(SAME AS WHEAT)		
Broad-beans	"	"	1st irrig. after planting: 4-8 weeks then 1 month later up to Mar 1	1 to 4
Birsim (after rice)	Often sown into rice before last irrig. of rice in mid-Sep - If not, then late Oct planting with irrig.		1st irrig. after rice is removed around Nov 1 then monthly to Feb 1 1st irrig. after planting is 1 to 2 weeks; then monthly to mid-Feb.	2 to 4 3 to 5
(after cotton)	Sometimes late Oct to assist cotton stalk removal & soil tillage	Yes: mid to late Nov.	1st irrig. after planting is 1 to 2 weeks; then after 1 month; then after about every 2 weeks	9 to 11
(after maize) (into cotton)	Sometimes	Yes; early Oct.	1st irrig. after planting is 1 to 2 weeks; then after 1 month & then about each 4 weeks	3 to 5

a) facilitates removal of the previous crop, i.e., pulling the cotton stalks from wet soil,

b) aids soil tillage for seed bed preparation for the next crop.

The second reason is largely dependent upon the inadequate supply of appropriate farm machinery to work the soil. Wetting the soil and allowing some drying, for 10 days to two weeks, greatly assists the farmers ability to work the soil with his usual tools. The heavy pre-irrigations can cause delays in soil tillage and planting leading to possible yield reductions. As various implements have appeared on the scene: tractors, chisel plows and 3-point hitch type bucket graders, farmer ability to work the soil has increased and the need to pre-irrigate has decreased. Further development along these lines can result in significant water savings as will be discussed in the next section.

Problem identification studies (Egyptian and American Field Team 1980a; EWUP, 1982b) showed that Abu Raya farmers tend to irrigate too frequently resulting in overirrigation of crops. For winter crops, farmers generally try to squeeze in an irrigation just prior to winter closure (usually 20 Jan - 10 Feb) even though soil moisture levels are still very high from the previous irrigation. This happens when farmers plant later than the recommended 15 Nov planting date for most winter crops. Late planting is a frequent occurence due to such factors as labor shortage and inadequate farm machinery supply as discussed above. If farmers were able to plant according to recommendation, the intervals would be about correct to span the closure period. Since farmers generally plant late, it may be better to adjust the closure period, i.e., move it forward in time by about 2 to 2 1/2 weeks. For summer crops, cotton is generally irrigated according to the recommended frequency and interval, but farmers usually continue to irrigate too long into the season, with 1 or 2 extra irrigations resulting. The last irrigation of cotton is recommended for early to mid - August. For rice irrigation frequency is influenced by the rotation. Farmers will try to irrigate twice during the 4-day on period to maintain a 10 to 15 cm ponded depth. One irrigation every on period (once every 8 days) could be possible with level fields and good dike maintenance. Maize is simply irrigated too frequently, with large water applications and drainage of the applied water after only short opportunity times. Farmers perceive some need to keep soil moisture levels high for maize production.

For all of the upland crops, at least one seasonal irrigation can be eliminated through improving farmers' knowledge of soil-water-plant relations. With mechanization (implements to do soil tillage), the need to pre-irrigate is eliminated. Implementation of dead level irrigation system designs encompasses this, as land leveling to dead level in Kafr El Sheikh has generally involved a much larger amount of land preparation than farmers' now use. Maintenance of dead level with seasonal plowing and smoothing is recommended. For rice the number of irrigations could be reduced by 1/3 to 1/2. If farmers had better weed control methods available to them, the need to maintain large ponded depths for this purpose could be alleviated, further assisting the reduction in the number of irrigations. Dead level systems with good dike maintenance will also assist this.

Recommended irrigation frequency and intervals are dependent mainly upon the crop, climate and soil. Where these conditions are similar, then design can be generalized to cover quite a large area with only an occassional check to be sure that the conditions have not changed appreciably. These topics are outside the scope of this report, and a separate technical report on this subject for Kafr El Sheikh could be developed.

How Much Farmers Irrigate

In determining how much to irrigate, Abu Raya farmers seem to depend mainly on visual inspection of the flooded field. Criteria such as whether the entire field is flooded, whether certain high spots are covered, what the flooded depth is, etc. are used. The farmer generally does not know the inflow rate to the field and does not use time as a factor to determine the volume applied per unit area. A common practice also used is to drain the "excess" surface water from the field or basin after some given time period. There are no set criteria farmers use in this decision. This practice combined with other factors, of which the farmer has limited knowledge, make the variability in applied irrigation depths through a season very large.

As stated, PI studies (Egyptian and American Field Team, 1980a; EWUP, 1982b) have shown that farmers overirrigate. Before irrigation soil moisture levels for conventional farmer practices are generally high, indicating that farmers could lengthen the irrigation intervals used somewhat. Consideration must be given to site specific factors in this aspect, however. The same PI studies (Egyptian and American Field Team, 1980a) showed saline (EC_e>4 mmhos/cm) conditions exist at soil profile depths greater than 25 cm over a

large part of Abu Raya. The soil survey also showed soil sodicity could be a problem with more than 75% of the samples showing SAR values greater than 10 at depths greater than 25 cm. Further study has revealed that groundwater quality is poor (EC>15 mmhos/cm) and depths below ground surface large just prior to irrigation, while quality is good and depth below ground surface small after irrigation (EWUP, 1981f). Irrigation water quality is generally very good with EC ranging between 0.4 to 0.6 mmhos/cm, while drain water quality is often much worse with EC ranging between 2.0 and 6.0 mmhos/cm. These factors indicate a need to apply some leaching fraction to flush salts from the root zone, or to suppress the salts at a lower level with a fresh water lens. Farmers may be perceiving this since a management practice used is to keep soil moisture depletion relatively low between irrigations.

Soil salinity changes due to rice cultivation in Abu Raya have been studied (EWUP, 1982a). Results have shown that paddy rice is used effectively to control salinity as an average 40% reduction of salinity in the 0-90 cm profile has been measured during 2 seasons. It is likely that soil salinity levels increase during the three upland crops grown between rice crops. For this reason a minimum 10% leaching fraction applied at each irrigation or at one irrigation is recommended for each of the upland crops. Combined with the obvious salinity management benefits of paddy rice cultivation, and with the added benefits of improved farm water management through irrigation system improvement, an overall favorable salt balance for crop production in Abu Raya should result.

For design purposes it is recommended to design level systems for Abu Raya farms for the maximum expected application depth. Typically, this condition is assumed to exist at the peak water use period of the crop. For Abu Raya, however, the cropping pattern and calendar and other considerations will generally result in the maximum application depth being at the initial irrigation of the season:

a) The "dry-down" period between crops (both summer-winter & winter-summer) has been shown to span anywhere from 50 to 90 days (EWUP, 1982a). The entire 0-90 cm profile becomes dry (Table 6), with large deep cracks appearing.

b) During this period secondary salinization of the expected root zone of the next crop is occurring with salt migration towards the surface.

Table 6. Measured soil water deficits at initial and succeeding irrigations on Abu Raya Farms, Kafr El Sheikh

SITE	SEASON	MEASURED SOIL WATER DEFICIT AT 1ST IRRIGATION (cm)	AVERAGE SOIL WATER DEFICIT AT SUCCEEDING IRRIGATIONS (cm)
3-01a (Wh)	79-80(W)	11.8	5.6 1/
3-02a (Wh)	79-80(W)	8.0	6.7 1/
3-08a (Wh)	79-80(W)	11.3	8.1 1/
3-09a (Wh)	79-80(W)	8.5	5.9 1/
3-10a (Wh)	79-80(W)	6.8	10.4 1/
3-11a (Wh)	79-80(W)	5.1	4.3 1/
3-12a (Wh)	79-80(W)	14.9	6.5 1/
3-16A_1(Co)	80(S)	10.0	6.0
3-17A_1(Co)	80(S)	8.0	6.3
3-13A_1(Co)	80(S)	13.0	8.4
3-14A_1(Cc)	80(S)	18.0	8.7
3-15(a)A_1(Co)	80(S)	18.0	9.4
3-15(b)A_1(Co)	80(S)	14.0	8.3
3-02(Wh)	80-81(W)	17.2	10.6 1/
3-19(Wh)	80-81(W)	13.9	7.6 1/
3-19(Beans)	80-81(W)	20.0	3.5 1/
3-10(A)(Wh)	80-81(W)	12.0	4.6
3-10(B)(Wh)	80-81(W)	12.0	5.0
3-10(B)(Fl)	80-81(W)	10.0	5.4
3-22(Wh)	80-81(W)	11.0	5.0
3-21(Wh)	80-81(W)	15.9	4.6
Mean ± std. dev.		12.4± 4.0 (C.V. = 32.3%)	6.5± 1.8 2/ (C.V. = 28.1%)

1/ Second irrigation only

2/ For sites with seasonal data only

Wh - wheat, Co - Cotton, Fl - flax

c) Pre-irrigations are not recommended with EWUP farm irrigation system design improvements. It is important to wet the entire 0-90 cm profile and to provide some downward leaching of salts in this case. EWUP root sampling studies (EWUP, 1982e, Table 7) show that maximum rooting depths in Abu Raya occur anywhere from 20 cm to 60 cm. Treating the entire 0-90 cm profile as the expected root zone is a component of salinity management and suppression of the highly saline permanent groundwater in the area.

Referring again to Table 6, note the largest soil water deficits have occurred at the initial irrigation, and that average deficits for succeeding irrigations are considerably less. It is also noted that these data are taken from "EWUP - management" strips or fields where farmers generally followed recommendations for intervals and frequencies of irrigation. For rice, it was reported in EWUP (1982a) that the puddling irrigation (initial) was always the largest, averaging 250 mm, and represented nearly 15% of the total water application to rice. For the upland crops given in Table 6, the mean deficit for all the sites given is 12.4 cm, the mean average deficit for succeeding irrigations for all the sites is 6.5 cm. The average deficit for succeeding irrigations was consistently higher for the cotton crop than for the winter crops indicating the effect of climate.

For design purposes, a designer could assume, based on the above results, a maximum root zone soil water deficit of around 12 cm. Adding the minimum 10% leaching fraction, the design requirement depth of about 13 cm to 13.5 cm for average conditions is proposed. Water application efficiency on the order of 90% for level systems, especially on heavier soils, is common. Given this, maximum gross application depths on the order of 14.5 cm to 15.0 cm will be necessary for design conditions in Abu Raya.

During the season, irrigation applications to replenish soil water deficits are recommended. Thus, considering data presented in Table 6, applications should be timed to replensih an average 6.5-cm soil water deficit. Assuming 90% application efficiency, a gross application of 7 cm to 7.5 cm is computed. Irrigation frequency recommendations would need to be developed to apply these amounts on an efficient, timely basis. Areas with similar conditions would have the same recommendations applied.

Given an appropriately designed level system, i.e., according to the considerations in Part I, a general recommendation such as irrigating until

the water reaches the end of the strip will often be appropriate. Some reduction or increase in actual performance as compared to design-performance will occur, but results may generally be adequate as long as the actual water advance time is not too much larger or smaller than the time required to apply the desired volume.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A review of the types of site specific factors, data and information which affect irrigation system design and of which the designer must have knowledge to produce effective and appropriate designs has been presented. The approach taken has been that of a case study: The Abu Raya area of Kafr El-Sheikh. Specific data collected at Abu Raya have been analyzed and summarized to give the designer background knowledge on the following factors and variables: a) water supply and delivery (saqia and field flow rates), b) soil intake characteristics, c) surface roughness, d) field topography, e) channel geometry and boundary conditions, f) soil moisture characteristics and g) management considerations.

As a result of the data summaries and analyses the following conclusions are drawn:

1) Saqia flow rates show a high degree of variability during irrigation and from irrigation to irrigation. A likely average discharge rate for the typical 3-m diameter, 6 kado saqia in Abu Raya is in the range of 30-35 lps.
2) Flow rates available at field inlets show nearly the same variation as saqia flow rates during an irrigation, however for unimproved marwas are as much as 25% to 40% less, i.e., in the range of 20-25 lps.
3) The nature of the soils in Abu Raya causes very high intake rates to exist when the soil is relatively dry (at 1st irrigation). Intake rates during the season are much less when the soil is relatively moist.
4) Surface roughness in Abu Raya may be higher than typical due to the difficulty farmers have in preparing smooth seed beds, furrows, etc. For the well-tilled soil condition in Abu Raya the typically assumed values would be representative.

5) Farmers attempt to keep their fields as flat as possible due to water management considerations for rice production, i.e., there is no slope in the field. General field topography can be highly variable, however, due to lack of precision leveling.
6) Farm ownership patterns and boundaries in Abu Raya often result in irregular shaped basins. Layout of farm water distribution and removal ditches complicate this.
7) Total available water in the 90-cm soil profile averages between about 16 cm and 22 cm of water.
8) The maximum depth of water needed to replenish soil water in the 90-cm profile to field capacity is at the initial irrigation of the season.
9) Rice cultivation reduces soil salinity.
10) The results of these studies are applicable to a variety of different areas, but which have similar conditions.

For level irrigation system design purposes using the SCS design methods, the following recommendations are made:

1) Assume the average saqia flow rate is 30-35 lps. For unimproved marwas assume the field flow rate is 20-25 lps.
2) An SCS intake family of at least 1.0 should be used to represent the high intake conditions at the initial irrigation of the season.
3) Surface roughness of 0.15 for broadcast small grains (i.e., all basin crops in Abu Raya) and 0.04 for furrow irrigation should be used if soil tillage is adequate.
4) Precision land leveling to dead level is not only recommended but is a necessary condition for efficient irrigation.
5) Consideration of redesigning the farm irrigation system layout is necessary, even if this means eliminating delivery and drainage ditches. New or renovated marwas are needed and drainage ditches which are not farm boundaries only occupy productive land.
6) A design requirement depth of about 13 cm should be considered. The average maximum soil water deficit of about 12 cm occurs at the initial irrigation of the season. A minimum 10% leaching fraction is suggested. Level systems on the heavy soils of Abu Raya should achieve a recommended design application efficiency of 90%.

III. LEVEL IRRIGATION SYSTEM DESIGN EXPERIENCE, ABU RAYA, KAFR EL SHEIKH

INTRODUCTION

In this part of this report, the experience of the Kafr El Sheikh Team with level irrigation system design in Abu Raya is reviewed and analyzed.

First, from a qualitative viewpoint, a review of the farm irrigation system design work implemented in Abu Raya is provided. What was done and how the work was accomplished is detailed. This will provide a basis of comparison between the conventional methods used in the area with the improved methods. Documentation of the benefits of the improved methods is included. Implementation problems are also reviewed.

Second, quantitative evaluation of several designs which have been constructed in Abu Raya is presented. Analyses include problems with selection of appropriate design parameter values, evaluation of advance and recession data and focus on the effectiveness and appropriateness of the design changes in producing improvements.

In the evaluation of irrigation system improvements several performance parameters will be used in the following sections. These are:

1) water application efficiency, E_a, the ratio of the depth of water made available for plant use (depth stored plus leaching) to the depth applied,
2) water requirement efficiency, E_r, the ratio of the depth of water made available for plant use (stored plus leaching) to the depth required to replenish soil moisture and for leaching.
3) farm conveyance efficiency, E_c, the ratio of the depth of water available at the head of the field to the depth of water available at the farm turnout (i.e., depth lifted at the saqia),
4) farm irrigation efficiency, E_i, the product of E_a and E_c or the ratio of water made available for plant use to that lifted at the saqia,

5) uniformity coefficient, UCH, for assessing distribution of applied water, where

$$UCH = 1 - \sqrt{\frac{2}{\pi}} \frac{s}{\bar{x}} .$$

s is the standard deviation of infiltrated depths at uniform intervals along the irrigation run, while $\bar{x}$ is the mean of those depths. (Hart, 1961).

The purpose of this section is not only to document the experience of the K.S. Team, but also to document results which show that upgrading the conventional farmer irrigation methods to the dead level irrigation system methods described produces many of the desired benefits of irrigation agriculture development.

BACKGROUND INFORMATION

The conventional farm irrigation method used by Abu Raya farmers is basically flooding of small basins. The flat topography of the area and natural and man-made boundary controls contribute to make the method very similar to level basin irrigation. Broadcast seed crops are grown within small basins, while row crops are grown on ridges (short furrows) within small basins. Small landholdings and the government-regulated crop rotation induce a farmer to grow several crops in his several small basins each season. Consequently the layout of the farm irrigation system (basins and distribution and removal ditches) can be quite complex. Basins are not laid out in a consistent manner with respect to such design considerations as flow rate and soil intake characteristics. Field micro-topography data indicate most fields are "unlevel" by 3 or 4 times when a standard levelness criterion for level basin irrigation is applied (EWUP, 1982a). Such a condition hampers effective farm water control, decreases irrigation basin size and increases water application, irrigation labor and irrigation time. Field drainage ditches in Abu Raya are not effective as they are too shallow to provide subsurface drainage and are often choked with weeds. They serve mainly for removal of excess surface water resulting from overirrigation. With level irrigation

systems and good water management these drains are not needed. They can be removed to increase the farm productive land area by up to 15% and to facilitate mechanization.

EWUP problem identification studies, for the Kafr El Sheikh area, summarized in Egyptian and American Field Team (1980a), Egyptian and American Team (1980b), EWUP (1982b), have shown that typically the farm irrigation system in Abu Raya suffers from these problems:

1) Poor design and layout of the farm irrigation system, with inefficient water distribution channels, poorly designed basins and ineffective water removal ditches.
2) Unlevel fields causing poor distribution of applied irrigation water and overirrigation.
3) Poor farm water management. Farmers tend to irrigate too frequently and overirrigate causing salinity and high water table problems.

Further information is included in the above reports.

Through problem identification and field trials studies, it was identified that solutions to the farm irrigation system problems in Abu Raya entailed precision land leveling and level irrigation system design. Such solutions require a significant increase in farmer's understanding and ability in farm water management to compliment the design improvements and to insure success. The farmer still applies water by surface irrigation methods using level long furrows or border strips. The small bunded basins, built by hand are eliminated. The next section is a season by season review of how these efforts were implemented in trials, how a development package evolved and what the benefits of the improvements have been as compared to the conventional methods.

REVIEW OF FARM IRRIGATION SYSTEM IMPROVEMENT IN ABU RAYA

1979-80 Winter Season

Precision land leveling and dead level border irrigation design were significant elements of a package of practices tested in field trials on the wheat crop on seven Abu Raya farms during this season. Also tested in the package were a recommended new variety (Sakha 8), zinc sulphate application,

fertilizer recommendations, field drain removal and water management recommendations for irrigation timing and frequency. In general, the package of practices was implemented on one or more level border strips on each farm. A field of wheat managed by the same farmer using the conventional methods was located nearby. Detailed measurements were made on both through the season to evaluate the package being tested.

This was the first season of precision land leveling to dead level by the K.S. Team. Significant training was conducted with TDY input from the U.S. A total of about 12.5 Feddans was precision leveled on the 7 farms. The level border strips constructed had lengths between 50 m and 100 m, however, strip widths were confined to 9 m to 11 m. Detailed information on how these designs were formulated is not available, however, the available data seem to indicate the average design dimensions: 10 m x 75 m, are based on applying a design depth of 8 cm to 10 cm with an available flow of about 28 lps and an SCS intake family value of about 0.5.

Measurements were taken through the season, evaluated and summarized, to formulate comparisons between the mean results for each management condition of the field trials. These results have been reported in EWUP (1981b) and further information is provided there. Generally, the mean results showed that the package of improvements gave an increased farm irrigation efficiency (62% vs. 38%), increased wheat grain yield (1.6 Ton/Feddan vs. 1.1 Ton/Feddan), reduced total water lifted for irrigation (65 cm vs. 87 cm), and reduced total irrigation time (1304 min./Feddan vs. 1907 min./Feddan). Precision land leveling and the level border design must have been a significant part of these improvements, especially the irrigation improvements, although the individual effects cannot be separated out. Very close coordination with the cooperating farmers by K.S. Team members in relation to irrigation frequency, timing and amount also contributed to the improvements. Without this key input, it is expected that relatively little would have been accomplished. The first season of tests thus indicated that the design improvements bring about increased efficiency; water, labor and time savings; and contribute to improved crop yield when compared to the conventional methods.

1980 Summer Season

Field trials on the summer crops of rice, cotton and maize were conducted. The trials for each crop were designed so that four sets of conditions were tested:

1) A_o B_o was designated the control condition or the farmers' conventional irrigation and crop cultural practices.
2) A_o B_1 was the farmers' conventional irrigation practice with EWUP-recommended crop cultural practices.
3) A_1 B_o was EWUP recommended irrigation practices with the conventional farmer crop cultural practices.
4) A_1 B_1 was combined EWUP recommendations for irrigation and crop cultural practices.

Recommended irrigation practices were precision land leveling to dead level, level irrigation system design (dead level borders for rice, dead level long furrows for cotton and maize), advice to farmers on irrigation timing, frequency and amount, and field drain removal. Six sets of trials were conducted on cotton, three on rice, and two on maize. Measurements were made through the season to evaluate each condition of the trials. Results for the cotton crop have been summarized and reported in EWUP (1981e). Results for the rice crop are included in EWUP (1982a). Evaluation of the trials from a sociological perspective has been detailed in EWUP (1981a).

For the cotton trials, the level furrow systems designed had furrow lengths ranging from 80 m to 140 m, furrow spacings of 55 cm and typical strip widths of 13 m to 18 m. This means there were about 24 to 32 long furrows in each strip (where the irrigation improvements were tried). The farmers conventional methods were on gross strip areas of the same size, but this area was always divided up into the small basins (typically 15 m to 20 m square) with furrows inside. Given the typical saqia discharge for Abu Raya, between 10 and 12 long furrows were irrigated in one set during each irrigation. This normally meant each furrow received at least 2 lps. As the season progressed, it became clear that the long furrows constructed were not being well-maintained and also had not been built large enough to begin with, i.e., there was furrow overtopping and surface flooding occuring. Large, well-defined and well-maintained furrows are necessary for successful level long furrow irrigation. Water control was being lost and thus the irrigation efficiency was less than desired. The mean results indicate this. The

improved method and the conventional method both yielded the same farm irrigation efficiency, about 52%, and the same amount of water lifted, about 105 cm. Mean yields were much higher on the A_1 B_1 and A_1 B_o cotton strips, 36% and 28%, respectively, due to improved crop cultural practices including the better seed bed preparation given by land leveling. Improved furrow construction and maintenance would be necessary before the long level furrows would be an improvement over the conventional methods.

For the rice trials, the level borders designed were patterned after the wheat trials: strip widths of 10 m and lengths from 70 m to 120 m. The mean results showed that the level systems gave a 14% water savings while yield levels were maintained. Further improvement could be possible if farmers practiced routine dike maintenance (to reduce perimeter seepage and leakage losses resulting from cracks in the soil used for the dikes) and if they followed recommendations to irrigate less frequently, once per "on" period or once each eight days, as opposed to the conventional once each four days.

For the maize trials, the long level furrows had lengths of 70 m to 85 m, furrow spacings of 70 cm and typical strip widths of 10 m. This means there were about 15 furrows per strip. The wider furrow spacing allowed construction of larger furrows and the improved results show the benefit of this. The mean results on the "improved" strips showed a 39% water savings. Accurate yield measurements were not obtained due to a severe stem borer infestation. The available data do show that yields were about the same regardless of the practices. Irrigation results for the long level furrows of the maize trials was better due to the wider furrow spacing and larger furrows.

1980-81 Winter Season

The 1980-81 Winter Season was the first season of EWUP demonstration program work in Kafr El Sheikh. A farm irrigation system improvement demonstration program was implemented which was designed similar to the field trials practices. This program includes improvements to the farm irrigation system through farm layout redesign, marwa improvement, land leveling, level irrigation system design, irrigation scheduling advice, and field drain removal. Farm crop production was also addressed through agronomic recommendations for improving crop cultural practices, fertilizer use, pest control, etc. Several saqia units, the areas or farms served by one saqia were to be chosen each season for improvement. The work would include all farmers and crops (if possible) on that unit during the season. Farms on Hammad and Manshia mesqas would be considered.

For the 1980-81 Winter season five farms were chosen. Wheat, flax, birsim, broadbeans and sugar beets were the winter crops grown on these farms. A total of about 20 Feddans was leveled and a wide range of designs considered so that more detailed evaluation of the designs could be conducted. The level border designs implemented during this season are the subject of detailed evaluations presented in a later section. It is pointed out here that strip configurations from long and narrow (12 m x 130 m) to square (45 m x 45 m) were tested. Long level furrows were constructed for sugar beets. Lengths were up to 50 m for the one site where beets were grown.

Considering the results for the wheat crop, where the main emphasis was placed, the same types of improvements were found this season as for the wheat field trials of the previous year. The mean farm irrigation efficiency was measured as about 52%, lower than the field trials but still much better than the conventional method, which ranges between 30% and 40%. The water application efficiency was about 70%. The high farm conveyance losses (about 30%) caused the low farm irrigation efficiency. Mean total water applied was 51 cm. The mean total irrigation time of 1534 min/Feddan was 20% less than the conventional method. Mean wheat grain yield on the five demonstration farms was measured to be 33% greater than the Abu Raya average. Further data analysis and information on the results are given in EWUP(1981d) and EWUP (1981f). Also, detailed design analyses are presented later.

1981 Summer Season

Seven farms were chosen for the demonstration program this season. Cotton was grown on six of the farms, rice on three and maize on two. A total area of 35 Feddans was leveled.

Much better success was achieved with the long level furrows this season. Beds (Mastabas), with two crop rows for each furrow, were constructed. The effective furrow spacing for both cotton and maize became 110 cm this season. The implement used for making furrows (a simple 2-bottom lister) was better suited to making larger, deeper and well-defined furrows for this spacing. As a result, the irrigation results for the level furrows were much improved. Mean water application efficiency was 76% for cotton and 74% for maize. Mean total depth applied for cotton was 76 cm and 84 cm for maize. These values represent significant water savings when compared to the conventional methods. The mean demonstration farm yields for cotton and maize were measured to be 16% greater and 52% greater, respectively, than the Abu Raya averages.

Measurements on the rice pilot areas indicate a mean total application of 179 cm, much less than the conventional method average (200 cm or more). Rice farm mean yield was measured to be 27% greater than the Abu Raya average.

Further information and results on the 1981 summer season demonstration program work in Abu Raya are given in EWUP (1982a) and EWUP (1982c). Level furrow
advance/recession data for some of the farms of this season is analyzed in a later section of this report.

1981-82 Winter Season and Other Pilot Program Work

For this and future seasons, the number of new farms on which the demonstration program work was to be implemented was scaled back somewhat. The stability of the land leveling and irrigation improvements over time, and farmer acceptance and continued use of the recommended practices on the previous sites was to be further evaluated.

The 1981-82 Winter Season included two new farms and two previous farms. Heavy emphasis was placed on improving the farm layout and water distribution system. Two methods to reduce farm conveyance losses: plastic lining of marwas and lay-flat tubing were tested. A total of about 16 Feddans was newly leveled or "touch-up" leveled during the program. Wheat, barley and birsim fields were designed for level border irrigation with lengths from 50 m to 120 m and widths from 13 m to 35 m. Sugar beets and broadbeans were grown on dead level long furrow systems. The furrows were again constructed using beds. Furrow spacings were 110 cm and lengths from 50 m to 105 m.

Preliminary results for the wheat and barley show that mean farm irrigation efficiency was about 70%. Mean water application efficiency was 74%. Farm conveyance losses were reduced to practically zero. Mean total depth applied was about 41 cm. Mean total irrigation time was about 1400 min/Feddan. All of these figures continue to illustrate the consistent irrigation system performance improvements produced by precision land leveling, level irrigation system design and improved water management as compared to the conventional methods. The mean wheat grain yield on program farms this season was 29% greater than the Abu Raya average. Crop production improvement continues to be a benefit of the package, also, and it is felt the irrigation improvements contributed to this.

For the 1982 summer season, a total area of about 37 Feddans was leveled or "touch-up" leveled under the program. Heavy emphasis was again placed on

marwa improvement using plastic lining. A laser land leveling system was used on part of the area. The maneuverability of this equipment and speed with which this leveling was completed are important advantages for this system. Level border and level furrow designs were implemented on the farms.

In terms of the water delivery system, farmers were organized on their mesqas to maintain and clean these mesqas. This program has been implemented successfully during two winter closure periods and farmers have perceived the benefits of improved water delivery to their saqia well inlets. EWUP has also interacted with the K.S. Irrigation Department to coordinate the cleaning of the branch canal and of several secondary drains in the area. These system improvements are necessary for the overall improvements desired.

Summary

Land leveling and level irrigation system design have been significant components of packages of practices to improve farm irrigation systems in Abu Raya as tested and implemented by the Kafr El Sheikh Team over the past 3 years (6 crop seasons). The entire irrigation system was improved through farmer organizations developed to do routine mesqa cleaning and through EWUP/MOI interaction to coordinate branch canal and drain cleaning in the area.

The work done in Kafr El Sheikh has been to modify the farm irrigation system layout such that:

1) land leveling is more easily accomplished, and mechanization aided,
2) on-farm water distribution channel (marwas) length is minimized,
3) ineffective field drains are eliminated,
4) level border strips are laid out in an effective arrangement for basin crops,
5) effective layout of level long furrows replace the conventional furrows in small basins for row crop irrigation,
6) and to improve the irrigation system through farmer organized mesqa cleaning.

Given that farmers are taught better water management practices (how to irrigate, when to irrigate and how much to apply) in conjunction with these design improvements, then significant improvements, as have been consistently demonstrated in Kafr El Sheikh, can result. Generally, these are improved irrigation efficiency, water savings, labor savings, time savings, and improved crop production. Other benefits such as improved farm layouts, more efficient farm water distribution and conveyance, and water table and soil

salinity management have also resulted. Crop cultural and production practices recommendations also have significantly contributed to crop production improvements. The emphasis here has been that the improvements to the farm irrigation system will have a very positive impact, i.e., compared with the traditional methods farmers use in Abu Raya. It must be emphasized, however, that the improvements require farm machinery inputs and trained personnel (such as EWUP's) for precision land leveling, level irrigation system design and construction, and teaching and advising farmers on improved farm water management.

DESIGN EVALUATION: CASE STUDIES

1980-81 Winter Season: Evaluating Selected Design Parameters and Advance/Recession Data

A wide range of design border strip dimensions was tried for the various design conditions in Abu Raya during this season. Irrigation evaluations were conducted on all sites to evaluate the designs and to determine if the assumptions used in formulating the designs were correct. It has been generally determined through these studies that the first seasonal irrigation conditions (when a dry planting method is used) are quite different from those of the remaining irrigations. The second seasonal irrigation represents the conditions for the remainder of the season adequately. This will be discussed further in the following analyses. Ten different design situations are analyzed in the following paragraphs. The design conditions for each farm or strip are compared with the measured conditions of the first and second seasonal irrigations. Where available, advance and recession data are used in this analysis. These data were generally collected for each 10-m interval of strip length. Often the recession was uniform enough that the entire field was considered to have completed this phase when between 50% to 70% of the total surface area had become "un-watered". Table 1 is a comparison of the design conditions and measured conditions for each of the ten situations for the first irrigation. Table 2 presents this comparison for the second irrigation. Advance and recession data are given in Appendix C. These tables will be referred to repeatedly in the following subsections.

It should be noted that the requirement depth in the following discussions is taken as the soil water deficit in the 0-90 cm soil profile. This applies

TABLE 1. Comparison of measured and design conditions of level border strips on Abu Raya pilot farms, 1st irrigation, 1980-81 Winter.

Site (Strip No.)	Strip Design Dimensions		Unit Width Inflow Rate (lps/m) 1/		SCS Intake Family		Irrigation Time (min)		Requirement Depth (cm)		Total Depth Applied (cm)		Water Application Efficiency (%)		Water Requirement Efficiency (%)	
	Width (m)	Length (m)	Design	Measured	Design	Measured	Design	Measured	Design	Measured	Design	Measured	Design	Measured	Design	Measured
3-21 (1-4)	15-18	80-90	1.48	0.72	0.5	0.7	78	179	7.5	10.0	8.3	8.9	90	100	100	89
(5-6)	20	75	1.23	0.52	0.5	0.5-0.7	85	260	7.5	12.6	8.3	10.9	90	100	100	87
(7-8)	21	75	1.00	0.99	0.5	0.6	104	187	7.5	14.9	8.3	14.9	90	100	100	100
(9-13)	19	75	1.10	0.51	0.5	0.5-0.7	95	167	7.5	11.9	8.3	6.8	90	100	100	57
3-10 (1-2)	45	45	0.70	0.40	0.5	0.7	89	226	7.5	12.6	8.3	13.5	90	93	100	100
(3-7)	12	130	2.48	1.40	0.5	0.7	73	330	7.5	11.3	8.3	21.3	90	53	100	100
3-22	15	70-100	1.87	1.49	0.5	2.0	63	143	7.5	17.9	8.3	15.7	90	100	100	88
3-19 (1-4)	20	65-70	1.05	1.12	0.5	1.0	123	118	10.0	20.0	11.1	11.4	90	100	100	57
(10-16)	10	75-85	1.05	2.50	0.5	4.0	142	95	10.0	17.6	11.1	18.0	90	98	100	100
3-02 (1-4)	20	70	0.86	1.38	0.5	2.0	152	126	10.0	17.4	11.1	15.2	90	100	100	87

1/ at field inlet (marwa losses have been subtracted from saqia flow rate).

TABLE 2. Comparison of measured and design conditions of level border strips on Abu Raya pilot farms, 2nd irrigation, 1980-81 Winter.

Site (Strip No.)	Strip Design Dimensions		Unit Width Inflow Rate 2/ (lps/m)		SCS Intake Family		Irrigation Time (min)		Requirement Depth (cm)		Total Depth (cm)		Water Application Efficiency (%)		Water Requirement Efficiency (%)	
	Width (m)	Length (m)	Design	Measured	Design	Measured	Design	Measured	Design	Measured	Design	Measured	Design	Measured	Design	Measured
3-21 (1-4)	15-18	80	1.48	1.14	0.5	1/	78	70	7.5	2.4	8.3	5.5	90	44	100	100
(5-6)	20	75	1.23	1.11	0.5	1/	85	90	7.5	3.8	8.3	8.1	90	47	100	100
(7-8)	21	75	1.00	0.87	0.5	1/	104	105	7.5	2.5	8.3	7.3	90	34	100	100
(9-13)	19	75	1.10	1.88	0.5	1/	95	50	7.5	6.4	8.3	7.7	90	83	100	100
3-10 (1-2)	45	45	0.70	0.43	0.5	1/	89	110	7.5	3.1	8.3	6.6	90	52	100	100
(3-7)	12	130	2.48	1.73	0.5	1/	73	83	7.5	3.6	8.3	6.5	90	56	100	100
3-22	15	70-80	1.87	1.09	0.5	1/	63	59	7.5	3.4	8.3	4.8	90	70	100	100
3-19 (1-4)	20	70	1.05	1.16	0.5	0.3-0.4	123	58	10.0	3.5	11.1	6.2	90	56	100	100
(10-16)	10	80	1.05	1.73	0.5	1/	142	55	10.0	8.5	11.1	7.0	90	100	100	82
3-02 (1-4)	20	70	0.86	1.39	0.5	0.3-0.4	152	121	10.0	11.8	11.1	8.8	90	100	100	74

1/ Assumed to be in the 0.3 to 0.4 range.

2/ At field inlet (marwa losses have been subtracted from saqia flow rate).

to both the design and measured condition. While EWUP studies may show roots do not penetrate this deep (EWUP, 1982e), seasonal soil moisture monitoring shows depletion is occuring this deep (EWUP, 1981b and EWUP, 1981e). Using the entire 0-90 cm profile in this way tends to also automatically account for any leaching requirement. For instance, early in the season when the actual root zone is small, a larger leaching fraction results and vice-versa later in the season.

For the following investigations, the uniformity of applied water was estimated using the UCH coefficient presented earlier. Calculations were made for two sets of infiltration conditions:

1) for the SCS intake family determined for the data of that irrigation. These intake family values are listed in Tables 1 and 2.
2) for the average measured soil intake conditions for that time of year as presented in part II of this report. For instance, the first irrigation presented here is represented by the mean intake function determined for the conditions of the first irrigation of a winter season crop (see Table 4, part D, section II). Similarly, the second irrigation is represented by the mean intake function determined in Table 4, part E, section II.

The results of the two sets of conditions are included in Table 3. For the first condition, the results indicate the levels of uniformity which would have occurred if the soils of Abu Raya followed the typical SCS intake family curves. Generally, for these tests, the uniformity level is about 10% lower using this "first condition" method. The second intake condition is more representative of actual Abu Raya conditions. The intake functions used are derived from actual tests. The characteristic high intake rate rapidly reducing to a low intake rate as the cracks swell shut is included. It is noted that calculated uniformity levels for this condition are higher, usually 0.90 or better. The first-irrigation uniformity levels range from 0.81 to 0.94 and the second irrigation values range from 0.90 to 0.97. Uniformity levels above 0.90 are generally very good. Thus, the designs formulated gave very acceptable levels of uniformity. The combined effects of proper farm irrigation system design and precision land leveling plus the nature of the soils in the area contributed to the good results. Without precision leveling farm irrigation design and good farm water management, the uniformity is less

Table 3. Application uniformity (UCH) for sites with available data using two different intake conditions, Winter Season 80-81, Kafr El Sheikh.

Site	Irrigation No.	SCS Intake Family 1/	UCH	Intake function No. 2/ $z = kt^a$	UCH
3-21-1	1	0.7	0.83	1	0.92
3-21-5	1	0.7	0.88	1	0.94
3-21-7	1	0.6	0.84	1	0.92
3-10-1	1	0.7	0.88	1	0.94
	2	0.4	0.96	2	0.97
3-10-5	2	0.4	0.96	2	0.97
3-19-1	1	1.0	0.64	1	0.81
	2	0.4	0.87	2	0.90
3-19-10	1	4.0	0.82	1	0.91
3-02-2	1	2.0	0.78	1	0.90

1/ From Tables 1, 2.

2/ Intake function no. 1: $z\ (cm) = 1.2436\ t\ (min)^{0.3378}$

2: $z\ (cm) = 0.3833\ t\ (min)^{0.4611}$

See parts D and E, Table 4, Section II.

(see Egyptian and American Field Team, 1980a). The values in Table 3 for the second condition indicate the designs implemented were good in terms of uniformity. The values presented in the following discussions are those determined using the second method.

Site 3-21 (1-4). -- Referring to Table 1 for the first irrigation, it is seen that the soil was somewhat drier than expected (larger intake family and requirement depth). The measured irrigation stream was less than half the desired design value. These factors caused an irrigation time about 2.3 times larger than the design value. The effect is illustrated in Figure C1, where it is seen that advance time was nearly 200 min. The distribution of applied water was good (UCH = 0.92). The combination of existing factors produced a relatively efficient irrigation when the average depths are considered (See Table 1). For the second irrigation (Table 2), it is noted that the soil is much wetter than the design conditions (lower intake family and smaller requirement). The flow rate - irrigation time combination used produced a relatively light, but still inefficient, application (E_a = 44%). The problem here was management: the farmer irrigated too soon. This irrigation was applied just prior to the closure period.

Site 3-21 (5-6). -- The same comments as for the previous case apply here as well (See Tables 1 and 2, Figure C2). Soil conditions were drier than anticipated for the first irrigation. An excessive application time was required but the distribution was good. The main factor was an inflow rate only 40% of the required design value. For the second irrigation, soil conditions were wetter than design conditions. As above, the coming closure period influenced the farmer to irrigate too soon. Note that the inflow rate - time combination was very close to the design, resulting in an applied depth close to design (Table 2). This indicates the design width/length dimensions are appropriate.

Site 3-21 (7-8). -- For the first irrigation, the design and measured conditions compare well, except the requirement depth (Table 1). The soil was somewhat drier. This factor caused the slow advance (Figure C3). Measurements indicate the efficiency was good, but advance - recession data indicate uniformity may be low. It is quite possible there is some error with the data set for this particular irrigation, as the UCH value was 0.92. For the second irrigation (Table 2), the design and measured conditions compare well, except the soil was much wetter than design. The management decision to irrigate was again influenced by the coming canal closure period.

Site 3-21 (9-13). -- Table 1 shows the same situation here for the first irrigation as for the previous cases. The small inflow stream caused a much slower advance than desired. The drier soil conditions compounded this to cause an underirrigation problem (E_r = 57%). Table 2 shows that an inflow stream larger than design resulted in a shorter application time, a lighter depth applied, resulting in a fairly efficient irrigation, even though the soil was wetter than the design condition. This represents a management consideration when conditions require irrigating too soon: apply the water as quickly as possible (i.e., with a larger stream), to get fast coverage and as light an application as possible.

Site 3-10 (1-2). -- Results from this particular site suggest that it is difficult to irrigate and manage square basin configurations as efficiently in Abu Raya as long, narrow strips. For the first irrigation, Table 1, the inflow stream was about half the design value. This plus the drier than anticipated soil conditions resulted in an excessive irrigation time and advance time (see Figure C4). Distribution was good (UCH = 0.94). For the second irrigation (Table 2, Figure C4), the results were improved: better distribution (UCH = 0.97). However, the soil conditions were wetter than the design. The small inflow stream again caused a slow application. Had the water been applied at the design rate, the efficiency of irrigation would have been better. The management again was influenced by the canal closure.

Site 3-10 (3-7). -- The drier measured soil conditions and an inflow stream only 55% of the design value caused an excessive irrigation time and gross overirrigation (on the average, Table 1). Advance data were not available, however, it is probable the distribution was relatively low. For the second irrigation, the results are improved (Table 2 and Figure C5). This site had the longest and narrowest strips. Data for the second irrigation indicated that reasonably good results were obtained. The soil conditions were wetter than the design. Had the inflow stream been up to the design value, the results would have been even better. The low requirement depth resulted from needing to irrigate too soon (canal closure again). The distribution was very good at UCH = 0.97.

Site 3-22. -- Advance - recession data were not available for including in this report. Tables 1 and 2 show much the same results for this site as for the previous sites discussed. Soil conditions were much drier than expected at the first irrigation. An inflow stream only 80% of the design value caused

a slow application time (more than twice the design). For this reason, uniformity may have been less than that possible, although the overall efficiency was relatively good. For the second irrigation, the wetter soil conditions were again a factor. An inflow stream only 60% of the design gave a relatively quick, light application, which was also relatively efficient (i.e., the wetter soil helped speed the advance). Had the inflow stream been larger, the results may have been even better, with a quicker, lighter application being desired.

Site 3-19 (1-4). Tables 1 and 2 and Figure C6 contain data for the first two irrigations. For the first irrigation, the measured soil conditions were again much drier than the design. The measured inflow stream was slightly larger than the design. Overall the application was achieved in an appropriate amount of time, but underirrigation (E_r = 57%) and relatively poor uniformity (UCH = 0.81) resulted (see Figure C6). For the second irrigation, the measured soil conditions are wetter than the design. An inflow stream larger than the design gave a light, quick application, however the irrigation occurred too soon (small requirement depth was found even though there was underirrigation at the first irrigation, probable causes are rainfall and water table fluctuation). Again, the influencing factor was the closure period. Application uniformity (UCH = 0.90) appears to be much better for the second irrigation (see Figure C6).

Site 3-19 (10-16). This site, located next to Drain No. 7, showed a very dry soil condition before the first irrigation. It occurred, however, that an inflow stream almost 2.5 times larger than the design value was used and the results were very good. Figure C7 shows the advance was reasonable but the distribution was not as good as at other sites (UCH = 0.91). For the second irrigation a similar situation occurred, although the soil conditions were now wetter than the design. A quick, light application was achieved (See Table 2).

Site 3-02 (1-4). The data of Tables 1 and 2 and Figure C8 show a situation for this site very similar to the previous one. The first irrigation had drier soil conditions but a larger inflow stream than the design. A quicker application with some underirrigation (E_r = 87%) resulted. It appears the uniformity of application was relatively less (UCH = 0.90). The second irrigation did not have the same characteristics as those of the other sites. A larger inflow stream (than design) gave a lighter application, but the requirement depth was measured to be large, so

underirrigation (E_r = 74%) occurred. In this case, reducing the inflow stream and increasing the application time or simply using the same inflow stream but increase the application time to the design value would have given better results.

It is noted the underirrigation may not always be undesirable in the cases discussed above. These are early season irrigations and the actual root zone is less than the 0-90 cm profile used for design. As long as adequate water is supplied until the next irrigation, there is really no problem. Salinity management considerations must be kept in mind in this aspect, however, which is the reason why the 0-90 cm profile is considered in design and for each individual irrigation. The previous discussion has shown the effects of irrigation system state and operation variable changes on irrigation performance. These variables are intake rate, flow rate, irrigation time, soil moisture (requirement depth), basin geometry and dimensions (boundaries). Variables such as surface roughness and surface slope (constant zero grade) were not analyzed. Comparison with design conditions illustrates what happens and why. Generally, the comparisons given would be considered extreme. The first irrigation conditions represent high intake and dry soil conditions, while the second irrigations represented wetter soil and lower intake conditions. The design conditions were actually in between these and it is expected the average seasonal conditions would also be in between. Management and/or other limitations constrained the performance of the first two irrigations to less than desirable either in terms of distribution or efficiency. Generally, one was good while the other was poor. Improved management at individual irrigations should improve this. On an overall season basis, the general results were actually good, much better than the conventional methods, as discussed earlier (see EWUP, 1981f).

It is felt that the systems (as designed) performed adequately. Improving farmer management ability and understanding for use of the new systems is the key to improvement at this point. The problems of the fluctuating water delivery flow rate and improving farmer ability to characterize the flow rate so that appropriate management changes can occur needs to be addressed. The physical condition of the branch canals and mesqas have a direct effect on this as does the present operation of the delivery system. Physical improvements to the delivery system, very regular cleaning and maintenance at a minimum, or possible raising mescas for gravity delivery to the farm, are

suggested improvements. Continuous flow in the branch canal, with rotations between mesqas (and with water control ability at mesqa inlets) will help to deliver water to the farmer on a more reliable basis (i.e., a more consistent rate and timing). It is possible (and it is recommended) that designing for the conditions of the first irrigation when the soil is driest and intake is high, would alleviate many management problems with successive irrigations. For instance, given that irrigation frequency recommendations (i.e., when to irrigate) are appropriate then designs for "first irrigation" conditions should give adequate performance for a management criteria of irrigating until the water just reaches the end of the field (or is within 5 m to 10 m of the end).

1981 Summer Season: Level Furrow Advance/Recession Data

Figures C9 to C13 present water advance/recession data for irrigations on level furrow systems constructed on Abu Raya farms during the 1981 summer season. Crops were cotton and maize. The "bed" (two plant rows per irrigation furrow) method was used in both cases giving an irrigated furrow spacing of 1.1 m. Furrow lengths ranged between 65 m and 130 m. Generally, the sets were managed so that 10 to 15 furrows were irrigated in a set. This resulted in a range of furrow inflow rates from 1 lps to 3 lps. The slower advance times in Figures C9 to C13 are for the smaller furrow inflow rates. Individual site and irrigation data analyses are not presented here (as in the previous section), but several comments on the advance/recession data plots follow. Uniformity (UCH) values for the irrigations presented in Figures C9 to C13 were calculated using intake functions determined in Table 4 of Section II of this report. Since most of the irrigations are mid-season, the mean intake function of part B of that Table is considered representative. Uniformity values calculated are summarized in the following discussion.

Figure C9 presents the advance/recession data for the first two irrigations of maize on Site 3-10. The first irrigation results show a slow advance, and the uniformity was good (UCH = 0.95). This indicates that the soil conditions were drier than the design and possibly the furrow inflow rate less than the design. The second irrigation results show reasonable uniformity (UCH = 0.96). The overall season results for this site are only fair. There were several irrigations with low efficiency (irrigated too soon) and a few with very high efficiency. Management of maize irrigation in Abu Raya could be improved.

Figures C10 to C13 present advance/recession data for mid-season irrigations of cotton at several of the pilot farms. The curves show very uniform applications (UCH values from 0.93 to 0.99) were achieved. This indicates the designs, which were formulated for the average seasonal conditions (i.e., those of mid-season irrigations), are achieving adequate results. Overall season results for the cotton pilot farms were good (EWUP, 1982c) as discussed previously. Some improvements with management (pre-irrigation methods vs. dry planting, stopping irrigation by mid-August, etc.) will further improve the overall results.

Generally the level furrow designs have achieved success in Abu Raya, especially after changing to the "bed" method with two plant rows per furrow, giving a wider furrow spacing and improving the furrow construction and maintenance. The irrigator can adapt to variable discharge by changing the number of furrows being irrigated in a set. This allows great flexibility as compared to the level borders, meaning that managing irrigations on level furrows should be much easier for farmers to learn. The system change in terms of length of run is of no major consequence as far as management is concerned, assuming that precision land leveling has been performed. As far as system improvements, however, the long level furrows have consistently shown labor, water and time savings during irrigation.

SUMMARY

Level farm irrigation system design, as has been applied by the Egypt Water Use and Management Project at its Kafr El Sheikh study area in the North Central Delta, has been presented, reviewed, evaluated and analyzed. This has been accomplished in three major parts of the report.

Part I: Level Border and Level Furrow Irrigation Systems Design provides a review of the USDA-SCS level irrigation system design methods used, their underlying assumptions, the general design processes used, design information requirements, and effects of design parameter changes on irrigation performance. A major offering of this part are the computer programs, user instructions and examples for level border and level furrow design using either the HP-9825 Desktop Computer or HP-67 Programmable Calculator. These tools effectively aid design formulation allowing the designer to consider a wide range of situations with minimal effort.

Part II: Farm Irrigation System Design Considerations, Abu Raya, Kafr El Sheikh is a summary of a factor-by-factor analysis of the state, operation and management variables which affect level irrigation system design. This part naturally focuses on data collected in Abu Raya, Kafr El Sheikh, but the process and analysis used are applicable to farm irrigation system design in any system. Also, the results determined are applicable to many areas which have similar conditions. Significant results for the Abu Raya data show that saqia water delivery flow rates are highly variable; soil intake rates can be very high for the dry, cracked conditions before the first irrigation, and decrease to low intakes rates for the remainder of the season; farmers manage their fields as if they were dead level, however, grid surveys indicate field topography is far from dead level. The mean measured field elevation variation was ± 6.5 cm from the mean field elevation. For efficient level basin irrigation a tolerance of ± 1.5 cm is recommended. Conventional farm water management practices of Abu Raya are also reviewed.

Part III: Level Irrigation System Design Experience, Abu Raya, Kafr El Sheikh provides a season by season summary of the experiences of the K.S. Team with level systems. Comparison to the conventional methods shows the improved methods of dead level border strip and dead level long furrows consistently yield improved irrigation efficiencies, water savings, irrigation labor and time savings and also contribute to better crop production. Better farm water

management practices are leading to water table and soil salinity management and control with no adverse effects. Design analyses show where system design improvements and management improvements can be made. Using appropriate values for design variables gives improved irrigation system performance over the existing farm irrigation system. When designs are formulated for "typical" conditions, results will be less than optimal when certain conditions are at an extreme. This was found to be the case in Abu Raya, when designs formulated for the seasonal average intake conditions did not perform as well as desired at the initial irrigation, when intake rates were considerably higher. Indications are that designs should be formulated for the conditions of the first seasonal irrigation when the soil intake rate is high and the soil water deficit is also high. Such designs should perform well for the succeeding irrigations during the season (when the above factors take on smaller values), although careful water management, particularly with respect to irrigation timing and application time is necessary.

CONCLUSIONS

Considering the scope and focus of each of the three parts of this report, the following conclusions are drawn:

1) The USDA-SCS level irrigation system design methods for level furrows and level border are easily applied and adequate tools for farm irrigation system design improvement.
2) The design programs for both the HP-9825 and HP-67 computer/calculators presented are extremely useful design aids. They allow the designer to consider a wide range of design conditions with relatively little effort.
3) The design parameters used in formulating farm irrigation system designs often exhibit different amounts of temporal variability. This variability can result in inappropriate designs unless the designer has adequate fore-knowledge of the effects of this variability on irrigation system performance.
4) Study, evaluation and analysis of certain site specific conditions and factors affecting farm irrigation system design is necessary before appropriate designs can be formulated. The Abu Raya area of Kafr El Sheikh was used as a case study of this and conclusions of that study are presented elsewhere in this report. Areas with similar conditions can often have similar designs with only detailed investigations necessary for some factors such as crop pattern, soil intake rate, climate, etc.
5) Farm water delivery in Abu Raya can be highly variable due to lifting by saqia, conveyance losses, etc. Raised, lined mesqas which deliver water to farm turnouts by gravity flow are a solution to this problem. Consistent flow rates aid in efficient level basin and level long furrow irrigation.
6) Several level system designs implemented in Abu Raya were evaluated. Results show in many cases that appropriate values for design variables gave significantly improved irrigation system performance over the existing farm irrigation system.
7) Level border strip and level long furrow irrigation methods have been shown to be a large improvement over the conventional methods Abu Raya farmers use. Benefits which have consistently been shown are

improved efficiency, water savings, irrigation time and labor savings, and water table and salinity management and control. Improved crop production through better water management, fertilizer use and uniform water application results.

8) Farm water management recommendations in terms of teaching and advising farmers on when to irrigate and how much to irrigate is a necessary component of level irrigation system design improvements, which also includes level system design and precision land leveling. All three components must be implemented together to ensure any measure of success and/or improvement. This has been adequately demonstrated over several seasons in Abu Raya, Kafr El Sheikh.

RECOMMENDATIONS

Based on the contents of this report, and supporting documentation, the following recommendations are made:

1) Site specific studies, evaluation and analysis of farm irrigation system design considerations similar to those presented have been carried out for the other EWUP areas (El Minya and Mansouria), and represent a wide range of irrigation agriculture conditions in Egypt. This information should be put to use in developing nation-wide improvement programs in irrigation in Egypt.
2) Analyses as presented in this report should be used to develop design recommendations and criteria for farm irrigation system design improvements in each major area where conditions are similar.
3) The computer/calculator programs presented here should be used to effectively assist in design formulation and analysis.
4) Farm irrigation system improvement programs which include level farm irrigation system design, precision land leveling, the associated farm water management recommendations and crop production and management recommendations should be modified and adapted as necessary for successful implementation in other areas of Egypt. The same program is used, but adapted according to the findings as suggested in (2) above, to effectively implement in other areas.
5) Training programs are necessary in Egypt to train professionals in farm water management, farm irrigation system design and precision land leveling. Technical training in crop production and management and soil-water-plant relations should be provided. Teams modelled after those of EWUP, and which have had the necessary training in the above, should be put to work implementing improvement programs, as suggested above, in large pilot areas.
6) Continued research and training in the above subject areas are recommended to assist and support pilot program development and implementation.

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APPENDIXES

Appendix A: Level Border and Level Furrow Irrigation System Design Programs for the HP-9825 Desktop Computer.

Level Border Design Program and Example Output

Special features of the program are:

1) Either a design may be formulated or a simple evaluation made of a level border system (see discussion in text, Part I).
2) Design parameters presented in Table 2 or Figure 3 of Gates and Clyma (1980a), T_t/T_u vs. E_a are represented in the program by the following least squares regression equation:

$$E_a = 69.98 - 15.39 \ln (T_t/T_u)$$

$$(r^2 = 0.99).$$

3) The Newton method for finding the roots of a function, $f(x) = 0$, is used to solve Equation 22 of Gates & Clyma (1980a) when either Q_u or T_t is the unknown.
4) Designs are formulated only for the cases when an integer number of strips results, based on the total field width, the total flow rate available at the field and the design unit width inflow stream (see discussion in Part I of text).
5) Maximum expected flow depth is calculated and the minimum required bund height determined as not less than this value plus 3 cm.
6) The ratio of inflow time to advance time is printed to allow easy comparison to the constraints:

   inflow time, T_a/advance time, $T_t \geq 0.5$ for clay soils

   inflow time, T_a/advance time, $T_t \geq 0.75$ for sandy soils

In using the program, the user is prompted to supply the following information or design data in the following order, press CONTINUE after each entry, the program is started by pressing RUN:

1) is this a design or evaluation?
   (1 = design or 2 = evaluation),
2) SCS intake parameter, a (mm),
   SCS intake parameter, b,
   SCS intake parameter, c, (mm), (6.985)
3) SCS intake family, I_f,
4) length of run, L (m)
5) required or design depth, D_u (mm),

6) surface roughness, n.

If design, then:

7) desired or minimum E_a (%),
8) total available flow at field, Q_t (lps),
9) total field width, W_t (m).

If evaluation, then:

7) strip width, w (m),
8) unit width inflow rate, Q_u (lps/m)
9) inflow time, T_a (min).

In either case (design or evaluation) all of the input data are printed. (Note: The HP-2631B printer was used. Be sure printer is on and on-line before starting).

The results or output are printed immediately after the calculations (usually only a few seconds or less) are completed. For a design the output is:

1) Number of strips, usually 2 cases will be given which are integer numbers of the whole number calculated for the input data.
2) strip width, w (m) for the two cases.
3) the unit inflow stream, Q_u (lps/m) for the 2 cases
4) estimated advance time (min) for the 2 cases.
5) estimated inflow time (min) for the 2 cases.
6) gross application depth, D_a (mm) for the 2 cases.
7) Water application efficiency, Ea (%) for the 2 cases.
8) Maximum flow depth, Y_m + 30 (mm) for the 2 cases.
9) Minimum bund height, y_m + 30 (mm) for the 2 cases.
10) ratio of inflow time to advance time for the 2 cases.

For an evaluation, a simple volume balance is performed and the SCS level border model assumptions used to generate these output:

1) gross application depth, D_a (mm).
2) depth stored in the root zone, Dau (mm).
3) deep percolation depth, DP (mm).
4) water application efficiency, E_a (%).
5) water requirement efficiency, E_r (%).'

No attempt is made to determine the uniformity of application, and the routine is not designed for use as a simulation tool. A program listing is provided in Figure A1. Example design and evaluation output are provided in Figure A2 for the following design and evaluation input data:

Design	Evaluation
a = 1.186 mm	a = 1.186 mm
b = 0.756	b = 0.756
c = 6.985 mm	c = 6.985 mm
I_f = 0.5	I_f = 0.5
L = 80 m	L = 80 m
D_u = 100 mm	D_u = 100 mm
n = 0.15	n = 0.15
E_a = 90%	w = 20 m
Q_t = 25.6 lps	Q_u = 1.28 lps/m
W_t = 80 m	T_a = 112.6 min.

Level Furrow Design Program and Example Output

Special features:

1) Either a design may be formulated or a simple evaluation made of a level furrow irrigation system (see discussion in text, Part I).
2) Up to 50 trial furrow inflow rates (i.e., 0.25 lps increments over a minimum - maximum range of 12.25 lps) may be tested in a design.
3) Results are printed for each trial furrow inflow rate in tabular form.
4) For designs, a plot of the performance parameters (E_a, E_r, R_p) vs. furrow inflow rate may be made. The HP-9872A plotter is used.
5) Surface roughness assumed equal to 0.04 in program.
6) The exponential advance function parameters, c, and, d, are calculated in the program using equations given by USDA (1979).

In using the program, the user is prompted to supply the following information or design data in the following order. The program is started by pressing RUN. Press CONTINUE after each data entry.

1) design or evaluation? (1 = design, 2 = evaluation),
2) SCS intake parameter, a (mm),
   SCS intake parameter, b
   SCS intake parameter, c (mm), (6.985)
3) SCS intake family, I_f,
4) length of run, L (m),
5) furrow spacing, W (m),
6) required or design depth, D_u (mm).

```
0: wtb 701,27,39.107,40,03
1: prt "Design or Evaluation(1=des,2=eval)",r0;if r0=2;jmp 3
2: fmt ,c3,n,wrt 701,"Level Border Irrigation Design"
3: fmt c18,2,wrt 701,"Date: ",c18,[d18],jmp 2
4: fmt ,c10,,wrt 701,"Time:",c10
5: wtb 701,2,3,10?,40,12
6: dim Q[10],[illegible]
7: ent "Q,mm",[illegible],fmt f16.4,5x,f16.4,5x,f16.4
8: wrt 701,"Q=",Q,"mm",B,"m",C
9: ent "Intake Family",H,fmt f12.3,wrt 701,"Intake Family=",H
10: ent "Length of run,L m",L,"Required or design depth,mm",F
11: ent "Surface Roughness",N
12: fmt f10.1,1x,c,f15.2,1x,c
13: wrt 701,"Length=",L," m","Surface Roughness=",N
14: fmt f16.2,1x,c,2,wrt 701,"Required or Design depth=",F,"mm"
15: if r0=1,goto "EVAL"
16: ent "Desired or minimum Ea(%)",E,"Total available flow at field(lps)",Q
17: ent "Total field width,m",W
18: fmt f16.1,1x,c,wrt 701,"Desired or minimum Ea=",E,"%"
19: wrt 701,"Total available flow at field=",Q,"lps"
20: wrt 701,"Total field width=",W,"m",fmt 2,wrt 701
21: [illegible]
22: [illegible]
23: "Start": [illegible],goto "FCT"
24: "Loop": [illegible]
25: [illegible]
26: "FCT": if r0=2=3+1 [illegible],jmp 2
27: =3+5
28: [illegible]
29: [illegible]
30: [illegible]
31: "REF": [illegible],jmp 3
32: =3+5,Q/B+[illegible]N[1]: int(H+1)+N[2]
33: for I=1 [illegible] Q/[illegible],2+r0;gto "Start"
34: next I
35: for I=1 to 2;Q/B+[illegible]
36: [illegible]
37: [illegible]
38: wtb 701,[illegible]
39: fmt c10,,wrt 701,"SUMMARY OF RESULTS"
40: wtb 701,27,39.107,40,03
41: fmt ,c2,,wrt 701,"Number of Strips ",
42: fmt [illegible]
43: fmt ,,wrt 701,"Strip width(m) ",
44: for I=1 to [illegible],wrt 701 [illegible],next I,wrt 701
45: wrt 701,"Max. Intake Stream(lps/m)"
46: for I=1 to [illegible],wrt 701 [illegible],next I,wrt 701
47: wrt 701,"Eff.max. advance time(min)"
48: for I=1 to 2,wrt 701 [illegible],next I,wrt 701
49: wrt 701,"Estimated Inflow time(min)"
50: for I=1 to [illegible],wrt 701 [illegible],next I,wrt 701
51: wrt 701,"Gross Application Depth(mm)"
52: for I=1 to 2,wrt 701 [illegible],next I,wrt 701
53: wrt 701,"Application Efficiency(%)"
54: for I=1 to 2,wrt 701 [illegible],next I,wrt 701
55: wrt 701,"Maximum Flow Depth(mm)"
56: for I=1 to 2,wrt 701 [illegible],next I,wrt 701
57: wrt 701,"Minimum Bund height(mm)"
58: for I=1 to [illegible],wrt 701 [illegible],next I,wrt 701
59: wrt 701,"[illegible] time"
60: for I=1 to [illegible],wrt 701 [illegible],next I,wrt 701;gto "END"
61: "EVAL": ent "Strip width,W m",[illegible] width in low Rate(lps/m)",Q[1]
62: ent "Inflow time,min",[illegible]
63: fmt [illegible],wrt 701,"Strip width= W m"
64: wrt 701,"Q= ",Q," width in low rate=",Q[1],"lps/m"
65: wrt 701,"Inflow time= ",[illegible],wrt 701
66: [illegible],jmp 2
67: [illegible]
68: [illegible]
69: [illegible]
70: fmt c10,,wrt 701,"SUMMARY OF RESULTS"
71: wrt 701,[illegible]
72: fmt [illegible],wrt 701,"Gross application depth(mm)",wrt 701
73: fmt [illegible],wrt 701 [illegible],wrt 701
74: wrt 701,"Max. stream(mm)" [illegible],wrt 701,2,,wrt 701
75: wrt 701,"Eff. [illegible] depth(mm)",wrt 701,2,,wrt 701
76: wrt 701,"[illegible]",wrt 701
77: wrt 701,"[illegible] time",wrt 701,2,,wrt 701
78: [illegible]
"END":
```

Figure A1. Level Border Design Program for HP 9825.

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SCS Level Border Irrigation Design

BASIC DESIGN DATA

```
a=      1.1060     b=      0.7560     c=      6.9050
Intake family=       0.500
Length=     80.00 m     Surface Roughness=      0.15
Required or Design depth=    100.00 mm

Desired or minimum Ea=     90.00 %
Total available flow at field=     25.60 lps
Total field width=     80.00 m
```

SUMMARY OF RESULTS

Number of Strips	3.00	4.00
Strip width(m)	26.67	20.00
Unit inflow stream(lps/m)	0.96	1.28
Estimated Advance Time(min)	97.75	74.13
Estimated Inflow Time(min)	157.37	112.59
Gross Application Depth(mm)	113.30	108.09
Application Efficiency(%)	88.26	92.51
Maximum Flow Depth(mm)	46.37	52.95
Minimum Bund Height(mm)	76.37	82.95
Inflow Time/Advance Time	1.61	1.52

EVALUATION DATA

```
a=      1.1860     b=      0.7560     c=      6.9050
Intake family=       0.500
Length=     80.00 m     Surface Roughness=      0.15
Required or Design depth=    100.00 mm

Strip width=     20.00 m
Unit width inflow rate=      1.20 lps/m
Inflow time=    113.00 min
```

SUMMARY OF RESULTS

Gross Application Depth(mm)	108.48
Depth stored(mm)	100.00
Deep percolation depth(mm)	8.48
Application Efficiency(%)	92.10
Requirement Efficiency(%)	100.00

Figure A2. Example Output for HP 9825 Level Border Design and Evaluation Program. (The design for n_s = 4 is used in the evaluation).

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If design, then:

7) lower limit for furrow inflow rate, Q_f (lps),
   upper limit for furrow inflow rate, Q_f (lps).

If evaluation then:

7) furrow inflow rate, Q_f (lps),
8) inflow time, T_a (min).

In either case (design or evaluation) all of the input data are printed (HP-26318 printer used).

The results are printed immediately after the calculations are completed. For a design the output in tabular form is:

1) the trial furrow inflow rate, Q_f (lps),
2) the adjusted furrow wetted perimeter, P + K (m),
3) computed inflow time, T_a (min),
4) estimated advance time, T_t (min),
5) average opportunity time, T_{oa} (min),
6) average inflow depth, D_a (mm),
7) average intake depth, D_i (mm),
8) average deep percolation depth, D_p (mm)
9) average root zone storage, D_{au} (mm),
10) water application efficiency, E_a (%),
11) water requirement efficiency, E_r (%),
12) deep percolation ratio, RP (dec.).

For an evaluation, a simple volume balance is performed and the SCS level furrow model assumptions are used to generate these output for the inflow time and furrow inflow rate specified:

1) adjusted furrow wetter perimeter, P + K (m),
2) estimated advance time, T_t (min),
3) inflow depth, D_a (mm),
4) average deep percolation depth, D_p (mm),
5) average root zone storage, D_{au} (mm),
6) water application efficiency, E_a (%),
7) water requirement efficiency, E_r (%),
8) deep percolation ratio, RP (dec).

No attempt is made to determine the distribution of applied water. The evaluation subroutine is not designed to be used as a simulation tool.

A program listing is provided in Figure A3. Example design and evaluation output are provided in Figures A4 and A5, respectively, for the following design and evaluation input data:

Design	Evaluation
$a = 1.7856$ mm	$a = 1.7856$ mm
$b = 0.785$	$b = 0.785$
$c = 6.985$ mm	$c = 6.985$ mm
$I_f = 1.00$	$I_f = 1.00$
$L = 100$ m	$L = 100$ m
$W = 1.1$ m	$W = 1.1$ m
$D_u = 100$ mm	$D_u = 100$ mm
$Q_f = 0.5$ to 5.0 lps	$Q_f = 2.0$ lps
	$T_a = 94$ min.

```
0: wtb 701,27,30,107,49,83
1: ent "Design or Evaluation(1=des,2=eval)",r13;if r13=2;jmp 3
2: fmt ,c39,4/;wrt 701,"SCS Level Furrow Irrigation Design"
3: fmt c18,2/;wrt 701,"BASIC DESIGN DATA";jmp 2
4: fmt ,c16,2/;wrt 701,"EVALUATION DATA"
5: wtb 701,27,30,107,48,83
6: dim Q[50],E[50],M[50],U[50],G[50],P[50],T[50],A[50],O[50]
7: dim D[50],F[50],S[50],V[50],Z[50],I[15],L[15],H[15]
8: ent "a,mm",a,"b",b,"c,mm",C;fmt f12.4,5x,f12.4,5x,f12.4
9: wrt 701,"a=",A,"b=",B,"c=",C
10: ent "Intake family",H;fmt f12.3;wrt 701,"Intake family=",H
11: ent "L,m",L,"W,m",W,"Required or design depth,mm",F
12: fmt f10.2,1x,c,5x,f10.2,1x,c
13: wrt 701,"Length=",L,"m","Furrow Spacing=",W,"m"
14: fmt f10.2,1x,c,2/;wrt 701,"SMD(Design depth)=",F,"mm"
15: 7.0747+1.7077H+K(0.2493e-5+3.263e-4H+D
16: fmt f10.4,10x,f10.4,2/;wrt 701,"c=",K,"d=",D;if r13=2;gto "EVAL"
17: ent "Low limit for Q,lps",r11,"Up limit for Q,lps",r12;fmt f10.2,1x,c
18: 0+Z,r11/r11+r9;(r12-r11)/.25+1+r10;0+r0;jmp 3
19: "EVAL":ent "Inflow rate,lps",r11,"Inflow time,min",r0;fmt f10.2,1x,c
20: 0+Z;1+r9+r10
21: for I=r9 to r10
22: r11+Z+Q[I];Z+.25+Z
23: .007492Q[I]↑.5419/L+S[I]
24: (.04Q[I]/FS[I])↑.4247×.2647+.2274+P[I]
25: P[I]/W+J
26: ((F/J-C)/A)↑(1/B)+O
27: O+(1/KL(D/Q[I]FS[I])↑2)((DL/Q[I]FS[I]-1)exp(DL/Q[I]FS[I])+1)+O[I]
28: if r0=0;r0+T[I];jmp 3
29: (A*O[I]↑B+C)+F[I]
30: (.01667P[I]L/Q[I])(AO[I]↑B+C)+T[I]
31: (L/K)×exp(DL/Q[I]FS[I])+A[I]
32: 60Q[I]T[I]/WL+D[I]
33: D[I]-F+V[I];if V[I]<0;0+V[I]
34: D[I]-V[I]+Z[I]
35: (Z[I]/D[I])100+E[I];if E[I]>100;100+E[I]
36: (Z[I]/F)100+M[I];if M[I]>100;100+M[I]
37: V[I]/D[I]+U[I]
38: "Iter":next I
39: wtb 701,27,30,107,49,83
40: fmt c18,2/;wrt 701,"SUMMARY OF RESULTS"
41: wtb 701,27,30,107,40,83
42: fmt 1,c24.z;wrt 701.1,"Furrow Inflow Rate(lps) "
43: fmt 2,z,f8.2;for I=r9 to r10;wrt 701.2,Q[I];next I
44: fmt 3;wrt 701;wrt 701.1,"Adjusted WP, P+K(m)     ";fmt 3,z,f8.3
45: for I=r9 to r10;wrt 701.3,P[I];next I;wrt 701
46: wrt 701.1,"Inflow Time(min)          "
47: for I=r9 to r10;wrt 701.2,T[I];next I;wrt 701
48: wrt 701.1,"Advance Time(min)         "
49: for I=r9 to r10;wrt 701.2,A[I];next I;wrt 701;if r13=2;jmp 3
50: wrt 701.1,"Av Opportunity Time(min)"
51: for I=r9 to r10;wrt 701.2,O[I];next I;wrt 701
52: wrt 701.1,"Av Inflow Depth(mm)       "
53: for I=r9 to r10;wrt 701.3,D[I];next I;wrt 701;if r13=2;jmp 3
54: wrt 701.1,"Av Intake Depth,0-L(mm)  "
55: for I=r9 to r10;wrt 701.3,F[I];next I;wrt 701
56: wrt 701.1,"Av Deep Perc Depth(mm)   "
57: for I=r9 to r10;wrt 701.3,V[I];next I;wrt 701
58: wrt 701.1,"Av Root Zone Storage(mm)"
59: for I=r9 to r10;wrt 701.3,Z[I];next I;wrt 701;wrt 701
60: wrt 701.1,"Water Appl Eff, EA(%)    "
61: for I=r9 to r10;wrt 701.3,E[I];next I;wrt 701
62: wrt 701.1,"Water Req'd Eff, ER(%)    "
63: for I=r9 to r10;wrt 701.3,M[I];next I;wrt 701
64: wrt 701.1,"Deep Perc Ratio, RP(dec)"
65: for I=r9 to r10;wrt 701.3,U[I];next I;wrt 701;if r13=2;gto "end"
66: ent "Is plot desired?(1=Y,2=N)",r14;if r14=2;gto "end"
67: dsp "Load paper for plot";stp
68: dsp "Set P1 and P2";stp
69: sclr;scl r11,r12,0,1;pen# 4
70: fxd 1;xax 0,.1,r11,r12,1
71: fxd 2;yax r11,.05,0,1,2;line ;csiz 3,2,1,0
72: for I=r9 to r10
73: plt Q[I],E[I]/100
74: next I;pen;lbl " Ea";pen;line 6
75: for I=r9 to r10
76: plt Q[I],M[I]/100
77: next I;pen;lbl " Er";pen;line 4
78: for I=r9 to r10
79: plt Q[I],U[I]
80: next I;pen;lbl " Rp";pen
81: csiz 3,2,1,90
82: plt r11-(r12-r11)/10,.05,1;lbl "Performance Parameter (dec)"
83: plt r11+(r12-r11)/5,-.2,1;csiz 3,2,1,0;lbl "Furrow Inflow Rate (lps)"
84: pen#
85: "end":end
```

Figure A3. Level Furrow Design Computer Program for HP 9825.

Best Available Document

SCS Level Furrow Irrigation Design

BASIC DESIGN DATA

a= 1.7056 b= 0.7850 c= 6.9950
Intake family= 1.000
Length= 100.00 m Furrow Spacing= 1.10 m
SMD(Design depth)= 100.00 mm

c= 0.0624 d=4.1879E-04

SUMMARY OF RESULTS

Furrow Inflow Rate(lps)	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75
4.00 4.25 4.50	4.75	5.00												
Adjusted WP, P*k(m)	0.463	0.499	0.528	0.553	0.574	0.594	0.611	0.628	0.643	0.657	0.670	0.683	0.695	0.707
0.718 0.728 0.738	0.748	0.758												
Inflow Time(min)	400.60	254.24	188.52	150.14	124.04	106.08	93.45	83.03	74.71	67.91	62.25	57.46	53.36	49.80
46.69 43.95 41.52	39.34	37.37												
Advance Time(min)	273.49	81.97	46.49	33.57	27.22	23.54	21.16	19.51	18.31	17.40	16.68	16.11	15.64	15.25
14.92 14.64 14.37	14.10	13.99												
Av Opportunity Time(min)	548.74	466.12	426.32	399.15	378.37	361.57	347.50	335.43	324.89	315.56	307.21	299.66	292.78	286.47
280.66 275.20 270.26	265.58	261.19												
Av Inflow Depth(mm)	109.256	104.007	102.828	102.369	102.143	102.019	101.946	101.903	101.878	101.864	101.859	101.859	101.863	101.870
101.879 101.890 101.902	101.915	101.928												
Av Intake Depth,0-L(mm)	109.234	103.908	102.008	102.348	102.123	101.999	101.926	101.883	101.857	101.844	101.838	101.838	101.842	101.849
101.858 101.869 101.881	101.894	101.908												
Av Deep Perc Depth(mm)	9.256	4.007	2.828	2.369	2.143	2.019	1.946	1.903	1.878	1.864	1.859	1.859	1.863	1.870
1.879 1.890 1.902	1.915	1.928												
Av Root Zone Storage(mm)	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000
100.000 100.000 100.000	100.000	100.000												
Water Appl Eff, EA(%)	91.528	96.146	97.250	97.686	97.902	98.021	98.091	98.133	98.157	98.170	98.175	98.175	98.171	98.165
98.156 98.145 98.134	98.121	98.108												
Water Reqt Eff, ER(%)	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000
100.000 100.000 100.000	100.000	100.000												
Deep Perc Ratio, RP(dec)	0.005	0.039	0.028	0.023	0.021	0.020	0.019	0.019	0.018	0.018	0.018	0.018	0.018	0.018
0.018 0.019 0.019	0.019	0.019												

Figure A4. Example Output for HP 9825 Level Furrow Design Program.

Best Available Document

EVALUATION DATA

a= 1.7056 b= 0.7850 c= 6.9050
Intake family= 1.000
Length= 100.00 m Furrow Spacing= 1.10 m
SMD(Design depth)= 100.00 mm

c= 0.8624 d=4.1077E-04

SUMMARY OF RESULTS

Furrow Inflow Rate(lps)	2.00
Adjusted WP, P*K(m)	0.611
Inflow Time(min)	93.00
Advance Time(min)	21.16
Av Inflow Depth(mm)	101.455
Av Deep Perc Depth(mm)	1.455
Av Root Zone Storage(mm)	100.000
Water Appl Eff, EA(%)	98.566
Water Reqt Eff, ER(%)	100.000
Deep Perc Ratio, RP(dec)	0.014

Figure A5.

Example Output for HP 9825 Level Furrow Simple Evaluation Program. (Evaluation of design in Figure A4 for Q_f = 2.0 lps).

Appendix B: Level Border and Level Furrow Irrigation System Design Programs for the HP-67 Programmable Calculator.

HP-67 Level Border Design Program

The SCS Level Border Design Program presented here is a revised and slightly more complicated version of that presented in EWUP (1982f). The program presented here is considered more complete in the sense that the strips are designed to meet the field dimensions. A program description, user instructions and program listing follow. The user must follow the instructions for data entry and key usage very closely. Table 2 or Figure 3 of Gates and Clyma (1980a) is used for the relationship: E_a vs. T_t/T_u (see part I). All depths in (mm).

Using the example of Appendix A for level borders, the following data inputs and outputs, in the order in which they are entered or read from the display, are given. (I) means input, (O) means output:

(I) $L = 80$ m
(I) $n = 0.15$
(I) $a = 1.186$ mm
(I) $b = 0.756$
(I) $c = 6.985$ mm
(I) $D_u = 100$ mm
(I) $T_t/T_u = 0.28$ (from Table 2, Gates & Clyma (1980a) (for $E_a = 90\%$).
(I) $E_a = 90\%$
(O) $T_u = 320.6$ min (flashes in display)
(O) $T_t = 89.8$ min
(I) Estimate of Q_u (lps/m)

(Program runs automatically to find actual Q_u; successively improving values in the trial and error procedure flash in the display. The routine may take from 30 to 90 seconds.)

(O) $Q_u = 1.05$ lps/m
(I) $Q_t = 25.6$ lps
(I) $W_t = 80$ m
(O) strip width, $w = 24.48$ m (flashes in display)
(O) no. of strips, $n_s = 3.27$ (round off to 3 and 4).

(I)	$n'_s = 3$	<u>or</u>	(I) $n_s' = 4$
(O)	$w' = 26.67$ m		(O) $w' = 20.0$ m
(O)	$Q_u' = 0.96$ lps/m ($Q_u' < 0.95\ Q_u$ therefore find new T_t).		(O) $Q_u' = 1.28$ lps/m ($Q_u' > 1.05\ Q_u$, therefore find new T_t).
(I)	$Q_u' = 0.96$ lps/m		(I) $Q_u' = 1.28$ lps/m

(Program runs automatically to find revised T_t; successively improving values in the trial and error procedure flash in the display.)

(O)	$T_t' = 97.7$ min	(O) $T_t' = 74.1$ min
(O)	$T_t'/T_u = 0.305$ $E_a' \cong 88\%$ (from E_a vs. T_t/T_u) (See Part I).	(O) $T_t'/T_u = 0.23$ $E_a' \cong 92\%$
(I)	$Q_u' = 0.96$ lps/m	(I) $Q_u' = 1.28$ lps/m
(I)	$E_a' \cong 88\%$	(I) $E_a' \cong 92\%$
(O)	$T_a = 157.8$ min (flashes in display)	(O) $T_a = 113.2$ min
(O)	$T_a/T_t = 1.61$ OK (Checks w/contraints)	(O) $T_a/T_t = 1.53$ OK
(I)	$Q_u' = 0.96$ lps/m	(I) $Q_u' = 1.28$ lps/m
(O)	$y_m = 46.4$ mm	(O) $y_m = 52.9$ mm

minimum bund height allowable = y_m + 30 mm

(I)	$E_a' = 0.88$	(I) $E_a' = 0.92$
(O)	$D_a = 113.6$ cm	(O) $D_a = 108.7$ mm

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Figure B1.

Program Description

Program Title SCS Level Border Design

Name Thomas W. Ley and Kamal Ezz El Din **Date** Summer 1982

Address EWUP

City **State** **Zip Code**

Program Description, Equations, Variables, etc. Revision of previous programs.

a) Procedure follows Gates and Clyma (1980). Newton method for finding roots of $f(x) = 0$ for Eqn. 22 in above paper is used.

b) Metric units are used. All depths are input and output in mm.

c) Design data input required:

1) Length of run, L (m).
2) SCS Intake family and parameters, I_f (a, b, c).
3) Design requirement depth (mm).
4) Surface roughness, n.
5) Desired or minimum E_a (%).
6) Ratio of advance time to requirement intake time, T_t/T_u (See part I of the report).
7) Total available flow rate at the field, Q_t (lps).
8) Total field width, W_t (m).

d) Program is designed to determine results when the number of strips is an integer number. This often will mean the initial design Q_u (lps/m) will change. If the revised Q_u (lps/m) is outside of a range of $\pm$ 10% of the original design, then a new advance time and application should be determined. A routine is programmed to allow this.

e) Output: Unit stream, Q_u (lps/m); strip width, w (m); number of strips, n_s; application time, T_a (min); gross applied depth, D_a (mm); required border ridge height (mm); maximum flow depth, y_m (mm).

Operating Limits and Warnings Program requires 222 steps. All storage registers except S5 - S9 are used. Labels A - E, a - e and 0 - 4 are used. Flag 0 is used. Display format is fixed with n = 4.

Figure B1 (Continued) **User Instructions**

SCS Level Border Design

Design Data $\hat{Q}_u$ (lps/m) Used Q_t (lps)+ W_t (m) or Q'_u+E_a:e $Q'_u+E'_a$:e Q'_u (lps/m)

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
01	Input the design data: Length, L(m)	L(m)		A	L(m)
	Roughness, n	n		R/S	n
	Intake equation parameter, a(mm)	a(mm)		R/S	a (mm)
	" " " , b	b		R/S	b
	" " " , c (mm)	c(mm)		R/S	c (mm)
	Design or requirement depth, D_u (mm)	D_u(mm)		R/S	D_u (mm)
	Ratio of advance time to intake time, T_t/T_u	T_t/T_u		R/S	T_t/T_u
	Desired or minimum application eff., E_a	E_a (%)		R/S	E_a (%)
02	Calculate T_u (required intake time)			R/S	T_u (min)
	" T_t (estimated advance time)		-	-	T_t (min)
03	Calculate Q_u (lps/m), unit width stream for				
	design data				
	Input an estimate, $\hat{Q}_u$	$\hat{Q}_u$(lps/m		B	
	(Calculator will loop thru a trial and error				
	solution routine; successively improving				
	values of Q_u flash in the display. When				
	iteration stops, Q_u is displayed).				Q_u(lps/m)
04	Input total available discharge, Q_t	Q_t(lps)		D	Q_t(lps)
	and total field width, W_t (m)	W_t (m)		R/S	
	output: strip width, w (m)				w(m)
	number of strip, n_s				n_s
05	Round off n_s to the next higher and lower				
	integers to get n'_{s1} and n'_{s2}				
	Key in n'_{s1} to find revised strip	n'_{s1}		R/S	
	width w' (m) and revised				w' (m)
	unit stream Q'_u (lps/m)			R/S	Q'_u (lps/m)
	If 0.95 Q_u > Q'_u or 1.05 Q_u < Q'_u				
	a revised T_t and E_a must be found.				
	If not go to step 07.				
06	Find T'_t (min): key in Q'_u (lps/m)	Q'_u (lps/m)		E	T'_t (min)
	(iterative routine is used again)				
	find T'_t/T_u			R/S	T'_t/T_u
	determine E'_a for T'_t/T_u (from Tables or Chart).				

Figure B1 (Continued)

User Instructions

CONTINUED

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
07	Find application time, T_a (min)				
	input: Q'_u, E_a or Q'_u, E'_a	Q'_u(lps/m)		Enter↑	Q'_u(lps/m)
	(T_a flashes in display):	E_a (%)	f	e	T_a(min)
	T_a/T_t calculated				T_a/T_t
	(check w/constraints:				
	$T_a/T_t \geq 0.5$ clay soils				
	$T_a/T_t \geq 0.75$ sandy soils)				
08	Find maximum flow depth, y_m (mm)				
	for Q'_u (lps/m)	Q'_u(lps/m)		R/S	y_m(mm)
	(Minimum border ridge height must be				
	y_m + 30 (mm)).				
09	Find depth applied, D_a(mm)	E_a or E'_a		R/S	D_a(mm)
	input E_a or E'_a in decimal form.				
10	Determine results for n'_{s2}				
	(i.e., from step 5)				
	press fP $\gtrless$ S		f	P<S	
	GTO 0		GTO	0	
	Key in n'_{s2}	n'_{s2}			
	(procedure is same from step 05).				
11	If T_a/T_t is not acceptable for either design				
	case, repeat steps 01-09 for a lower E_a				
	or shorter L.				

Figure B1 (Continued)

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	f LBL A	31 25 11	
	STO 2	33 02	L
	R/S	84	
	STO 8	33 08	n
	R/S	84	
	STO A	33 11	a
	R/S	84	
	STO B	33 12	b
	R/S	84	
010	STO C	33 13	c
	R/S	84	
	STO 3	33 03	D_u
	R/S	84	
	STO 4	33 04	T_t/T_u
	R/S	84	
	STO 5	33 05	E_a
	R/S	84	
	RCL 3	34 03	
	RCL C	34 13	
020	—	51	
	RCL A	34 11	
	÷	81	
	RCL B	34 12	
	h 1/x	35 62	
	h y^x	35 63	
	STO 9	33 09	
	— x —	31 84	T_u
	RCL 4	34 04	
	x	71	
030	STO D	34 14	
	h RTN	35 22	T_t
	f LBL B	31 25 12	
	h SF 00	35 51 00	set flag 0
	STO 0	33 00	
	2	02	
	÷	81	
	STO 7	33 07	
	g GSB f a	32 22 11	
	f LBL C	31 25 13	
040	STO 0	33 00	
	2	02	
	÷	81	
	h CF 0	35 61 00	clear flag 0
	STO 7	33 07	
	g GSB f a	32 22 11	
	f LBL 3	31 25 03	
	STO E	33 15	
	h ABS	35 64	
	2	02	
050	EEX	43	
	4	04	
	CHS	42	
	h x≷y	35 52	
	g x≠y	32 71	check true false
	GTO 4	22 04	
	RCL E	34 15	

$$T_t = T_u \cdot T_t/T_u \qquad T_u = \left(\frac{D_u - c}{a}\right)^{1/b}$$

for finding roots of $f(x) = 0$.

STEP	KEY ENTRY	KEY CODE	COMMENTS
	RCL 6	34 06	
	h x≷y	35 52	
	STO 6	33 06	
060	—	51	
	h 1/x	35 62	
	RCL 6	34 06	
	x	71	
	RCL 7	34 07	
	x	71	
	STO 7	33 07	
	STO − 0	33 51 00	
	RCL 0	34 00	
	h ABS	35 64	
070	h y^x	35 72	Iterative routine
	g GSB f a	32 22 11	
	f LBL 2	31 25 02	
	RCL D	34 14	
	RCL B	34 12	
	h y^x	35 63	
	RCL A	34 11	
	x	71	
	RCL B	34 12	
	1	01	
080	+	61	
	÷	81	
	RCL C	34 13	
	+	61	
	6	06	
	0	00	
	÷	81	
	RCL D	34 14	
	.	83	
	1	01	
090	8	08	
	7	07	
	5	05	
	h y^x	35 63	
	RCL 1	34 01	
	.	83	
	5	05	
	6	06	
	2	02	
	5	05	
100	h y^x	35 63	
	x	71	
	RCL 8	34 08	
	.	83	
	3	03	
	7	07	
	5	05	
	h y^x	35 63	
	x	71	
	.	83	
110	6	06	
	1	01	
	5	05	

$$L_t = Q_u T_t - \left[\frac{1}{60}\left(\frac{a}{1+b} T_t^{b} + c\right) + 0.615\,(n^{0.375}\, Q_u^{0.5625}\, T_t^{0.1875})\right]$$

REGISTERS

0 used	1 $\hat{Q}_u$	2 L	3 D_u	4 T_t/T_u	5 E_a	6 used	7 used	8 n	9 T_u
S0 Q_t	S1 W_t	S2 n_s'	S3 w'	S4 Q_u'	S5	S6	S7	S8	S9
A a	B b	C c	D T_t	E used	I				

Figure B1 (Continued) **Program Listing**

STEP	KEY ENTRY	KEY CODE	COMMENTS
	x	71	
	+	61	
	h 1/z	35 62	
	RCL 1	34 01	
	RCL D	34 14	
	x	71	
	x	71	
120	RCL 2	34 02	
	−	51	
	f GSB 3	31 22 03	Iterate
	g LBL f a	32 25 11	
	h F? 0	35 71 00	check
	g GSB f b	32 22 12	true
	STO D	33 14	false (find T_t)
	f GSB 2	31 22 02	
	g LBL f b	32 25 12	
	STO 1	33 01	(find Q_u)
130	f GSB 2	31 22 02	
	f LBL 4	31 25 04	
	h F? 0	31 71 00	check
	GTO f c	22 31 13	true
	RCL D	34 14	false (revised T_t).
	GTO 01	22 01	
	g LBL f c	32 25 13	
	RCL 1	34 01	(Q_u)
	R/s	84	
	f LBL D	31 25 14	
140	f P⇄S	31 42	
	STO 0	33 00	
	R/s	84	
	STO 1	33 01	
	RCL 0	34 00	
	f P⇄S	31 42	
	RCL 1	34 01	
	÷	81	
	−x−	31 84	w
	h 1/x	35 62	
150	f P⇄S	31 42	
	RCL 1	34 01	
	x	71	
	R/s	84	η_s
	f LBL 0	31 25 00	
	STO 2	33 02	
	h 1/x	35 62	
	RCL 1	34 01	
	x	71	
	STO 3	33 03	
160	R/s	84	w'
	h 1/x	35 62	
	RCL 0	34 00	
	x	71	
	STO 4	33 04	
	f P⇄S	31 42	
	h RTN	35 22	Q_u'
	f LBL E	31 25 15	
	STO 1	33 01	

$w = Q_t/Q_u$

$\eta_s = W_t/w$

$w' = W_t/\eta_s'$

$Q_u' = Q_u/w'$

STEP	KEY ENTRY	KEY CODE	COMMENTS
	RCL D	34 14	
170	GTO C	22 13	
	LBL 1	31 25 01	
	R/s	84	
	RCL 9	34 09	
	÷	81	
	R/s	84	T_t'/T_u
	g LBL f e	32 25 15	
	x	71	
	.	83	
	6	06	
180	x	71	
	h 1/z	35 62	
	RCL 2	34 02	
	RCL 3	34 03	
	x	71	
	x	71	
	−x−	31 84	T_a
	RCL D	34 14	
	÷	81	
	R/s	84	T_a/T_t
190	.	83	
	4	04	
	6	06	
	1	01	
	5	05	
	$h\ y^x$	35 63	
	RCL 8	34 08	
	.	83	
	4	04	
	6	06	
200	1	01	
	5	05	
	$h\ y^x$	35 63	
	x	71	
	RCL 2	34 02	
	.	83	
	2	02	
	3	03	
	0	00	
	8	08	
210	$h\ y^x$	35 63	
	x	71	
	4	04	
	1	01	
	.	83	
	2	02	
	4	04	
	6	06	
	x	71	
	R/s	84	y_m (mm)
220	h 1/x	35 62	
	RCL 3	34 03	
	x	71	
	h RTN	35 22	D_a (mm)

$T_a = D_u L / 0.6 \cdot Q_u' E_a$

$y_m(mm) = 41.246\, n^{0.4115}\, Q_u^{0.4115}\, L^{0.2308}$

$D_a = \frac{D_u}{E_a}$ (mm)

LABELS									
-	✓	B	✓	C	✓	D	✓	E	✓
a	✓	b	✓	c	✓	d	✓	e	✓
-	✓	1	✓	2	✓	3	✓	4	✓
-		6		7		8		9	

FLAGS	
0	✓
1	
2	
3	

SET STATUS				
FLAGS	ON	OFF	TRIG	DISP
0	☐	☑	DEG ☑	FIX ☑
1	☐	☐	GRAD ☐	SCI ☐
2	☐	☐	RAD ☐	ENG ☐
3	☐	☐		n 4

Best Available Document

Slight differences in the results using the HP-67 program and the HP-9825 program are found. The most likely source of the deviations are in the use of either the least squares regression equation for (E_a) as a function of (T_t/T_u) or in reading the values from Figure 3 in Gates & Clyma (1980a).

HP-67 Level Furrow Design Program

The version of the SCS level furrow design program presented here is slightly revised from that in EWUP (1982f). Equations given by the SCS (USDA, 1979) for determining the advance function parameters, c, and, d, as functions of I'_f are programmed making the data entry less tedious. A program description, user instructions and program listing follow. The user is advised to be careful in the data entry and key usage.

The example of Appendix A for level furrows is repeated here. The same format as for the HP-67 level border design example is used.

(I)	$L = 100$ m	
(I)	$W = 1.1$m	
(I)	$D_u = 100$ mm	
(I)	$a = 1.7856$ mm	
(I)	$b = 0.785$	(The c-value is pre-programmed).
(I)	$I_f' = 1.0$	
(I)	$n = 0.04$	
(I)	$Q_f = 2.0$ lps	(Trial furrow inflow rate)
(O)	$S_o = 0.00111$ m/m	(flashes in display)
(O)	$P + K = 0.611$ m	(flashes in display)
(O)	$T_{oa} = 347.5$ min	(flashes in display)
(O)	$T_I = 93.4$ min	(flashes in display)
(O)	$D_a = 101.9$ mm	(flashes in display)
(O)	$T_t = 21.16$ min	(flashes in display)
(O)	$D_p = 1.926$ mm	
(O)	$D_{au} = 100.0$mm	
(O)	$E_a = 0.98$	(flashes in display)
(O)	$E_r = 1.00$	(flashes in display)
(O)	$RP = 0.02$	

The above procedure should be repeated for other trial furrow inflow rates. The design Q_f or range of design Q_f's and the total available flow at the field will determine the number of furrows to be irrigated in one set.

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Figure B2.

Program Description

Program Title SCS Level Furrow Design

Name Kamal Ezz El Din and Thomas W. Ley **Date** Summer 1982

Address EWUP

City **State** **Zip Code**

Program Description, Equations, Variables, etc. Revised version of earlier programs.

a) Uses SCS Level furrow exponential advance function, and SCS wetted perimeter function.

b) Metric units are used with all depths in (mm).

c) follows design equations given in USDA (1979)

d) design results must be computed for individual trial furrow inflow rates.

e) Required design data input:

1) furrow length, L(m).
2) furrow spacing, W(m).
3) Design or requirement depth, D_u(mm).
4) SCS Intake family and function parameters I_f' (a,b,c).
5) Surface roughness, n (usually 0.04).
6) Trial furrow inflow rate, Q_f (lps).

f) advance function parameters, c, and, d, are calculated internally by:

$$c = 7.0747 + 1.7877 I_f'$$

$$d = 9.2493 \times 10^{-5} + 3.263 \times 10^{-4} I_f'$$

g) output: hydraulic gradient, S_o(m/m); P+K,(m); average opportunity time, T_{oa} (min); inflow time (min); depth applied, D_a (mm); estimated advance time, T_t(min); deep percolation, DP (mm); root zone storage, D_{au} (mm); application effic., E_a (dec.); requirement effic., E_r (dec.); deep perc. ratio, R_p (dec.)

Operating Limits and Warnings

Program requires 217 steps.
Memory registers used: 1-9; S3-S9; A,C,D,E.
Labels used: A and B.
Display notation fixed w/n = 4.
The value C = 6.985 mm is preprogrammed.

Figure B2 (Continued) **User Instructions**

SCS Level Furrow Design

1 Design Data Q_f (lps) 2

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
01	Enter design data: length, L (m)	L(m)	A	L(m)
	furrow spacing, W (m)	W(m)	R/S	W(m)
	design depth, D_u (mm)	D_u (mm)	R/S	D_u (mm)
	SCS Intake equation parameter, a(mm)	a(mm)	R/S	a(mm)
	" " " " , b	b	R/S	b
	" " Intake family, I'_f	I'_f	R/S	I'_f
	Roughness, n	n	R/S	n
02	input: trial furrow inflow rate, Q_f (lps)	Q_f (lps)	B	
03	Output: Hydraulic gradient,	S_o		S_o (m/m)
	(flash in display) Adjusted wetted perimeter,	P + K		P + K (m)
	Ave. Opportunity Time, T_{oa}			T_{oa} (min)
	Inflow time, T_a (min)			T_a (min)
	Inflow depth, D_a			D_a (mm)
	(to continue press R/S)		R/S	
	estimated advance time,	T_t		T_t (min)
	deep percolation depth,	DP		DP (mm)
	root zone storage, D_{au}			D_{au} (mm)
04	Calculate performance		R/S	
	output: water application effic., E_a			E_a (dec.)
	" requirement " , E_r			E_r (dec.)
	deep percolation ratio, RP			RP (dec.)
05	Repeat steps 02 - 04 for a new trial			
	furrow inflow rate.			

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Figure B2 (Continued)

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	f LBL A	31 25 11	
	STO 3	33 03	L
	R/S	84	
	STO 4	33 04	W
	R/S	84	
	STO 6	33 06	D_u
	R/S	84	
	STO 7	33 07	a
	R/S	84	
010	STO 8	33 08	b
	R/S	84	
	f P≷S	31 42	
	STO 7	33 07	I_f'
	R/S	84	
	STO 4	33 04	n
	f P≷S	31 42	
	R/S	84	
	f LBL B	31 25 12	
	STO 1	33 01	Q_f
020	f P≷S	31 42	
	STO 9	33 09	Q_f
	.	83	
	3	03	
	4	04	
	1	01	
	9	09	
	h y^x	35 63	
	.	83	
	0	00	
030	8	08	
	7	07	
	5	05	
	x	71	
	f P≷S	31 42	
	RCL 3	34 03	
	f P≷S	31 42	
	÷	81	
	STO 8	33 08	
	− x −	31 84	S_o
040	RCL 9	34 09	
	RCL 4	34 04	
	x	71	
	RCL 8	34 08	
	f √	31 54	
	÷	81	
	.	83	
	4	04	
	2	02	
	4	04	
050	7	07	
	h y^x	35 63	
	.	83	
	2	02	
	6	06	
	4	04	
	7	07	

$S_o = 0.0875\, Q_f^{0.5419} / L$

$P+K = 0.2647 \left(\frac{Q_f\, n}{S_o^{1/2}}\right)^{0.4277} + 0.2234$

STEP	KEY ENTRY	KEY CODE	COMMENTS
	x	71	
	.	83	
	2	02	
060	2	02	
	7	07	
	4	04	
	+	61	
	STO E	33 15	P+K
	− x −	31 84	
	RCL 7	34 07	
	1	01	
	.	83	
	7	07	
070	8	08	
	7	07	
	7	07	
	x	71	
	7	07	
	.	83	
	0	00	
	7	07	
	4	04	
	7	07	
080	+	61	
	STO 6	33 06	c
	RCL 7	34 07	
	3	03	
	.	83	
	2	02	
	6	06	
	3	03	
	EEX	43	
	4	04	
090	CHS	42	
	x	71	
	9	09	
	.	83	
	2	02	
	4	04	
	9	09	
	3	03	
	EEX	43	
	5	05	
100	CHS	42	
	+	61	
	STO 5	33 05	d
	f P≷S	31 42	
	RCL 6	34 06	
	RCL 4	34 04	
	x	71	
	RCL E	34 15	
	÷	81	
	6	06	
110	.	83	
	9	09	
	8	08	

$c = 7.0747 + 1.3877\, I_f'$

$d = 9.2493 \times 10^{-5} + 3.263 \times 10^{-4}\, I_f'$

$T_n = \left(\frac{W}{P+K} D_u - c\right)^{1/6} / a$

REGISTERS

0	1 Q_f	2 T_a	3 L	4 W	5 D_a	6 D_u	7 a	8 b	9 OP
S0	S1	S2	S3 $dL/Q S^{1/2}$	S4 n	S5 advance c	S6 advance d	S7 I_f'	S8 S_o	S9 Q_f
A D_{au}	B	C T_n	D T_t	E P+K	I				

Figure B2 (Continued) **Program Listing**

STEP	KEY ENTRY	KEY CODE	COMMENTS
	5	05	
	−	51	
	RCL 7	34 07	
	÷	81	
	RCL 8	34 08	
	h 1/x	35 62	
	h y^x	35 63	
120	STO C	33 13	T_{oa}
	RCL 3	34 03	
	f P⇄S	31 42	
	RCL 5	34 05	
	x	71	
	RCL 9	34 09	
	÷	81	
	RCL 8	34 08	
	f √	31 54	
	÷	81	
130	STO 3	33 03	$\frac{dL}{Q^{5/2}}$
	1	01	
	−	51	
	RCL 3	34 03	
	g e^x	32 52	
	x	71	
	1	01	
	+	61	
	RCL 3	34 03	
	0 X²	32 54	
140	RCL 6	34 06	
	x	71	
	f P⇄S	31 42	
	RCL 3	34 03	
	÷	81	
	÷	81	
	RCL C	34 13	
	+	61	
	− x −	31 84	T_{oa}
	RCL 8	34 08	
150	h y^x	35 63	
	RCL 7	34 07	
	x	71	
	6	06	
	.	83	
	9	09	
	8	08	
	5	05	
	+	61	
	6	06	
160	0	00	
	÷	81	
	RCL E	34 15	
	RCL 3	34 03	
	x	71	
	x	71	
	RCL 1	34 01	
	÷	81	
	STO 2	33 02	

$$T_a = \frac{PL}{60Q_f}\left(a\,T_{oa}^{\,b} + 6.985\right)$$

$$T_{oa} = T_n + \left(\frac{1}{\frac{c}{-1}\left(\frac{dL}{Q^{5/2}}\right)^2}\left(\left(\frac{dL}{Q^{5/2}} - 1\right)e^{(dL/Q^{5/2})} + 1\right)\right)$$

STEP	KEY ENTRY	KEY CODE	COMMENTS
	− x −	31 84	T_a
170	− x −	31 84	
	6	06	
	0	00	
	RCL 1	34 01	
	RCL 2	34 02	
	x	71	
	x	71	
	RCL 3	34 03	
	÷	81	
	RCL 4	34 04	
180	÷	81	
	STO 5	33 05	
	R/S	84	D_a
	f P⇄S	31 42	
	RCL 3	34 03	
	g e^x	32 52	
	RCL 6	34 06	
	÷	81	
	f P⇄S	31 42	
	RCL 3	34 03	
190	x	71	
	STO D	33 14	
	− x −	31 84	T_t
	RCL 5	34 05	
	RCL 6	34 06	
	−	51	
	f x<0	31 71	check true false
		00	
	STO 9	33 09	
	CHS	42	
200	RCL 5	34 05	
	+	61	
	STO A	33 11	
	RCL 9	34 09	
	− x −	31 84	DP
	RCL A	34 11	
	R/S	84	D_{au}
	RCL 5	34 05	
	÷	81	
	− x −	31 84	E_a
210	RCL A	34 11	
	RCL 6	34 06	
	÷	81	
	− x −	31 84	E_r
	RCL 9	34 09	
	RCL 5	34 05	
	÷	81	
	h RTN	35 22	R_p
220			

$$D_a = \frac{60Q_f T_a}{WL}$$

$$T_t = \frac{L}{a}e^{(dL/Q^{5/2})}$$

$$DP = D_a - D_u \quad (\text{if } D_a > D_u)$$

$$D_{au} = D_a - D_p$$

$$R_p = \frac{DP}{D_a},\ E_r = \frac{D_{au}}{D_a},\ E_a = \frac{D_{au}}{D_a}$$

LABELS					FLAGS
A ✓	B ✓	C	D	E	0
a	b	c	d	e	1
0	1	2	3	4	2
5	6	7	8	9	3

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☐	DEG	☑	FIX	☑
1	☐	☐	GRAD	☐	SCI	☐
2	☐	☐	RAD	☐	ENG	☐
3	☐	☐			n	4

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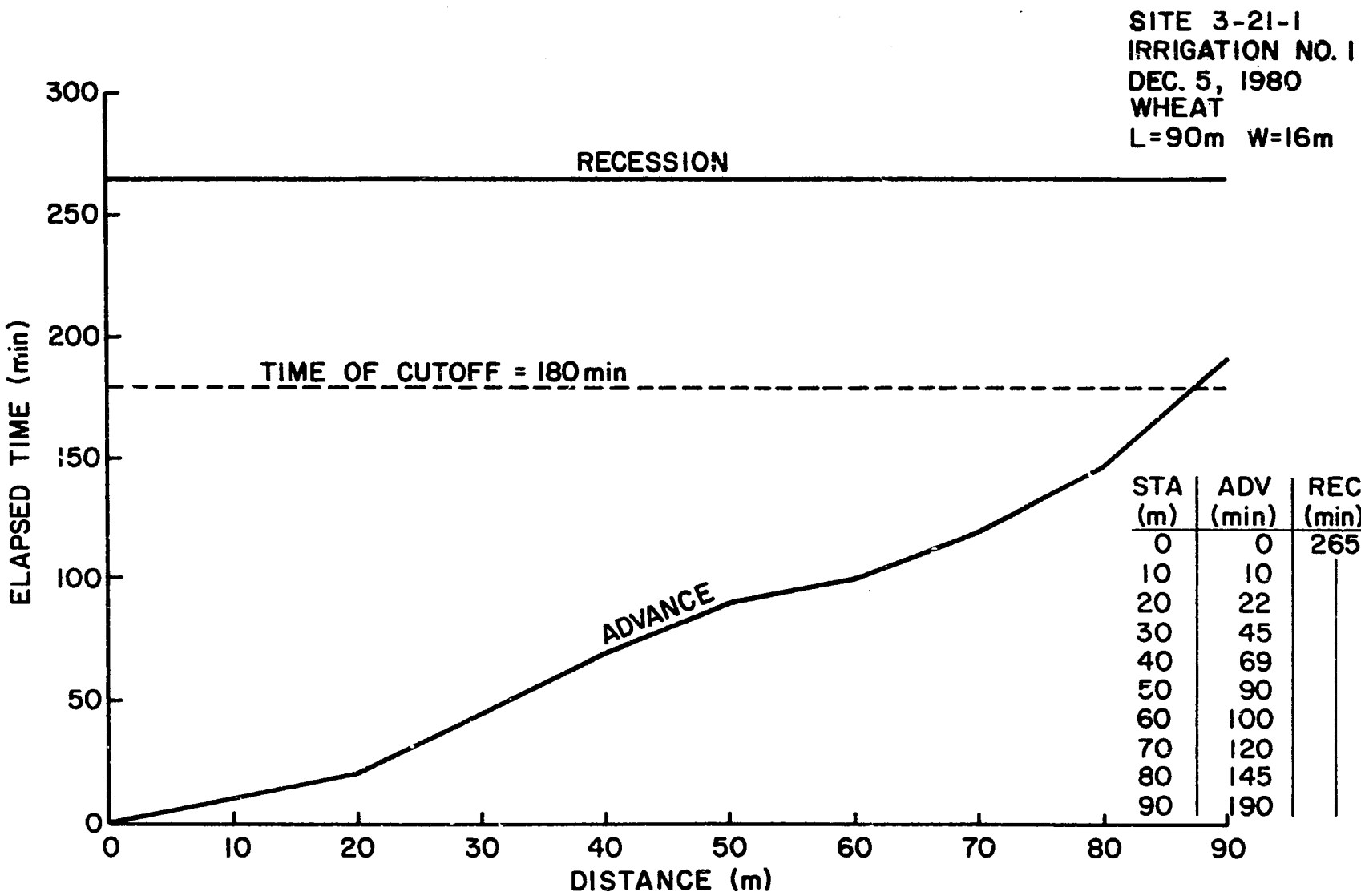
Appendix C: Advance/Recession Data

1980-81 Winter Season, Level Borders

The following figures, C1 to C8, present advance/recession data for the cases discussed in Part III of this report. Recession has been shown to occur simultaneously over the entire strip where the actual conditions approximated this.

1981 Summer Season, Level Furrows

Figure C9 to C13 present advance/recession data for some irrigations during the season on cotton and maize. Recession is shown to occur simultaneously over the entire strip, i.e., when from 50% to 70% of the surface had become de-watered.



STA (m)	ADV (min)	REC (min)	INFIL OPPOR TIME (min)
0	0	265	265
10	10		255
20	22		243
30	45		220
40	69		196
50	90		175
60	100		165
70	120		145
80	145		120
90	190		75

Figure C1. Advance/Recession Data, Site 3-21-1, 1st Irrigation.

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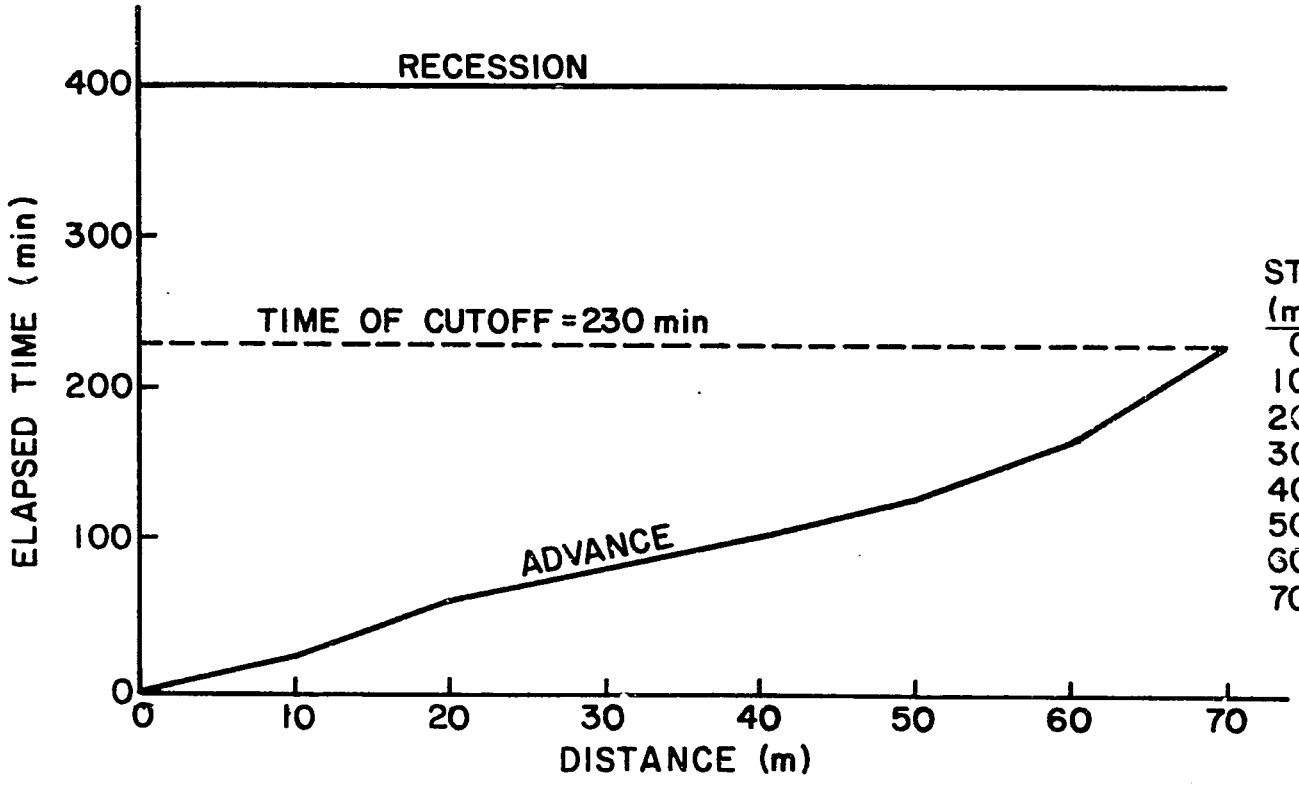
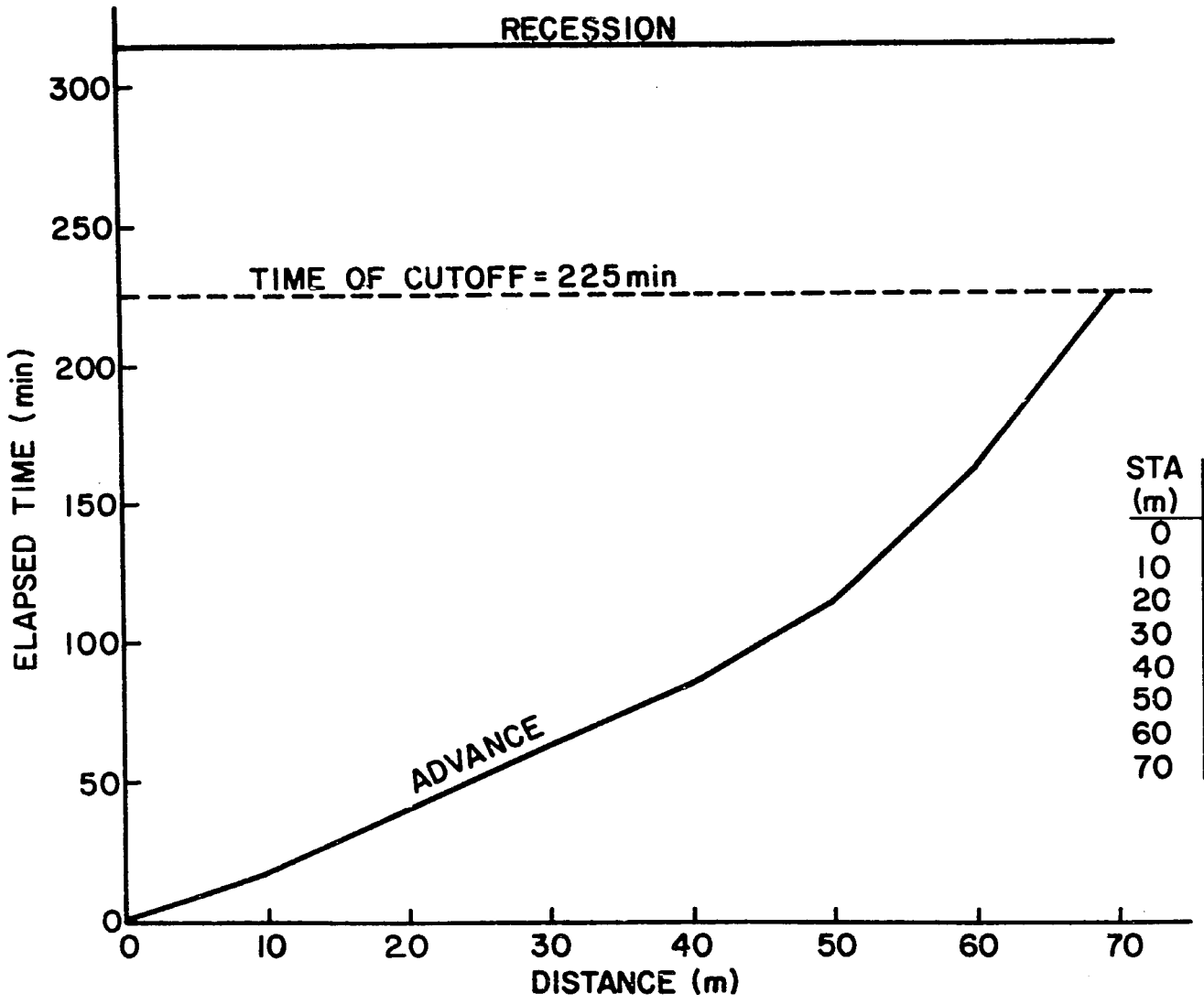


SITE 3-21-5
IRRIGATION NO. 1
DEC. 6, 1980
WHEAT
L = 75 m W = 20 m

STA (m)	ADV (min)	REC (min)	INFIL OPPOR TIME (min)
0	0	400	400
10	25		375
20	60		340
30	80		320
40	102		298
50	128		272
60	165		235
70	230		170

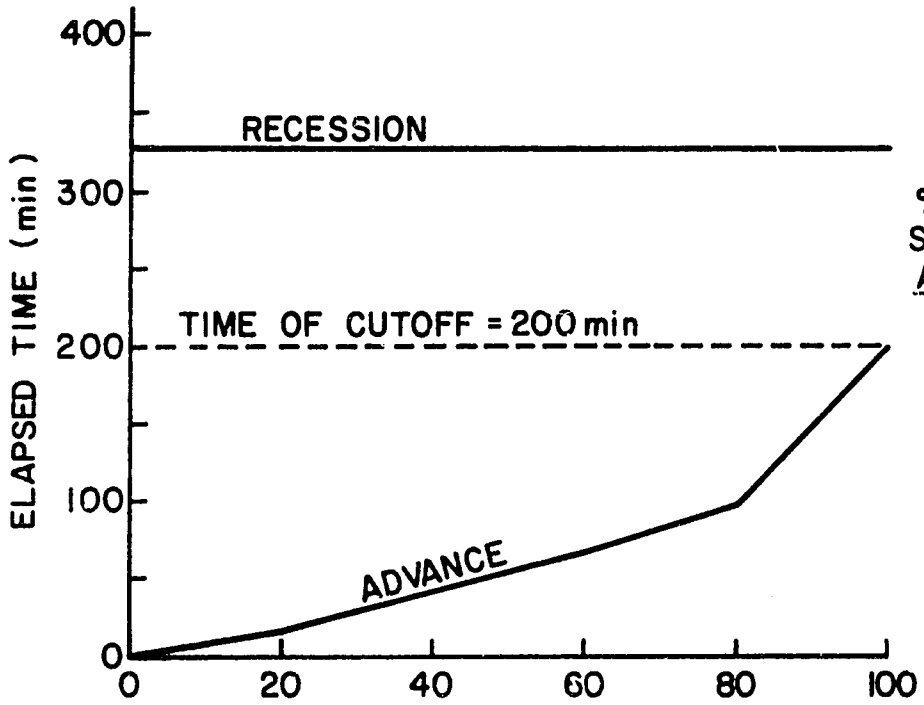
Figure C2. Advance/Recession Data, Site 3-21-5, 1st Irrigation.



SITE 3-21-7
IRRIGATION NO. 1
DEC. 7, 1980
WHEAT
L=75m W=21m

STA (m)	ADV (min)	REC (min)	INFIL OPPOR TIME (min)
0	0	315	315
10	17		298
20	40		275
30	62		253
40	85		230
50	115		200
60	160		155
70	225		90

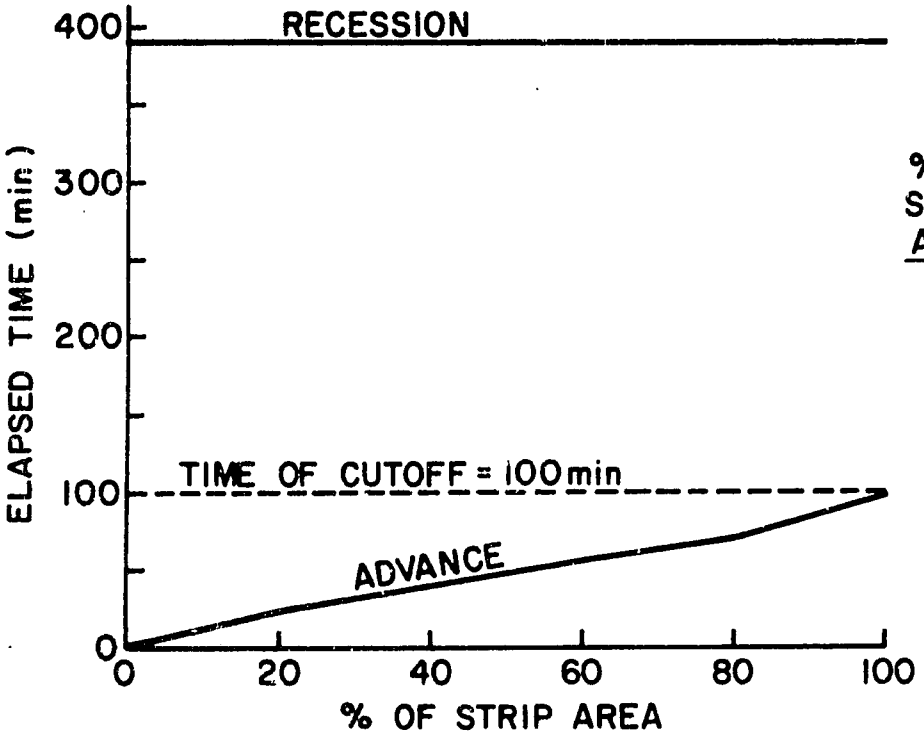
Figure C3. Advance/Recession Data, Site 3-21-7, 1st Irrigation.



SITE 3-10-1
WHEAT
L=45m W=45m

IRRIGATION NO. 1
DEC. 5, 1980

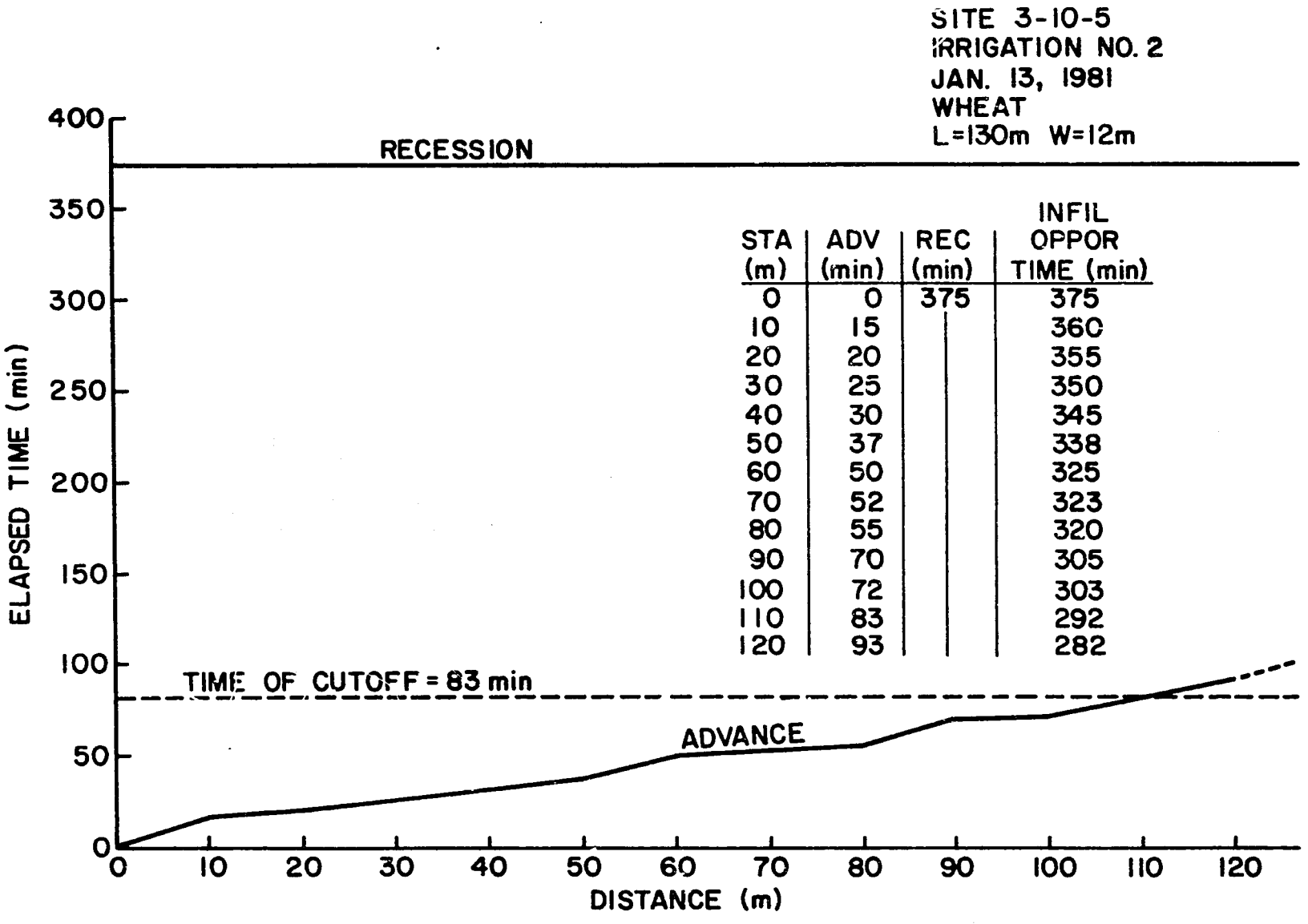
% OF STRIP AREA	ADV (min)	REC (min)	INFIL OPPOR TIME (min)
0	0	227	327
20	18		309
40	42		285
60	67		260
80	99		228
100	198		129



IRRIGATION NO. 2
JAN. 14, 1981

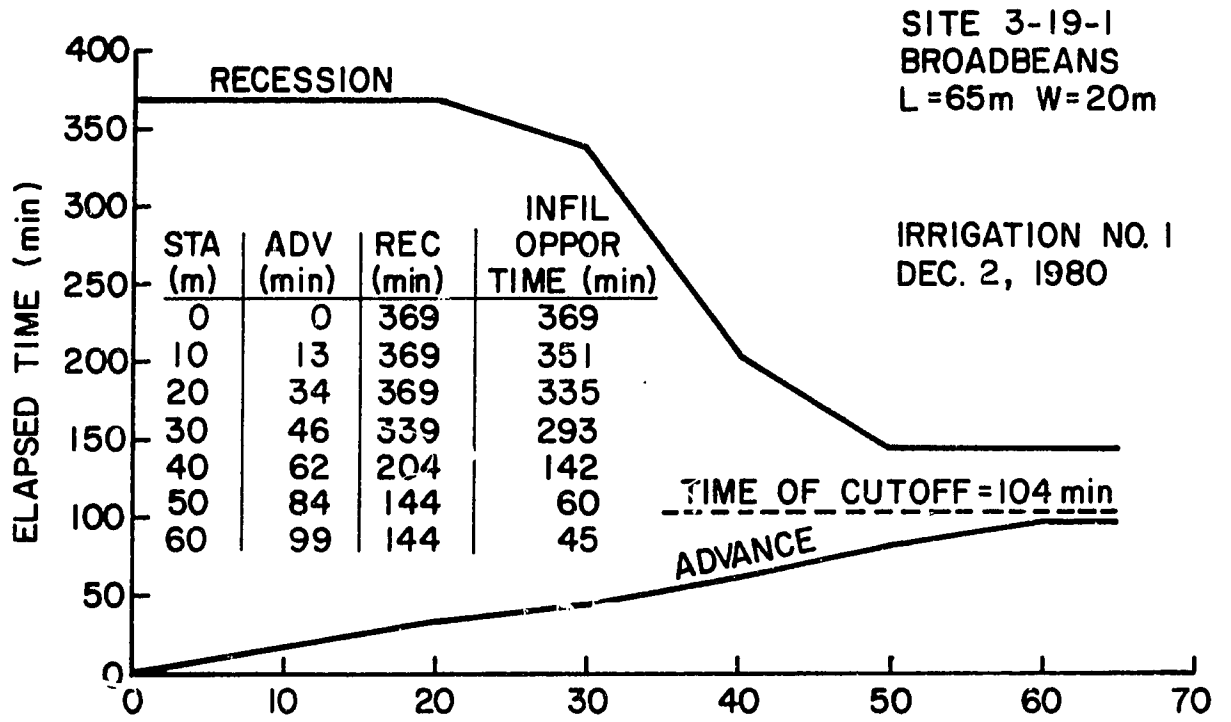
% OF STRIP AREA	ADV (min)	REC (min)	INFIL OPPOR TIME (min)
0	0	390	390
20	24		366
40	39		351
60	57		333
80	70		320
100	98		292

Figure C4. Advance/Recession Data, Site 3-10-1, 1st and 2nd Irrigation.

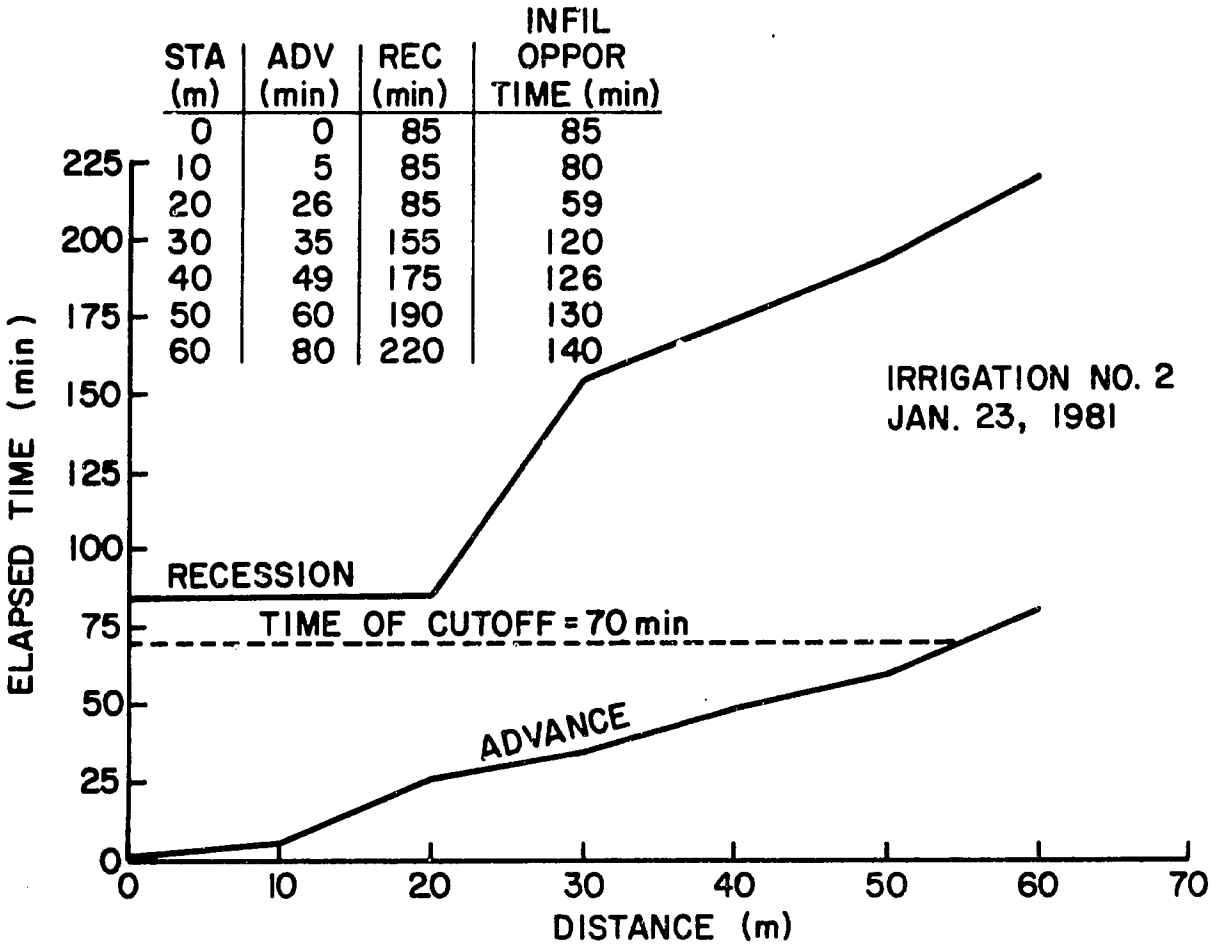


STA (m)	ADV (min)	REC (min)	INFIL OPPOR TIME (min)
0	0	375	375
10	15		360
20	20		355
30	25		350
40	30		345
50	37		338
60	50		325
70	52		323
80	55		320
90	70		305
100	72		303
110	83		292
120	93		282

Figure C5. Advance/Recession Data, Site 3-10-5, 2nd Irrigation.

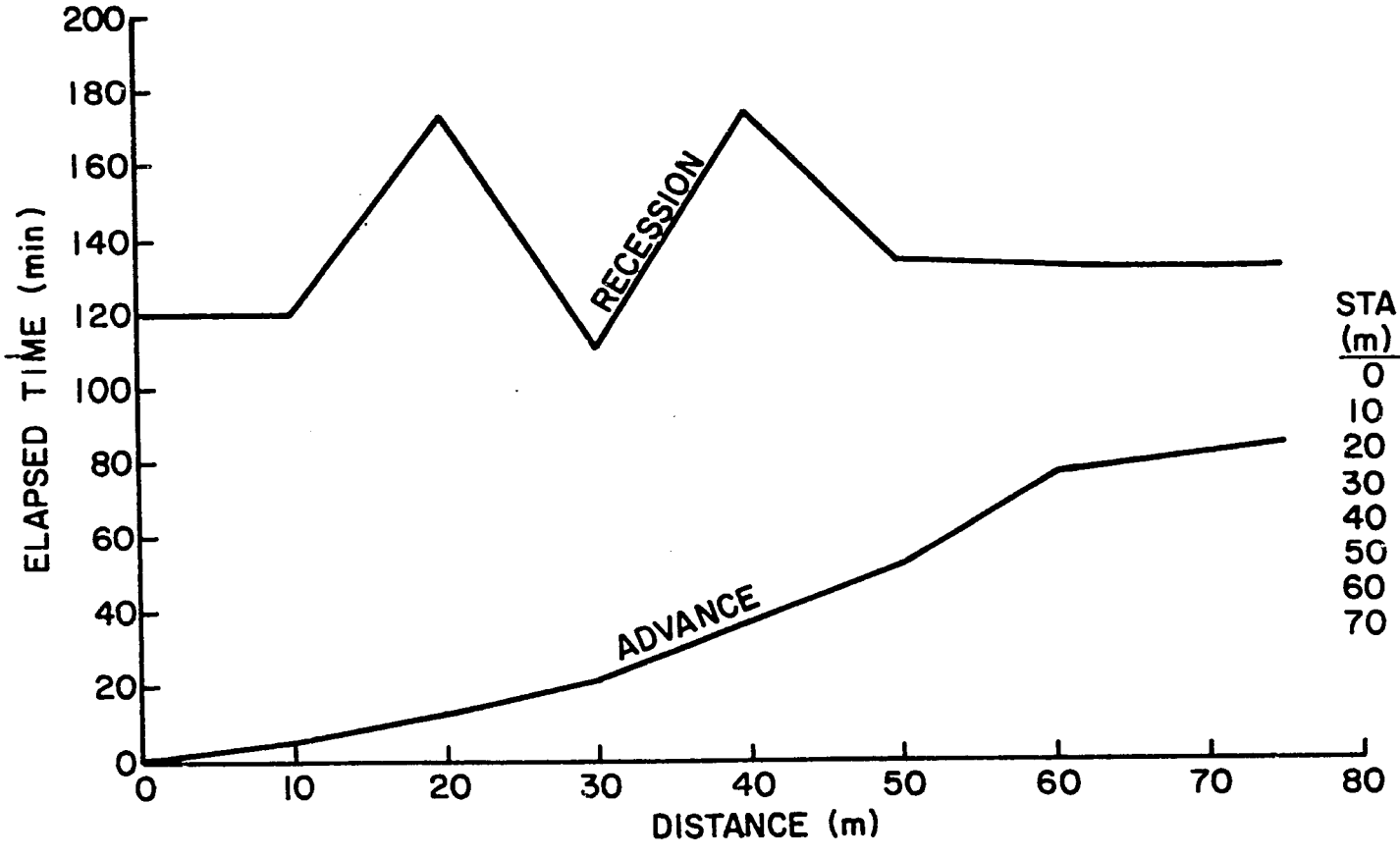


STA (m)	ADV (min)	REC (min)	INFIL OPPOR TIME (min)
0	0	369	369
10	13	369	351
20	34	369	335
30	46	339	293
40	62	204	142
50	84	144	60
60	99	144	45



STA (m)	ADV (min)	REC (min)	INFIL OPPOR TIME (min)
0	0	85	85
10	5	85	80
20	26	85	59
30	35	155	120
40	49	175	126
50	60	190	130
60	80	220	140

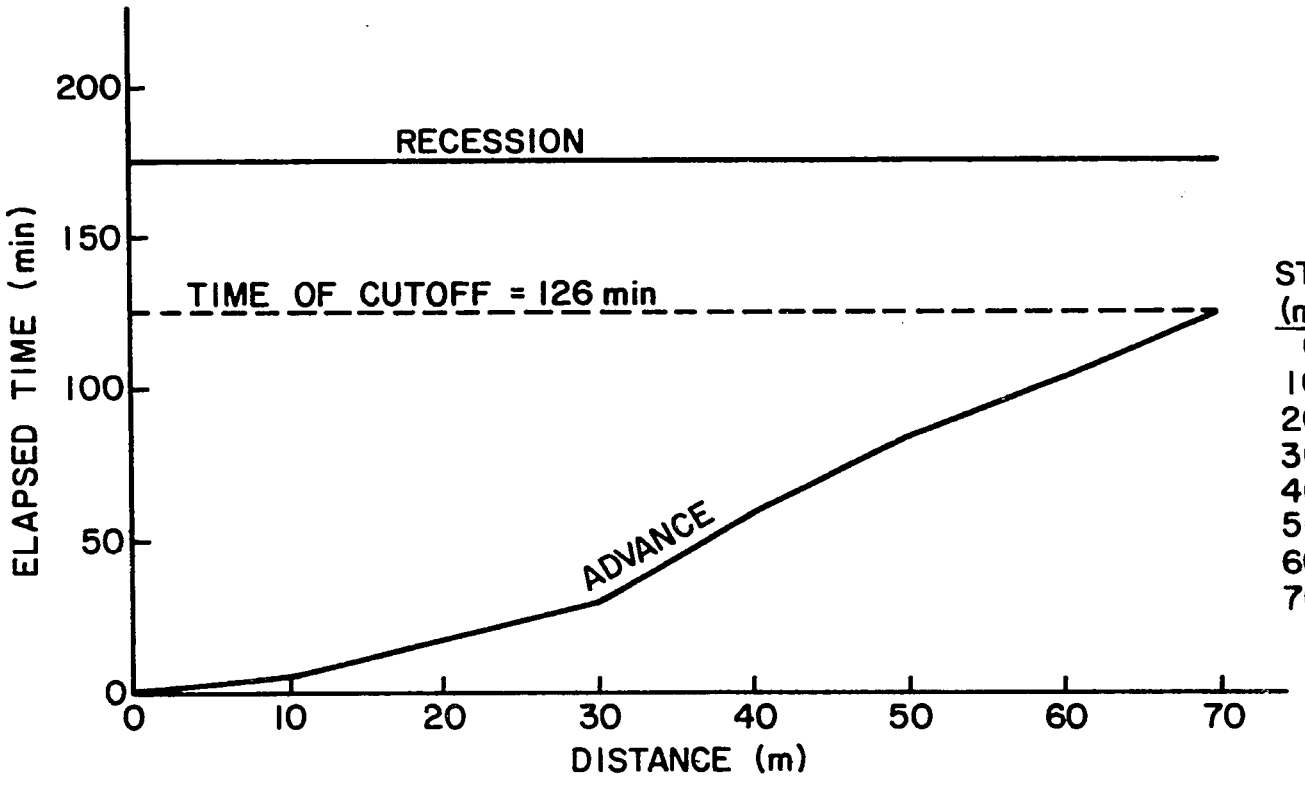
Figure C6. Advance/Recession Data, Site 3-19-1, 1st and 2nd Irrigation.



SITE 3-19-10
IRRIGATION NO. 1
DEC. 16, 1980
WHEAT
L=75m W=10m

STA (m)	ADV (min)	REC (min)	INFIL OPPOR TIME (min)
0	0	120	120
10	5	120	115
20	13	175	162
30	21	110	89
40	38	175	137
50	52	135	83
60	77	132	55
70	82	132	50

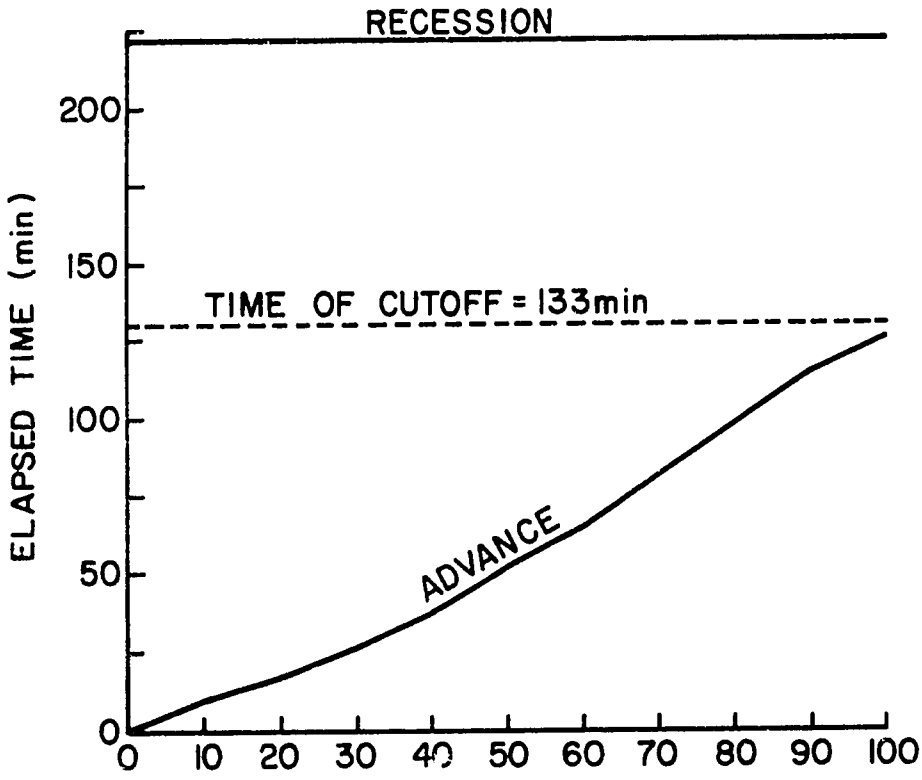
Figure C7. Advance/Recession Data, Site 3-19-10, 1st Irrigation.



SITE 3-02-2
IRRIGATION NO. 1
DEC. 9, 1980
WHEAT
L=70m W=20m

STA (m)	ADV (min)	REC (min)	INFIL OPPOR TIME (min)
0	0	175	175
10	5		170
20	17		158
30	30		145
40	60		115
50	85		90
60	104		71
70	125		50

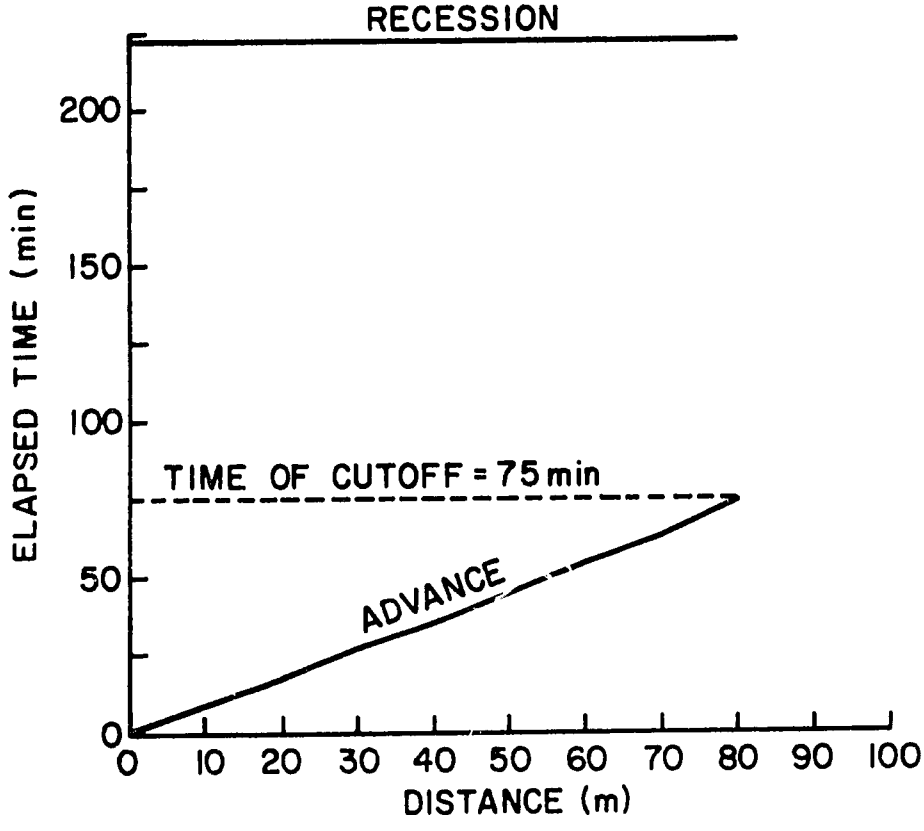
Figure C8. Advance/Recession Data, Site 3-02-2, 1st Irrigation.



SITE 3-10
MAIZE

IRRIGATION NO. 1
MAY 25, 1981
L=100 m
(AVG. OF 5 FURROWS)

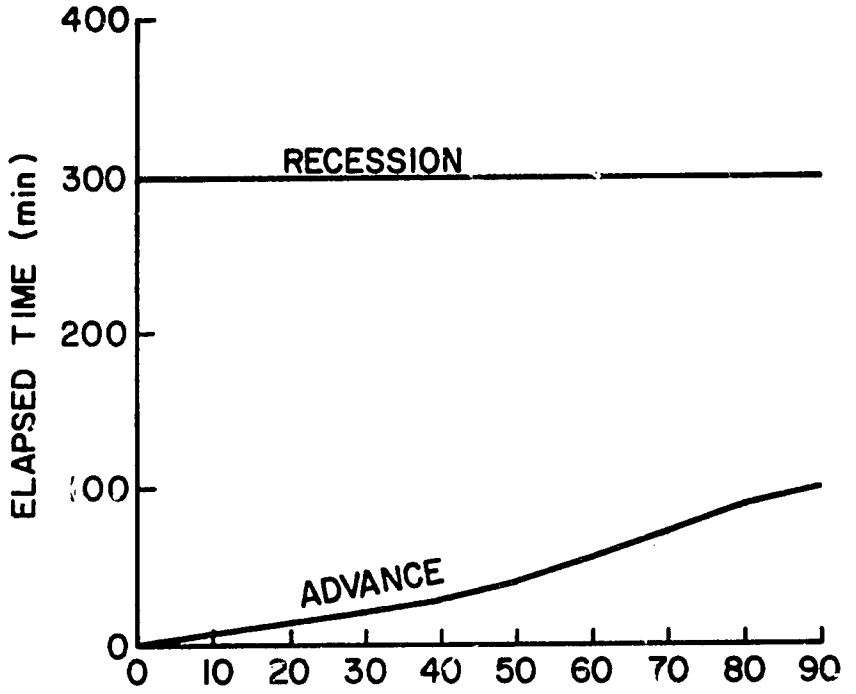
STA (m)	ADV (min)	REC (min)	INFIL OPPOR TIME (min)
0	0	223	223
10	10		213
20	17		206
30	27		196
40	38		185
50	52		171
60	65		158
70	82		141
80	99		124
90	115		108
100	126		97



IRRIGATION NO. 2
JUNE 18, 1981
L=80m (1st 20m USED FOR VEGETABLE PLOT)
(AVG. OF 4 FURROWS)

STA (m)	ADV (min)	REC (min)	INFIL OPPOR TIME (min)
0	0	223	223
10	8		215
20	17		206
30	27		196
40	35		188
50	45		178
60	55		168
70	62		161
80	74		149

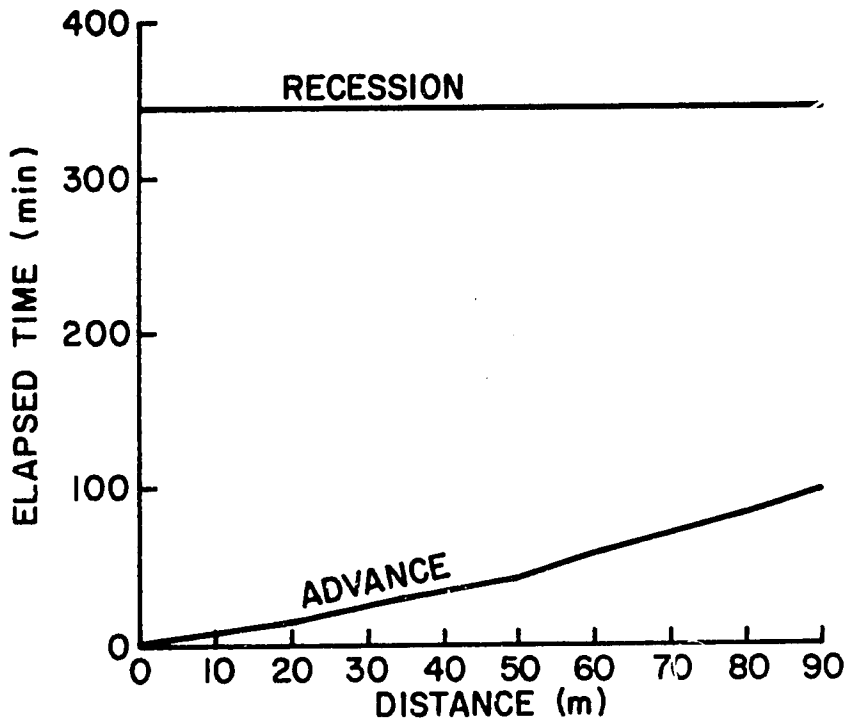
Figure C9. Advance/Recession Data, Site 3-10, 1st and 2nd Irrigation.



SITE 3-10-5
COTTON
L = 90m

IRRIGATION NO. 3
MAY 15, 1981
(AVG. OF 3 FURROWS)

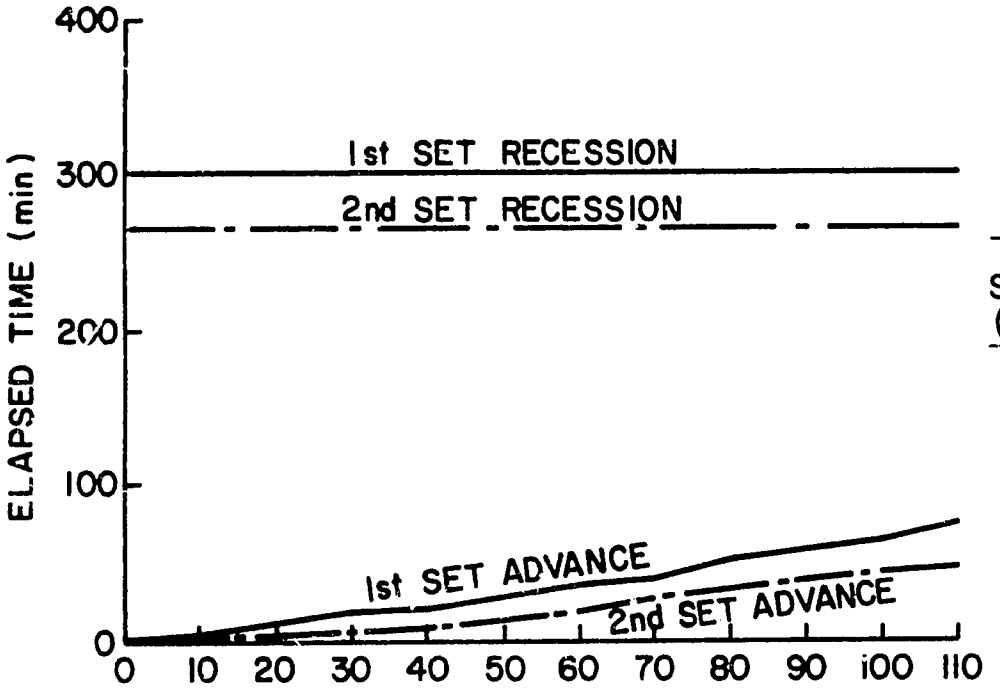
STA (m)	ADV (min)	REC (min)	INFIL OPPOR TIME (min)
0	0	300	300
10	7		293
20	12		288
30	22		278
40	29		271
50	40		260
60	56		244
70	73		227
80	90		210
90	100		200



IRRIGATION NO. 4
JUNE 10, 1981
(AVG. OF 3 FURROWS)

STA (m)	ADV (min)	REC (min)	INFIL OPPOR TIME (min)
0	0	345	345
10	7		338
20	14		331
30	24		321
40	35		310
50	42		303
60	57		288
70	70		275
80	84		261
90	98		247

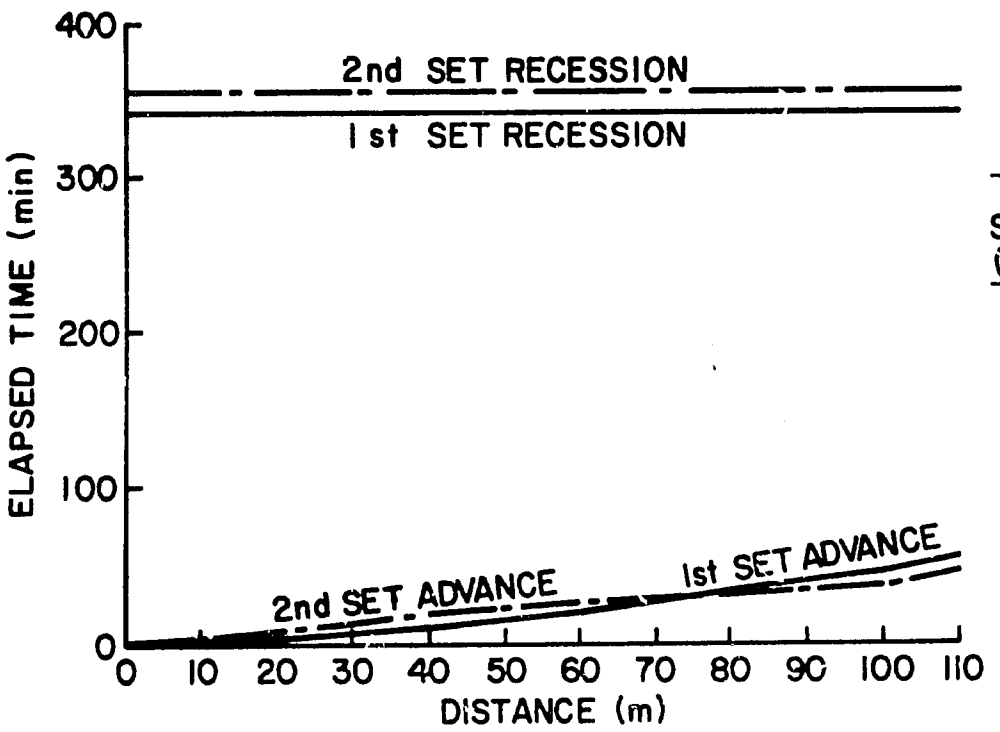
Figure C10. Advance/Recession Data, Site 3-10-5, 3rd and 4th Irrigation.



SITE 3-22-3
COTTON
L=110 m

IRRIGATION NO. 3
MAY 11, 1981
(EACH SET: AVG. OF 4 FURROWS)
AVG. OF 2 SETS

STA (m)	ADV (min)	REC (min)	INFIL OPPOR TIME (min)
0	0	283	283
10	3		280
20	7		276
30	12		271
40	16		267
50	21		262
60	28		255
70	34		249
80	42		241
90	48		235
100	53		230
110	62		221



IRRIGATION NO. 4
JUNE 18, 1981
(EACH SET: AVG. OF 4 FURROWS)
AVG. OF 2 SETS

STA (m)	ADV (min)	REC (min)	INFIL OPPOR TIME (min)
0	0	349	349
10	3		346
20	7		342
30	12		337
40	17		332
50	21		328
60	25		324
70	30		319
80	34		315
90	40		309
100	45		304
110	50		299

Figure C11. Advance/Recession Data, Site 3-22-3, 3rd and 4th Irrigation.

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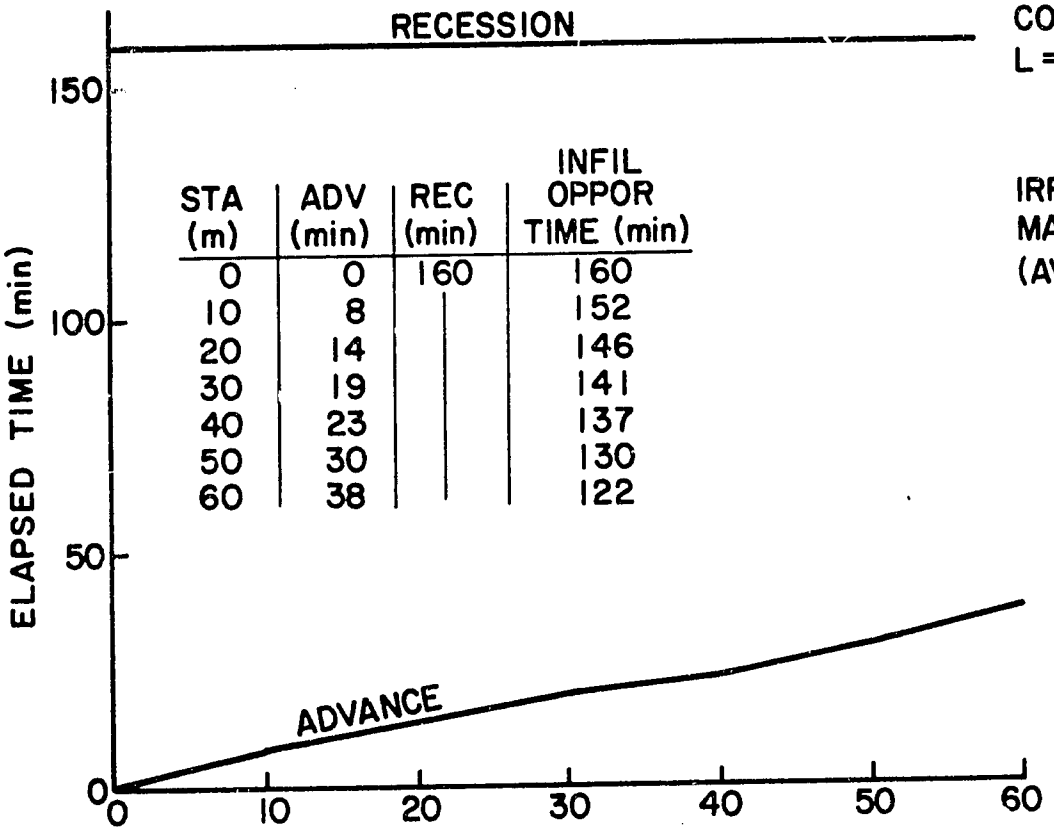
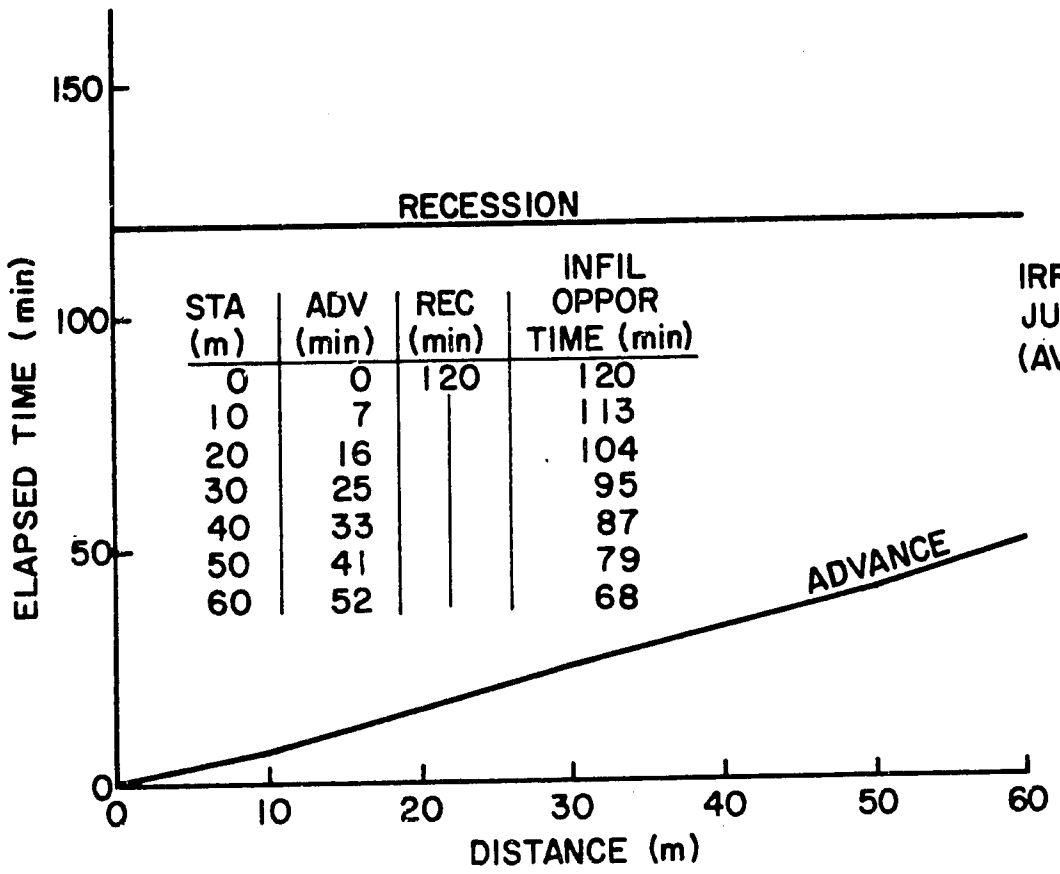
SITE 3-10-3
COTTON
L = 65 m

IRRIGATION NO. 3
MAY 16, 1981
(AVG. OF 3 FURROWS)



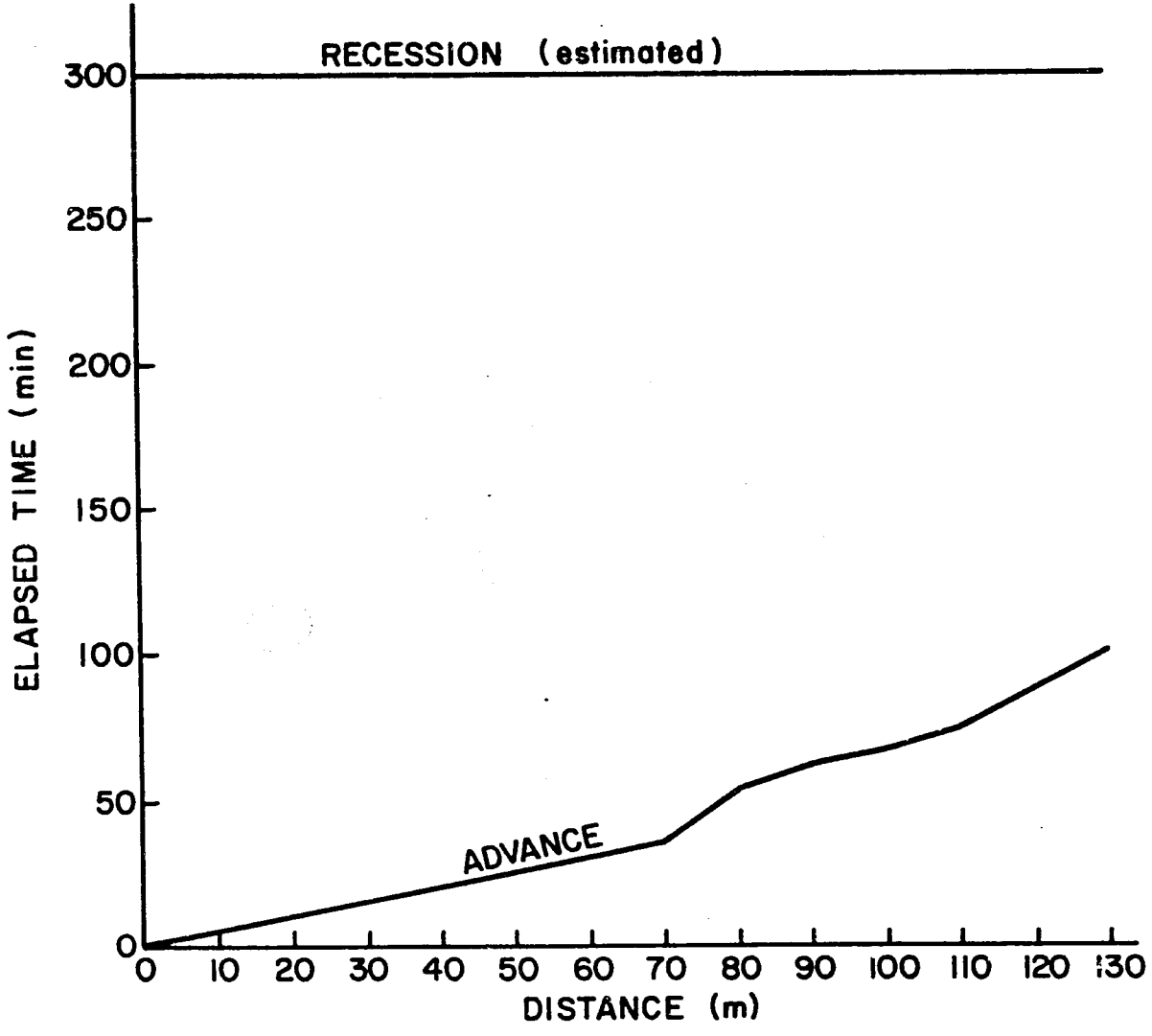
STA (m)	ADV (min)	REC (min)	INFIL OPPOR TIME (min)
0	0	160	160
10	8		152
20	14		146
30	19		141
40	23		137
50	30		130
60	38		122

IRRIGATION NO. 4
JUNE 10, 1981
(AVG. OF 3 FURROWS)



STA (m)	ADV (min)	REC (min)	INFIL OPPOR TIME (min)
0	0	120	120
10	7		113
20	16		104
30	25		95
40	33		87
50	41		79
60	52		68

Figure C12. Advance/Recession Data, Site 3-10-3, 3rd and 4th Irrigation.

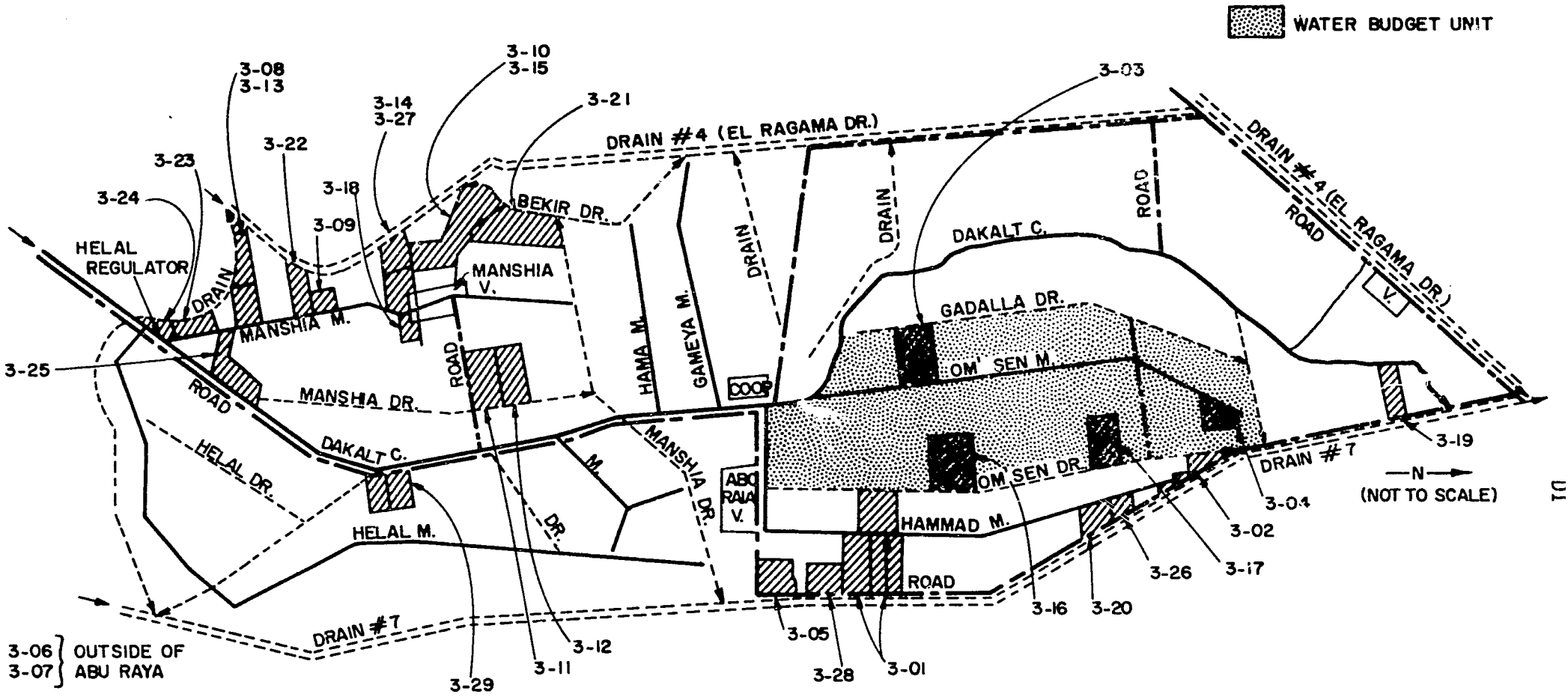


SITE 3-22-1
IRRIGATION NO. 4
(AVG. OF 4 FURROWS)
COTTON
L=130m

STA (m)	ADV (min)	REC* (min)	INFIL OPPOR TIME (min)
0	0	300	300
10	6		294
20	10		290
30	15		285
40	20		280
50	25		275
60	33		267
70	41		259
80	54		246
90	62		238
100	67		233
110	75		225
120	88		212
130	101		199

*estimated

Figure C13. Advance/Recession Data, Site 3-22-1, 4th Irrigation.



PI PHASE SITES (SUMMER '78 - SUMMER '79)		FIELD TRIALS (WINTER '79-'80)		FIELD TRIALS (SUMMER '80)		PILOT PROGRAM SITES (WINTER '80-'81)		(SUMMER '81)		(WINTER '81-'82)		(SUMMER '82)	
3-01	(FIELD TRIALS)	3-08	3-01	3-02	3-16	3-02	3-10	3-20	3-10	3-20	3-10	[illegible]	3-29
3-02	3-05	3-09	3-02	3-13	3-17	3-19	3-21	3-01	3-22	3-26	3-27	3-05	
3-03	3-06	3-10		3-14	3-18		3-22		3-23			3-28	
3-04	3-07	3-11		3-15	3-10				3-24				
		3-12			3-11				3-25				

Figure D1. Summary of EWUP work locations in Abu Raya, Kafr El Sheikh.

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

Land Area	in *sq meters*	in *acres*	in *feddans*	in *hectares*
1 acre	4,046.856	1.000	0.963	0.405
1 *feddan*	4,200.833	1.038	1.000	0.420
1 hectare(ha)	10,000.000	2.471	2.380	1.000
1 *sq* kilometer	100 x 10⁴	247.105	238,048	100.000
1 *sq* mile	259 x 10⁶	640.000	616.400	259.000

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

Other Conversions

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

Egyptian Units for Field Crops

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

Egyptian Farming and Irrigation Terms

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