United States
Department of
Agriculture

Soil
Conservation
Service

Irrigation Training Series

Module 911 - Graded Border Irrigation Evaluation

Study Guide

IRRIGATION TRAINING SERIES

MODULE 911

GRADED BORDER IRRIGATION EVALUATION

National Employee Development Staff
Soil Conservation Service
United States Department of Agriculture
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ACKNOWLEDGMENT

The design and development of this training program is the result of a concerted effort by practicing engineers in the SCS. The contributions of many technical and procedural reviews has helped to make this program one that will provide basic skills to employees in their work place.

PREFACE

This module consists of a study guide, video tape presentation, and field exercise. The module is designed as either a self-study or facilitator-led package. It may be given as self-study providing that two needs are met:

1. That there is a qualified technical person (resource person) either nearby or available by telephone to answer any questions that you may have.
2. That you receive close supervision and guidance while actually making a field irrigation evaluation within three months following completion of this module.

If a facilitator is used, you will be guided step-by-step through the study guide. Again, an actual field evaluation should be made, with supervision and guidance, within three months following completion of this module.

This Study Guide is designed as a training tool and reference manual for those who perform irrigation system evaluations. It has step-by-step procedures for conducting graded border irrigation system evaluations. Included is background material, equipment list, evaluation procedures, example data, and blank worksheets.

Procedures for graded border irrigation system evaluations are, in part, from the publication "Farm System Evaluation: A Guide for Management" by John L. Merrian and Jack Keller, published by Agricultural & Irrigation Engineering Department, Utah State University, Logan, Utah. This reference is recommended for anyone involved in graded border evaluations.

Graphic methods of analysis are used in this Study Guide because they are easy to understand. Computational procedures can also be used. These procedures are in the SCS National Irrigation Guide Notice No. 2, Engineering Irrigation Water Management, April 6, 1981.

VIDEO TAPE PRESENTATION

A two-part video presentation is available for use with this module.

The first part consists of a brief, ten (10) minute overview of an evaluation being made in the field. It will give you an idea of what you will be doing during the field portion of the module.

At this time, put video cassette, Part A in the player and view. When you are finished with Part A, rewind and continue at this point in your study guide.

The second part consists of a deeper analysis of the advance - recession curves found on pages 4 - 9 in your study guide. This part should be viewed following a quick review of your study guide material on advance - recession. The video presentation should impress upon you the importance of information derived from advance - recession curves.

IRRIGATION TRAINING SERIES

MODULE 911

ENGINEERING - GRADED BORDER IRRIGATION EVALUATION

OBJECTIVES
Upon completion of this module, participants will be able to:

1. Perform an evaluation of graded border irrigation using accepted procedures.

2. Determine how well the irrigation system is being managed by calculating the application efficiency.

3. Determine how well the irrigation system is performing by calculating the distribution uniformity.

4. Make recommendations for improvement, if needed, using the results of the evaluation.

This module is designed to bring the trainee to an ASK level 2 (Understanding) upon completion of the self-paced portion, and ASK level 3 (Perform with Supervision) upon completion of the field evaluation.

PREREQUISITES
Module 101, Glossary of Soil and Water Terms. In addition, it is recommended that in order to more fully understand this module, the participant completes one module each from the 300 and 400 series, all modules in the 600 series, and module 960.

TIME
Approximately 28 hours (self-study portion: 8 hours; Facilitator's Local example: 4 hours; Field evaluation and report: 16 hours). Credit will be given for 28 hours.

WHO MAY TAKE MODULE
All employees at any level who need training in conducting graded border irrigation system evaluations.

METHOD OF COMPLETION
This module consists of 2 parts: (1) The study guide, although basically self-study, should have a state-assigned technical specialist serve as a resource person to answer questions or provide assistance beyond the supervisor's capability. (2) Field activity. A technical facilitator should be assigned to coordinate this portion of the module.

CONTENT
This module provides a participant with enough data to perform, with supervision, a graded border irrigation system evaluation. Covered is calculation of application efficiency and distribution uniformity, performance of a field evaluation, and development of an evaluation report complete with recommendations for improvement.

CONTENTS

INTRODUCTION

Irrigation water management is determining and controlling the rate, amount, and timing of irrigation water application in a planned and efficient manner. The effective use of irrigation water helps to manage and control the moisture environment of crops. This, in turn, promotes the desired crop response, minimizes soil erosion and loss of plant nutrients, controls undesirable water loss, and protects water quality.

The irrigator must have the knowledge and capability to manage and apply water in such a manner that these objectives can be obtained. Irrigation system evaluations can provide some relatively accurate basic information to manage a system for optimum efficiency.

Evaluations may also provide information which can be used to improve the system. The data provides the best possible basis for detailed design because it reflects actual site conditions.

CHARACTERISTICS OF GRADED BORDER IRRIGATION

Graded border irrigation is a method of controlled surface flooding. The field to be irrigated is divided into strips by parallel dikes or border ridges, and each strip is irrigated separately.

This method is a balanced advance and recession kind of water application. The border strips have some slope in the direction of irrigation, and the ends usually are not closed. Each strip is irrigated by turning in a stream of water at the upper end. The stream size must be such that the desired volume of water is applied to the strip in a time equal to or slightly less than that needed for the soil to absorb the net amount required. When the desired volume of water has been delivered onto the strip, the stream is turned off. The water, temporarily stored on the ground surface, then moves on down the strip and completes the irrigation. Uniform and efficient application of water depends on the use of an irrigation stream of the proper size. Too large a stream results in inadequate irrigation at the upper end of the strip or excessive surface runoff at the lower end (fig. 1). If the stream is too small, the lower end of the strip is inadequately irrigated or the upper end has excessive deep percolation (fig. 2).

METHOD ADVANTAGES

1. When gravity flow to the field is available, no power usage is required.
2. Water with relatively high suspended sediment loads can be used.
3. Graded borders can be used in rotation with other methods of applying water, including furrow irrigation and sprinkler irrigation.
4. With good system design and maintenance, the method requires relatively little labor.
5. With well designed and maintained systems plus good management, relatively high application efficiencies are possible.
6. Distance between dikes can be set to fit existing cultivation and harvesting equipment. Properly designed and constructed dikes can be crossed by equipment.

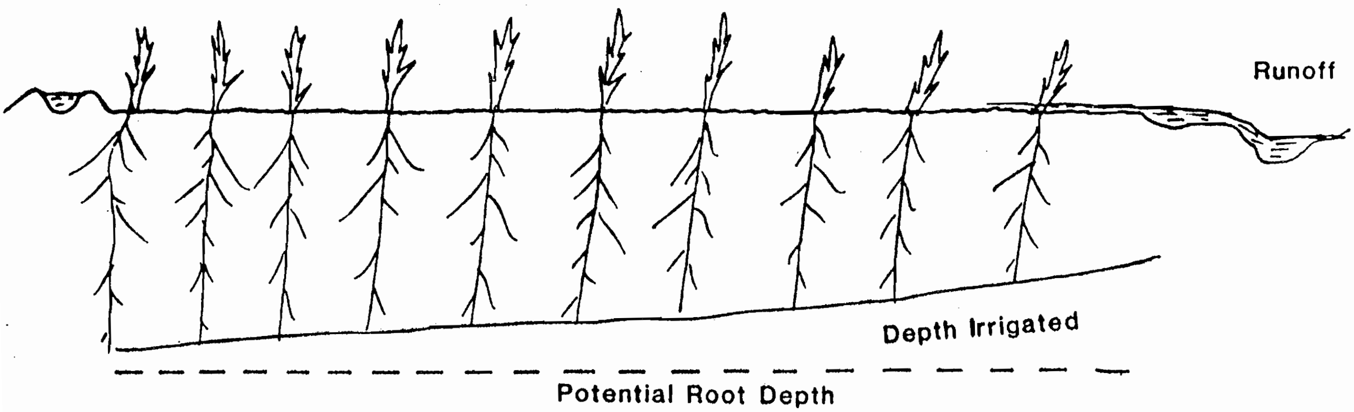


Figure 1. -- Too large a stream for too short a time.

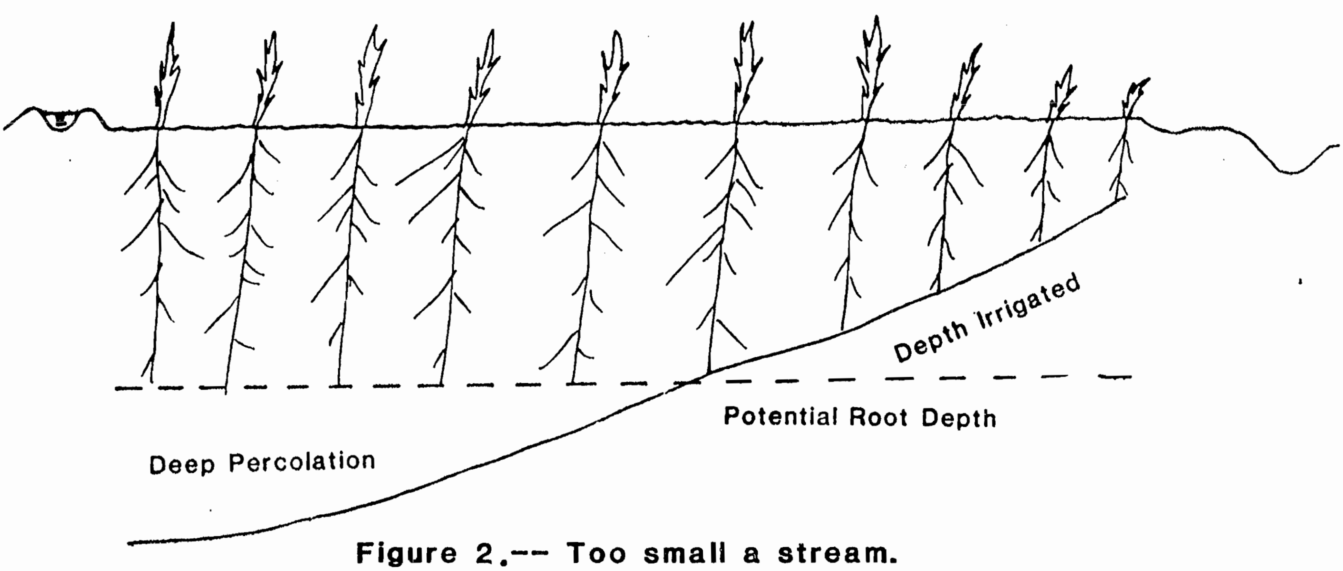


Figure 2.-- Too small a stream.

LIMITATIONS OF METHOD

1. Frequent observation or automation needed to shut the water off at the time required for high efficiency.
2. Topography must be relatively smooth. If modification is needed, soils must be deep enough for adequate leveling.
3. Slope in the direction of irrigation should not exceed about 4 percent, or less depending on soil, groundcover and potential rainfall.
4. Border strips should have little or no cross slope.
5. For highest efficiency, slope should be uniform in the direction of irrigation. There should be no reverse slopes.
6. Skilled labor and management are necessary.
7. Light applications of water are difficult to apply.

DESIGN CONSIDERATIONS

Five factors must be considered in system design:

1. Water intake rate of the soil.
2. Available flow rate.
3. Flow resistance of the crop to be grown.
4. Quantity of water to be applied.
5. Topography of the site.

With this information, slope, border widths, initial flow rates, and times can be designed.

As a general rule, for a well designed and managed system, water should be shut off when it has reached three-fourths of the strip length. However, design is based on estimates of intake rates, water holding capacity and soil water deficit levels. All of these are variable factors even within the same soil and the same field. For this reason, designs must provide for field adjustment of flow rates and application times.

Detailed design information is in National Engineering Handbook, Section 15, Chapter 4, Border Irrigation. Aids in design include various programmable calculator and computer programs.

GLOSSARY OF TERMS, DEFINITIONS AND EXPLANATIONS

Appendix No. B in your Study Guide contains a complete listing of terms, definitions, and explanations used in this module.

ADVANCE-RECESSION CURVES

Advance and recession curves are a plot of time of water front advance and recession against distance down the border strip. They are a very useful tool in analyzing how a border functions. Both curves are plotted on coordinate paper, a separate sheet for each strip.

Figure 3 shows a normal (ideal) graded border advance curve along with a group of advance curves with various deviations from normal. The normal curve is shown in each sketch (dashed line) for comparative purposes.

Figure 4 shows a normal border strip recession curve along with a group of recession curves with various deviations from normal. (A recession curve is a plot of the position where water has just disappeared from the surface, that is the location of the water front as it just recedes down the border, versus the length of time from the beginning of irrigation .) As before, the normal curve and associated curves with various deviations from normal are shown.

Figure 5 shows a normal combined advance curve and recession curve with the associated irrigation curve (dashed line), cutoff time and runoff portion (dotted tip). Figure 5 also shows a set of combined curves representing various deviations from the normal curve.

For the normal combined curves, the advance and recession are nearly parallel. The irrigation curve is always plotted parallel to the advance curve (a uniform time interval above the advance curve). The proper interval is the opportunity time, To, needed for the water to infiltrate the depth corresponding to the soil water deficit (SWD). The time of irrigation, Ti, is the time water is applied to the border strip or time of cutoff. The time of cutoff equals To minus the small lag time, Tl. Usually the proper time of cutoff is when the advance has reached about three-fourths the strip length; but it must be such that the lower end is adequately irrigated and there is little runoff. The distance between the advance and recession curves represents the opportunity time, To, or the time the soil has the opportunity for water to infiltrate in.

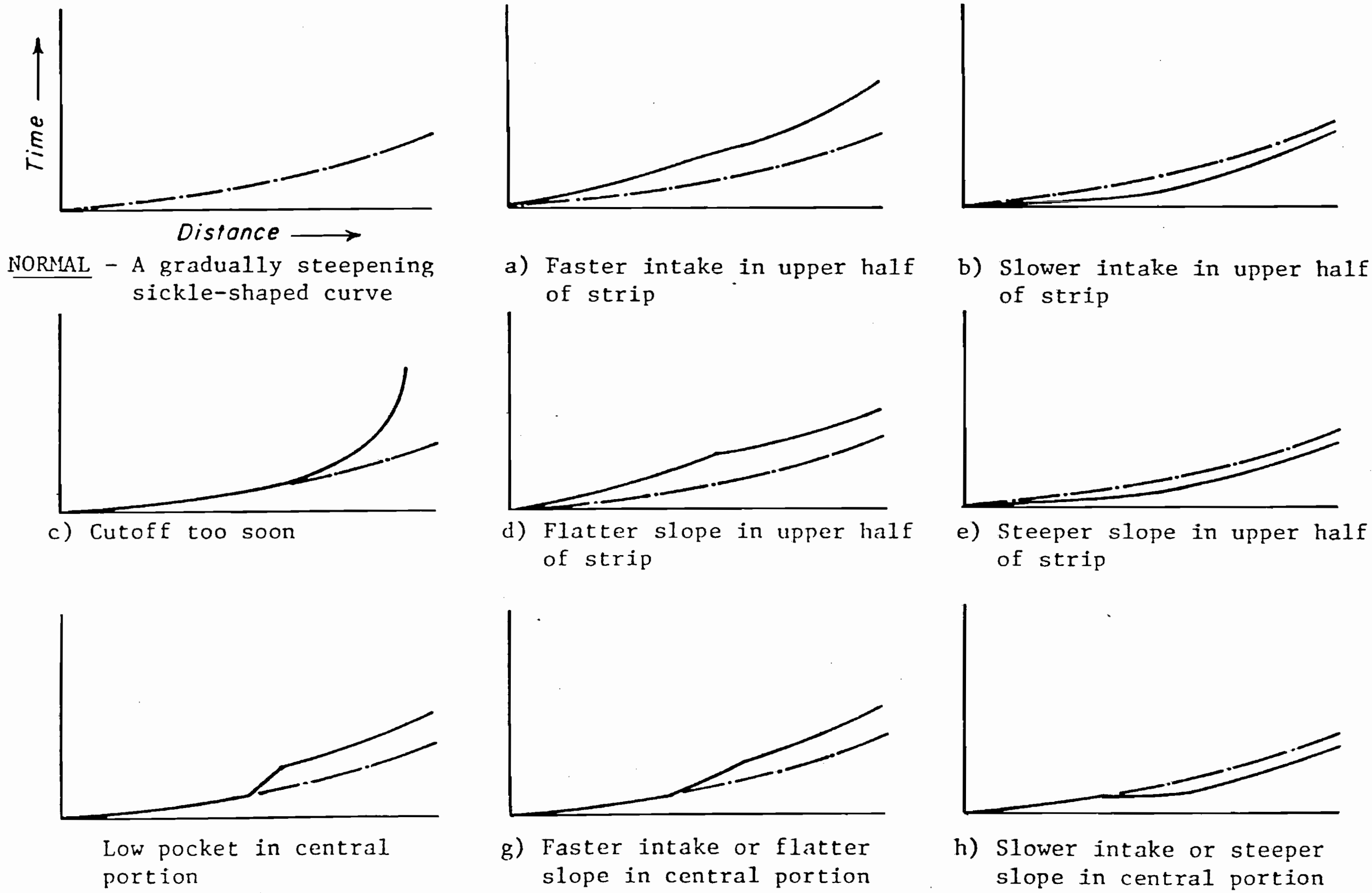


Figure 3.--Various advance curves.

For the other combined curves, the irrigation curve is also parallel to the advance curve; but the time of irrigation is such that there is too little or too much irrigation along all or part of the strip.

Figure 7a illustrates advance-recession curves plotted as part of a system evaluation.

AFTER REVIEWING THIS SECTION ON ADVANCE - RECESSION CURVES, VIEW THE SECOND VIDEO PRESENTATION, PART B. WHEN COMPLETED, REWIND THE TAPE.

CUMULATIVE CYLINDER INTAKE CURVES

Cylinder infiltrometers are used to obtain data for cumulative intake curves for each of three to five infiltrometers. Cumulative intake depth (inches) is plotted against cumulative time (minutes) on 3-cycle log-log paper. Detailed procedure for performing infiltrometer tests are in "The Use of Cylinder Infiltrometers to Determine the Intake Characteristics of Irrigated Soils", USDA ARS & SCS, ARS 41-7, May 1956.

Figure 6 illustrates typical curves. Intake curves usually display a slight concave curve. Some curves steepen after only a few minutes either because of sudden release of air (usually in very sandy soil) trapped by water covering the soil surface or because the infiltrometer was not driven deeply enough. Soils that have openings into which water quickly disappears often yield curves that for a few minutes are steep and then flatten. Plow pans have a similar effect, but this effect usually is delayed. Frequently the curves for individual cylinders for a test site will vary widely. This confirms the variable nature of soil intake rates throughout a field. Procedures are in this Study Guide for adjusting the individual curves for the border strip as a whole.

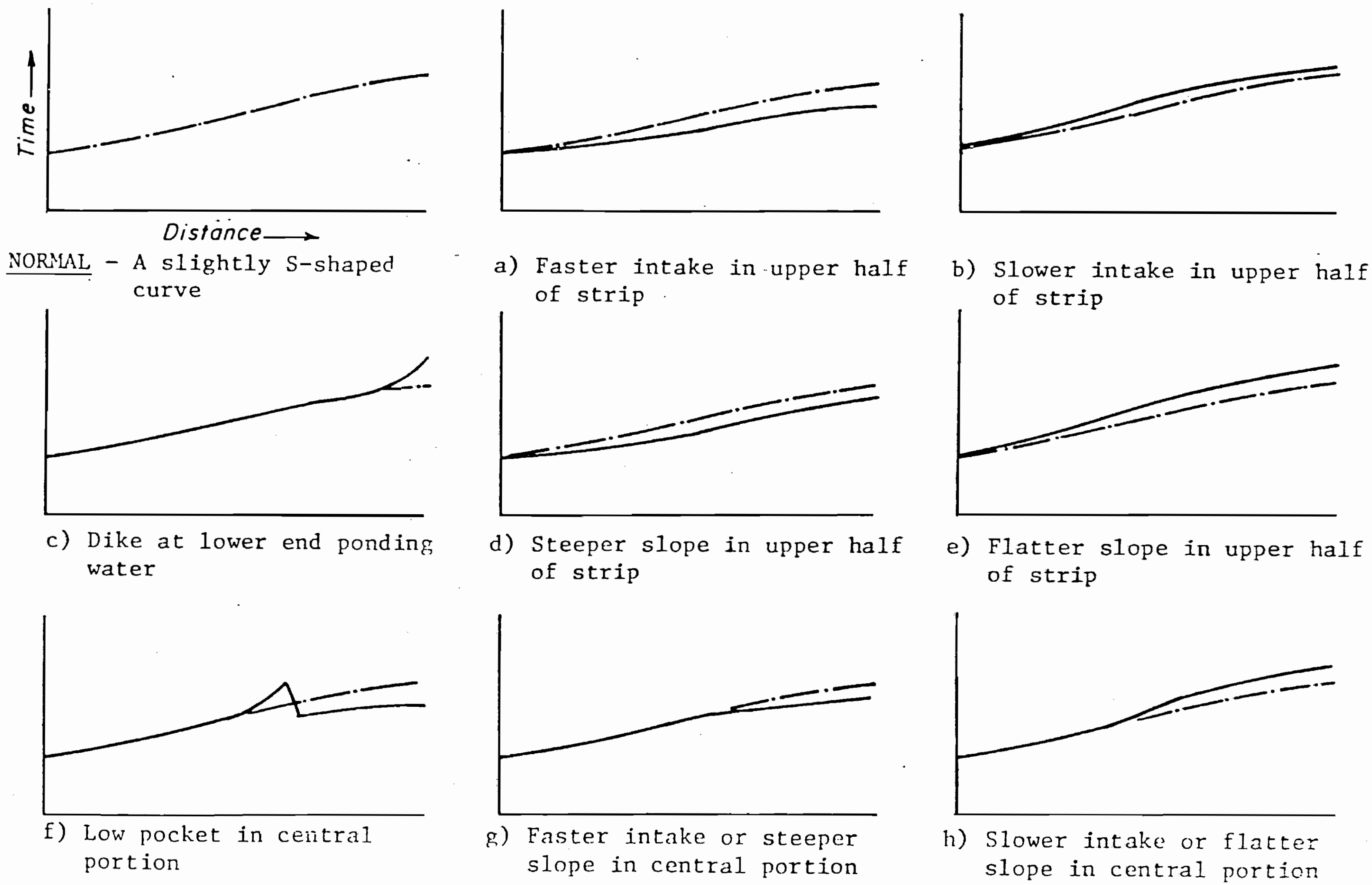
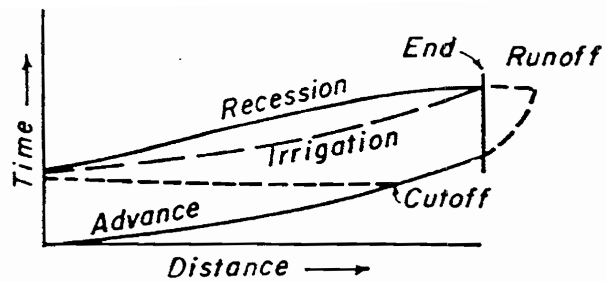
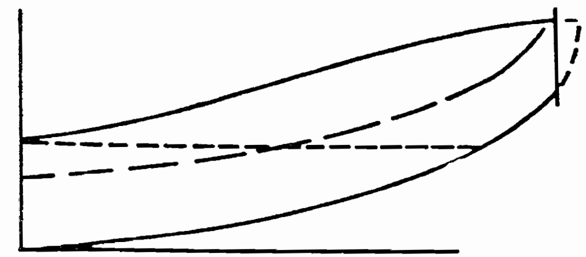


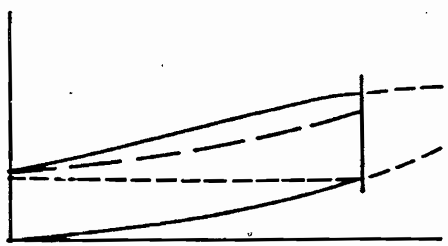
Figure 4.--Various recession curves.



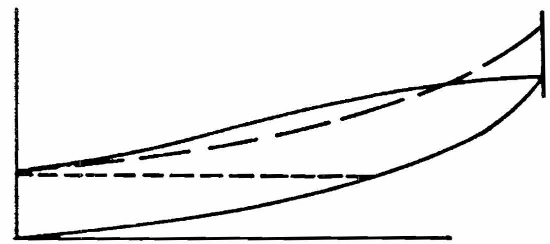
NORMAL - Advance and recession nearly parallel, adequate irrigation, minimal runoff



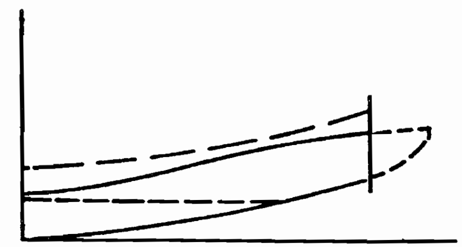
a) Strip too long, over irrigates whole strip



b) Strip too short, large amount of runoff, over irrigates lower portion

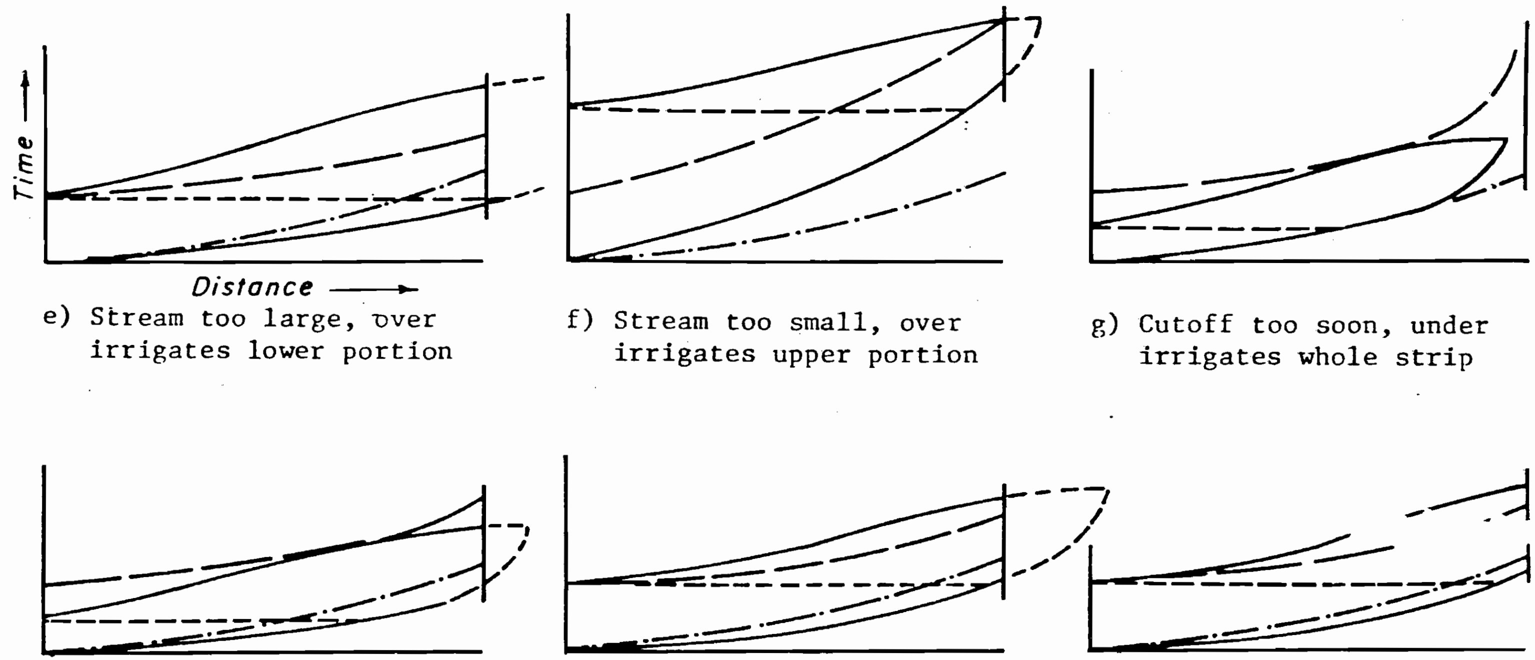


c) Strip too long, under irrigates the lower portion, no runoff



d) Strip too short, under irrigates whole strip

Figure 5. -- Various combined advance - recession curves.



e) Stream too large, over irrigates lower portion

f) Stream too small, over irrigates upper portion

g) Cutoff too soon, under irrigates whole strip

h) Stream too large, under irrigates upper and lower portions

i) Steeper slope in upper portion, adequate irrigation, excessive runoff

j) Slower intake in upper portion, adequate irrigation, excessive runoff

Figure 5. -- Various combined advance - recession curves (continued).

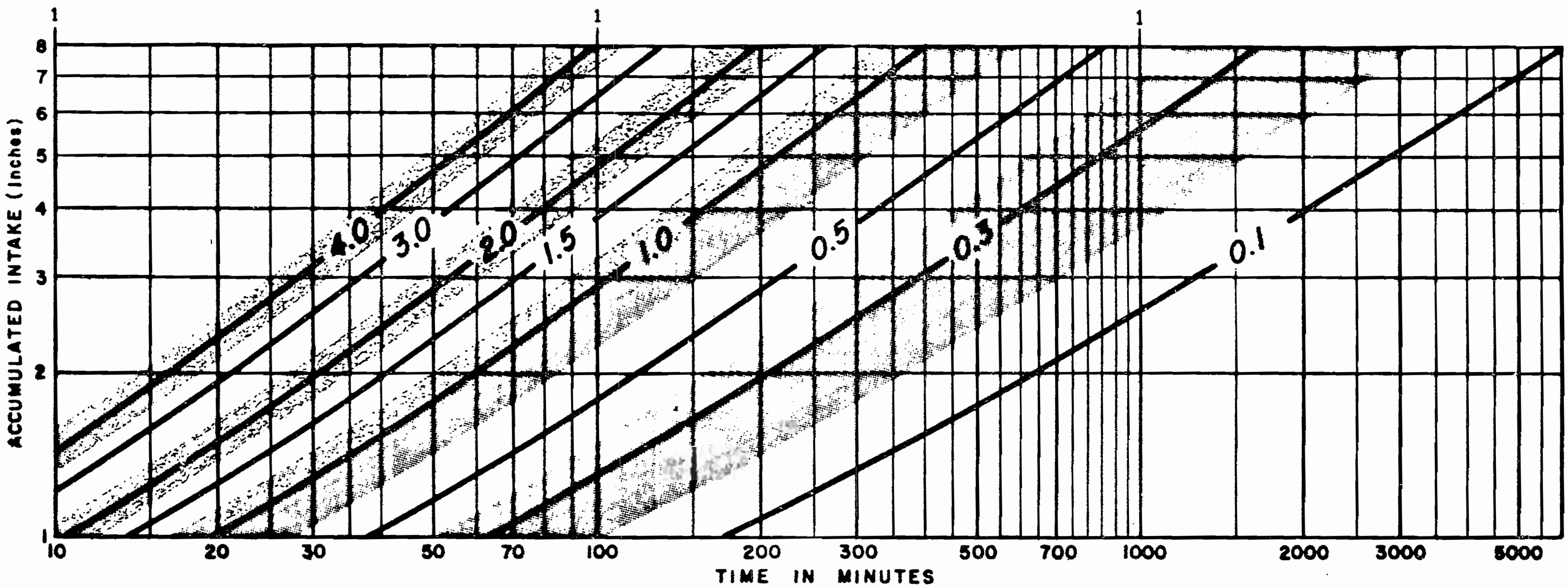


Figure 6. -- Intake grouping for surface irrigation design.

DEPTH INFILTRATED CURVE

Figure 7b illustrates a depth infiltrated curve. This curve depicts the approximate depth infiltrated at any given point along the strip. Area under the curve represents the total application. Area beyond the end of the strip represents runoff volume. When depth stored in the root zone is plotted on the curve, the area below that point and within the strip is the volume of water stored in the root zone. This is equal to the soil water deficit when the entire root zone is filled to field capacity. Area above this point, within the strip, is equal to deep percolation.

Runoff can be estimated, when it is not measured, by extending the advance and recession curves beyond the actual end of border in accordance with typical shapes determined by experience. This provides an estimated opportunity time. This guide illustrates the procedure.

INITIAL EVALUATION

Many important factors concerning how well an irrigation system is operating and how well it is being managed can be determined with simple observations and evaluation procedures. These same procedures are used whether a simple evaluation or a complete evaluation is performed.

The only equipment needed is a soil auger or, if the soil is rocky, a shovel.

The steps are as follows:

1. Determine basic data about the system and the management of the system from the irrigator. Some of the questions which might be asked include:

    a. How does the irrigator determine when to irrigate?
    b. Length of time for each set?
    c. How does the irrigator determine when to turn the water off?
    d. How long does it take for water to reach the end of the field?
    e. What is the rate of flow onto the field or into the system?
    f. What are the problems that the irrigator has experienced with the system?
    g. Are there usually dry spots in the field? Wet spots? Are parts of the field underirrigated? Overirrigated?
    h. Does crop production vary throughout the field? If so, what does the irrigator feel are the causes?
    i. How much control does the irrigator have over when and how much irrigation water is available?
    j. What are the irrigators objectives?
    k. What is the availability of labor?

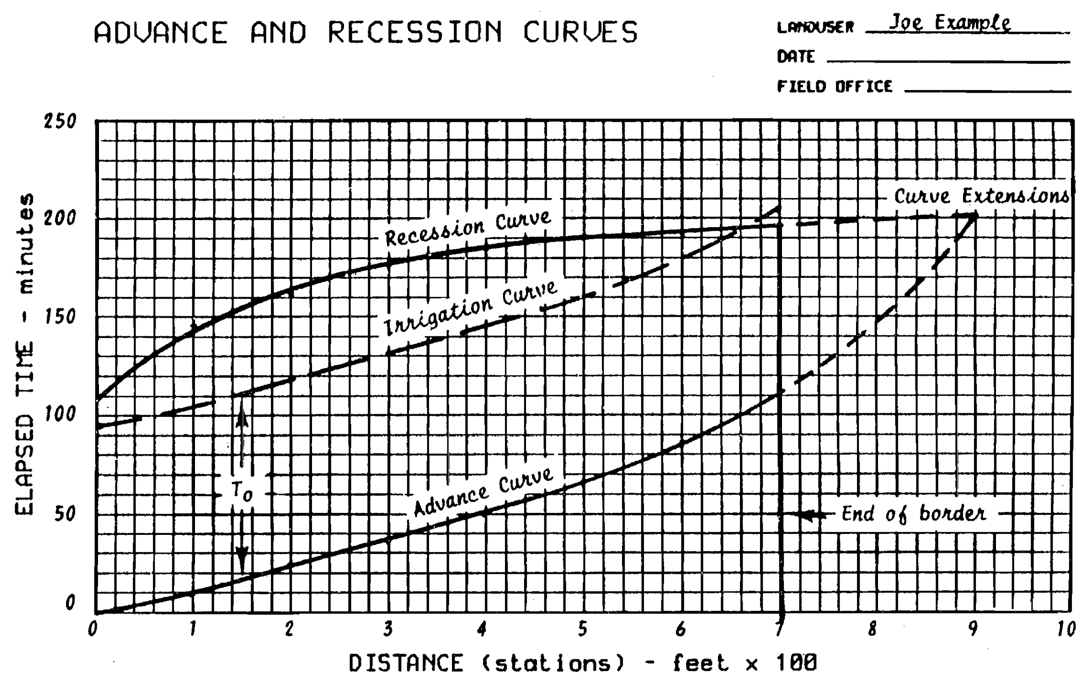


Figure 7a. -- Advance-recession curves

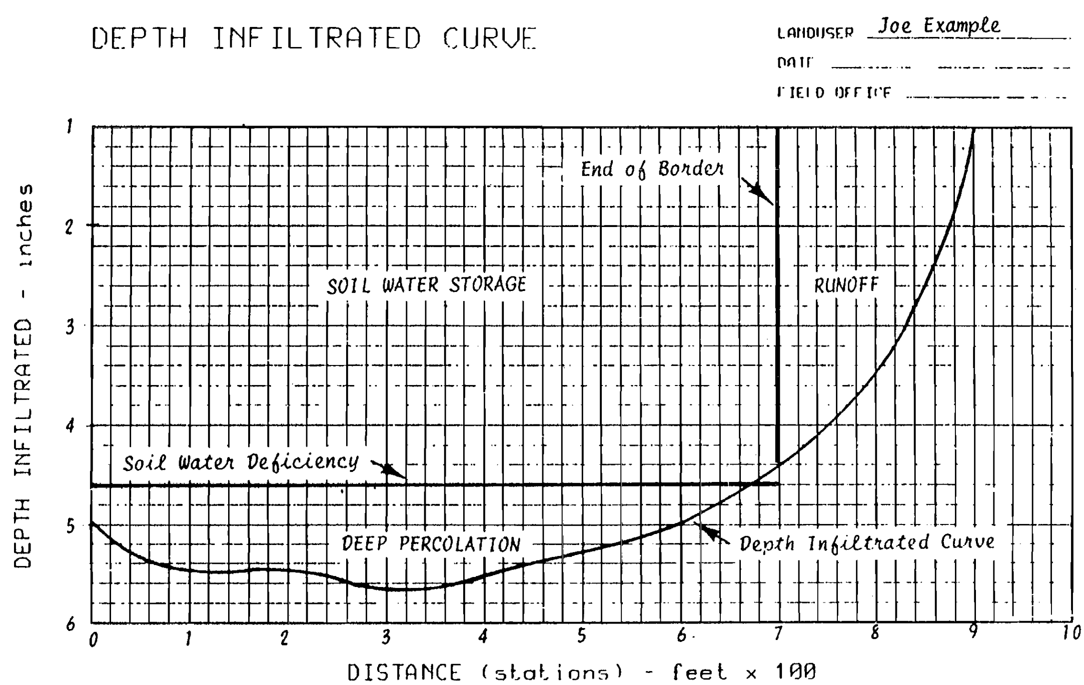


Figure 7b. -- Depth infiltrated curve.

2. Look around:

Look around the field in question. Look in adjacent fields. Look at the supply system. Look for such things as:

a. Erosion problems.
b. Indications of excessive runoff.
c. Problems caused by excessive tailwater.
d. Leaky ditches and pipes.
e. Uneven or discolored crops.
f. Water-loving plants, weeds.
g. Saline and/or swampy areas.
h. Poorly maintained equipment.

3. With the irrigator along, auger some holes at selected locations in the field. Look for such information as:

a. High water table or indications of a fluctuating water table.
b. Hard pans, compacted layers, mineral layers or other characteristics that can restrict root growth and the movement of water in the soil.
c. Soil texture at various levels in the soil profile.
d. Moisture content of the soil layers. (Demonstrate the feel and appearance method).
e. Root penetration.
f. Tilth and condition of the soil.

4. Discuss the findings and information so far obtained with the irrigator. Make recommendations if there is enough information to do so.

DETAILED EVALUATION PROCEDURES

Choosing an evaluation site

Choose a typical location in the field to be irrigated. The typical location should be representative of the type of soil that the entire field is managed for. It is desirable to select a site which will allow measurement of runoff if it occurs. The evaluation should be run at a time when soil moisture conditions are as they are when irrigation would normally be done.

Equipment needed

Engineers level and rod
100 ft. chain
Pocket tape marked in inches and tenths/hundredths of feet
Stakes or flags
Marker for stakes or flags
Flumes, weirs, or other measuring devices to measure inflow and outflow
Carpenters level for setting flumes or weirs
Infiltrometer set with hammer (minimum 4 rings)
Hook gauge for infiltrometer
Equipment for determining soil moisture amounts (i.e. Speedy Moisture Meter and Ely Volumeasure)
Buckets to supply infiltrometer with water
Bucket auger
Soil Probe
Shovel
Graded border evaluation worksheet
Clip board and pencil
Soils data for field
Watch
Camera
Boots

Field procedure

Before start of irrigation:

1. From the farmer, get basic information about existing irrigation procedures and problems.
2. Set stakes or flags at 50 to 100 foot stations down the border. Mark stations on them.
3. Run levels at field elevation on each station and on a typical cross section of the border.
4. Record border width (center to center of border dike), strip width (distance between toes of border dike), and wetted width (width to which water soaks or spreads beyond the edge of dike).
5. Set flumes, weirs, or other measuring devices at the upper end of the border and at the lower end if runoff is to be measured.
6. Set three to five cylinder infiltrometers in a carefully chosen "typical" location within the border strip. Usually the most convenient location is a couple of hundred feet from the upper end of the strip.

7. Estimate soil water deficit at several locations along the border. Use the Feel and Appearance, Ely Volumeasure/Speedy Moisture Meter, Push Sampler/Oven dry, or some other method. Pick one location as being typical for the border strip and record the data for that location on the worksheet.

8. At the same time, make note of soil profile conditions such as:
   a. Depth to water table
   b. Apparent root depth
   c. Compacted layers
   d. Mineral layers
   e. Hard pans or bedrock
   f. Soil texture changes

Field observations

Record observations about the field such as crop color differences in different parts of the field, crop uniformity, salinity, wet areas, etc.

Duties during irrigation

Irrigate with the flow rate normally used by the farmer and record start time.

Check the flow rate at 5 to 10 minute intervals until it reaches a constant rate. Each time the flow is checked, record the flow rate and time of measurement. Periodically during the trial, check the flow rate and record it. If there is considerable fluctuation in the flow rate, frequent checks should be made.

Observe and record a description of how well water spreads across the strips.

Record the time the leading edge of the water reaches each station. If the leading edge is an irregular line across the border strip, average the time as different parts of the leading edge reach the station.

Fill the infiltrometers at the time the leading edge reaches them. (An alternative is to build dams around the infiltrometers and pour water in the dams at the same time water is poured into the infiltrometers.) Record infiltrometer readings at times shown on the infiltrometer work sheet.

Record the time that runoff starts, if there is any. If outflow is being measured, periodically measure the flow rate and record the rate and time of measurement until it ceases.

Record the time when water is turned off at the head end of the field. As the sheet of water recedes past each station, record the time. This requires good judgment. On slopes of 0.5 percent or greater, a large part of the water remaining in the border strip when the supply is shut off may move down slope in a fairly uniform manner. On these fields, record recession time at each station when the water has disappeared from the area above it. If the recession line across the border strip is irregular, record the time when there is about as much cleared area below as there is water-covered area above the station. On slopes of less than 0.5 percent, a smaller proportion of the water moves down the strip. Some may be trapped in small depressions and may not be absorbed for some time after surrounding areas are clear. The important thing is to determine when the intake opportunity time is essentially gone; the recession time usually may be recorded for a station when 80 to 90 percent of the area between it and the next station upstream has no water on the surface.

Before leaving the field, use a probe or auger to check depth of penetration at several locations in the strip. A check at this time will indicate whether water has already percolated too deeply.

If possible, check for adequacy and uniformity of irrigation at a time when the soil profile has reached the field capacity moisture level. Sandy soils can be checked about 24 hours after irrigation. Clayey soils should be checked about 48 hours after irrigation so that gravitational water has drained.

Establishing the field capacity is necessary to determine the soil water content when checking the adequacy of irrigation.

IRRIGATION WATER MANAGEMENT

GRADED BORDER IRRIGATION SYSTEM EVALUATION

ACTIVITY 1 (WITH STEP-BY-STEP EXERCISE)

GRADED BORDER IRRIGATION SYSTEM EVALUATION
Procedure for Completion of Module

1. If self-study, you will carefully proceed through the step-by-step evaluation procedure. Be sure you do not move to the next step until you fully understand where all the information came from and where and how it is to be recorded. Data from the field example is usually recorded on the even numbered page facing a worksheet. Solutions to each item are included, but try not to look at them until you have exhausted every effort to do the work on your own. You should fill out each blank on the various worksheets as though you were actually doing the evaluation. If you have trouble with any item, you should look at the solution. If you still do not understand, call or talk to your resource person.

2. If facilitator-led, you will be led through this exercise step-by-step. You will fill out blanks on the various worksheets as though you were actually doing the evaluation.

3. As an aid to you when you return to your headquarters and perform your own evaluations, we have included a step-by-step procedure to guide you through the worksheets and computations. At first it may seem complicated, but, if you follow the procedure in this appendix, you should be able to perform a complete evaluation with no additional assistance.

GRADED BORDER IRRIGATION SYSTEM EVALUATION

ACTIVITY 1

The data recorded below was taken from the landuser's conservation plan (plan map, soils map, irrigation plan), State Irrigation Guide, and on-site observations and measurements. This information contains brief explanations to help complete the worksheets. Transfer this data to Surface System Evaluation Worksheet A.

1. Landuser's name - Joe Example. Use current date. Use your field office.

2. Field name/number (from conservation plan) - West 40

3. Field area (from conservation plan) - 40 acres

4. Border location (on-site determination) - Border No. 5 counted from North side of field.

5. Crop (on-site observation) - Alfalfa

6. Root zone depth (conservation plan soils map, Irrigation Guide, field observation) - 5 feet

7. Stage of crop (on-site observations) - one week after cutting

8. Soil-water data for controlling soil (conservation plan soils map, Irrigation Guide, on-site observations and measurements):
   a. Soil name (conservation plan soils map) - Glenberg loam
   b. Location of sample (on-site selection. usually any location in upper ½ of border length would be okay) - 2 + 00
   c. Method used to determine soil moisture content (may use "Feel and Appearance", Ely Volumeasure/Speedy Moisture meter, or the Volume Sampler/Oven-dry methods). Ely/Speedy was used.
   d. Data for chart:

Depth	Texture	AWC (in) 1/	SWD (%) 2/	SWD (in) 3/
0-1'	loam	2.0	50	
1-2'	loamy fine sand	1.5	45	
2-3.5'	very fine loamy sand	2.2	40	
3.5-5'	gravelly loamy sand	1.5	20	

1) Depth, Texture, and Available Water Capacity (AWC) from Irrigation Guide
2) Soil Water Deficit (SWD). This is the actual percent of available water remaining in the crop at given increments. Measured by use of "Feel and Appearance", Ely/Speedy, or Volume Sampler/Oven-dry methods.
3) SWD (in) Computed by multiplying AWC (in) by SWD (%).

e. MAD (%) Management Allowed Deficit (from landuser, Irrigation Guide, NEH-15). Irrigate when approximately 50% of the available water in the root zone depth is depleted.

f. MAD (in) = $\frac{\text{MAD (\%)}}{100}$ x total AWC (in.)

9. Comments about soils: There is a very compact layer between 10 and 14 inches. Could not dig with auger much past 3½ feet due to gravel. Used information from soils map (field observation).

10. Typical irrigation duration (from landuser or irrigator) - 1½ hr.

11. Typical irrigation frequency - (from landuser or irrigator) - 14 days

12. Typical number of irrigations per year (from landuser or irrigator) - 12±

13. Annual Irrigation Requirement (from Irrigation Guide, Use rate of crops) - 22.1 inches

14. Type of delivery system (on-site observation and measurements, if necessary) - Siphon tubes from earth ditch. Electric pump delivers 1.4 cfs to the ditch. TDH (Total dynamic head) = 100 ft. Concrete checks in ditch.

15. Type and size of turn outs (on-site observation) - 5-4" siphon tubes per set.

16. Border Spacing = 30 ft. Strip width (between border) = 28 ft. The wetted width is 29 ft. Length = 700 ft. (See border cross section)

17. Field observations (on-site observations)
    a. Crop uniformity - Thin spots within first 100 ft. of upper end. Best stand between 3+00 and 6+00.
    b. Salinity problem - none observed.
    c. Other observations - Field was touch-up leveled 4 years ago (landuser). Low next to borders where soil was taken for border. Alfalfa stand is 4 years old. Other grass and weeds are beginning to invade the stand.

SURFACE SYSTEM EVALUATION WORKSHEET A

GRADED BORDERS
CROP AND SOIL DATA

Landuser ____________ Date ________ Field Office ____________
Observer ____________ Field name/number ____________

FIELD DATA INVENTORY

Field area ______ acres
Border number ________ as counted from ________ side of field.
Crop ________ Root zone depth ______ ft
Stage of crop ____________
Soil-water data for controlling soil:
Soil name ____________
Location of sample ____________
Moisture determination method ____________

Depth	Texture	AWC (in)*	SWD (%)*	SWD (in)
	Totals			

$$MAD^{*} \text{ (in)} = \frac{MAD\ (\%)}{100} \times \text{total AWC (in.)} = \frac{\_\_\_ \times \_\_\_}{100} = \_\_\_\_ \text{ in.}$$

Comments about soils: ____________

Typical irrigation duration ______ hr, irrigation frequency ______ days
Typical number of irrigations per year ____________
Annual Irrigation Requirement ______ inches
Type of delivery system (gated pipe, turnouts, siphon tubes) ____________

Delivery system size data (pipe size and gate spacing, tube size and length, turnout size) ____________

Border Spacing: ____ ft, Strip Width ____ ft, Wetted Width ____ ft,
Length ________ ft

FIELD OBSERVATIONS

Crop uniformity ____________

Uniformity of water spread across border ____________

Other observations ____________

* MAD = Management allowed deficit AWC = Available water capacity
SWD = Soil water deficit

SURFACE SYSTEM EVALUATION WORKSHEET A

GRADED BORDERS
CROP AND SOIL DATA

Landuser *Joe Example* Date ______ Field Office ______
Observer ______ Field name/number *West 40*

FIELD DATA INVENTORY

Field area *40* acres
Border number *5* as counted from *North* side of field.
Crop *Alfalfa* Root zone depth *5.0* ft
Stage of crop *one week after cutting*
Soil-water data for controlling soil:
Soil name *Glenberg loam*
Location of sample *2+00*
Moisture determination method *Ely/Speedy*

Depth	Texture	AWC (in)*	SWD (%)*	SWD (in)
0 - 1'	*loam*	*2.0*	*50*	*1.0*
1 - 2'	*loamy fine sand*	*1.5*	*45*	*0.7*
2 - 3.5'	*very fine loamy sand*	*2.2*	*40*	*0.9*
3.5 - 5'	*gravelly loamy sand*	*1.5*	*20*	*0.3*
	Totals	*7.2*		*2.9*

$$MAD^* \text{ (in)} = \frac{MAD\ (\%)}{100} \times \text{total AWC (in.)} = \frac{50 \times 7.2}{100} = 3.6 \text{ in.}$$

Comments about soils: *There is a very compact layer between 10 & 14 inches. Could not dig with auger past 3 1/2 feet due to gravel. Used information from soil survey.*

Typical irrigation duration *1 1/2* hr, irrigation frequency *14* days
Typical number of irrigations per year *12+*
Annual Irrigation Requirement *22.1* inches
Type of delivery system (gated pipe, turnouts, siphon tubes) *Siphon tubes from earth ditch w/conc. checks. Elect. pump delivers 1.4 cfs at 100' TDH*
Delivery system size data (pipe size and gate spacing, tube size and length, turnout size) *5 - 4" siphon tubes per set*

Border Spacing: *30* ft, Strip Width *28* ft, Wetted Width *29* ft,
Length *700* ft

FIELD OBSERVATIONS

Crop uniformity *Thin spot within 100' of upper end. Best stand between 3+00 and 6+00*
Uniformity of water spread across border *Low next to borders.*

Other observations *Field touch-up leveled 4 yrs. ago. Alfalfa 4 yrs. old. Grass and weeds beginning to invade.*

* MAD = Management allowed deficit AWC = Available water capacity
SWD = Soil water deficit

Evaluation Computations - Profile and Cross Section (page 27)

1. Stakes were set at 100 foot stations down the border and rod readings were taken as shown:

0+00 - 2.5	3+00 - 3.5	6+00 - 4.4
1+00 - 2.9	4+00 - 3.7	7+00 - 4.6
2+00 - 3.3	5+00 - 4.1	

2. A cross-section was taken at station 3+00 as shown:

0+00 - 3.1	0+10 - 3.5	0+28 - 3.6
0+02 - 3.6	0+20 - 3.5	0+30 - 3.15

3. Plot profile and cross-section on your Surface System Evaluation Worksheet (page 27 in exercise).
   a. Complete landuser, date, and field office blanks. Use your own field office. Use current date.
   b. On profile grid, circle "ROD". It is suggested that, in order to have slope from left to right, you plot rod readings starting with 2.0 at the upper left corner and 5.0 at the lower left corner. Plot the profile.
   c. On cross-section grid, it is suggested that you plot rod readings starting with 3.0 at the upper left corner of grid and 4.0 at the lower left corner. Each square can equal 1 foot. Plot the cross-section.
   d. Compute the slope of the border.
      (1) Draw best fit line. As an example: Lay your straight edge at 2.9 (1+00) and 4.4 (6+00). Draw a straight line. The 0+00 reading is now 2.6 ft. The reading at 6+00 is 4.4 ft. The difference is 4.4-2.6 = 1.8 ft. The length between readings is 600 ft. The slope is 1.8/600 = 0.003 ft/ft, or 0.3% slope. Record the slope of the border.

PROFILE AND CROSS SECTION

LANDUSER ____________________

DATE ____________________

FIELD OFFICE ____________________

CROSS SECTION at sta.

DISTANCE - feet

PROFILE

ROD READING OR ELEVATION - feet

DISTANCE (stations) - feet x 100

PROFILE AND CROSS SECTION

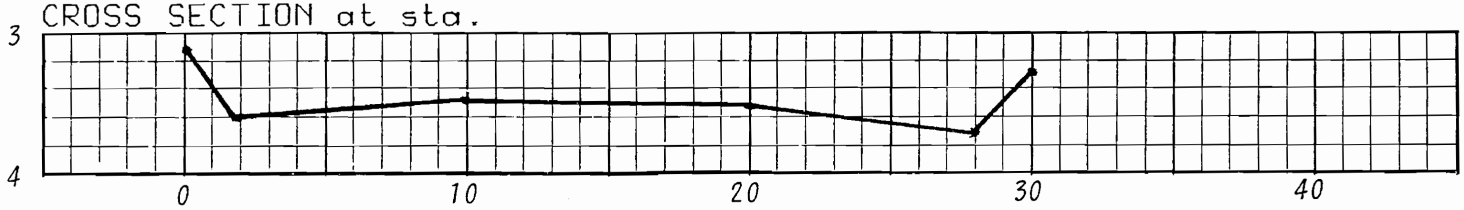
LANDUSER Joe Example

DATE ____________

FIELD OFFICE ____________

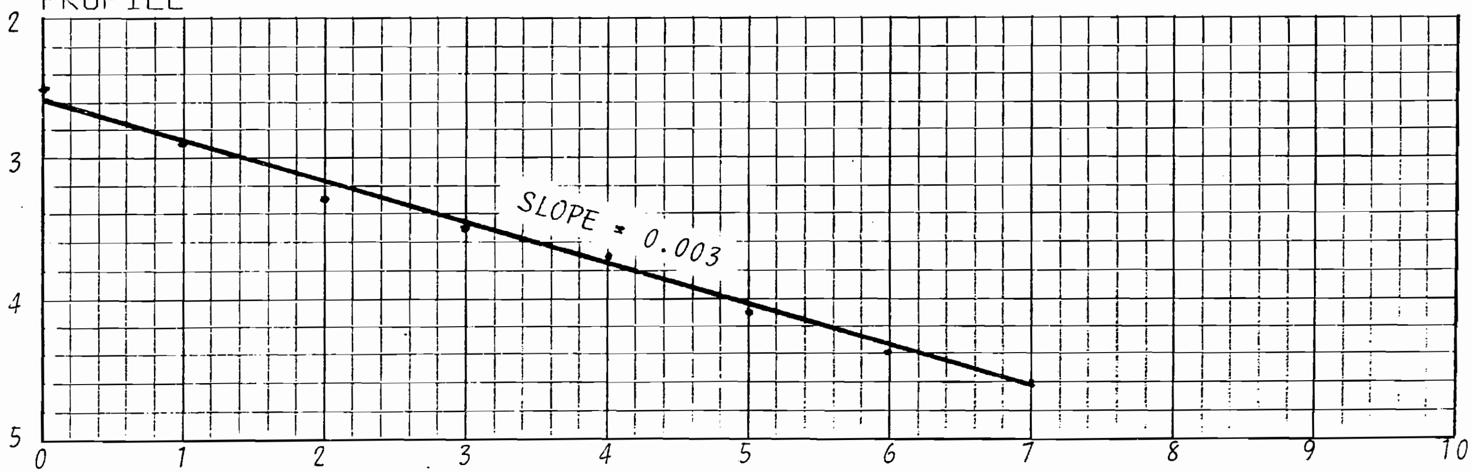
ROD READING OR ELEVATION - feet

CROSS SECTION at sta.



DISTANCE - feet

PROFILE



DISTANCE (stations) - feet x 100

Evaluation Computations - Cylinder Infiltrometer Test Data Worksheet - Accumulated Intake (Page 31)

1. 4 cylinder infiltrometers were set at station 2+00, a location that seemed typical of the border. The information on the data sheet (next page) was collected.

2. Calculate "Accumulated Intake" as follows:
   a. Enter "0" at 0 minutes elapsed time.
   b. Subtract the reading at 0 minute elapsed time (1.80 for cylinder 1) from the reading at 5 minutes elapsed time (2.44 for cylinder 1). The difference, 0.64, is entered under "Accumulated Intake" at 5 minutes elapsed time.
   c. Subtract the reading at 0 minutes elapsed time (1.80 for cylinder 1) from the reading at 10 minutes elapsed time (2.57 for cylinder 1). The difference, 0.77, is entered under "Accumulated Intake" at 10 minutes elapsed time.
   d. Complete "Accumulated Intake" for all Cylinders.

3. Calculate the "Average Accumulated Intake". Enter data in the last column of the Cylinder Infiltrometer Test Data Worksheet. This is obtained by adding the "Accumulated intake" amount obtained from the 4 cylinders and dividing by 4. For the example: for 5 minuted elapsed time, the amounts are 0.64, 0.70, 0.35, 1.20. Added, these equal 2.89. Divided by 4, the average "Accumulated Intake" for 5 minute elapsed time is 0.72 inches. Continue to calculate the averages for all times given.

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

CYLINDER INFILTROMETER TEST DATA

SCS-ENG-322
02-85

FARM	COUNTY	STATE	LEGAL DESCRIPTION	DATE
Joe Example			NW 1/4 S27, T3N, R28E	

SOIL MAPPING SYMBOL	SOIL TYPE	SOIL MOISTURE:
	Glenberg loam	0'-1'-% OF AVAILABLE 40% 1'-2'-% OF AVAILABLE 50%

CROP	STAGE OF GROWTH
Alfalfa	1 week after cutting

GENERAL COMMENTS
Compacted layer between 10 and 14 inches

ELAPSED TIME	CYLINDER NO. 1			CYLINDER NO. 2			CYLINDER NO. 3			CYLINDER NO. 4			CYLINDER NO. 5			AVERAGE ACCUM. INTAKE
	TIME OF READING	HOOK GAGE READING	ACCUM. INTAKE	TIME OF READING	HOOK GAGE READING	ACCUM. INTAKE	TIME OF READING	HOOK GAGE READING	ACCUM. INTAKE	TIME OF READING	HOOK GAGE READING	ACCUM. INTAKE	TIME OF READING	HOOK GAGE READING	ACCUM. INTAKE	
MIN		INCHES	INCHES		INCHES	INCHES		INCHES	INCHES		INCHES	INCHES		INCHES	INCHES	
0	11:15	1.80		11:16	2.10		11:18	3.21		11:19	4.10					
5	11:20	2.44		11:22	2.80		11:23	3.56		11:24	5.30					
10	11:25	2.57		11:26	3.05		11:27	3.64		11:28	5.75					
20	11:35	2.76		11:37	3.45		11:38	3.72		11:39	6.30					
30	11:45	2.95		11:46	3.80		11:47	3.82		11:48	6.85					
45	12:00	3.25		12:01	4.35		12:03	3.97		12:04	7.60					
60	12:15	3.58		12:17	4.80		12:18	4.15		12:19	8.20					
90	12:45	4.05		12:46	5.50		12:47	4.51		12:47	9.20					
120	13:15	4.50		13:16	6.10		13:17	4.91		13:18	10.10/ 3.90					
180	14:15	5.30		14:17	7.50		14:18	5.71		14:19	5.6					
240	15:15	6.20		15:16	8.80		15:18	6.61		15:19	6.9					

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

CYLINDER INFILTROMETER TEST DATA

SCS-ENG-322
02-85

FARM	COUNTY	STATE	LEGAL DESCRIPTION	DATE
Joe Example			NW 1/4 S27,T3N, R28E	
SOIL MAPPING SYMBOL	SOIL TYPE: Glenberg Loam		SOIL MOISTURE: 0'-1' - % OF AVAILABLE 40%; 1'-2' - % OF AVAILABLE 50%	
CROP: Alfalfa	STAGE OF GROWTH: 1 week after cutting			

GENERAL COMMENTS
compacted layer between 10 & 14 inches

ELAPSED TIME	CYLINDER NO. 1			CYLINDER NO. 2			CYLINDER NO. 3			CYLINDER NO. 4			CYLINDER NO. 5			AVERAGE ACCUM. INTAKE
MIN.	TIME OF READING	HOOK GAGE READING (INCHES)	ACCUM. INTAKE (INCHES)	TIME OF READING	HOOK GAGE READING (INCHES)	ACCUM. INTAKE (INCHES)	TIME OF READING	HOOK GAGE READING (INCHES)	ACCUM. INTAKE (INCHES)	TIME OF READING	HOOK GAGE READING (INCHES)	ACCUM. INTAKE (INCHES)	TIME OF READING	HOOK GAGE READING (INCHES)	ACCUM. INTAKE (INCHES)	
0	11:15	1.80	0	11:16	2.10	0	11:18	3.21	0	11:19	4.10	0				0
5	11:20	2.44	.64	11:22	2.80	.70	11:23	3.56	.35	11:24	5.30	1.20				.72
10	11:25	2.57	.77	11:26	3.05	.95	11:27	3.64	.43	11:28	5.75	1.65				.95
20	11:35	2.76	.96	11:37	3.45	1.35	11:38	3.72	.51	11:39	6.30	2.20				1.26
30	11:45	2.95	1.15	11:46	3.80	1.70	11:47	3.82	.61	11:48	6.85	2.75				1.55
45	12:00	3.25	1.45	12:01	4.35	2.25	12:03	3.97	.76	12:04	7.60	3.50				1.99
60	12:15	3.58	1.78	12:17	4.80	2.70	12:18	4.15	.94	12:19	8.20	4.10				2.38
90	12:45	4.05	2.25	12:46	5.50	3.40	12:47	4.51	1.30	12:47	9.20	5.10				3.01
120	13:15	4.50	2.70	13:16	6.10	4.00	13:17	4.91	1.70	13:18	10.10/ 3.90	6.00				[illegible]
180	14:15	5.30	3.50	14:17	7.50	5.40	14:18	5.71	2.50	14:19	5.6	7.70				4.78
240	15:15	6.20	4.40	15:16	8.80	6.70	15:18	6.61	3.40	15:19	6.9	9.00				5.88

Evaluation Computations - Cylinder Infiltrometer Curves (page 35)

1. Using data from Cylinder Infiltrometer Test Data worksheet (page 31), plot all 4 Accumulated Intake vs. Elapsed Time data on the Cylinder Infiltrometer Curves Worksheet (page 35). Draw a "best fit" line through the accumulated intake data points for each cylinder. This line should be nearly straight on a log-log plot. Be sure to label all curves.
2. Plot the Average Accumulated Intake vs. Elapsed Time curve. Data for this curve comes from the last column of the Cylinder Infiltrometer Test Data Worksheet, page 31. Draw a "best fit" line through the average accumulated intake data points. This line should be nearly straight on a log-log plot. Label it "Average Intake Curve".

Accumulated Intake using typical Intake Family Curves. (Fig. 6)

As an alternative to using the Cylinder Infiltrometer Test, you may choose to use the Intake Families (page 10) for surface irrigation design. This is only applicable when your soil is listed in your Irrigation Guide and fits a typical family of curves.

1. In our example problem, the Glenberg loam fits the 1.0 intake curve. This would be given in your Irrigation Guide for Glenberg loam.

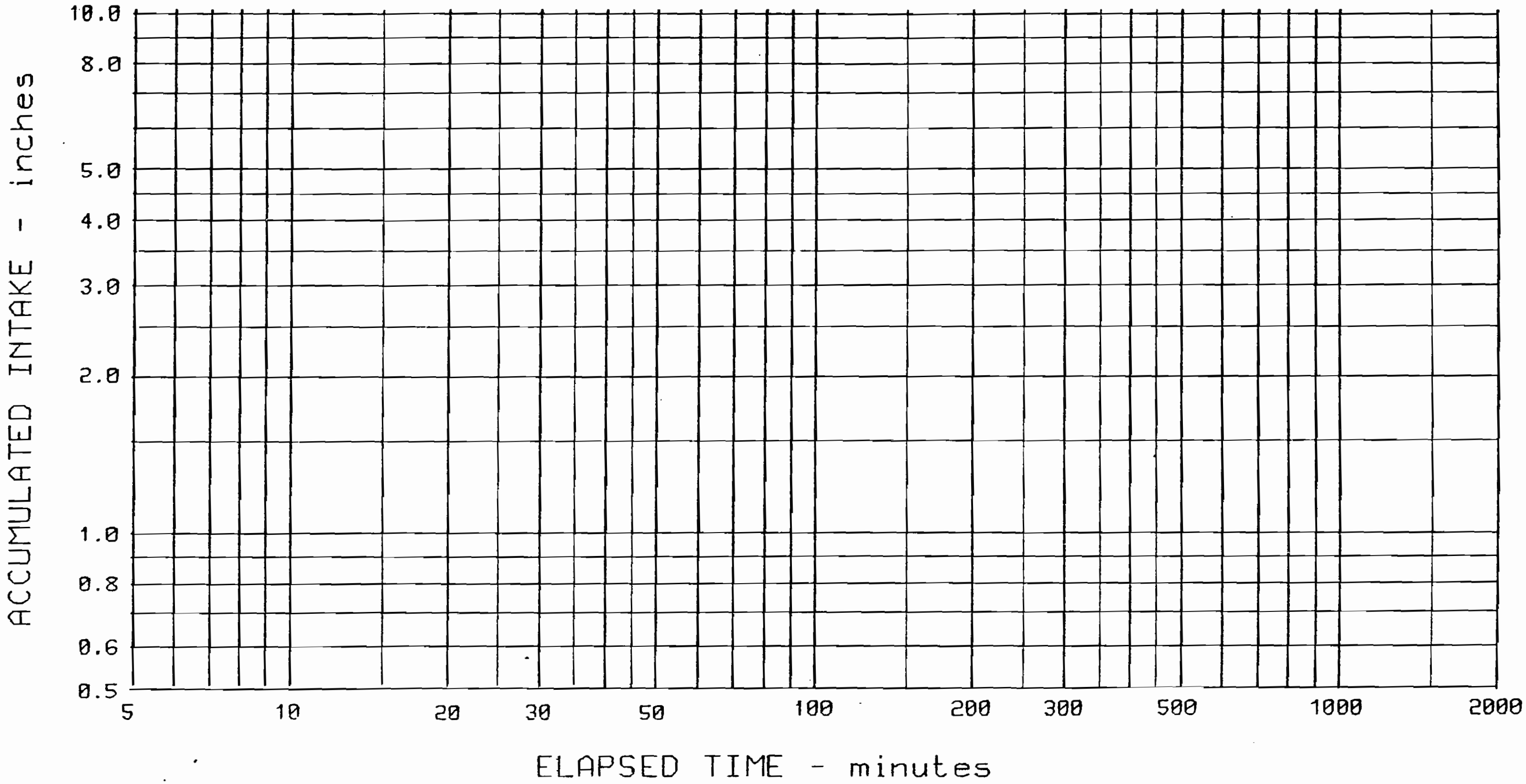
2. Find the 1.0 intake curve and use it in the computations when infiltrometer tests are not run.

CYLINDER INFILTROMETER CURVES

LANDUSER ______________________

DATE ______________________

FIELD OFFICE ______________________

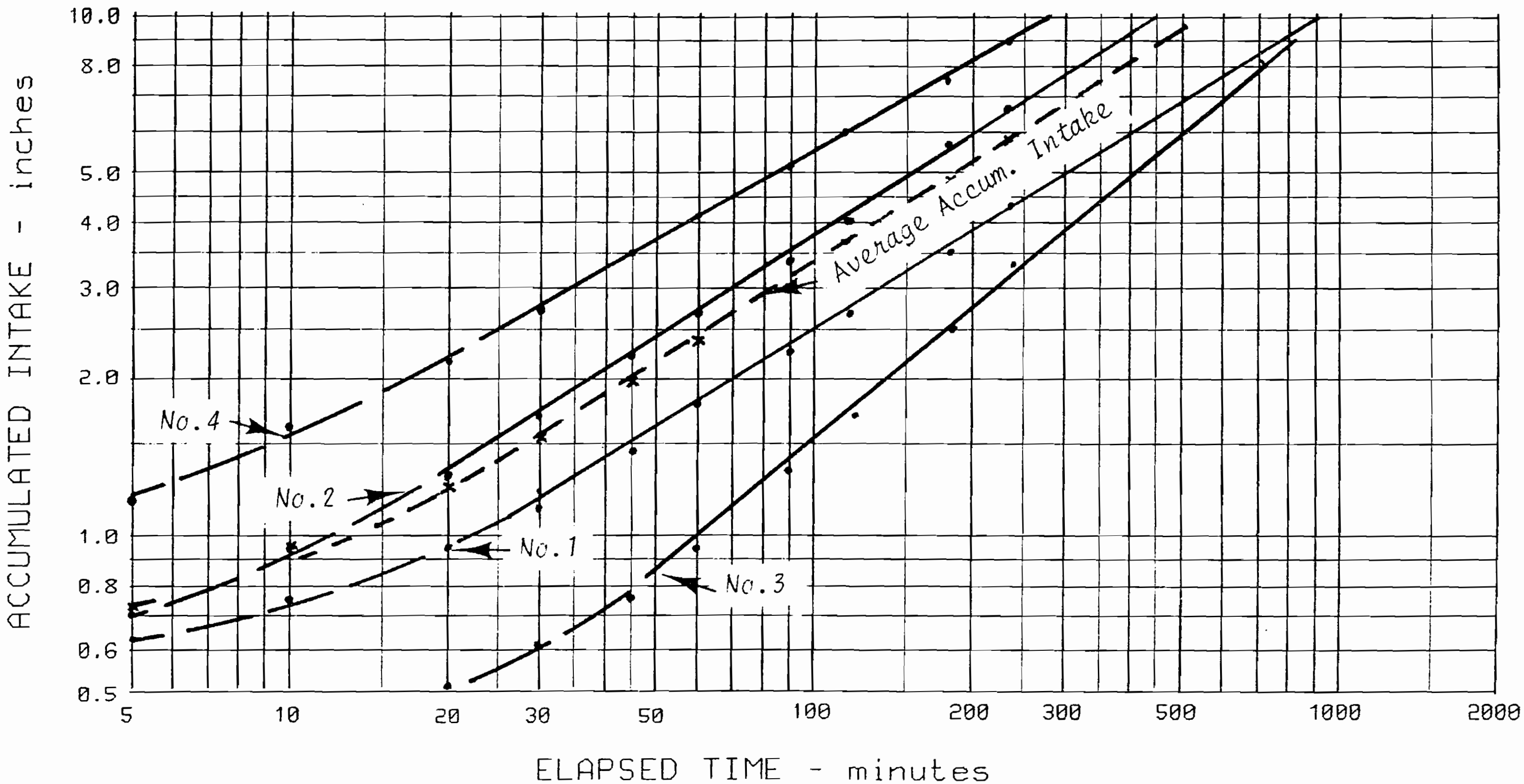


CYLINDER INFILTROMETER CURVES

LANDUSER Joe Example

DATE

FIELD OFFICE

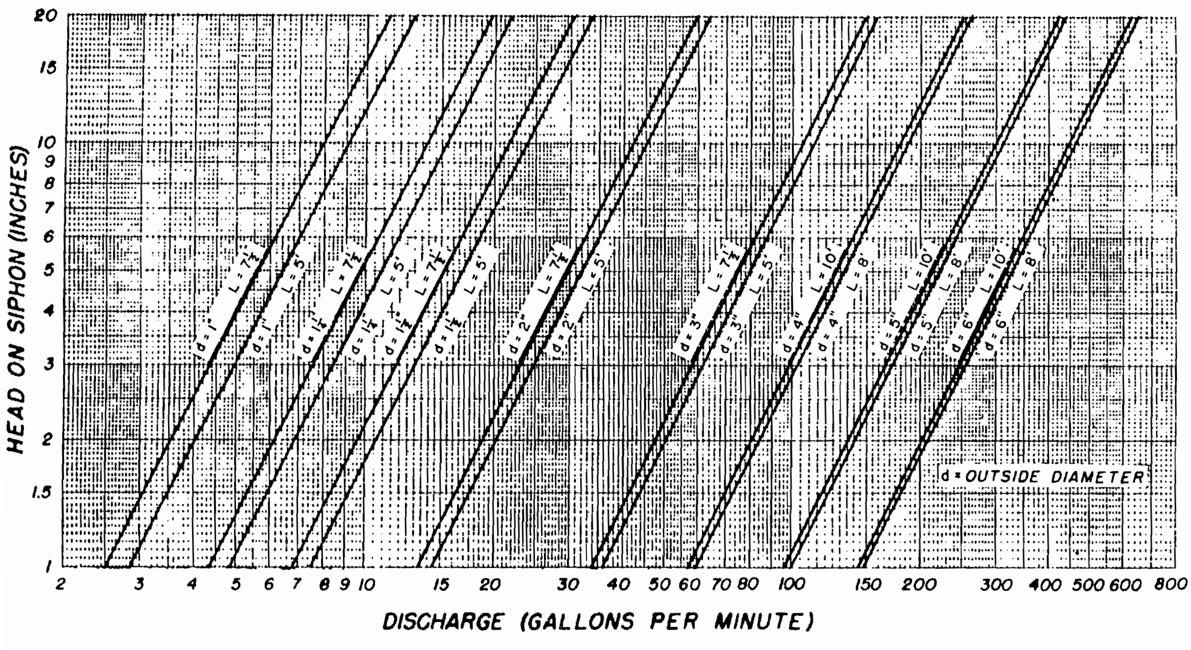


Evaluation Computations - Surface System Evaluation Worksheet B - Inflow/outflow (page 39)

1. Using the field data recorded on Surface System Evaluation Data Worksheet B and the Siphon Discharge Tables Sheet (below), complete the flow rate in gpm for 5 - 4" x 10' siphon tubes. Record this data on Surface System Evaluation Worksheet - B, column 5.

2. Using the field data recorded on the Surface System Evaluation Data Worksheet B, compute the total inflow volume. 5 - 4" x 10' siphon tubes were used.

   a. The elapsed time is computed by subtracting the clock time of the reading from the "turn on" clock time. 11:00 - 10:51 = 9 min., 11:11 - 10:51 = 19 min. etc.
   b. The Δt is the time difference between each reading. 9 - 0 = 9, 19 - 9 = 10, etc.
   c. The ΔH is the head difference between the water surface at the siphon inlet and the water surface (or center of siphon outlet if free flowing) in the field.
   d. The flow rate is taken from 4" siphon flow rate tables.
   e. The average flow rate represents the average flow rate for the Δt. (490 + 560) ÷ 2 = 525, etc.
   f. Volume for Δt. See footnote 2/ on data sheet.
      Volume (ac. in.) = .00003683 x Δt x flow (gpm)
      = .00003683 x 9 x 525 = .1740 ac. in. etc.
   g. The cumulative volume is found by adding each volume (ac. in.) .1740 + .2302 + etc. The total volume is the total onflow (ac. in.) onto the field for the evaluation.
   h. The average flow rate is computed by multiplying the total volume (ac. in.) x 60.5 and dividing by total onflow time (elapsed time between turn on and turn off).
   i. The unit flow rate is found by dividing the average flow rate by the border strip spacing: $\frac{1.4 \text{ cfs}}{30 \text{ ft.}} = 0.047$ cfs/ft.



SURFACE SYSTEM EVALUATION WORKSHEET B

GRADED BORDERS
INFLOW/OUTFLOW DATA

Landuser *Joe Example* Date ________ Field Office ________________

DATA: Inflow *X* Outflow ____

Type of Measuring device *5 - 4" x 10' siphon tubes*

Clock 1/ Time	Elapsed Time (min)	T (min)	Gage H (*ft*)	Flow Rate (*gpm*)	Average Flow Rate (*gpm*)	2/ Volume (ac-in)	Cum. Volume (ac-in)
Turn on (*1051*)		//////	.25		//////	//////	//////
1100			.33				
1110			.50				
1120			.41				
1135			.42				
1150			.43				
1228			.43				
Turn off (*1228*)							

Total Volume (ac-in) ________

Average flow rate =

$$\frac{\text{Total irrigation volume (ac-in)} \times 60.5}{\text{Inflow time (min)}} = \underline{\hspace{3cm}} = \underline{\hspace{2cm}} \text{ cfs}$$

Unit flow:

$$qu = \frac{\text{Average flow rate (cfs)}}{\text{Border strip spacing (ft)}} = \underline{\hspace{4cm}} = \underline{\hspace{2cm}} \text{ cfs/ft}$$

1/ Use a 24-hour clock reading; i.e., 1:30 p.m. should be recorded as 1330
2/ Flow rate to volume factors:

To find volume using cfs:
volume (ac-in) = .01653 x time (min) x flow (cfs)

To find volume using gpm:
volume (ac-in) = .00003683 x time (min) x flow (gpm)

SURFACE SYSTEM EVALUATION WORKSHEET B

GRADED BORDERS
INFLOW/OUTFLOW DATA

Landuser *Joe Example* Date ______ Field Office __________

DATA: Inflow *X* Outflow _____

Type of Measuring device *5 - 4"x 10' siphon tubes*

Clock Time 1/	Elapsed Time (min)	ΔT (min)	Gage H (*ft*)	Flow Rate (*gpm*)	Average Flow Rate (*gpm*)	2/ Volume (ac-in)	Cum. Volume (ac-in)
Turn on		//////			//////////	//////////	//////////
(*1051*)	*0*		*.25*	*490*			
		9			*525*	*.1740*	*.1740*
1100	*9*		*.33*	*560*			
		10			*625*	*.2302*	*.4042*
1110	*19*		*.50*	*690*			
		10			*657*	*.2420*	*.6462*
1120	*29*		*.41*	*625*			
		15			*627*	*.3464*	*.9926*
1135	*44*		*.42*	*630*			
		15			*632*	*.3491*	*1.3417*
1150	*59*		*.43*	*635*			
		38			*635*	*.8887*	*2.2304*
1228	*97*		*.43*	*635*			
Turn off							
(*1228*)							

Total Volume (ac-in) *2.23*

Average flow rate =

$$\frac{\text{Total irrigation volume (ac-in)} \times 60.5}{\text{Inflow time (min)}} = \frac{2.23\ (60.5)}{97} = 1.4 \text{ cfs}$$

Unit flow:

$$qu = \frac{\text{Average flow rate (cfs)}}{\text{Border strip spacing (ft)}} = \frac{1.4}{30} = 0.047 \text{ cfs/ft}$$

1/ Use a 24-hour clock reading; i.e., 1:30 p.m. should be recorded as 1330

2/ Flow rate to volume factors:

To find volume using cfs:
volume (ac-in) = .01653 x time (min) x flow (cfs)

To find volume using gpm:
volume (ac-in) = .00003683 x time (min) x flow (gpm)

Evaluation Computations - Surface System Evaluation Worksheet C - Advance and Recession (page 43)

1. Using data recorded on the Surface System Evaluation Worksheet C determine Δ T's, elapsed times, and opportunity times.
   a. ΔT's: " Δ " signifies a "change in" and in this case, signifies the amount of time for the water to travel between each station - or recede after the water is turned off.
      (1) In our example, the water is turned on at 10:51 (station 0+100). It reaches station 1+00 at 11:01. Δ T = 11.01 - 10:51 = 10 minutes. Enter "10" under Δ T for "Advance Time". Continue the same way for all stations.
      (2) For "Lag" under "Recession Time", Δ T is the difference between the time the water was turned off and the time the water receded or disappeared from station 0+00. In our example, the water receded from station 0+00 13 minutes after being turned off (12:41 - 12:28). Enter this under "Lag" for 0+00 (in the parenthesis). The next Δ T would be 13:16 - 12:41 = 35 minutes.
   b. Elapsed Time: This is the accumulated time since the water was turned on at station 0+00.
      (1) In our example, the first elapsed time under "Advance Time" would be calculated by adding the time for water to reach 0+00 (0 minutes) plus the time to reach 1+00 (10 minutes). This is 10 minutes. Next, add the time to reach 1+00 (10 minutes) to the Δ T between sta. 1+00 and 2+00 (14 minutes). This is 24 minutes. Continue this process for all stations.
      (2) Elapsed time under "Recession Time" is the difference between the time water is turned on at station 0+00 and the time it recedes from a station. The elapse time for Station 0+00 is 12:41 - 10:51, or 110 min. The other stations can be computed in similar manner, or you can calculate the elapsed time at station 1+00 by adding Δ T between 0+00 and 1+00 (35 minutes) to elapse time at Station 0+00 (110 min). The elapsed time at station 1+00 would then be 145 minutes. Complete this column using the same procedures.
   c. Opportunity Time: This is the total time at each station that the water actually stood over the surface - the difference in time between when water reached the station and when it left the station.
      (1) Inflow Time (inside the parenthesis under the Opportunity time) column is calculated by subtracting the time the water was turned on (10:51) from the time is was turned off (12:28). Inflow T is equal to 97 minutes.
      (2) Opportunity Time at each station is calculated by subtracting the elapsed time under "Advance Time" from the elapsed time under "Recession time". For station 0+00, it is 110 minutes - 0 min = 110 min. For station 1+00, it is 145 min - 10 min = 135 min. Complete the Opportunity Time column using this procedure.

SURFACE SYSTEM EVALUATION WORKSHEET C

GRADED BORDERS
ADVANCE AND RECESSION DATA

Landuser ____________________ Date __________ Field Office ____________________

Station (ft)	Advance Time			Recession Time			
	Clock* Time	ΔT (min)	Elapsed Time 1/ (min)	Clock* Time (min)	ΔT (min)	Elapsed Time 1/ (min)	Opportunity Time (To)
0+00	////////	///////	/////////	Turn off (1228)	////// lag	//////////	inflow T 2/ ( )
0+00	Turn on (1051)	///////	0	1241	( )		
1+00	1101			1316			
2+00	1115			1332			
3+00	1127			1348			
4+00	1141			1356			
5+00	1156			1401			
6+00	1215			1404			
7+00	1241			1407			
		////////			//////		

* Use a 24-hour clock reading: i.e., 1:30 p.m. should be recorded as 1330

1/ Time since water was turned on.
2/ Inflow time = Turn off time − Turn on time

SURFACE SYSTEM EVALUATION WORKSHEET C

GRADED BORDERS
ADVANCE AND RECESSION DATA

Landuser *Joe Example* Date ________ Field Office ________________

Station (ft)	Advance Time: Clock* Time	Advance Time: ΔT (min)	Advance Time: Elapsed Time 1/ (min)	Recession Time: Clock* Time (min)	Recession Time: ΔT (min)	Recession Time: Elapsed Time 1/ (min)	Opportunity Time (To)
		///////		Turn off	//////		inflow T 2/
0+00	////////		/////////	(1228)	lag	//////////	(97)
	Turn on	///////			(13)		
0+00	(1051)		0	1241		110	110
		10			35		
1+00	1101		10	1316		145	135
		14			16		
2+00	1115		24	1332		161	137
		12			16		
3+00	1127		36	1348		177	141
		14			8		
4+00	1141		50	1356		185	135
		15			5		
5+00	1156		65	1401		190	125
		19			3		
6+00	1215		84	1404		193	109
		26			3		
7+00	1241		110	1407		196	86
		////////			//////		

* Use a 24-hour clock reading: i.e., 1:30 p.m. should be recorded as 1330

1/ Time since water was turned on.
2/ Inflow time = Turn off time − Turn on time

Evaluation Computations - Advance and Recession Curves (page 47)

1. Using data taken from Surface System Evaluation Worksheet C - station numbers vs. elapsed time, plot the Advance and Recession Curves.

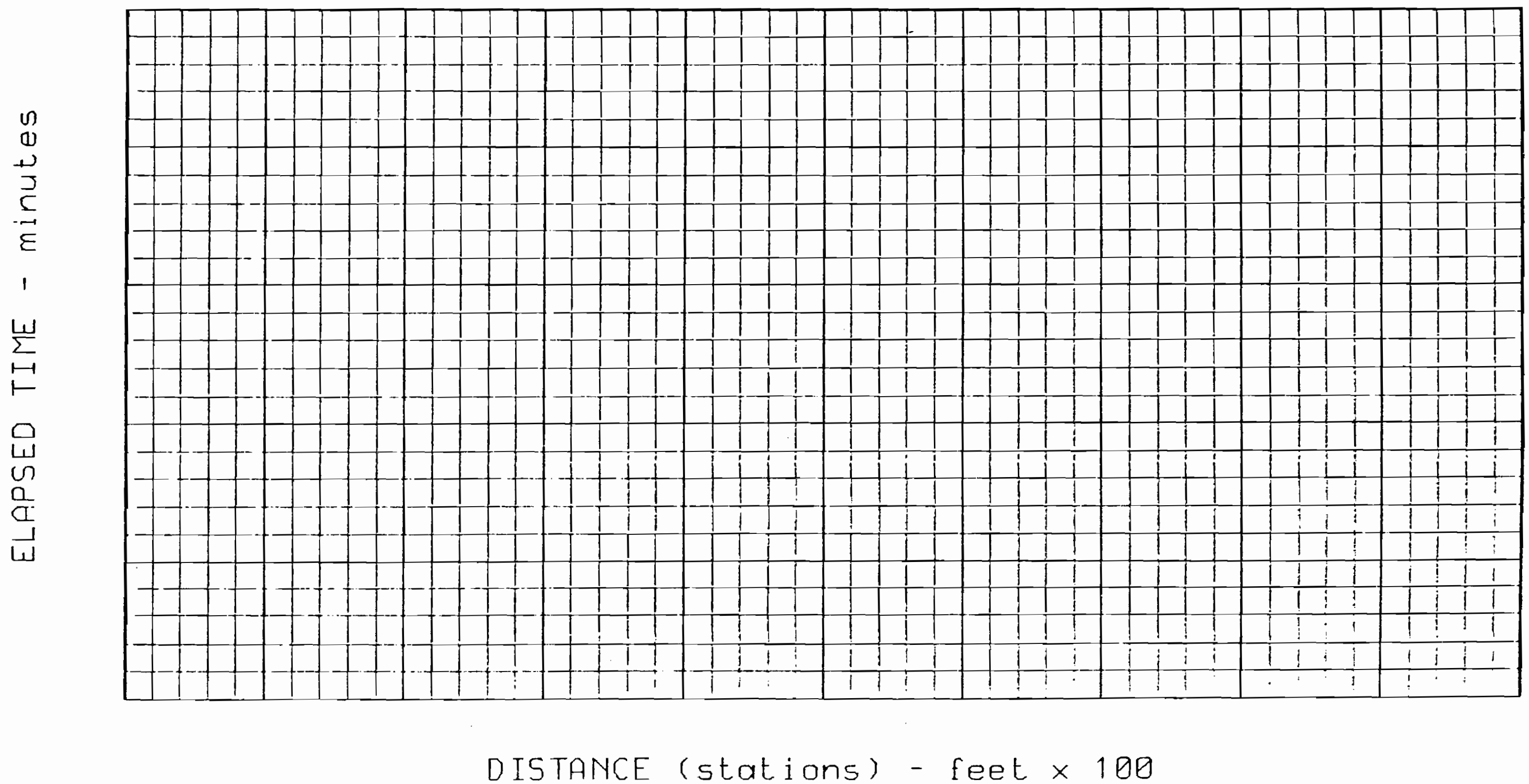
   The difference between the two curves is the opportunity time for the water to infiltrate into the soil. If the runoff was not measured, extend the advance and recession curves until they meet. The area between the curves and beyond the end station represents an estimate of the runoff. (In this example, this will be at about Station 9+00 at 200 minutes)

ADVANCE AND RECESSION CURVES

LANDUSER ______________________

DATE ______________________

FIELD OFFICE ______________________

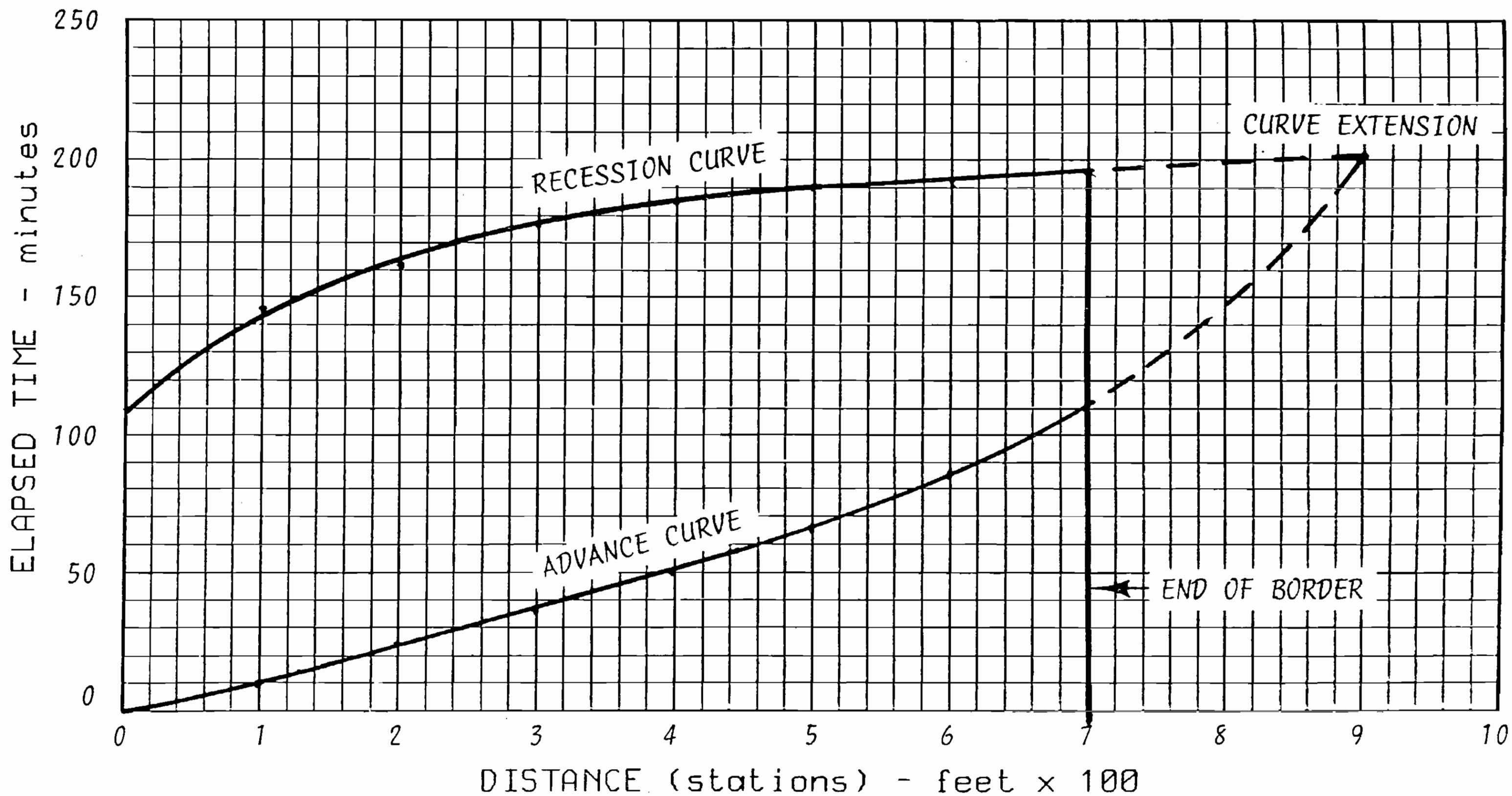


ADVANCE AND RECESSION CURVES

LANDUSER Joe Example

DATE

FIELD OFFICE



Evaluation Computations - Surface System Evaluation Worksheet D, Depth Infiltrated (page 51)

1. Complete Surface System Evaluation Worksheet D, Depth Infiltrated as follows:
   a. Using Surface System Evaluation Worksheet C or the Advance and Recession Curves record the Opportunity time for each station.
      Opportunity at station 0+00 = 110 min. etc.
   b. Using the average accumulated intake curve from the cylinder infiltrometer data plotted on the Cylinder Infiltrometer Curve worksheet, page 53, read the accumulated intake opposite the opportunity time. 110 minutes = 3.6 inches, etc. The opportunity time for the extended (runoff) area is read off the Advance and Recession Curves. It is vertical difference between the advance and recession curves for the station in question.
   c. The average depth infiltrated between each station is computed by averaging the depth infiltrated of each station.
      (3.6 + 4.1)/2 = 3.9, etc.
   d. Total the Average depth infiltrated column (Average Intake Curve), and record opposite "Sum of depths".
   e. Find the average depth infiltrated by dividing the "sum of depths" by the length in hundreds of feet, including extended length.
   f. Compute the area of the border strip (acres) including the extended area, (extended wetted length x width)/43,560.
   g. Using the average inflow rate computed on the inflow-outflow worksheet, multiply this value (1.4 cfs.) by the inflow time from Worksheet C (97 min./60 min. per hr.) and divide by border area (0.6 acres). This gives the actual depth applied. If the inches applied is different than the inches applied computed by using the average intake curve, an adjusted intake curve is needed.
   h. Using the average intake curve and the average depth infiltrated (3.48 inches), find the corresponding average opportunity time (100 minutes). Then plot a point on 100 minutes and the actual depth applied (3.8 inches). Now draw a line parallel to the average intake curve and through the point at 100 min and 3.8 inches. This is the adjusted intake curve. (the adjusted curve can be plotted on the same worksheet as the field curves (page 37) or you may want to replot the average accumulated intake on a separate worksheet).
   i. Now recompute on the depth infiltrated worksheet the average depth infiltrated using the adjusted curve in the same manner as for the average curve. This adjusted average depth infiltrated should be close to the actual depth applied.

SURFACE SYSTEM EVALUATION WORKSHEET D

GRADED BORDERS
DEPTH INFILTRATED DATA

Landuser ____________________ Date __________ Field Office __________

Station	Opportunity Time 1/ To (min)	Average Intake Curve: Depth 2/ Infil. (in)	Average Intake Curve: Av Depth Infil. (in)	Adjusted Intake Curve: Depth 3/ Infil. (in)	Adjusted Intake Curve: Av Depth Infil. (in)
0 + 00					
Sum of depths					

1/ Difference in time between advance and recession curve.
2/ From "average" cumulative intake curve.
3/ From "adjusted" cumulative intake curve.

Average depth infiltrated

$$= \frac{\text{Sum of depths (average)}}{\text{Length (hundreds of feet- extended)}} = \underline{\hspace{3cm}} = \underline{\hspace{2cm}} \text{ in}$$

Extended border area (acres)

$$= \frac{\text{Extended border length x wetted width}}{43,650} = \frac{\underline{\hspace{3cm}}}{43,560} = \underline{\hspace{2cm}} \text{ acres}$$

Actual average depth applied to extended border length

$$= \frac{\text{Av inflow (cfs) x duration (hr)}}{\text{Extended border area (acres)}} = \underline{\hspace{3cm}} = \underline{\hspace{2cm}} \text{ in}$$

Average depth infiltrated (adjusted)

$$= \frac{\text{Sum of depths (adjusted)}}{\text{Length (hundreds of feet- extended)}} = \underline{\hspace{3cm}} = \underline{\hspace{2cm}} \text{ in}$$

(Should be close to actual depth applied)

SURFACE SYSTEM EVALUATION WORKSHEET D

GRADED BORDERS
DEPTH INFILTRATED DATA

Landuser *Joe Example* Date ________ Field Office ________

Station	Opportunity Time 1/ To (min)	Average Intake Curve: Depth 2/ Infil. (in)	Average Intake Curve: Av Depth Infil. (in)	Adjusted Intake Curve: Depth 3/ Infil. (in)	Adjusted Intake Curve: Av Depth Infil. (in)
0 + 00	110	3.6		4.0	
1+00	135	4.1	3.9	4.5	4.3
2+00	137	4.1	4.1	4.5	4.5
3+00	141	4.2	4.2	4.7	4.6
4+00	135	4.1	4.1	4.5	4.6
5+00	125	3.9	4.0	4.3	4.4
6+00	109	3.6	3.8	4.0	4.1
7+00	86	3.1	3.3	3.4	3.7
Border Extension					
8+00	51	2.3	2.7	2.5	3.0
9+00	0	0	1.2	0	1.3
	Sum of depths		31.3		34.5

1/ Difference in time between advance and recession curve.
2/ From "average" cumulative intake curve.
3/ From "adjusted" cumulative intake curve.

Average depth infiltrated

$$= \frac{\text{Sum of depths (average)}}{\text{Length (hundreds of feet- extended)}} = \frac{31.3}{9} = 3.48 \text{ in}$$

Extended border area (acres)

$$= \frac{\text{Extended border length x wetted width}}{43{,}650} = \frac{900 \times 29}{43{,}560} = 0.60 \text{ acres}$$

Actual average depth applied to extended border length

$$= \frac{\text{Av inflow (cfs) x duration (hr)}}{\text{Extended border area (acres)}} = \frac{1.4\ (97/60)}{0.60} = 3.8 \text{ in}$$

Average depth infiltrated (adjusted)

$$= \frac{\text{Sum of depths (adjusted)}}{\text{Length (hundreds of feet- extended)}} = \frac{34.5}{9} = 3.8 \text{ in}$$

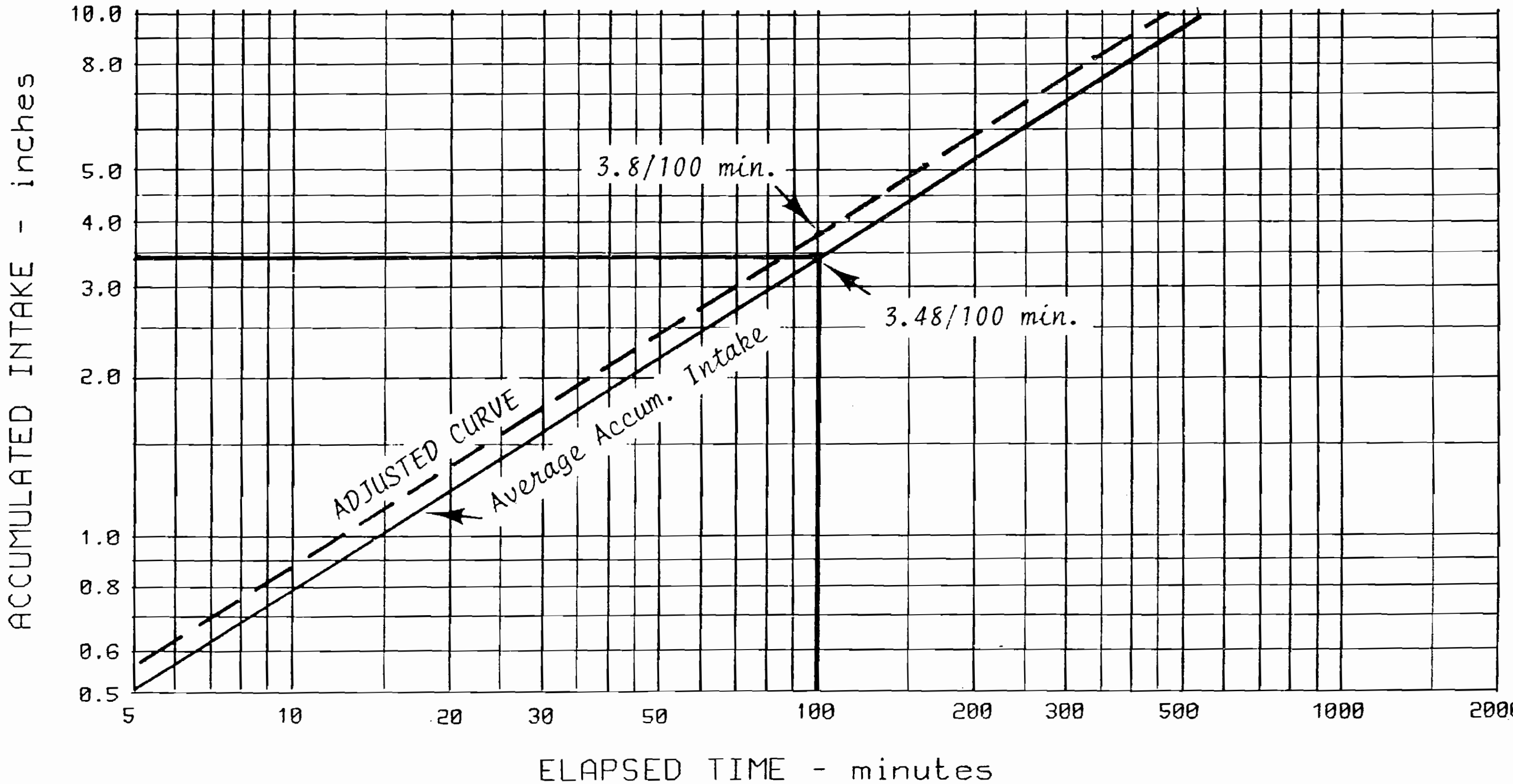
(Should be close to actual depth applied)

CYLINDER INFILTROMETER CURVES

LANDUSER *Joe Example*

DATE

FIELD OFFICE



Evaluation Computations - Depth Infiltrated Curve

1. Plot the Depth Infiltrated Curve on the Depth Infiltrated Curve Worksheet as follows:

> Plot a depth infiltrated curve on the Depth Infiltrated Curve Worksheet using adjusted depths recorded in the previous step.
>
> Draw a horizontal line at a depth equal to the SWD. (2.9 inches from page 23 or 25).
>
> Draw a vertical line at the end of the border. (7+00)

2. The depth infiltrated curve depicts the approximate depth infiltrated at any given point along the strip. Area under the curve represents the total application. Area beyond the end of the strip represents runoff volume. When depth stored in the root zone is plotted on the curve, the area below that point and within the strip is the volume of water stored in the root zone. This is equal to the soil water deficit when the entire root zone is filled to field capacity. Area above this point, within the strip, is equal to deep percolation.

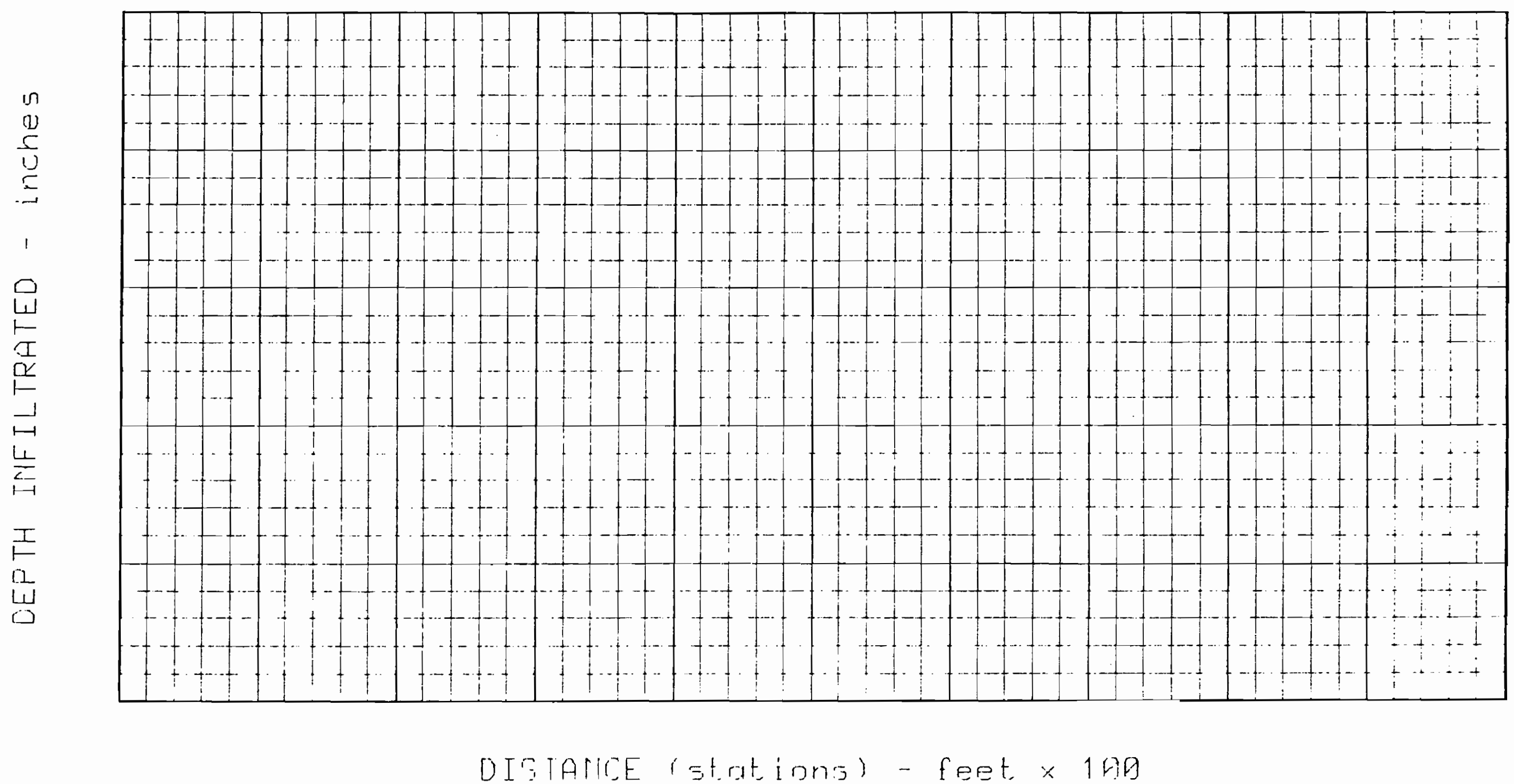
3. The depth infiltrated curve gives you a visual picture of where the water applied went and can be used to complete the computations.

DEPTH INFILTRATED CURVE

LANDUSER ____________

DATE ____________

FIELD OFFICE ____________

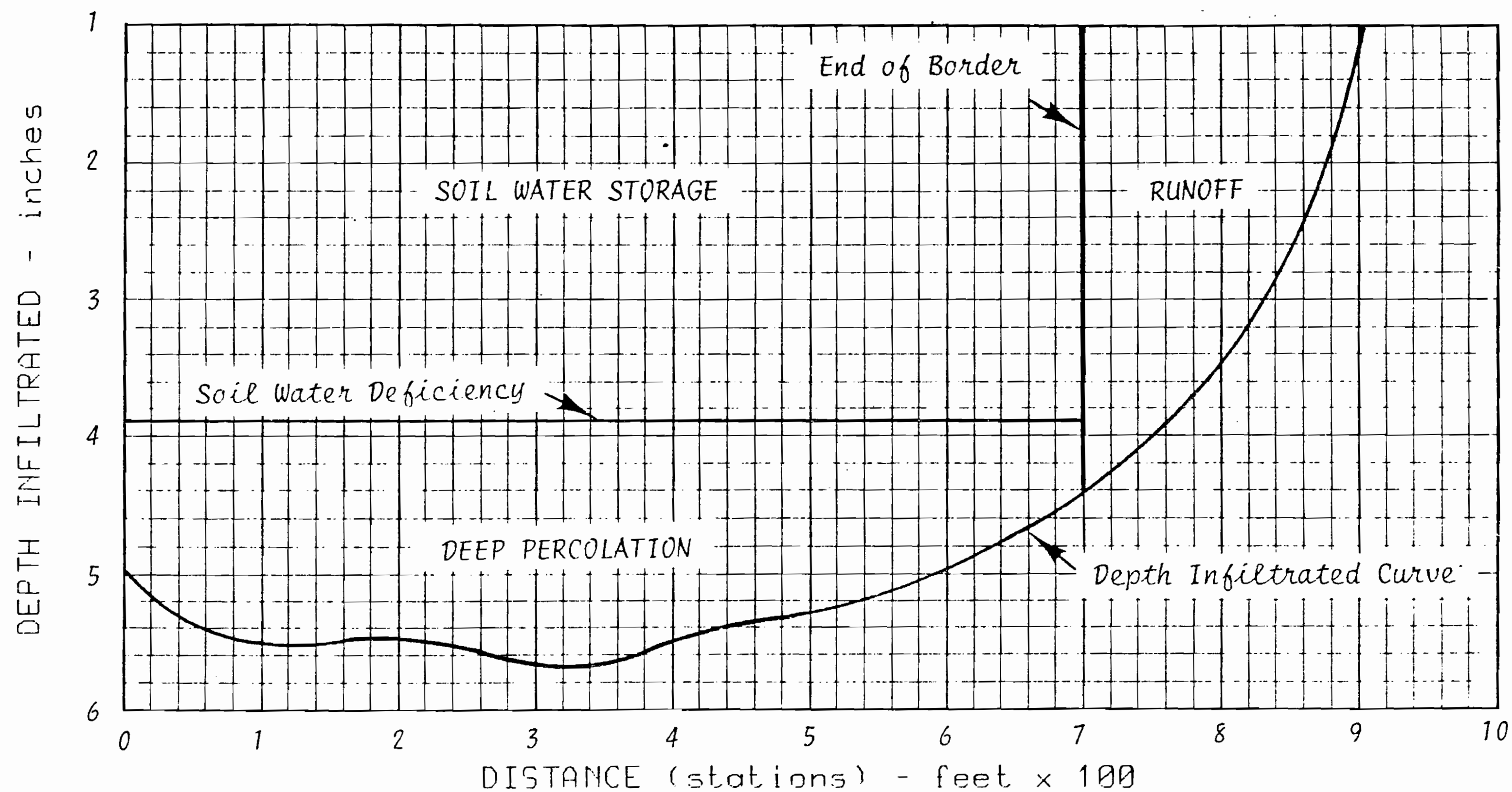


DEPTH INFILTRATED CURVE

LANDUSER Joe Example

DATE ____________

FIELD OFFICE ____________



Evaluation Computations - Surface System Evaluation Worksheet E

1. Average Depth Infiltrated Low ¼ (LQ)

Determine location and length of low quarter segment of actual border length. This is usually located at the lower end of the border.

Length of L¼ is: $\frac{\text{Actual border length}}{4}$ ($\frac{700}{4}$ = 175 ft. or from Sta 5 + 25 to 7+00)
Compute average depth infiltrated for low ¼ (use Depth Infiltrated Curve)

$$LQ = \frac{\text{Depth inf. begin of L¼ (Sta 5+25) + depth inf. end of L¼ (Sta 7+00)}}{2}$$

$$LQ = \frac{4.1 + 3.4}{2} = \underline{3.75} \text{ in.}$$

2. Areas under depth curve

You can determine the areas under the curve by measuring, using a planimeter or counting squares. Measure the area under the entire curve and record on worksheet C.

a. Plot the LQ (low quarter) point on the infiltration curve. Measure the area below the point and to the left of the down stream end of the border. This is the low quarter infiltration. Example area = 3.8 x 7 = 26.6
b. Measure runoff, which is the area to the right of the end of the strip. (If runoff was measured this can be checked by computing total actual runoff volume.) Example runoff volume = 4.4 square units.
c. Measure deep percolation, which is the area to the left of the end of border and above SWD. Example deep percolation = 9.2 square units.

3. Actual border strip area (acres):

$$\frac{\text{actual border length x wetted width}}{43560} = \_\_\_\_ \text{(acres)} \qquad \frac{700 \times 29}{43560} = .47 \text{ ac.}$$

4. Distribution uniformity low ¼ (DU):

$$\frac{\text{low quarter infiltration area x 100}}{\text{(whole curve area - runoff area)}} = \text{DU (\%)}$$

$$\text{DU(example)} = \frac{26.6 \times 100}{33.9 - 4.4} = 90\%$$

5. Runoff (RO)

$$\text{RO(\%)} = \frac{\text{Runoff area x 100}}{\text{whole curve area}} = \_\_\_\_\% \qquad \text{RO(example)} = \frac{4.4 \times 100}{33.9} = 13\%$$

$$\text{RO(in)} = \frac{\text{Total irrigated volume (ac. in.) x RO(\%)}}{\text{Act. Strip Area (ac.) x 100}} = \_\_\_\_ \text{ in.}$$

$$\text{RO(example)} = \frac{2.26 \times 13}{.47 \times 100} = 0.63 \text{ in.}$$

SURFACE SYSTEM EVALUATION WORKSHEET E

GRADED BORDERS
EVALUATION COMPUTATIONS

Landuser ______________ Date ________ Field Office ________

1. Average depth infiltrated low 1/4 (LQ):

$$\text{Low 1/4 strip length} = \frac{\text{Actual strip length}}{4} = \frac{\_\_\_\_}{4} = \_\_\_\_\_\_ \text{ ft.}$$

$$LQ = \frac{\text{Depth inf. at begin of L1/4 strip + Depth inf. at end of L1/4 strip}}{2}$$

$$= \frac{\_\_\_\_\_\_}{2} = \_\_\_\_ \text{ in.}$$

2. Areas under depth curve:

1.	Whole curve	________	sq. units
2.	Runoff	________	sq. units
3.	Deep percolation	________	sq. units
4.	Low quarter infiltration	________	sq. units

3. Actual border strip area:

$$= \frac{\text{Actual border length x Wetted width}}{43{,}560} = \frac{\_\_\_\_\_\_}{43{,}560} = \_\_\_\_\_\_ \text{ acres}$$

4. Distribution Uniformity low 1/4 (DU):

$$DU\% = \frac{\text{Low quarter infiltration area x 100}}{\text{(Whole curve area - Runoff area)}} = \_\_\_\_\_\_ = \_\_\_\_\_\_ \%$$

5. Runoff (RO):

$$RO\% = \frac{\text{Runoff area x 100}}{\text{Whole curve area}} = \_\_\_\_\_\_ = \_\_\_\_\_\_ \%$$

$$RO \text{ (in.)} = \frac{\text{Total irrigation volume (ac-in) x RO\%}}{\text{Act. strip area (ac) x 100}} = \_\_\_\_\_\_ = \_\_\_\_\_\_ \text{ in.}$$

6. Deep percolation (DP) percent:

$$DP\ (\%) = \frac{\text{Deep percolation area}}{\text{whole curve area}} \times 100 = \_\_\_\_\_\_\_ = \_\_\_\_\_\_\_\ \%$$

$$DP(\text{example}) = \frac{9.2}{33.9} \times 100 = 27\%$$

$$DP(\text{in}) = \frac{\text{Total irrigation volume (ac-in)} \times DP\%}{\text{Actual strip area (ac)} \times 100} = \_\_\_\_\_\_\_ = \_\_\_\_\_\_\_\ \text{in.}$$

$$DP(\text{example}) = \frac{2.26 \times 27}{.47 \times 100} = 1.3\ \text{in.}$$

7. Gross application (Fg):

$$Fg(\text{in}) = \frac{\text{Total irrigation volume (ac-in)}}{\text{Actual border strip area (acres)}} = \_\_\_\_\_\_\_ = \_\_\_\_\_\_\_\ \text{in.}$$

$$Fg(\text{example}) = \frac{2.29\ \text{ac-in}}{.47\ \text{acres}} = \underline{4.8}\ \text{in.}$$

8. Application efficiency (Ea):

Average depth stored in root zone = soil water deficit (SWD) if entire root zone depth will be filled to field capacity by this irrigation. Otherwise, use Fg (in.) - Ro (in.)

$$Ea(\%) = \frac{\text{Av. depth stored in root zone} \times 100}{\text{Gross application (in.)}} = \_\_\_\_\_\_\_ = \_\_\_\_\_\_\_\ \%$$

9. Application efficiency low ¼ (Eq) (%)

$$Eq(\%) = \frac{DU(\%) \times Ea(\%)}{100} = \_\_\_\_\_\_\_ = \_\_\_\_\_\_\_\ \%$$

$$Eq(\text{example}) = \frac{90 \times 60}{100} = 54\%$$

10. Average Net Application

$$\text{Avg. Net Application} = \frac{\text{Total irrigated volume (ac. in.)} \times EA(\%)}{\text{Act. strip area (ac.)} \times 100} = \_\_\_\_\_\_\_\ \text{in.}$$

$$(\text{example}) = \frac{2.26 \times 60}{.47 \times 100} = \underline{2.9}\ \text{in.}$$

THIS COMPLETES THE COMPUTATIONS OF THE EVALUATIONS. IT IS NOW TIME TO ANALYZE THE DATA AND MAKE RECOMMENDATIONS. BEFORE WE COMPLETE THE WORKSHEETS AND MAKE RECOMMENDATIONS, LET'S DISCUSS HOW OUR FINDINGS, COMPUTATIONS, AND CURVES CAN BE USED TO HELP MAKE RECOMMENDATIONS.

SURFACE SYSTEM EVALUATION WORKSHEET E (continued)
GRADED BORDERS
EVALUATION COMPUTATIONS

Landuser ____________ Date ________ Field Office __________

6. Deep Percolation (DP):

$$DP\% = \frac{\text{Deep percolation area} \times 100}{\text{Whole curve area}} = \_\_\_\_\_\_ = \_\_\_\_\_\_ \%$$

$$DP(in) = \frac{\text{Total irrigation volume (ac-in)} \times DP\%}{\text{Act. strip area (ac)} \times 100} = \_\_\_\_\_\_ = \_\_\_\_\_\_ \text{ in.}$$

7. Gross application (Fg):

$$Fg = \frac{\text{Total irrigation volume (ac-in)}}{\text{Act. strip area (ac)}} = \_\_\_\_\_\_ = \_\_\_\_\_\_ \text{ in.}$$

8. Application efficiency (Ea):

Average depth stored in root zone = soil water deficit (SWD) if entire root zone depth will be filled to field capacity by this irrigation. Otherwise, use Fg (in.) - Ro (in.)

$$Ea(\%) = \frac{\text{Av. depth stored in root zone} \times 100}{\text{Gross application (in.)}} = \_\_\_\_\_\_ = \_\_\_\_\_\_ \%$$

9. Application efficiency low 1/4 (Eq)

$$Eq(\%) = \frac{DU(\%) \times Ea(\%)}{100} = \frac{\_\_\_\_\_\_}{100} = \_\_\_\_\_\_ \%$$

10. Average Net Application

$$= \frac{\text{Total irrigated volume (ac. in)} \times Ea(\%)}{\text{Act. strip area (ac)} \times 100} = \_\_\_\_\_\_ = \_\_\_\_\_\_ \text{ in.}$$

SURFACE SYSTEM EVALUATION WORKSHEET E

GRADED BORDERS
EVALUATION COMPUTATIONS

Landuser *Joe Example* Date ________ Field Office ________

1. Average depth infiltrated low 1/4 (LQ):

$$\text{Low 1/4 strip length} = \frac{\text{Actual strip length}}{4} = \frac{700}{4} = 175 \text{ ft.}$$

$$LQ = \frac{\text{Depth inf. at begin of L1/4 strip} + \text{Depth inf. at end of L1/4 strip}}{2}$$

$$= \frac{4.2 + 3.4}{2} = 3.8 \text{ in.}$$

2. Areas under depth curve:

1.	Whole curve	33.9	sq. units
2.	Runoff	4.4	sq. units
3.	Deep percolation	9.2	sq. units
4.	Low quarter infiltration	26.6	sq. units

3. Actual border strip area:

$$= \frac{\text{Actual border length x Wetted width}}{43{,}560} = \frac{700 \text{ x } 29}{43{,}560} = .47 \text{ acres}$$

4. Distribution Uniformity low 1/4 (DU):

$$DU\% = \frac{\text{Low quarter infiltration area x 100}}{(\text{Whole curve area} - \text{Runoff area})} = \frac{26.6 \text{ x } 100}{33.4 - 4.4} = 92 \%$$

5. Runoff (RO):

$$RO\% = \frac{\text{Runoff area x 100}}{\text{Whole curve area}} = \frac{4.4 \text{ x } 100}{33.9} = 13 \%$$

$$RO \text{ (in.)} = \frac{\text{Total irrigation volume (ac-in) x RO\%}}{\text{Act. strip area (ac) x 100}} = \frac{2.26 \text{ x } 13}{.47 \text{ x } 100} = 0.6 \text{ in.}$$

SURFACE SYSTEM EVALUATION WORKSHEET E (continued)
GRADED BORDERS
EVALUATION COMPUTATIONS

Landuser *Joe Example* Date ________ Field Office ____________

6. Deep Percolation (DP):

$$DP\% = \frac{\text{Deep percolation area} \times 100}{\text{Whole curve area}} = \frac{9.2 \times 100}{33.4} = \underline{\ 28\ }\ \%$$

$$DP(in) = \frac{\text{Total irrigation volume (ac-in)} \times DP\%}{\text{Act. strip area (ac)} \times 100} = \frac{2.26 \times 28}{.47 \times 100} = \underline{\ 1.3\ }\ \text{in.}$$

7. Gross application (Fg):

$$Fg = \frac{\text{Total irrigation volume (ac-in)}}{\text{Act. strip area (ac)}} = \frac{2.26}{.47} = \underline{\ 4.8\ }\ \text{in.}$$

8. Application efficiency (Ea):

Average depth stored in root zone = soil water deficit (SWD) if entire root zone depth will be filled to field capacity by this irrigation. Otherwise, use Fg (in.) - Ro (in.)

$$Ea(\%) = \frac{\text{Av. depth stored in root zone} \times 100}{\text{Gross application (in.)}} = \frac{2.9 \times 100}{4.8} = \underline{\ 60.4\ }\ \%$$

9. Application efficiency low 1/4 (Eq)

$$Eq(\%) = \frac{DU(\%) \times Ea(\%)}{100} = \frac{92 \times 60.4}{100} = \underline{\ 56\ }\ \%$$

10. Average Net Application

$$= \frac{\text{Total irrigated volume (ac. in)} \times Ea(\%)}{\text{Act. strip area (ac)} \times 100} = \frac{2.26 \times 60.4}{.47 \times 100} = \underline{\ 2.9\ }\ \text{in.}$$

Analysis of Data

The purpose of an irrigation evaluation is to help make recommendations to improve the irrigation system and it's management. Analysis of the data obtained, the computations, the advance, recession, and depth infiltrated curves, field observations and discussions with the farmer are needed to make practical recommendations.

Using the depth infiltrated curves, compare the soil water deficit (SWD) with the management allowed deficit (MAD) recorded on worksheet A. This will indicate whether the irrigation was correctly timed, too early, or too late. In this example, the deficit was only 2.9" compared to the MAD of 3.6". The irrigation was too early. If the irrigation had been delayed until the SWD was equal to the MAD at 3.6", nearly ½ of the 1.3 inches of deep percolation would have been stored in the root zone. We can estimate the effect by using the curves we have developed. Using the adjusted intake curve, we find that a 95 minute opportunity time is necessary for a 3.6" inch depth infiltration. If we draw in an irrigation curve using an opportunity time (To) of 95 minutes (See figure 8), you can see that nearly the entire border had the needed opportunity time of 95 minutes necessary for a 3.6" irrigation. This indicates that if the irrigation would have been properly timed, the application efficiency would have been much higher.

We can estimate the amount of improvement by changing SWD from 2.9 inches to 3.6 inches. The resulting computations are listed below:

Change SWD to 3.6"

(from Depth Infiltrated Curve - figure 9)

Total area under curve = 34.4 sq. units (Change from original 33.9 due to measurement error. This is satisfactory)

Deep percolation area = 5.1 sq. units

Runoff area = 4.2 sq. units

Soil water storage - 25.1 sq. units

Low quarter area = 26.5 sq. units

Inflow time - 97 min. (Worksheet B)

$$\text{Total inflow} = 1.4 \text{ cfs} \times \frac{97}{60} = 2.26 \text{ ac. in.}$$

$$\text{Gross Application} = \frac{2.26 \text{ ac. in}}{.47 \text{ ac.}} = 4.8 \text{ in.}$$

$$\text{Application Efficiency} = \frac{25.1 \text{ sq. units} \times 100}{34.4 \text{ sq. units}} = 73.0\%$$

$$\frac{73.0\%}{100} \times 4.8 \text{ in} = 3.5 \text{ in.}$$

$$\%\ \text{Deep Percolation} = \frac{5.1 \text{ sq. units} \times 100}{34.4 \text{ sq. units}} = 14.8\%$$

$$\frac{14.8\% \times 4.8 \text{ in.}}{100} = 0.7 \text{ in.}$$

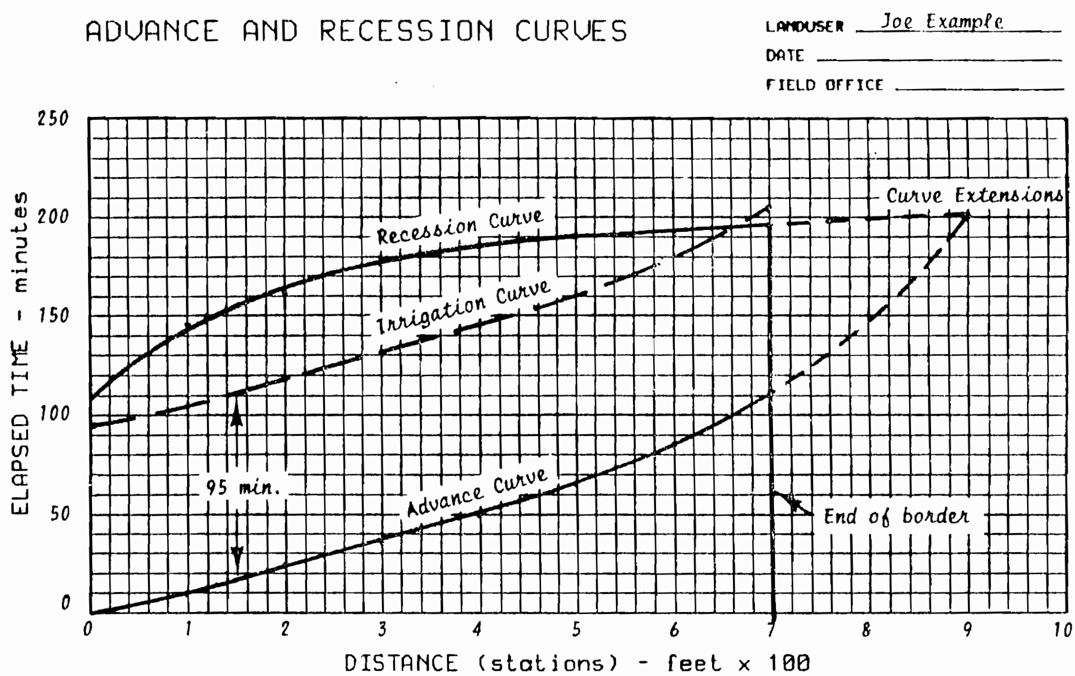


Figure 8.--Advance and recession curves.

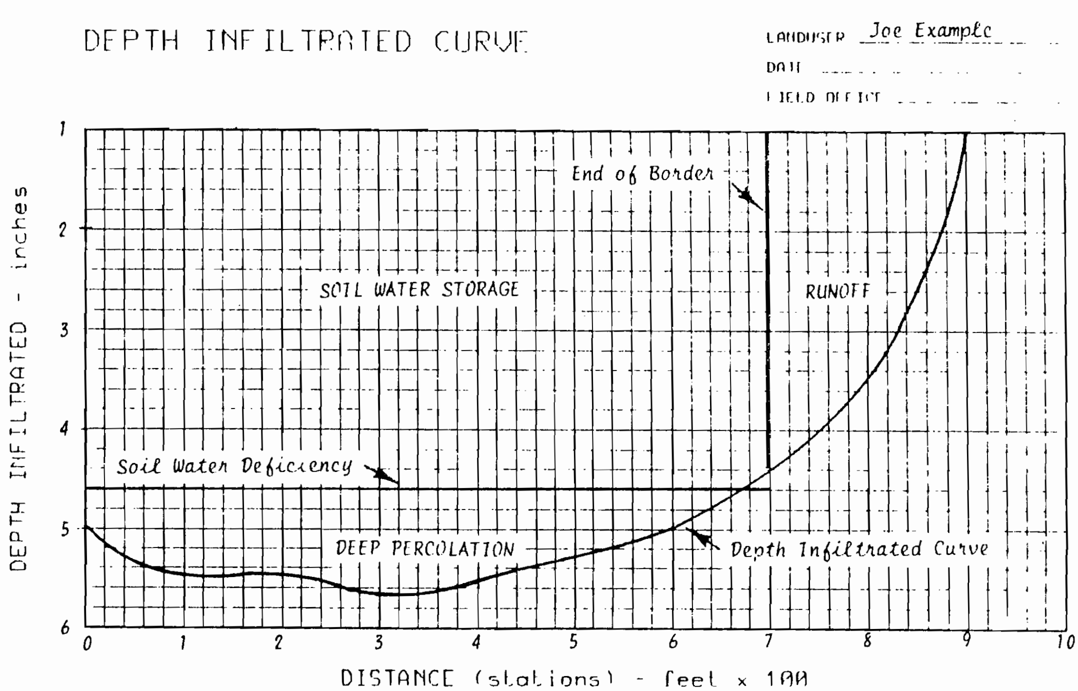


Figure 9.--Depth infiltrated curve.

$$\% \text{ Runoff} = \frac{4.2 \text{ sq. units} \times 100}{34.4 \text{ sq. units}} = 12.2\%$$

$$\frac{12.2\% \times 4.8 \text{ in.}}{100} = 0.6 \text{ in.}$$

$$\% \text{ Distribution Uniformity, (DU)} = \frac{26.5 \text{ sq. units} \times 100}{34.4 \text{ sq. units} - 4.2 \text{ sq. units}} = 87.7\%$$

$$\text{Application efficiency, low } \tfrac{1}{4} \text{ (Eq)} = \frac{87.7\% \times 73.0\%}{100} = 64.0\%$$

Proper scheduling alone would increase the application efficiency from 61% to 73% and cut the deep percolation losses from about 1.4 inches to 0.6 inches.

The closer the recession curve parallels the advance curve, the less the deep percolation will be (see figure 5). Examination of the example advance and recession curves shows that the advance curve is steeper than the recession curve. Also, note that the opportunity time at Sta 0+00 is 110 minutes and that only 95 minutes are needed to infiltrate 3.6 inches. The excess opportunity time is 15 min. If the speed of advance can be increased, the advance curve will be flatter and the irrigation turn-off time could be earlier reducing deep percolation at the upper end and still fully irrigating the bottom end. A larger unit stream size is usually needed to speed up advance. The required flow rate must be determined by trial and error in the field. Remember that the larger stream increases the amount of water applied per unit time. If the stream size is increased too much you will increase runoff at the expense of decreased deep percolation.

In figure 10 we have reduced the inflow time by 15 minutes (110-95) and have drawn a new recession curve parallel to our field curve giving us a recession time of 181 minutes at Sta 7+00. The shape and slope of the recession curve should not change significantly with minor changes of inflow or duration of flow, but the bottom end of the field will not be fully irrigated without changing the advance curve.

If we subtract our needed 95 minute opportunity time from 181 minute recession time, we want the water to reach the lower end within 86 minutes (181-95) after the water is turned on. This means we would have to speed up the advance by 24 minutes (110-86), about a 22% decrease. Changing the flow rate will change the slope of the advance curve. A larger stream will increase the rate of advance and flatten the advance curve. The estimated decrease in advance time will give some idea of the magnitude of the flow rate charge required. In this example we will use the 22% decrease in advance time and increase the stream size by 22%.

$$(1.4 \text{ cfs.} \times \frac{22}{100}) + 1.4 \text{ cfs} = 1.7 \text{ cfs.}$$

We can draw the new advance curve by using approximately the same shape as the field curve, but dropping the end of the curve down to 86 minutes at Sta. 7+00.

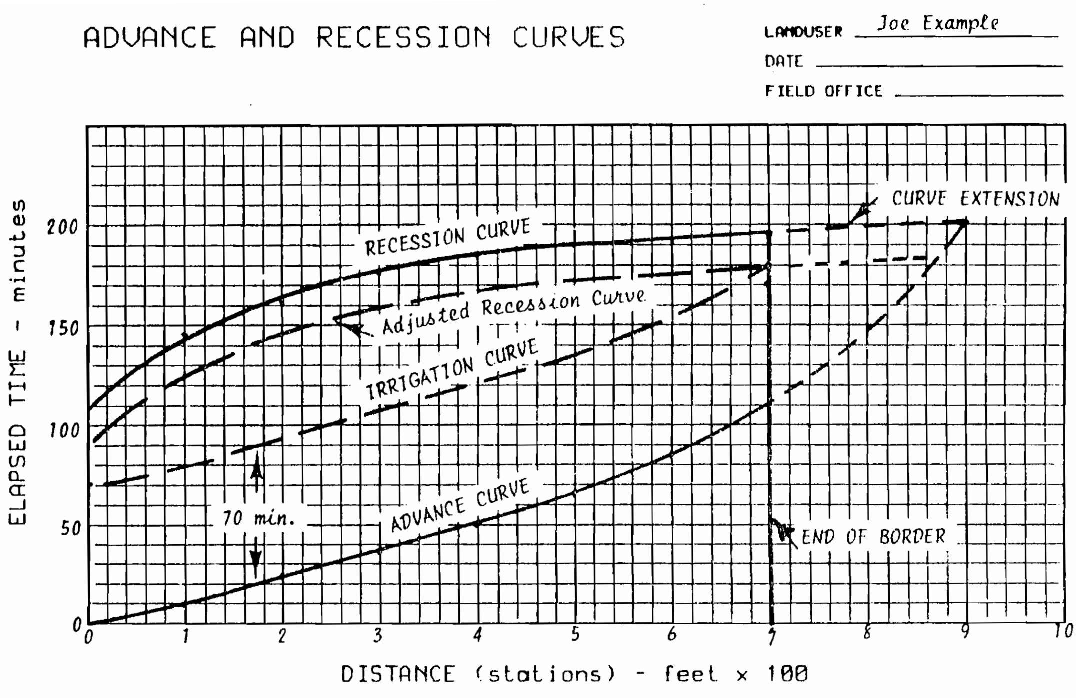


Figure 10.--Advance and recession curves.

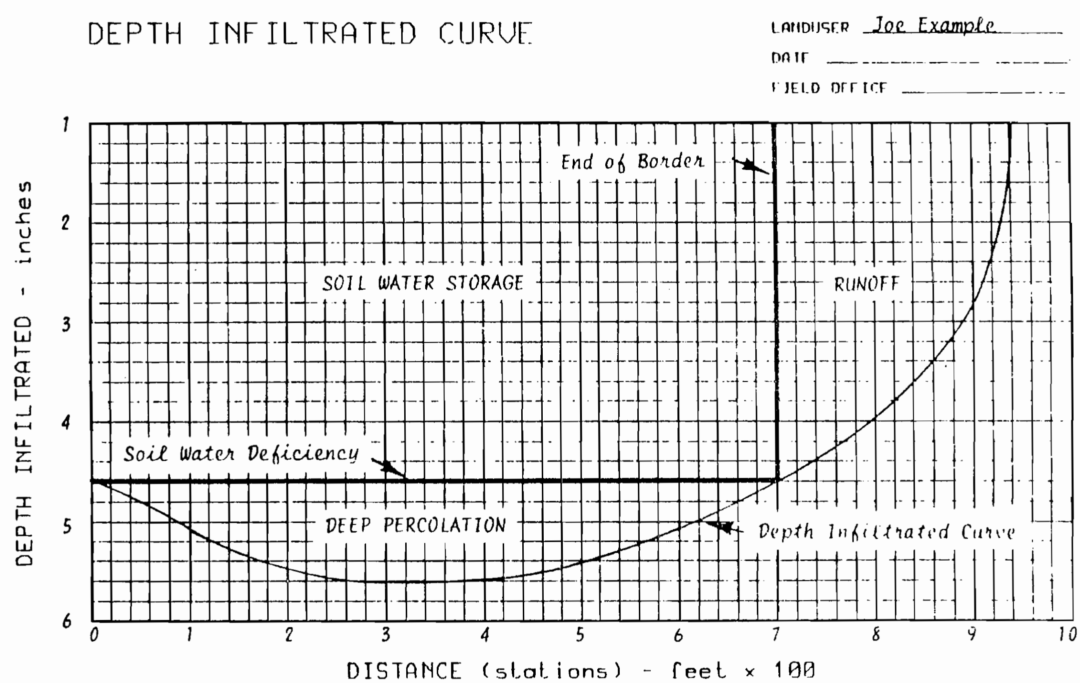


Figure 11.--Depth infiltrated curves.

Using the new advance and recession curve (to find opportunity time) and the adjusted intake curve we can develop a new Depth Infiltrated Curve. (See figure 11) The results of these changes are listed below.

Increased stream size - 1.7 cfs
(from Depth Infiltrated Curve)
Total area under curve - 35.9 sq. units
Deep percolation area = 4.5 sq. units
Runoff area = 6.2 sq. units
Soil water storage = 25.2 sq. units
Low quarter area - 27.5 sq. units

$$\text{Total Inflow} = \frac{1.7 \text{ cfs.} \times (95 - 13)}{60} = 2.32 \text{ ac. in.}$$

$$\text{Gross Application} = \frac{2.32 \text{ ac. in.}}{.47 \text{ ac.}} = 5.0 \text{ in.}$$

$$\text{Application Efficiency, Ea} = \frac{25.2 \text{ sq. units} \times 100}{35.9 \text{ sq. units}} = 70.2\%$$

$$= \frac{70.2\% \times 5.0 \text{ in.}}{100} = 3.5 \text{ in}$$

$$\text{Deep Percolation, DP}(\%) = \frac{4.5 \text{ sq. units} \times 100}{35.9 \text{ sq. units}} = 12.5\%$$

$$\frac{12.5\% \times 5.0\text{in.}}{100} = 0.6 \text{ in}$$

$$\text{Runoff, RO}(\%) = \frac{6.2 \text{ sq. units} \times 100}{35.9 \text{ sq. units}} = 17.3\%$$

$$\frac{17.3\% \times 5.0}{100} = 0.9 \text{ in.}$$

$$\text{Distribution Uniformity, DU}(\%) - \frac{27.5 \text{ sq, units} \times 100}{35.9 \text{ sq. units} - 6.2 \text{ sq. units}} = 92.6\%$$

$$\text{Application Efficiency, low } \tfrac{1}{4}\text{, Eq}(\%) = \frac{92.6\ \% \times 70.2\%}{100} = 65\%$$

Analysis of these revised curves indicate that we would reduce deep percolation by reducing inflow time. However, we increased runoff by using the larger stream size. These assumptions indicate that the changes would not improve our irrigation efficiency.

Unless the farmer was either concerned about deep percolation or was using a tail water recovery system, increasing stream size would not be a strong recommendation. Usually the overall irrigation stream is set, so the farmer would have to increase the unit stream size by decreasing border width.

There are cases where the farmer does not have complete control over when he can irrigate. An example is a "turn" system from an irrigation district. If he irrigates when his turn comes, his SWD may be less than MAD; if he waits for his next turn, the crop may be stressed.

Use these procedures to make some management recommendations to apply smaller applications. For example: The inflow time that is required to apply 3.0 inches, 2.5 inches or other application amounts the farmer may desire.

NOW, WE WILL COMPLETE THE RECOMMENDATIONS PORTION OF THE EVALUATION.

Recommendations - Surface System Evaluation Worksheet F - Recommendations and Cost Savings (page 73)

We will now continue with our example problem. To complete the example problem, we are going to assume that the farmer plans to apply a net application of 3 inches. From the adjusted accumulative intake curve, determine the opportunity time required to infiltrate the planned application (SWD). An irrigation curve (for the 3.0 inch application) should be plotted for this amount of time above, and parallel to, the advance curve on the original field Advance and Recession Curves Worksheets (page 49). The required time to infiltrate 3.0 inches is about 70 minutes. If we add 70 minutes to the advance time (110 min.) at Sta. 7+00 the target recession time should be 180 min. Therefore we can drop the recession curve by 16 minutes (196 - 180). The recession time at 0+00 would them be 94 minutes (110 - 16). Draw the revised Recession Curve parallel to the Field Curve, but 16 min. lower. From an analysis of the advance-recession curve and the irrigation curve, estimate the inflow time required to infiltrate the SWD. Subtract the 13 minute lag time (Surface System Evaluation Worksheet C) from 94 minute recession time at Sta. 0+00 to give an inflow time of 81 minutes. We will use the present inflow rate of 1.4 cfs. Record the following information on Worksheet F:

SWD = 3.0 inches
To = 70 minutes, or 1 hr. - 10 min.
Tin = 81 minutes, or 1 hr. - 21 min.
Inflow = 1.4cfs.

Potential water and cost savings

Based on information about present irrigation scheduling and application practices obtained from the farmer and on data derived from the evaluation, estimate the present average net application per irrigation. In this example, we will use 3.0". From Worksheet A, the farmer irrigates about 12 times per year.

From the irrigation guide, determine annual net irrigation requirements for the crop to be managed. In this example, use 22.1" for alfalfa.

From information in the Irrigation Guide, or from table 4-12 (Design Efficiency for Graded Borders) in National Engineering Handbook section 15, Ch. 4, determine recommended design efficiency (Edes). Use 70% in this example.

Annual net irrigation requirement - 22.1 inches
Crop - Alfalfa
Present number of irrigations per year = 12
Present net applications = 3 in.
Application efficiency
Present = 60% (Worksheet E)
Potential = 70%

Compute an estimate of the gross amount of irrigation water used per year. Use the estimated average net application, average number of annual irrigations (from farmer), and application efficiency (Ea) found by this evaluation to compute annual gross:

Present annual gross appl. (in) =

$$\frac{\text{Net applied per irrigation (in) x number of irrig. x 100}}{\text{Application efficiency Ea(\%)}} =$$

$$\frac{3.0 \times 12 \times 100}{60} = 60 \text{ inches}$$

$$\text{Potential gross appl/yr (in.)} = \frac{22.1 \text{ in. } \times 100}{70\% \text{ eff.}} = 31.6 \text{ in.}$$

Total Annual water conserved (ft.) =

$$\frac{\text{(Present gross applied - Potential gross applied) x Area Irrig (ac.)}}{12}$$

$$= \frac{(60 - 31.6) \times 40}{12} = \underline{95.0} \text{ ac. ft.}$$

Record this on Worksheet F.

Annual cost savings

Information for this part of Worksheet F would come from a pumping plant evaluation. If you do not make the pumping plant evaluation, you may omit this section of Worksheet F.

If cost is a factor, compute cost savings:
- Pumping cost savings: From a separate pumping plant evaluation, determine pumping plant efficiency, kind of fuel, cost per unit of fuel, fuel cost per acre inch. Compute fuel cost savings:

Fuel cost per acre foot x acre feet conserved per year. In this example use a pumping plant efficiency of 55%, electric for fuel, electric cost of 7¢/KWH and a fuel cost of $14.33 per ac. ft. Record the data on Worksheet F and complete computations.

Water purchase cost savings: Obtain purchase cost data from farmer or water company. Water purchase cost is $12.00 per acre foot. Compute as follows:

Cost savings = Fuel Cost per acre foot x acre foot conserved per year =
14.33 x 95 = $1361

Water Purchase Savings =
Cost per acre foot of water x Acre feet saved per year = $12 x 95 = $1140

Compute total potential cost savings:

Pumping cost + water cost = Total potential savings
$1,361 + $1,140 = Total potential savings = $2,501

SURFACE SYSTEM EVALUATION WORKSHEET F

GRADED BORDERS
RECOMMENDATIONS & COST SAVINGS

Landuser ____________________ Date __________ Field Office __________________

Time factors:

Required opportunity time to infiltrate soil water deficit of _______ inches:
To = ______________min (____________hr - ____________min)

Estimated required irrigation inflow time from adv.-recession curves:
Tin = ______________min (____________hr - ____________min)

At inflow rate of:
Q = ______________cfs Per border strip

POTENTIAL WATER AND COST SAVINGS

Present management:

Estimated present average net application per irrigation ___________ inches

$$\text{Present gross applied per year} = \frac{\text{Net applied per irrig.} \times \text{No. irrig.} \times 100}{\text{Application Efficiency (Ea)}\ 1/}$$

= ______________________ = ____________ inches

Potential Management:

Annual net irrig requirement __________inches, for ________________(crop)

Potential application efficiency (Epa) ____________percent (from irrigation guide, NEH or other source)

$$\text{Potential annual gross applied} = \frac{\text{Annual net irrigation requirement} \times 100}{\text{Potential application efficiency (Epa)}}$$

= __________ = ___________ inches

Total annual water conserved

$$= \frac{\text{(Present gross applied - Potential gross applied)} \times \text{Area irrig. (ac)}}{12}$$

$$= \frac{\qquad\qquad\qquad\qquad}{12} = \_\_\_\_\_\_\_\_\_\_\_\_ \text{ acre feet}$$

1/ Use the best estimate of what the application efficiency of a typical irrigation during the season may be. The application efficiency from irrigation to irrigation can vary depending on the SWD, set times, etc.

Recommendation Summary - Surface System Evaluation Worksheet F (Continued)

Use field observations, data obtained by discussion with the farmer, study of the advance recession curves, and data obtained by computations to make some practical recommendations. Remember that the data is not exact, that there are many variables. Changes are a trial and error procedure. After each new trial the field should be probed to determine penetration and observations should be made to determine amount of runoff, distribution, etc. Enough instruction should be given to the operator that he can make these observations and adjustments.

For the example, record on Worksheet F(continued) the following information:

> Try reducing set times to one hour twenty minutes while maintaining the same flow rate. Since the pump maintains nearly constant flow rate, it is not practical to change the flow rate per border. Mr. example expressed interest in an automated pipeline system so that labor can be reduced. We agreed to provide feasibility and cost estimates of cablegation and buried pipe/pneumatic valve type automatic systems.

SURFACE SYSTEM EVALUATION WORKSHEET F (Continued)

GRADED BORDERS
RECOMMENDATIONS & COST SAVINGS

Landuser ____________ Date ________ Field Office ____________

Annual Cost Savings:

From pumping plant evaluation:

Pumping plant efficiency ________ Kind of fuel ____________

Cost per unit of fuel ________ fuel cost per acre foot $______

Cost savings = Fuel cost per acre foot x acre feet conserved per year
= ________________ = $________________

Water purchase cost

= Cost per acre foot x acre feet saved per year = $____________
= $____________

Cost savings = Pumping cost + water cost =
____________ = $________.

RECOMMENDATIONS

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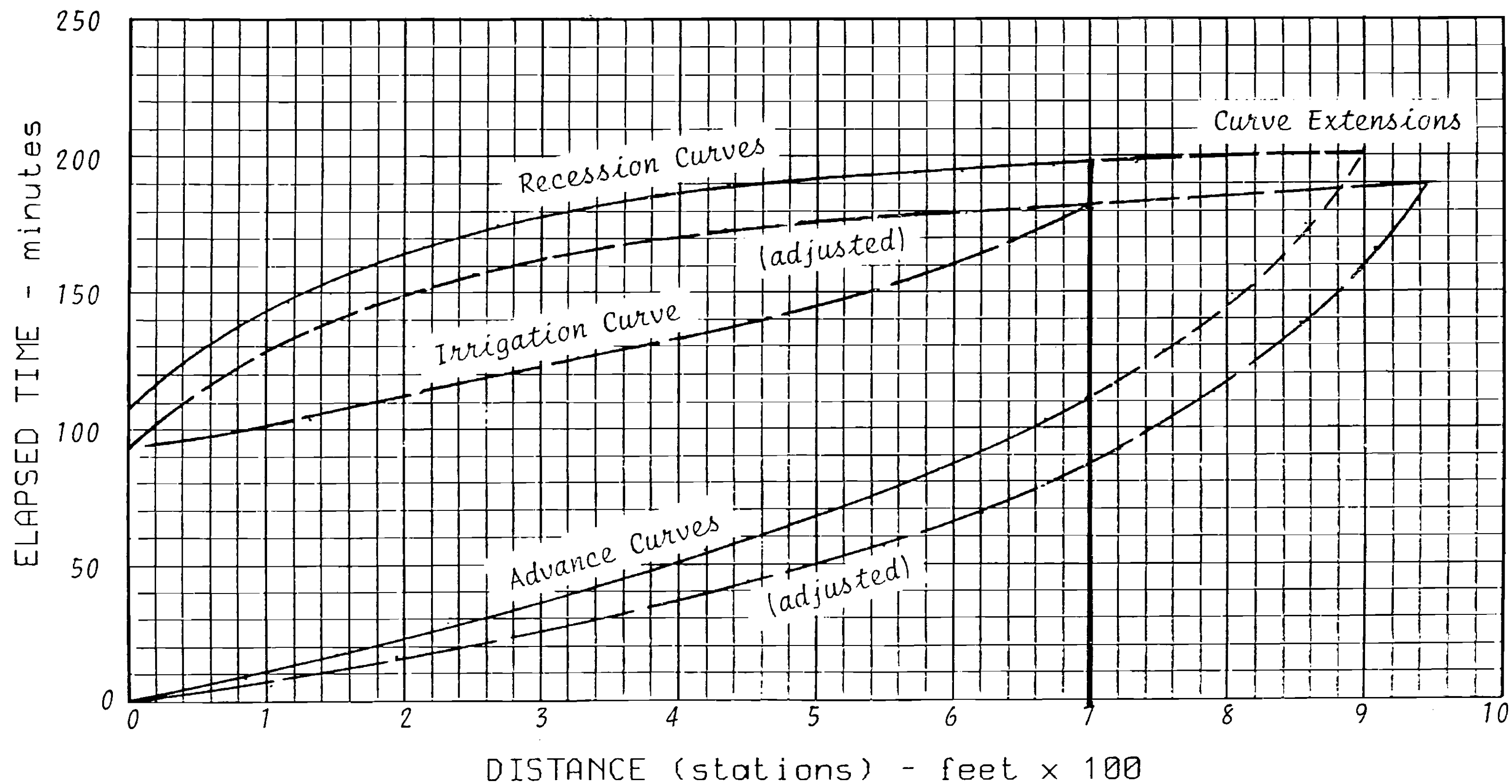
ADVANCE AND RECESSION CURVES

LANDUSER *Joe Example*

DATE ______________________

FIELD OFFICE ______________________



SURFACE SYSTEM EVALUATION WORKSHEET F

GRADED BORDERS
RECOMMENDATIONS & COST SAVINGS

Landuser *Joe Example* Date ________ Field Office ________

Time factors:

Required opportunity time to infiltrate soil water deficit of *3.0* inches:
To = *70* min (*1* hr - *10* min)

Estimated required irrigation inflow time from adv.-recession curves:
Tin = *81* min (*1* hr - *21* min)

At inflow rate of:
Q = *1.4* cfs Per border strip

POTENTIAL WATER AND COST SAVINGS

Present management:

Estimated present average net application per irrigation *3.0* inches

$$\text{Present gross applied per year} = \frac{\text{Net applied per irrig. x No. irrig. x 100}}{\text{Application Efficiency (Ea) 1/}}$$

$$= \frac{3.0 \times 12 \times 100}{61 \quad 1/} = 59 \text{ inches}$$

Potential Management:

Annual net irrig requirement *22.1* inches, for *Alfalfa* (crop)

Potential application efficiency (Epa) *70* percent (from irrigation guide, NEH or other source)

$$\text{Potential annual gross applied} = \frac{\text{Annual net irrigation requirement x 100}}{\text{Potential application efficiency (Epa)}}$$

$$= \frac{22.1 \times 100}{70} = 31.6 \text{ inches}$$

Total annual water conserved

$$= \frac{\text{(Present gross applied - Potential gross applied) x Area irrig. (ac)}}{12}$$

$$= \frac{(59 - 31.6)\ 40}{12} = 91 \text{ acre feet}$$

1/ Use the best estimate of what the application efficiency of a typical irrigation during the season may be. The application efficiency from irrigation to irrigation can vary depending on the SWD, set times, etc.

SURFACE SYSTEM EVALUATION WORKSHEET F (Continued)

GRADED BORDERS
RECOMMENDATIONS & COST SAVINGS

Landuser Joe Example Date ____ Field Office ____

Annual Cost Savings:

From pumping plant evaluation:

Pumping plant efficiency 55 Kind of fuel Electric

Cost per unit of fuel 7¢ / KWH fuel cost per acre foot $ 14.33

Cost savings = Fuel cost per acre foot x acre feet conserved per year

= 14.33 x 91 = $ 1304

Water purchase cost

= Cost per acre foot x acre feet saved per year = $12 x 91
= $ 1092

Cost savings - Pumping cost + water cost = 1304 + 1092 = $ 2396

RECOMMENDATIONS

Try reducing set times to one hour twenty minutes while maintaining the same flow rate. Since the pump maintains nearly constant flow rate, it is not practical to change the flow rate per border. Mr. Example expressed interest in an automated pipeline system so that labor can be reduced. We agreed to provide feasibility and cost estimates on cablegation and buried pipe/pneumatic valve type automatic systems.

APPENDIX A

IRRIGATION TRAINING SERIES

GRADED BORDER SYSTEM EVALUATION

SOLUTION TO ACTIVITY

SURFACE SYSTEM EVALUATION WORKSHEET A

GRADED BORDERS
CROP AND SOIL DATA

Landuser *Joe Example* Date ______ Field Office ______
Observer ______ Field name/number *West 40*

FIELD DATA INVENTORY

Field area *40* acres
Border number *5* as counted from *North* side of field.
Crop *Alfalfa* Root zone depth *5.0* ft
Stage of crop *one week after cutting*
Soil-water data for controlling soil:
Soil name *Glenberg loam*
Location of sample *2+00*
Moisture determination method *Ely/Speedy*

Depth	Texture	AWC (in)*	SWD (%)*	SWD (in)
0 - 1'	*loam*	*2.0*	*50*	*1.0*
1 - 2'	*loamy fine sand*	*1.5*	*45*	*0.7*
2 - 3.5'	*very fine loamy sand*	*2.2*	*40*	*0.9*
3.5 - 5'	*gravelly loamy sand*	*1.5*	*20*	*0.3*
	Totals	*7.2*		*2.9*

$$\text{MAD}^{*} \text{ (in)} = \frac{\text{MAD (\%)}}{100} \times \text{total AWC (in.)} = \frac{50 \times 7.2}{100} = 3.6 \text{ in.}$$

Comments about soils: *There is a very compact layer between 10 & 14 inches. Could not dig with auger past 3 1/2 feet due to gravel. Used information from soil survey.*

Typical irrigation duration *1 1/2* hr, irrigation frequency *14* days
Typical number of irrigations per year *12+*
Annual Irrigation Requirement *22.1* inches
Type of delivery system (gated pipe, turnouts, siphon tubes) *Siphon tubes from earth ditch w/conc. checks. Elect. pump delivers 1.4 cfs at 100' TDH*
Delivery system size data (pipe size and gate spacing, tube size and length, turnout size) *5 - 4" siphon tubes per set*

Border Spacing: *30* ft, Strip Width *28* ft, Wetted Width *29* ft,
Length *700* ft

FIELD OBSERVATIONS

Crop uniformity *Thin spot within 100' of upper end. Best stand between 3+00 and 6+00*
Uniformity of water spread across border *Low next to borders.*

Other observations *Field touch-up leveled 4 yrs. ago. Alfalfa 4 yrs. old. Grass and weeds beginning to invade.*

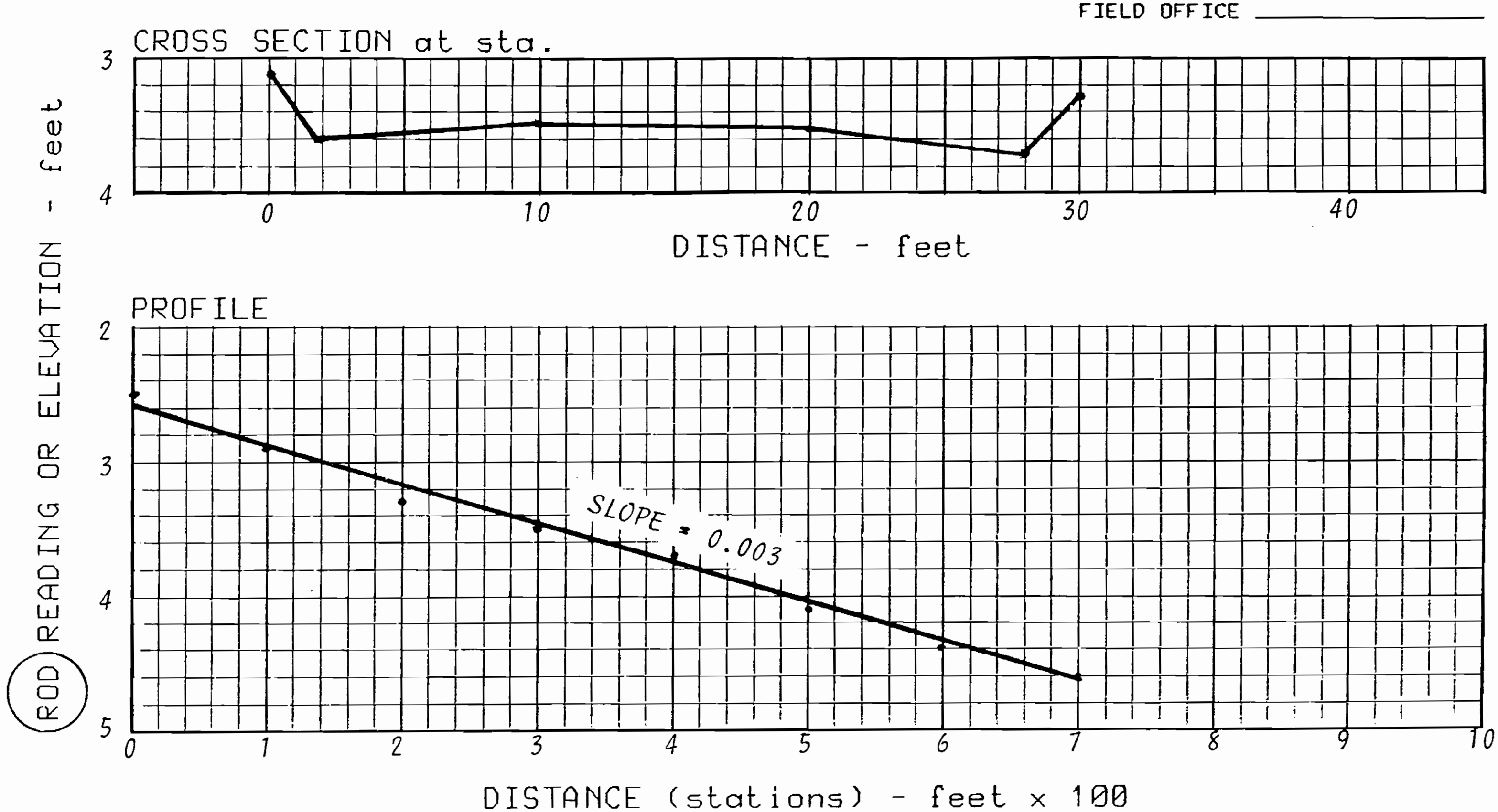
* MAD = Management allowed deficit AWC = Available water capacity
SWD = Soil water deficit

PROFILE AND CROSS SECTION

LANDUSER Joe Example

DATE ______________

FIELD OFFICE ______________



U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

CYLINDER INFILTROMETER TEST DATA

SCS-ENG-322
02-85

FARM	COUNTY	STATE	LEGAL DESCRIPTION	DATE
Joe Example			NW 1/4 S27, T3N, R28E	

SOIL MAPPING SYMBOL	SOIL TYPE	SOIL MOISTURE:
	Glenberg Loam	0'-1'-% OF AVAILABLE 40% 1'-2'-% OF AVAILABLE 50%

CROP	STAGE OF GROWTH
Alfalfa	1 week after cutting

GENERAL COMMENTS

compacted layer between 10 & 14 inches

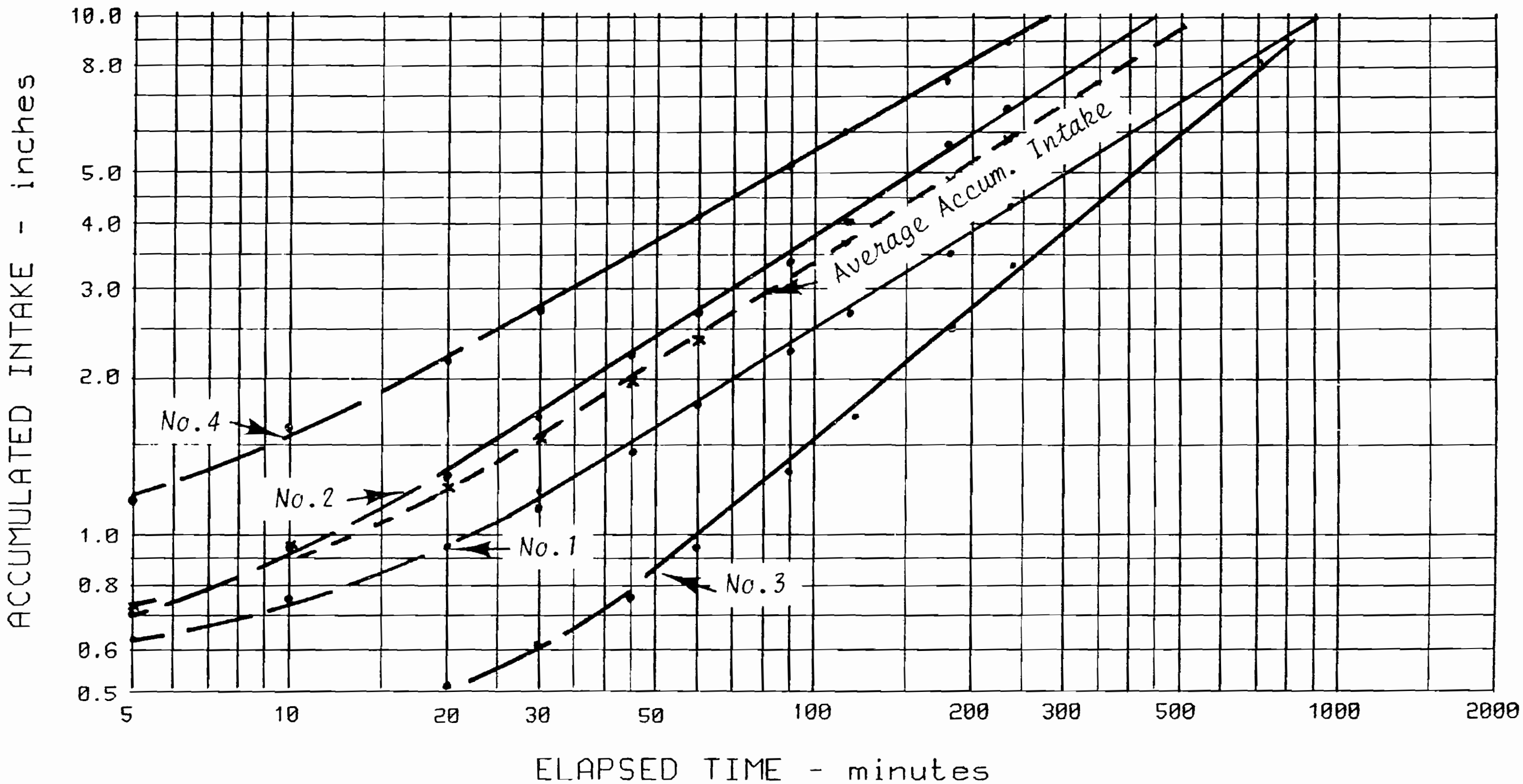
ELAPSED TIME	CYLINDER NO. 1			CYLINDER NO. 2			CYLINDER NO. 3			CYLINDER NO. 4			CYLINDER NO. 5			AVERAGE ACCUM. INTAKE
	TIME OF READING	HOOK GAGE READING	ACCUM. INTAKE	TIME OF READING	HOOK GAGE READING	ACCUM. INTAKE	TIME OF READING	HOOK GAGE READING	ACCUM. INTAKE	TIME OF READING	HOOK GAGE READING	ACCUM. INTAKE	TIME OF READING	HOOK GAGE READING	ACCUM. INTAKE	
MIN.		INCHES	INCHES		INCHES	INCHES		INCHES	INCHES		INCHES	INCHES		INCHES	INCHES	
0	11:15	1.80	0	11:16	2.10	0	11:18	3.21	0	11:19	4.10	0				0
5	11:20	2.44	.64	11:22	2.80	.70	11:23	3.56	.35	11:24	5.30	1.20				.72
10	11:25	2.57	.77	11:26	3.05	.95	11:27	3.64	.43	11:28	5.75	1.65				.95
20	11:35	2.76	.96	11:37	3.45	1.35	11:38	3.72	.51	11:39	6.30	2.20				1.26
30	11:45	2.95	1.15	11:46	3.80	1.70	11:47	3.82	.61	11:48	6.85	2.75				1.55
45	12:00	3.25	1.45	12:01	4.35	2.25	12:03	3.97	.76	12:04	7.60	3.50				1.99
60	12:15	3.58	1.78	12:17	4.80	2.70	12:18	4.15	.94	12:19	8.20	4.10				2.38
90	12:45	4.05	2.25	12:46	5.50	3.40	12:47	4.51	1.30	12:47	9.20	5.10				3.01
120	13:15	4.50	2.70	13:16	6.10	4.00	13:17	4.91	1.70	13:18	10.10/ 3.90	6.00				3.60
180	14:15	5.30	3.50	14:17	7.50	5.40	14:18	5.71	2.50	14:19	5.6	7.70				4.78
240	15:15	6.20	4.40	15:16	8.80	6.70	15:18	6.61	3.40	15:19	6.9	9.00				5.88

CYLINDER INFILTROMETER CURVES

LANDUSER Joe Example

DATE ______________________

FIELD OFFICE ______________________



SURFACE SYSTEM EVALUATION WORKSHEET B

GRADED BORDERS
INFLOW/OUTFLOW DATA

Landuser *Joe Example* Date ______ Field Office ______

DATA: Inflow *X* Outflow ____

Type of Measuring device *5 - 4"x 10' siphon tubes*

Clock 1/ Time	Elapsed Time (min)	ΔT (min)	Gage H (*ft*)	Flow Rate (*gpm*)	Average Flow Rate (*gpm*)	2/ Volume (ac-in)	Cum. Volume (ac-in)
Turn on (*1051*)	*0*	//////	*.25*	*490*	//////////	//////////	//////////
		9			*525*	*.1740*	*.1740*
1100	*9*		*.33*	*560*			
		10			*625*	*.2302*	*.4042*
1110	*19*		*.50*	*690*			
		10			*657*	*.2420*	*.6462*
1120	*29*		*.41*	*625*			
		15			*627*	*.3464*	*.9926*
1135	*44*		*.42*	*630*			
		15			*632*	*.3491*	*1.3417*
1150	*59*		*.43*	*635*			
		38			*635*	*.8887*	*2.2304*
1228	*97*		*.43*	*635*			
Turn off (*1228*)							

Total Volume (ac-in) *2.23*

Average flow rate =

$$\frac{\text{Total irrigation volume (ac-in)} \times 60.5}{\text{Inflow time (min)}} = \frac{2.23\ (60.5)}{97} = 1.4 \text{ cfs}$$

Unit flow:

$$qu = \frac{\text{Average flow rate (cfs)}}{\text{Border strip spacing (ft)}} = \frac{1.4}{30} = 0.047 \text{ cfs/ft}$$

1/ Use a 24-hour clock reading; i.e., 1:30 p.m. should be recorded as 1330

2/ Flow rate to volume factors:

To find volume using cfs:
volume (ac-in) = .01653 x time (min) x flow (cfs)

To find volume using gpm:
volume (ac-in) = .00003683 x time (min) x flow (gpm)

SURFACE SYSTEM EVALUATION WORKSHEET C

GRADED BORDERS
ADVANCE AND RECESSION DATA

Landuser Joe Example Date ________ Field Office ____________________

Station (ft)	Advance Time: Clock* Time	ΔT (min)	Elapsed Time 1/ (min)	Recession Time: Clock* Time (min)	ΔT (min)	Elapsed Time 1/ (min)	Opportunity Time (To)
		///////		Turn off:	//////		inflow T 2/
0+00	////////		/////////	(1228)	lag	//////////	(97)
	Turn on	///////			(13)		
0+00	(1051)		0	1241		110	110
		10			35		
1+00	1101		10	1316		145	135
		14			16		
2+00	1115		24	1332		161	137
		12			16		
3+00	1127		36	1348		177	141
		14			8		
4+00	1141		50	1356		185	135
		15			5		
5+00	1156		65	1401		190	125
		19			3		
6+00	1215		84	1404		193	109
		26			3		
7+00	1241		110	1407		196	86
		////////			//////		

* Use a 24-hour clock reading: i.e., 1:30 p.m. should be recorded as 1330

1/ Time since water was turned on.

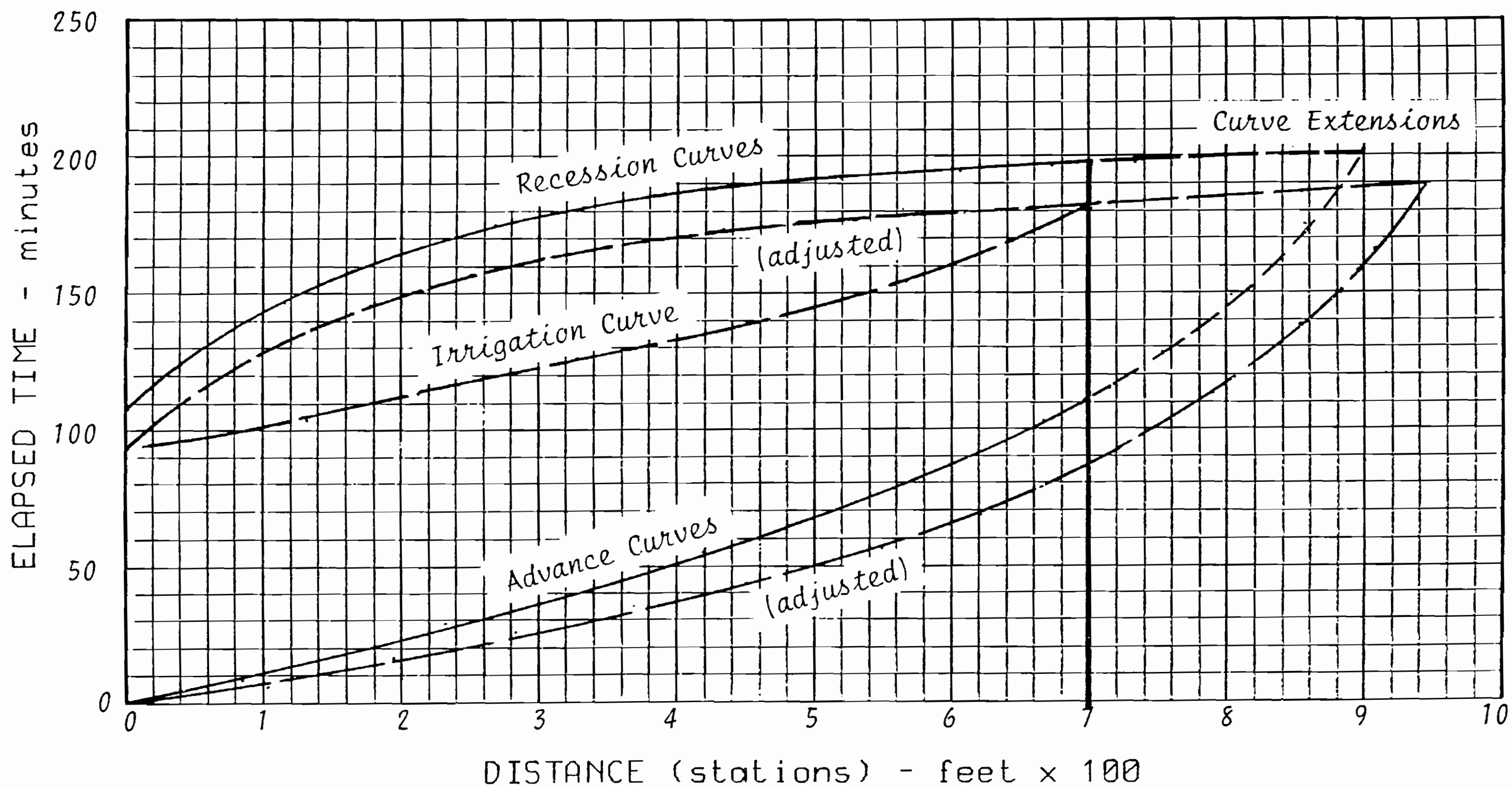
2/ Inflow time = Turn off time - Turn on time

ADVANCE AND RECESSION CURVES

LANDUSER *Joe Example*

DATE ____________

FIELD OFFICE ____________



SURFACE SYSTEM EVALUATION WORKSHEET D

GRADED BORDERS
DEPTH INFILTRATED DATA

Landuser *Joe Example* Date ________ Field Office ________

Station	Opportunity Time 1/ To (min)	Average Intake Curve: Depth 2/ Infil. (in)	Average Intake Curve: Av Depth Infil. (in)	Adjusted Intake Curve: Depth 3/ Infil. (in)	Adjusted Intake Curve: Av Depth Infil. (in)
0 + 00	110	3.6		4.0	
1+00	135	4.1	3.9	4.5	4.3
2+00	137	4.1	4.1	4.5	4.5
3+00	141	4.2	4.2	4.7	4.6
4+00	135	4.1	4.1	4.5	4.6
5+00	125	3.9	4.0	4.3	4.4
6+00	109	3.6	3.8	4.0	4.1
7+00	86	3.1	3.3	3.4	3.7
Border Extension					
8+00	51	2.3	2.7	2.5	3.0
9+00	0	0	1.2	0	1.3
Sum of depths			31.3		34.5

1/ Difference in time between advance and recession curve.
2/ From "average" cumulative intake curve.
3/ From "adjusted" cumulative intake curve.

Average depth infiltrated

$$= \frac{\text{Sum of depths (average)}}{\text{Length (hundreds of feet- extended)}} = \frac{31.3}{9} = 3.48 \text{ in}$$

Extended border area (acres)

$$= \frac{\text{Extended border length x wetted width}}{43,650} = \frac{900 \times 29}{43,560} = 0.60 \text{ acres}$$

Actual average depth applied to extended border length

$$= \frac{\text{Av inflow (cfs) x duration (hr)}}{\text{Extended border area (acres)}} = \frac{1.4\ (97/60)}{0.60} = 3.8 \text{ in}$$

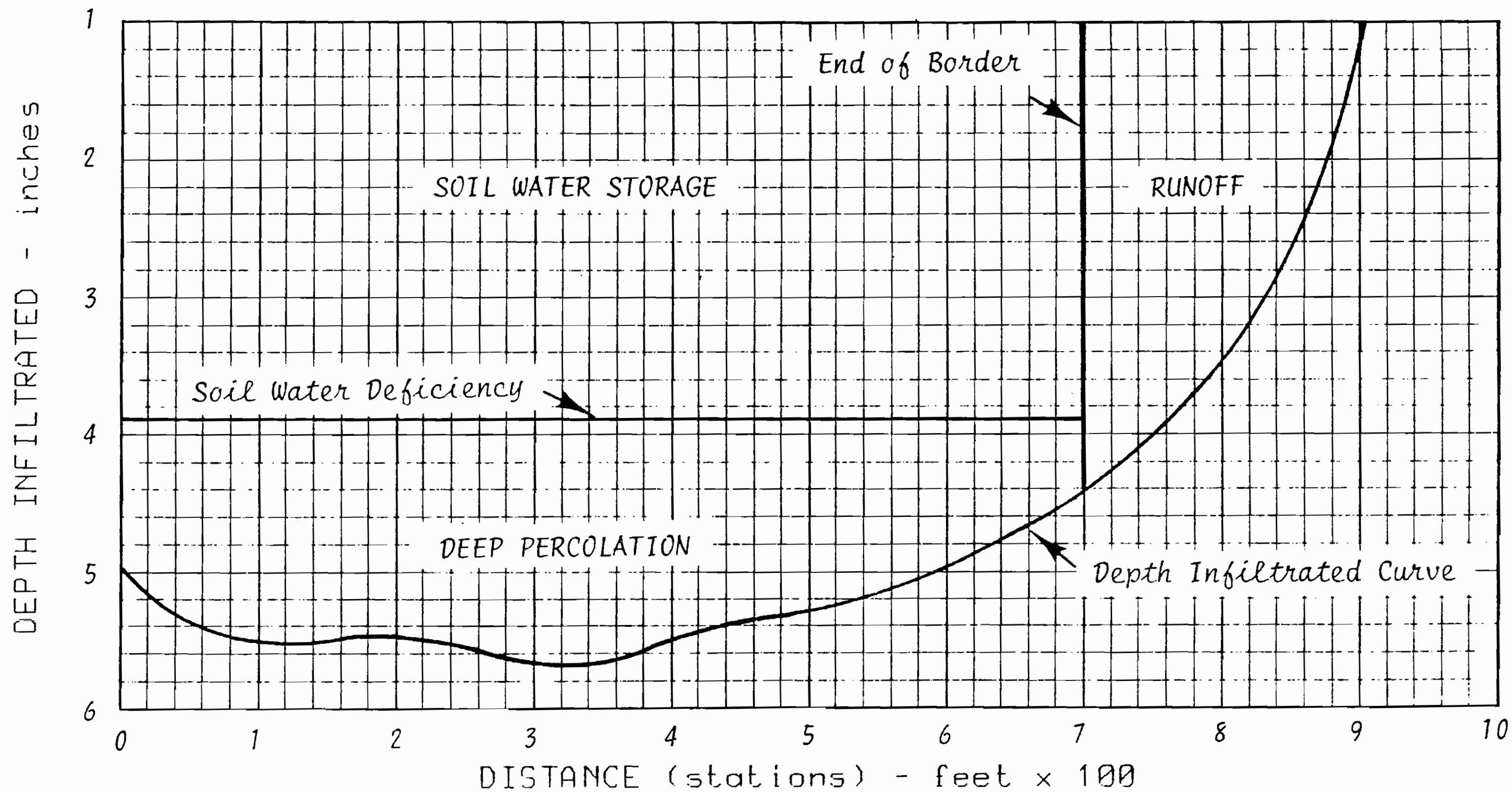
Average depth infiltrated (adjusted)

$$= \frac{\text{Sum of depths (adjusted)}}{\text{Length (hundreds of feet- extended)}} = \frac{34.5}{9} = .3.8 \text{ in}$$

(Should be close to actual depth applied)

DEPTH INFILTRATED CURVE

LANDUSER Joe Example
DATE
FIELD OFFICE



SURFACE SYSTEM EVALUATION WORKSHEET E

GRADED BORDERS
EVALUATION COMPUTATIONS

Landuser *Joe Example* Date ______ Field Office ______

1. Average depth infiltrated low 1/4 (LQ):

Low 1/4 strip length $= \frac{\text{Actual strip length}}{4} = \frac{700}{4} = 175$ ft.

$$LQ = \frac{\text{Depth inf. at begin of L1/4 strip + Depth inf. at end of L1/4 strip}}{2}$$

$$= \frac{4.2 + 3.4}{2} = 3.8 \text{ in.}$$

2. Areas under depth curve:

1.	Whole curve	33.9	sq. units
2.	Runoff	4.4	sq. units
3.	Deep percolation	9.2	sq. units
4.	Low quarter infiltration	26.6	sq. units

3. Actual border strip area:

$$= \frac{\text{Actual border length x Wetted width}}{43,560} = \frac{700 \times 29}{43,560} = .47 \text{ acres}$$

4. Distribution Uniformity low 1/4 (DU):

$$DU\% = \frac{\text{Low quarter infiltration area x 100}}{\text{(Whole curve area - Runoff area)}} = \frac{26.6 \times 100}{33.4 - 4.4} = 92 \%$$

5. Runoff (RO):

$$RO\% = \frac{\text{Runoff area x 100}}{\text{Whole curve area}} = \frac{4.4 \times 100}{33.9} = 13 \%$$

$$RO \text{ (in.)} = \frac{\text{Total irrigation volume (ac-in) x RO\%}}{\text{Act. strip area (ac) x 100}} = \frac{2.26 \times 13}{.47 \times 100} = 0.6 \text{ in.}$$

SURFACE SYSTEM EVALUATION WORKSHEET E (continued)
GRADED BORDERS
EVALUATION COMPUTATIONS

Landuser *Joe Example* Date ________ Field Office ____________

6. Deep Percolation (DP):

$$DP\% = \frac{\text{Deep percolation area} \times 100}{\text{Whole curve area}} = \frac{9.2 \times 100}{33.4} = \underline{28}\ \%$$

$$DP(in) = \frac{\text{Total irrigation volume (ac-in)} \times DP\%}{\text{Act. strip area (ac)} \times 100} = \frac{2.26 \times 28}{.47 \times 100} = \underline{1.3}\ \text{in.}$$

7. Gross application (Fg):

$$Fg = \frac{\text{Total irrigation volume (ac-in)}}{\text{Act. strip area (ac)}} = \frac{2.26}{.47} = \underline{4.8}\ \text{in.}$$

8. Application efficiency (Ea):

Average depth stored in root zone = soil water deficit (SWD) if entire root zone depth will be filled to field capacity by this irrigation. Otherwise, use Fg (in.) - Ro (in.)

$$Ea(\%) = \frac{\text{Av. depth stored in root zone} \times 100}{\text{Gross application (in.)}} = \frac{2.9 \times 100}{4.8} = \underline{60.4}\ \%$$

9. Application efficiency low 1/4 (Eq)

$$Eq(\%) = \frac{DU(\%) \times Ea(\%)}{100} = \frac{92 \times 60.4}{100} = \underline{56}\ \%$$

10. Average Net Application

$$= \frac{\text{Total irrigated volume (ac. in)} \times Ea(\%)}{\text{Act. strip area (ac)} \times 100} = \frac{2.26 \times 60.4}{.47 \times 100} = \underline{2.9}\ \text{in.}$$

SURFACE SYSTEM EVALUATION WORKSHEET F

GRADED BORDERS
RECOMMENDATIONS & COST SAVINGS

Landuser *Joe Example* Date ________ Field Office ________

Time factors:

Required opportunity time to infiltrate soil water deficit of *3.0* inches:
To = *70* min (*1* hr - *10* min)

Estimated required irrigation inflow time from adv.-recession curves:
Tin = *81* min (*1* hr - *21* min)

At inflow rate of:
Q = *1.4* cfs Per border strip

POTENTIAL WATER AND COST SAVINGS

Present management:

Estimated present average net application per irrigation *3.0* inches

$$\text{Present gross applied per year} = \frac{\text{Net applied per irrig.} \times \text{No. irrig.} \times 100}{\text{Application Efficiency (Ea) } 1/}$$

$$= \frac{3.0 \times 12 \times 100}{61 \quad 1/} = 59 \text{ inches}$$

Potential Management:

Annual net irrig requirement *22.1* inches, for *Alfalfa* (crop)

Potential application efficiency (Epa) *70* percent (from irrigation guide, NEH or other source)

$$\text{Potential annual gross applied} = \frac{\text{Annual net irrigation requirement} \times 100}{\text{Potential application efficiency (Epa)}}$$

$$= \frac{22.1 \times 100}{70} = 31.6 \text{ inches}$$

Total annual water conserved

$$= \frac{(\text{Present gross applied} - \text{Potential gross applied}) \times \text{Area irrig. (ac)}}{12}$$

$$= \frac{(59 - 31.6)\ 40}{12} = 91 \text{ acre feet}$$

1/ Use the best estimate of what the application efficiency of a typical irrigation during the season may be. The application efficiency from irrigation to irrigation can vary depending on the SWD, set times, etc.

SURFACE SYSTEM EVALUATION WORKSHEET F (Continued)

GRADED BORDERS
RECOMMENDATIONS & COST SAVINGS

Landuser Joe Example Date ______ Field Office ______

Annual Cost Savings:

From pumping plant evaluation:

Pumping plant efficiency 55 Kind of fuel Electric

Cost per unit of fuel 7¢ / KWH fuel cost per acre foot $ 14.33

Cost savings = Fuel cost per acre foot x acre feet conserved per year

= 14.33 x 91 = $ 1304

Water purchase cost

= Cost per acre foot x acre feet saved per year = $12 x 91
= $ 1092

Cost savings - Pumping cost + water cost = 1304 + 1092 = $ 2396

RECOMMENDATIONS

Try reducing set times to one hour twenty minutes while maintaining the same flow rate. Since the pump maintains nearly constant flow rate, it is not practical to change the flow rate per border. Mr. Example expressed interest in an automated pipeline system so that labor can be reduced. We agreed to provide feasibility and cost estimates on cablegation and buried pipe/pneumatic valve type automatic systems.

APPENDIX B

IRRIGATION TRAINING SERIES

GRADED BORDER IRRIGATION SYSTEM EVALUATION

GLOSSARY OF TERMS USED IN MODULE

GLOSSARY OF TERMS, DEFINITIONS AND EXPLANATIONS

Accumulated Intake:

The amount of water (inches) that has infiltrated into the soil since water was first applied.

Acre Foot:

The volume of water that would cover an area of one acre in size one foot deep.

Acre Inch:

The volume of water that would cover an area of one acre in size one inch deep.

Advance, Border:

The movement of the border stream from the head or upper end of the border toward the tail or lower end of the border.

Advance Curve:

A curve that illustrates the rate of advance of the irrigation water down the field with surface flood irrigation. It is drawn by plotting a number of advance distances (horizontal axis) against elapsed time (vertical axis) from the beginning of the irrigation.

Advance Time:

The time it takes water to advance from the upper end to a selected station along the border, or the lower end frequently called travel time, (minutes or hours).

Annual Irrigation Requirement:

The amount of irrigation water that is needed for a crop. The annual or seasonal crop water requirement less effective rainfall.

Application Efficiency:

The ratio of the average depth of the irrigation water stored in the root zone to the average depth of irrigation water applied.

$$Ea = \frac{\text{Average depth of water stored in root zone}}{\text{Average depth of water applied}}$$

Ea gives no indication of the adequacy of the irrigation, and with under irrigation it can equal 100 percent. Ea merely shows the fraction of applied water stored within the root zone that is potentially accessible for evaporation and transpiration.

Application Rate:

The rate at which water is applied to a given area. Usually expressed in inches of depth per hour or in gallons per minute.

Application Time:

The actual amount of time that water is applied to an irrigation set (minutes or hours).

Available Soil Water Capacity (AWC):

The water that can be held in the soil's root zone between field capacity and wilting point (inches of water).

Available Soil Water (ASW):
The difference at any given time between the actual water content in the soil's root zone and the wilting point (inches of water).

Average Depth Infiltrated:
The average depth of irrigation water infiltrated (intake) in the border strip.

Average Intake Curve:
The curve drawn from the average accumulated intake (horizontal axis) from a number of cylinder infiltrometer tests plotted against elapsed time (vertical axis) from the beginning of the tests.

Border Ridges:
The small dikes or both sides of a border strip that contain the irrigation water on the border strip.

Border Spacing:
The space between the center of the border ridges on both sides of the border strip.

Border Strip:
The strip of land between two border ridges that is flooded with water under Graded Border Irrigation.

Border Strip Wetted Width:
The width between the border ridges that is wetted during irrigation. This is usually greater than the border width because the water depth extends up on the slope of the ridges.

Border Strip Widths:
The width between the bottom of the inside slopes of the border ridges on both sides of the border strip.

Cfs:
Cubic feet per second (flow rate).

Consumptive Use:
Another term for Evapotranspiration (see Evapotranspiration).

Cumulative Intake Curve:
The curve drawn from the accumulated intake (vertical axis) vs. various elapsed time (horizontal axis) intervals from the beginning of the cylinder infiltrometer test. It is plotted on log-log paper.

Cylinder Infiltrometer:
A cylinder that is driven into the soil and filled with water. The loss of water, due to infiltration into the soil, is measured at various elapsed time intervals. The test is used to determine the intake characteristics of the soil under surface flood irrigation.

Deep Percolation:
The water that percolates below the root-zone depth. It is lost to the plants and frequently contributes to the buildup of the groundwater level.

Delta (△):

A symbol that is used to indicate the difference or change between two values: the △ time (minutes) between 9:10 and 9:33 is 23 minutes.

Depth Infiltrated:

The amount of irrigation water that has infiltrated (moved) into the soil.

Depth Infiltrated, Lower ¼ (LQ):

The average amount of irrigation water that has infiltrated into the "¼ of the border strip" that infiltrates the least.

Depth Infiltrated Curve:

A curve that illustrates the distribution of irrigation water applied to a border strip. The depth infiltrated (vertical axis) is plotted at various distances (horizontal axis) down the border strip length.

Distribution Uniformity (DU):

The ratio of the minimum depth of irrigation water infiltrated to the average depth of the irrigation water infiltrated.

$$DU = \frac{\text{Minimum depth of water infiltrated}}{\text{Average depth of water infiltrated}}$$

The minimum depth can be determined as the average of the lowest one-fourth of measured values of water stored, where each measured value represents an equal area. DU is a useful indicator of distribution problems. A low DU indicates that deep percolation losses are excessive if adequate irrigation is supplied to all areas.

Duration of Irrigation:

The amount of time that irrigation water is applied to the border strip. Also known as set time.

Erosive Stream Size:

A furrow stream that produces a velocity that exceeds the nonerosive velocity that is dependent on the erodibility of the soil (gpm).

Evapotranspiration (ET):

The sum of the transpiration and evaporation from an area covered by vegetation. It is composed of four factors: evaporation from water surfaces, soil-water evaporation, evaporation from the surface of plants, and transpiration.

Field Capacity (FC):

Water remaining a soil following wetting and natural drainage until free drainage has practically ceased. The time required for cessation of free drainage varies with soil textures and structure and the rate of water used by crops (inches of water).

Final Intake Rate:

The rate at which the soil absorbs water when the infiltration velocity has become nearly constant (inches per hour).

Gpm:
Gallons per minute (flow rate).

Gross Application (Fg):
The total amount of irrigation water that is applied to the border strip to provide the net irrigation requirement. The net irrigation requirement + losses (deep percolation and tail water runoff.)

Head of Field:
The end of the field where the water is applied to the borders for irrigations.

Initial Intake:
The depth of water absorbed by a soil during the period of rapid or comparatively rapid intake following the initial application (inches).

Initial Intake Rate:
The average rate at which water is absorbed by a soil during the period of rapid or comparatively rapid intake following the initial application of water (inches per hour).

Infiltration (intake):
The absorption of the water from the furrow stream into the soil.

Infiltration Rate (intake rate):
The rate at which the water is absorbed by the soil. The rate varies with time (inches per hour).

Intake Family of Curves:
A family or group of accumulated intake curves that represent the intake characteristics of most irrigated soils.

Irrigation Curve:
A curve that is drawn above and parallel to the advance curve at a distance that represents the amount of opportunity time that is necessary to infiltrate the desired irrigation application.

Irrigation Time:
The irrigation time is the total time the water is being applied to a set or sets, includes ontime and offtime with surge irrigation.

Intake, Family Curves:
A series of intake-family curves have been developed that relate cumulative depth of intake to opportunity time. Each type of soil has unique intake characteristics. Many soils differ so little that, for practical purposes, they can be grouped in one of a number of intake families.

Management Allowed Deficit (MAD):
The desired soil moisture deficit at the time of irrigation. It can be expressed as the percentage of available soil water capacity or as the depth of water that has been depleted from the root zone. In arid areas, the ideal irrigation is generally scheduled to just cancel MAD if no leaching is required. In humid areas, ideal supplemental irrigations are often scheduled only to partly cancel MAD, i.e., to leave some root-zone capacity for the storage of anticipated rainfall.

Nonerosive Stream Size:
A stream size that produces a velocity that is less than the maximum nonerosive velocity that is dependent on the erodibility of the soil (gpm).

Opportunity Time:
Opportunity is the time that water stands on the surface enabling water to penetrate or infiltrate the soil. It is computed for stations by finding the difference between advance time and recession time (minutes or hours).

Outflow:
The flow that leaves the field from the end of the furrow.

Percolation:
The movement of water through the soil.

Permeability (as used in describing soils):
The readiness with which water penetrates or passes through soil pores.

Recession Curve:
A curve that illustrates the recession time (the lapsed time that water disappears from the ground surface in surface flood irrigation) down the border strip. It is drawn by plotting the recession time (vertical axis) against various distances (horizontal axis) down the border strip.

Recession Time:
The descending part of a stream flow or the time lapse after water application has stopped until the water recedes or disappears from the surface at selected stations along the furrow (minutes or hours).

Root Zone:
The soil depth that is managed to store the available water for the crop. The depth of root zone is generally the depth from which the crop is currently capable of extracting soil water. However, it may also be expressed as the depth from which the crop can extract water when mature or the depth from which a crop to be planted in the future can extract soil water (expressed in inches).

Runoff, Border (Tailwater):
The water that leaves the border at the end of the field.

Slope:
The grade or drop in the direction of irrigation. Usually expressed in feet per foot or %.

Soil Water Deficit (SWD):
The difference between field capacity and the actual moisture in the soil root zone at any given time. It is the amount of water required to bring the soil in the root zone to field capacity.

Soil Water Storage:
The water that is stored in the soil for the use of crops.

Stream Size, Border:
The flow rate of water that is applied to the border (cfs.)

Surface Flood Irrigation:
The application of irrigation water by flooding the soil surface.

Surface Storage, Border:
The water that is on the border strip surface and is available for infiltration.

Tail of Field:
The bottom end of the field where excess irrigation or rainwater is removed.

Tailwater (Border Runoff):
The water that leaves the border strip at the tail end of the field.

Wilting Point (WP):
The water content in the soil's root zone at which plants can no longer extract water at a sufficient rate for survival.

APPENDIX C

IRRIGATION TRAINING SERIES

GRADED BORDER IRRIGATION SYSTEM EVALUATION

VIDEO NARRATIVE

VIDEO NARRATIVE
GRADED BORDER SYSTEM EVALUATION

Music (and then blend into sound over of water)

Sound of Water.

Graded Border Irrigation is a method of controlled surface flooding. It's used to irrigate hay and grass, and sometimes grain crops. In fact, graded border irrigation is adaptable to any crop that is sown, drilled or sodded. It can be used in orchards and vineyards as well.

The field to be irrigated is divided into strips by parallel dikes called border ridges. The dikes can be straight or follow the contour of the land. The strips usually slope in the direction of irrigation.

Each strip in the field is irrigated separately by turning a stream of water into the upper end.

The water floods the entire width of the strip, and flows slowly toward the lower end, wetting the soil as it advances.

When the proper amount of water has been delivered onto the strip, the stream is turned off. The water still on the surface of ground continues toward the end to complete the irrigation.

Graded border is known as a balanced "Advance and Recession" irrigation method. In other words, each strip is flooded with just enough water to saturate the entire length of the strip to the proper depth.

A system evaluation can provide the farmer with information he needs to determine if management of his Graded Border System is adequate or if improvements are needed.

Before beginning a detailed evaluation, you should be familiar with the terms and computations on the evaluation worksheets. Your Study Guide defines and illustrates this information.

After you've gathered the necessary equipment listed in your Study Guide, it's back to the field to begin the evaluation. Don't forget personal comfort items like insect repellent, a hat and your lunch.

You should choose one border strip in the field to be irrigated. That strip should be typical of the other strips. The soil should also be typical of the rest of the field. If there is a wide variance, more than one border should be evaluated. Try to do your evaluation when the field would normally be irrigated, in order to have the same soil moisture conditions.

There are several things that need to be done in the field before starting the evaluation. Interview the farmer and obtain information about the existing system...how it operates, how it is managed...and what the problems are.

Set stakes or flags at fifty or one hundred foot intervals down the border, and number each one.

Run levels to determine the field elevation at each station and a typical cross section of the border strip. Take enough readings to define smoothness and cross slope.

Measure and record...the border width--which is the distance from center to center of border dikes. The strip width--the distance from toe to toe of the border dikes. And the wetted width--the width to which water soaks or spreads beyond the edge of the strip.

You must be able to determine the flow rate being turned into the borders. If a flow measuring device is not available on the field, one must be temporarily installed. The device may be a flume, wier, or flow meter.

The tailwater or runoff should also Care must be used during installation of the flume or wier in order to get accurate measurements.

Next, three to five infiltrometer rings should be set in a carefully chosen "typical" location within the border strip. Usually, the most convenient location is a couple of hundred feet from the upper end of the strip.

Locate the rings away from holes, cracks, wheel tracks or anything which will distort the water intake. Pound the ring into the ground just deep enough to provide a good seal.

If the rings are set in the border to be evaluated, no buffer ring is required. If they are set in an adjacent dry border, buffer rings are needed. Segments of steel barrel or an earthen dike can be used as buffers.

Mark the edge of the rings where measurements will be taken. Get your buckets and measuring gauge ready.

Estimate the soil water deficit at several locations along the strip to be irrigated. Use the "feel and appearance"; the Ely Volumeasure/Speedy Moisture Meter, push sampler/oven, or other method. Pick one location as being typical for the border strip and record the data for that location on your worksheet.

Make a note of the soil profile conditions, such as...depth to water table, apparent rooting depth, compaction, mineral layers, and hardpan or bedrock.

Record your observations about the field, including uniformity of the crop, color changes, weedy areas, salt affected areas and similar characteristics.

Now it's time to begin the irrigation. Record the start time, and irrigate with the flow rate that is normally used.

If siphon tubes are used, check the flow at five to ten minute intervals, until it reaches a constant rate. Each time the flow is checked, record the rate and time of measurement on your worksheet. Periodically, check and record the flow rate. If there is considerable fluctuation, frequent checks should be made.

Observe and record a description of how well water spreads across the strips.

Record the time the leading edge of the water reaches each station. If the leading edge is an irregular line across the border strip, average the time as different parts of the leading edge reach the station.

Fill the infiltrometers at the time the leading edge reaches them. If the soil will be disturbed, put a cloth in the bottom of the ring to break the force of the water as it's poured in. Then remove the cloth immediately. Since time is critical, this is when extra hands are needed.

Measure the water surface in each of the rings at the time indicated on your worksheet. Take care to measure at the location marked on the ring each time the measurement is taken.

Record the clock time and gauge reading on the infiltrometer worksheet.

When the infiltrometer needs to be refilled, show gauge readings before and after filling. As you see here, it may not be as easy as you think to get water for refilling the infiltrometer.

Record the time that runoff starts (if there is any). If outflow is being measured, periodically measure and record the flow rate and time of measurement until it ceases.

Record the time when water is turned off at the head end of the field. As the sheet of water recedes past each station, record the time.

After the water has receded past all stations, your in-field evaluation is almost complete.

But before leaving, use a probe or auger to check depth of penetration. Checking now will indicate if the water has already percolated to deeply.

If it's possible later, check for adequacy and uniformity of irrigation at a time when the soil profile has reached the field capacity moisture level. Sandy soils can be checked about twenty-four hours after irrigation. Clay soils should be checked about forty-eight hours after irrigation so that gravitational water has drained.

Finally, if it is necessary to establish the field capacity, determine the soil water content when checking the adequacy of irrigation.

This completes the gathering of field data. The proper filling out of your worksheet and performing the calculations will be covered by the facilitator in a moment. After completing the computations, you'll be ready to give the farmer some practical recommendations.

Just remember that even after a detailed evaluation, your data is not perfect. Any changes that you suggest are a "Trial and error" procedure.

When you go over the results of your evaluation with the farmer, also give him instructions on how he can make his own evaluations and adjustments to ensure the most efficient and cost-effective way of irrigating by the graded border method.

Music

Music continuing

GRADED BORDER IRRIGATION

PART B

Characteristics of Graded Border Irrigation

SCS Logo

Characteristics of Graded Border Irrigation

Graded border irrigation is a method of controlled surface flooding. A field to be irrigated is divided into strips by parallel dikes or border ridges, and each strip is irrigated separately.

Here, the water is turned into the center border. The water moves down the length of the border. In the border strip immediately to the right, the water was turned off a short time ago. The water is shown receding toward the lower end of the border strip.

Graded Border irrigation uses a balanced advance and recession application. The border strips have some slope in the direction of irrigation. Each strip is irrigated by turning in a stream of water at the upper end. As soon as the water enters the border strip, water starts to infiltrate into the soil.

The stream size should be such that the desired volume of water is applied to the strip in a time equal to or slightly less than that needed for the soil to absorb the water required. Here the water has advanced down the strip and continues to infiltrate into the soil. The upper end has absorbed more water than at the point of advance.

When the desired volume of water has been delivered onto the strip, the stream is turned off. Water will remain at the upper end for a short period after the discharge has stopped. The time between when the water is shut off and when the water disappears from the surface is know as recession lag time.

The water temporarily stored on the ground surface then moves down the strip and completes the irrigation. Here, the upper end of the strip has been irrigated and we have the desired amount of water infiltrated into the soil. There is still water left at the lower end of the strip that is continuing to infiltrate.

Uniform and efficient application of water depends on the use of an irrigation stream of the proper size. Too large a stream results in inadequate irrigation at the upper end of the strip or excessive runoff at the lower end. If we put in too large a stream, the time between when we turn the water into the strip and turn it off is not long enough to adequately irrigate the upper end or, if we adequately irrigate the upper end, we have excessive runoff taking place at the lower end.

If the stream is too small, the lower end of the strip is inadequately irrigated or the upper end has excessive deep percolation. When we use too small a stream, we must apply the water for a much longer time to get the required volume applied to the strip. This means that water is available for infiltration at the upper end for too long a time. Also, the water does not advance rapidly enough towards the lower end to adequately irrigate this area.

Graded Border Irrigation is an effective and efficient method of irrigation when proper site conditions are available. Some advantages of graded border irrigation are as follows:
1) when gravity flow to the field is available, no power usage is required. Water is applied to graded borders by gravity. Pumping would be required only when necessary to convey the water to the field.

2) Water with relative high suspended sediment loads can be used. Do not use sprinkler nozzles where sediment can be a problem.

3) Graded borders can be used in rotation with other methods of applying water including furrow irrigation and sprinkler irrigation.

4) With good system design and maintenance, the method requires relative little labor.

5) With a well designed and maintained system, plus good management, relatively high application efficiencies are possible.

6) The distance between dikes can be set to fit existing cultivation and harvesting equipment. Properly designed and constructed dikes can be crossed by farm equipment.

7) Border irrigation is adaptable to most crops and soil conditions.

Here are some of the limitations of border irrigation:
1) Frequent observation or automation is needed to shut the water off at the time required for high efficiency. As discussed earlier, the water should be available at the head of the field only long enough to infiltrate the desired irrigation. If it is there longer, we will over-irrigate the upper end.

2) Topography must be relative smooth. If surface modification is needed, soils must be deep enough to allow for adequately leveling. If we have shallow soils, leveling may decrease your surface soils to a depth that is impractical for crop growth.

3) Slope in the direction of irrigation should not exceed about 4%. It may be less depending on soil, ground cover and potential rainfall. We can tolerate steeper slopes on sod crops such as grass, especially in arid climates. In humid climates where we have more rainfall, the slopes on cultivated crops must be less.

4) Border strips should have little or no cross slope. If we have cross slope, the lower side of the border will receive more water.

5) For highest efficiency, slopes should be uniform in the direction of irrigation. There should be no reverse slopes.

6) Skilled labor and management are necessary. We need to apply the proper amount of water in the most effective application time.

7) Light applications of water are difficult to apply. You usually need to apply from 3 to 4 inches or more to get efficient application with border irrigation.

8) We usually need a larger stream size for border irrigation. We want the border strips to be wide enough to accommodate farm machinery.

A number of design considerations are necessary with border irrigation:
1) The water intake rate of the soil. This is necessary to determine the application time needed to have the proper amount of water infiltrate the soil.

2) The available flow rate. We need to know how much water is available so we can determine the size of border that can be irrigated.

3) The flow resistance of the crop to be grown. If we are applying irrigation when the crop is just beginning to come up, we have little flow resistance. If we're irrigating a growing crop, flow resistance will be greater.

4) Quantity of water to be applied. We need to know how much water is necessary to properly irrigate the border strip. For instance, do we need to apply a 3" net irrigation or a 5" net irrigation.

5) The topography of the site is a prime consideration in determining whether border irrigation is practical. With topographic information, the slope, border widths, initial flow rates and times can be designed.

The water intake rate of the soil is a prime factor to be considered in the design of a graded border irrigation system. As this example illustrates, the intake rate of the soil is much greater when the water is first made available for infiltration. The initial intake rate, as shown by the nearly vertical beginning of the intake rate curve, can be many times the basic intake rate, which is illustrated by the more horizontal part of the curve. As water is applied, the intake rate slows from the rapid initial rate to the slower or basic rate.

We need to know how much time is required to apply the amount of water needed for an irrigation. To determine this, we use accumulative intake curves. There is a great variance in the intake of soils. Therefore, we have a family of curves. The family of curves range from 1/10th of an inch per hour to 3 inches per hour. This example illustrates only one of these curves.

Using LogLog paper, we can plot the accumulated intake rate for a particular soil against the elapsed time. With the red line on this curve, if we want to apply 3½ inches of water we extend a line from 3½ inches on the vertical scale to a point where it intersects with the accumulated intake curve. We then read vertically down for time in minutes. In this example, it would take 100 minutes to apply or infiltrate 3½ inches of water.

In evaluating border irrigation, we pay a great deal of attention to the advance and recession curves. They are useful for analyzing how a border functions. This slide shows a normal advance curve. The curve illustrates how long it takes for water to advance from the upper end of the border to the lower end of the border, from left to right. We plot distance traveled versus elapsed time. When the curve is flatter, like at the beginning of this curve, the advance is faster. It travels a greater distance for a smaller amount of time. The stream size will diminish as water travels down the border because water is lost to infiltration. As the stream size diminishes, the velocity of travel decreases. This is shown by the gradually increasing steepness of this advance curve.

The dot and dashed line indicates a normal shaped advance curve. The solid line indicates an actual field curve. The field curve is much steeper than the normal curve. This indicates that it takes twice as much time for the water to advance to the half way point. This may indicate that the intake rate of the soil is much greater at the upper end of the field thereby decreasing the stream size and slowing the velocity of advance.

This field curve is much flatter at the upper end of the field. Water advances to the mid-point of the field much faster -- in only about half as much time. This could indicate a much slower intake rate of soil at the upper end. Less of the stream is infiltrating; so we're maintaining a larger stream to advance down the border.

The solid blue field curve is normal until we get about two-thirds of the way down the border. Then it climbs steeply. This may indicate that the water was shut off too soon and not enough water was left to advance the stream to the end of the border.

Here the field curve starts off much steeper and then parallels the dashed blue normal curve to the lower end. This may indicate a much flatter slope at the upper end of the field, causing the water to slow its rate of advance.

The beginning of this field curve is much flatter than the normal curve -- taking only about half as much time to reach the mid-point of the field. This indicates that the slope may be much steeper at the upper end of the field. It then parallels the normal curve.

This solid blue field curve follows the normal curve until about mid-point of the field, rises sharply for a short time and then parallels the normal curve. This would indicate a low pocket or maybe some reverse slope in the center point of the field that pocketed the water and kept it from advancing.

Similar to the previous example, this advance followed the normal curve for a distance, slowed and then became normal towards the end. A faster intake soil or flatter slope in the center of the field could cause the curve to look like this.

Here we have a normal curve about 1/3 of the way down the strip. Then the curve flattens out, indicating that the water advance increased. This could reflect either a slower intake, less water lost to infiltration or a steeper section 1/2 the distance to the end.

This is a normal shaped recession curve. The recession curve illustrates how long water takes to recede or disappear from the surface of a border, starting at the upper end and proceeding to the lower end. The curve represents the elapsed time from the beginning of the irrigation. The time when the water disappears from the surface is called recession time. This means there is no more water available for infiltration into the soil. This typical dashed green recession curve is slightly "S" shaped.

This solid green field curve is flatter than the normal recession curve. This may indicate a faster intake at the upper end of the strip, which caused the water to disappear from the surface at a faster than normal rate.

Here the field curve is slightly steeper than the dashed green normal recession curve. This may indicate that we have a slower intake soil at the upper end of the border, which allowed the water to remain on the surface for a greater period and slowed down the recession at the upper end of the field.

This is a normal field curve until the end where it steepens up. This may indicate ponding at the lower end of the border, or it may indicate that we have end blocks in the border that caused the water to pond or stand there longer.

Here we have a flatter slope at the upper end of the curve and then a more normal curve toward the lower end. This may indicate a steeper border slope at the upper end that caused the recession to occur at a faster rate.

This solid green recession curve is flatter at the upper end before it begins to parallel the normal curve. This may indicate a flatter slope at the upper end that allowed the water to remain longer or move away at a slower rate.

This curve indicates some sort of a problem about mid-point in the field. There may be a pocket or reverse slope in the center or part way down the strip. There the water stood much longer than it did either at the upper end or the lower end of the strip.

Here we have a normal curve until about mid-point of the field and then it flattens. This may indicate, either faster intake at the lower end of the strip or a steeper slope that allowed the water to recede much faster.

This solid green field curve matches the normal curve until about the mid-point and then it steepens before becoming normal again. This could indicate either a slower intake at the center portion of the strip or a flatter slope that slows down the recession in the center of the field.

All of these curves are illustrated in your study guide for reference when you are examining actual field curves from a graded border evaluation. They can tell a great deal about the problems you are encountering in the field.

When using these curves to evaluate irrigation, we plot both the advance and recession curve on the same chart. The advance curve is indicated by the blue line. The recession curve is indicated by the green line. The time that the water is turned off from the border is indicated by the orange dashed line. The recession curve will start a short time, or lag time, after the cut-off time. The dashed grey line illustrates the irrigation curve that is drawn parallel to the advance curve. Earlier we talked about the amount of time necessary for our irrigation water to infiltrate into the soil. This is known as opportunity time or the amount of time that water needs to remain on the surface of the border. The orange vertical line at the right side of the chart indicates the end of the border strip. We can make an estimate of how much water runs off the end of the border by projecting both the advance curves and the recession curve until they meet. This is an indication of how far the water would advance down an extension of the border. The point where the advance and recession curves meet would be the greatest distance that water would advance. If our advance curves and recession curves were similar to these in our field evaluations, we would have an efficient irrigation system. The irrigation curve is below the recession curve at all points indicating that the entire field was adequately irrigated. The area between the irrigation curve and the recession curve indicates over irrigation or deep percolation. The area indicated by the extended recession and advanced curves at the end of the field is small, indicating a nominal amount of runoff. In border strip irrigation, our goal is to have the recession curve closely match the irrigation curve.

This is a border strip that has excessive length. Water takes too long to advance to the lower end of the border. Water was applied too long, which over-irrigated not only the upper end, but the entire border strip. The space between the dashed grey irrigation curve and the green recession curve indicates over-irrigation of the entire strip or excess deep percolation.

This strip is too short and has a large amount of runoff. The convergence of the blue advance and green recession curves is far to the right. We do not have a great deal of deep percolation (the area between the dashed gray irrigation curve and the recession curve), but we do have an excessive amount of runoff. A longer border length could be used. If the water was turned off sooner, we would not have sufficient time to irrigate the upper end...

This strip is too long. The water just barely advances to the bottom end of the strip before recession occurs. The lower end is under-irrigated. This is shown by the gray dashed irrigation curve crossing the green recession curve before reachinng the end of the border. If we shorten the border length to where the irrigation curve and the recession curve cross, we would have an efficient design.

This strip is too short. The border managed to have a minimum amount of runoff but we under-irrigated the entire strip. Note that the gray irrigation curve is totally above the green recession corve. The application time was too short to irrigate the border. This is especially true of the upper end. The dashed orange line is the time water was turned off at the upper end of the border.

This stream is too large. The blue advance curve is much flatter than the normal advance curve, which is illustrated by the yellow dots and dashes. The water reached the lower end of the field too quickly. The water at application time needs to be long enough to satisfy the necessary opportunity time at the upper end of the field. That, in combination with the larger stream size, puts more water on the field than was necessary to refill the soil profile. We produced both excessive runoff and excessive deep percolation. Whenever you run across these conditions in the field, you should either reduce the stream size or widen the border.

In this curve, the stream is too small. The advance time is much slower than normal. We had to apply water an excessive length of time to force its advance to the lower end of the field and to apply the necessary amount. Thereby, as a result, we had deep percolation at the upper end of the field. This is indicated by the wide difference between the dashed gray irrigation curve and the green recession curve.

These curves indicate that the irrigation cutoff was too soon. Not only did we have insufficient opportunity time to get the necessary irrigation infiltrated at the upper end of the field (as indicated by the dashed grey line) but the water did not advance to the lower end. This was a poor irrigation, under-irrigated at the upper end, and a slow advance time to the lower end.

Here the stream size was too large, as is illustrated by the flat advance curve in blue. Because of the large stream size, water flow was turned off too soon. This resulted in insufficient opportunity time at the upper end of the field. As a result, we under-irrigated the upper end of the field. The green recession curve is located below the grey dashed irrigation curve. Remember that the orange line is the time water was turned off at the upper end.

This advance curve has a steeper slope near the upper end of the border strip. The blue advance curve is flatter than the yellow normal advance curve. The curves also indicate excessive runoff. The management suggestion here is to reduce the stream size. The application time is about right because the right amount of water infiltrated at the upper end. A smaller stream size would have slowed the advance and resulted in less tailwater runoff.

These curves are similar to the previous ones. Here again, the blue advance curve is flatter at the upper end of the border. This may be an indication of a slower intake that speeded the advance rate. For these conditions, the stream size was too large, resulting in excessive tail water. Management's suggestion would be to reduce the stream size because of the soil's slower intake. The advance and recession curves derived from your field evaluations can tell you a great deal about the problems you may encounter. You must learn to interpret these curves to make good, logical irrigation improvement recommendations to the landuser.

The orange curve depicts the approximate depth infiltrated at any point along the strip. The green area above the curve represents the total water applied at any particular location down the strip. We plot depth infiltrated versus the distance down the length of the border strip. We can also extend the curve beyond another border in the same manner illustrated here by the orange dashes.

The area beyond the end of the strip representing the runoff volume is indicated here by light green shading. The white dashed line is the soil water defficiency line. This indicates the amount of water that we need to apply to replenish the water supply for the crop. Any depth infiltrated or water applied in excess of the soil water defficiency is deep percolation. This is the area shaded dark green below the soil water deficiency line and above the orange depth infiltrated curve. If any part of the soil water deficiency line falls below the depth infiltrated curve, we have a section of the field that is under-irrigated; it is indicated by the red-shaded area. The depth infiltrated curve gives you a visual picture of how much water you have stored in the soil that is available for plant use. It also indicates how much deep percolation you have, how much runoff you have experienced, and how much of the field did not receive adequate irrigation.

This concludes this video presentation. Please rewind the tape to the beginning. Then, return to your Study Guide.

APPENDIX D

IRRIGATION TRAINING SERIES

GRADED BORDER IRRIGATION SYSTEM EVALUATION

BLANK WORKSHEETS FOR DUPLICATION

SURFACE SYSTEM EVALUATION WORKSHEET A

GRADED BORDERS
CROP AND SOIL DATA

Landuser________________________ Date__________ Field Office________________
Observer__________________________ Field name/number________________________

FIELD DATA INVENTORY

Field area_______ acres
Border number ____________ as counted from ____________ side of field.
Crop _______________ Root zone depth ________ ft
Stage of crop ____
Soil-water data for controlling soil:
Soil name ____
Location of sample ____
Moisture determination method ____

Depth	Texture	AWC (in)*	SWD (%)*	SWD (in)
	Totals			

$$\text{MAD}^* \text{ (in)} = \frac{\text{MAD (\%)}}{100} \times \text{total AWC (in.)} = \frac{\quad x \quad}{100} = \_\_\_\_\_ \text{ in.}$$

Comments about soils: ____

Typical irrigation duration ________ hr, irrigation frequency _________days
Typical number of irrigations per year __________________________
Annual Irrigation Requirement __________ inches
Type of delivery system (gated pipe, turnouts, siphon tubes) _______________

Delivery system size data (pipe size and gate spacing, tube size and length, turnout size) ____

Border Spacing:_____ ft, Strip Width _____ft, Wetted Width _____ft,
Length _______________ ft

FIELD OBSERVATIONS

Crop uniformity ____

Uniformity of water spread across border ____________________________________

Other observations ____

* MAD = Management allowed deficit AWC = Available water capacity
SWD = Soil water deficit

PROFILE AND CROSS SECTION

LANDUSER ____________________

DATE ____________________

FIELD OFFICE ____________________

CROSS SECTION at sta.

DISTANCE - feet

PROFILE

ROD READING OR ELEVATION - feet

DISTANCE (stations) - feet x 100

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

CYLINDER INFILTROMETER TEST DATA

SCS-ENG-322
02-85

FARM	COUNTY	STATE	LEGAL DESCRIPTION	DATE
SOIL MAPPING SYMBOL	SOIL TYPE		SOIL MOISTURE: 0' - 1' - % OF AVAILABLE 1' - 2' - % OF AVAILABLE	
CROP	STAGE OF GROWTH			
GENERAL COMMENTS				

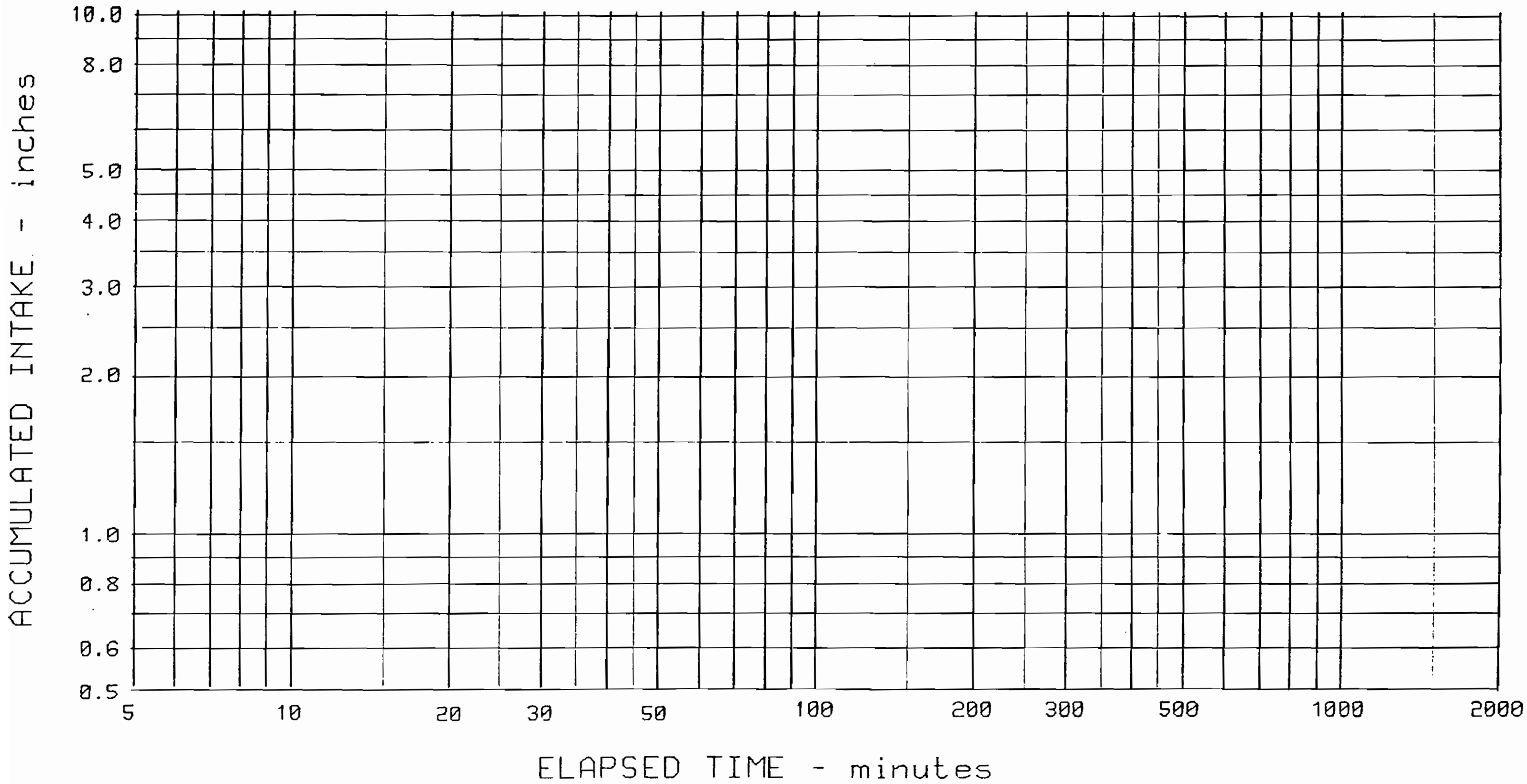
ELAPSED TIME	CYLINDER NO. 1			CYLINDER NO. 2			CYLINDER NO. 3			CYLINDER NO. 4			CYLINDER NO. 5			AVERAGE ACCUM. INTAKE
	TIME OF READING	HOOK GAGE READING	ACCUM. INTAKE	TIME OF READING	HOOK GAGE READING	ACCUM. INTAKE	TIME OF READING	HOOK GAGE READING	ACCUM. INTAKE	TIME OF READING	HOOK GAGE READING	ACCUM. INTAKE	TIME OF READING	HOOK GAGE READING	ACCUM. INTAKE	
MIN.		INCHES	INCHES		INCHES	INCHES		INCHES	INCHES		INCHES	INCHES		INCHES	INCHES	
0																
5																
10																
20																
30																
45																
60																
90																
120																
180																
240																

CYLINDER INFILTROMETER CURVES

LANDUSER ______________________

DATE ______________________

FIELD OFFICE ______________________



SURFACE SYSTEM EVALUATION WORKSHEET B

GRADED BORDERS
INFLOW/OUTFLOW DATA

Landuser ____________________ Date __________ Field Office ____________________

DATA: Inflow __________ Outflow _____

Type of Measuring device ____

Clock 1/ Time	Elapsed Time (min)	T (min)	Gage H ( )	Flow Rate ( )	Average Flow Rate ( )	2/ Volume (ac-in)	Cum. Volume (ac-in)
Turn on ( )		//////			//////	//////	//////
Turn off ( )							

Total Volume (ac-in) ________

Average flow rate =

$$\frac{\text{Total irrigation volume (ac-in) x 60.5}}{\text{Inflow time (min)}} = \underline{\qquad\qquad} = \underline{\qquad\qquad}\text{cfs}$$

Unit flow:

$$qu = \frac{\text{Average flow rate (cfs)}}{\text{Border strip spacing (ft)}} = \underline{\qquad\qquad\qquad} = \underline{\qquad\qquad}\text{cfs/ft}$$

1/ Use a 24-hour clock reading; i.e., 1:30 p.m. should be recorded as 1330
2/ Flow rate to volume factors:

To find volume using cfs:
volume (ac-in) = .01653 x time (min) x flow (cfs)

To find volume using gpm:
volume (ac-in) = .00003683 x time (min) x flow (gpm)

SURFACE SYSTEM EVALUATION WORKSHEET C

GRADED BORDERS
ADVANCE AND RECESSION DATA

Landuser ________________ Date ________ Field Office ____________________

	Advance Time			Recession Time			
Station (ft)	Clock* Time	ΔT (min)	Elapsed Time 1/ (min)	Clock* Time (min)	ΔT (min)	Elapsed Time 1/ (min)	Opportunity Time (To)
0+00	////////	///////	/////////	Turn off ( )	////// lag	///////////	inflow T 2/ ( )
0+00	Turn on ( )	///////	0		( )		
		/////////			//////		

* Use a 24-hour clock reading: i.e., 1:30 p.m. should be recorded as 1330

1/ Time since water was turned on.

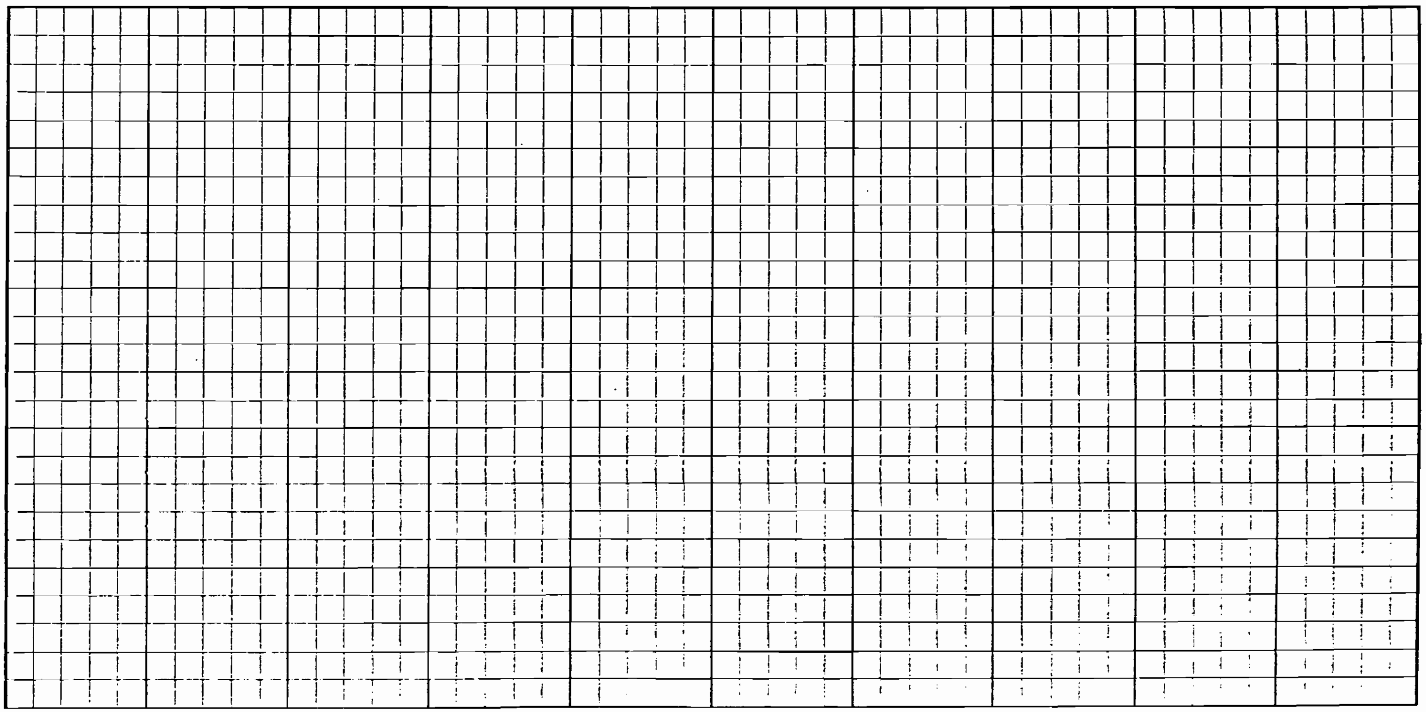
2/ Inflow time = Turn off time - Turn on time

ADVANCE AND RECESSION CURVES

LANDUSER ______________________

DATE ______________________

FIELD OFFICE ______________________



SURFACE SYSTEM EVALUATION WORKSHEET D

GRADED BORDERS
DEPTH INFILTRATED DATA

Landuser ______________________ Date __________ Field Office ____________

Station	Opportunity Time 1/ To (min)	Average Intake Curve Depth 2/ Infil. (in)	Average Intake Curve Av Depth Infil. (in)	Adjusted Intake Curve Depth 3/ Infil. (in)	Adjusted Intake Curve Av Depth Infil. (in)
0 + 00					
			----------		----------
			----------		----------
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			----------		----------
			----------		----------
			----------		----------
Sum of depths			______		______

1/ Difference in time between advance and recession curve.
2/ From "average" cumulative intake curve.
3/ From "adjusted" cumulative intake curve.

Average depth infiltrated

$$= \frac{\text{Sum of depths (average)}}{\text{Length (hundreds of feet- extended)}} = \frac{\qquad}{} = \underline{\qquad}\text{ in}$$

Extended border area (acres)

$$= \frac{\text{Extended border length x wetted width}}{43,650} = \frac{\qquad}{43,560} = \underline{\qquad}\text{ acres}$$

Actual average depth applied to extended border length

$$= \frac{\text{Av inflow (cfs) x duration (hr)}}{\text{Extended border area (acres)}} = \underline{\qquad} = \underline{\qquad}\text{ in}$$

Average depth infiltrated (adjusted)

$$= \frac{\text{Sum of depths (adjusted)}}{\text{Length (hundreds of feet- extended)}} = \underline{\qquad} = \underline{\qquad}\text{ in}$$

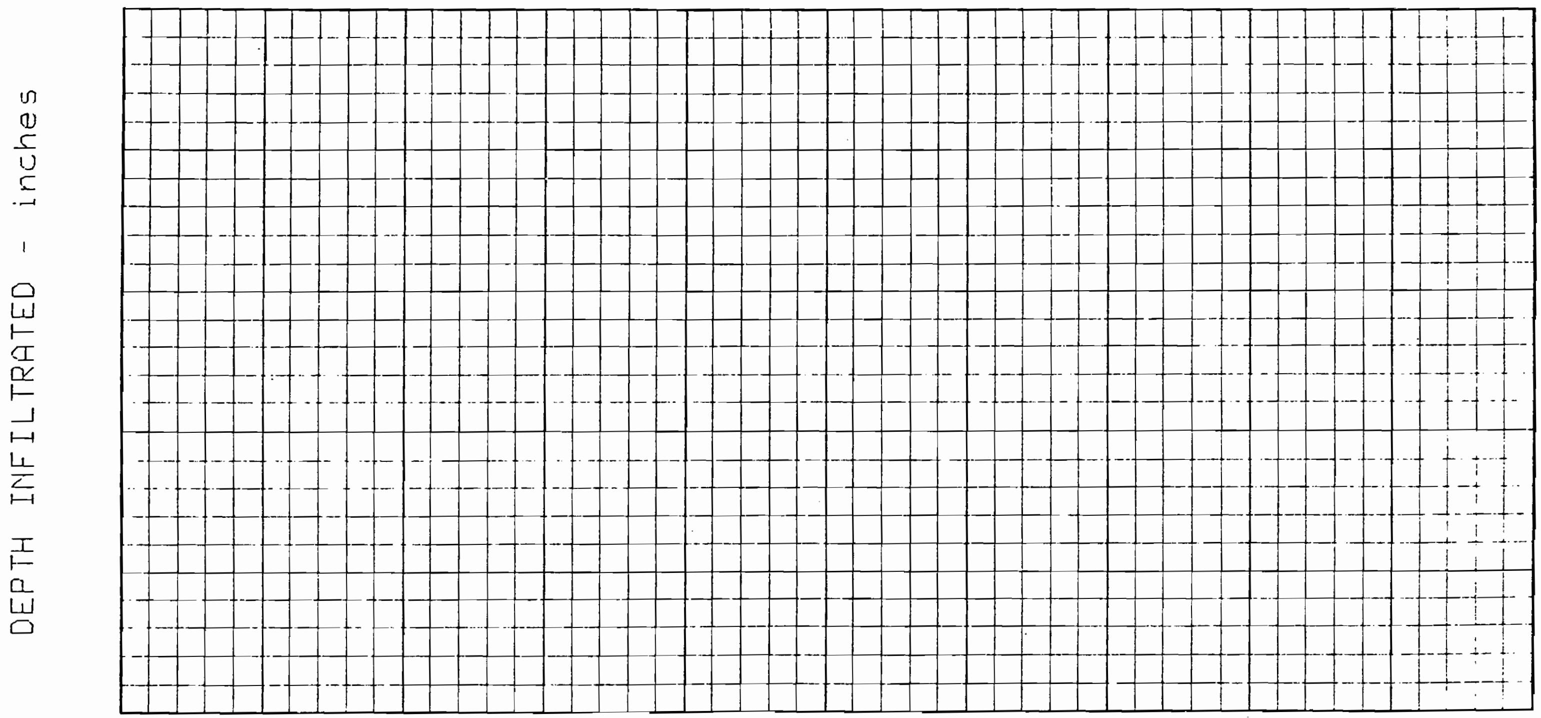
(Should be close to actual depth applied)

DEPTH INFILTRATED CURVE

LANDUSER ______________________

DATE ______________________

FIELD OFFICE ______________________



SURFACE SYSTEM EVALUATION WORKSHEET E

GRADED BORDERS
EVALUATION COMPUTATIONS

Landuser ______________________ Date __________ Field Office _____________

1. Average depth infiltrated low 1/4 (LQ):

$$\text{Low 1/4 strip length} = \frac{\text{Actual strip length}}{4} = \frac{\_\_\_\_\_\_}{4} = \_\_\_\_\_\_\_\_ \text{ ft.}$$

$$LQ = \frac{\text{Depth inf. at begin of L1/4 strip + Depth inf. at end of L1/4 strip}}{2}$$

$$= \frac{\_\_\_\_\_\_\_\_}{2} = \_\_\_\_\_ \text{ in.}$$

2. Areas under depth curve:

   1. Whole curve ______________ sq. units
   2. Runoff ______________ sq. units
   3. Deep percolation ______________ sq. units
   4. Low quarter infiltration ______________ sq. units

3. Actual border strip area:

$$= \frac{\text{Actual border length x Wetted width}}{43{,}560} = \frac{\_\_\_\_\_\_\_\_}{43{,}560} = \_\_\_\_\_\_\_ \text{ acres}$$

4. Distribution Uniformity low 1/4 (DU):

$$DU\% = \frac{\text{Low quarter infiltration area x 100}}{\text{(Whole curve area - Runoff area)}} = \_\_\_\_\_\_\_\_ = \_\_\_\_\_\_\_\_ \%$$

5. Runoff (RO):

$$RO\% = \frac{\text{Runoff area x 100}}{\text{Whole curve area}} = \_\_\_\_\_\_\_\_\_\_ = \_\_\_\_\_\_\_\_\_ \%$$

$$RO \text{ (in.)} = \frac{\text{Total irrigation volume (ac-in) x RO\%}}{\text{Act. strip area (ac) x 100}} = \_\_\_\_\_\_\_ = \_\_\_\_\_ \text{ in.}$$

SURFACE SYSTEM EVALUATION WORKSHEET E (continued)
GRADED BORDERS
EVALUATION COMPUTATIONS

Landuser ____________________ Date __________ Field Office ______________

6. Deep Percolation (DP):

$$DP\% = \frac{\text{Deep percolation area} \times 100}{\text{Whole curve area}} = \_\_\_\_\_\_\_\_ = \_\_\_\_\_\_\_\_\ \%$$

$$DP(in) = \frac{\text{Total irrigation volume (ac-in)} \times DP\%}{\text{Act. strip area (ac)} \times 100} = \_\_\_\_\_\_\_\_ = \_\_\_\_\_\_\ \text{in.}$$

7. Gross application (Fg):

$$Fg = \frac{\text{Total irrigation volume (ac-in)}}{\text{Act. strip area (ac)}} = \_\_\_\_\_\_\_\_ = \_\_\_\_\_\_\ \text{in.}$$

8. Application efficiency (Ea):

Average depth stored in root zone = soil water deficit (SWD) if entire root zone depth will be filled to field capacity by this irrigation. Otherwise, use Fg (in.) - Ro (in.)

$$Ea(\%) = \frac{\text{Av. depth stored in root zone} \times 100}{\text{Gross application (in.)}} = \_\_\_\_\_\_\_\_ = \_\_\_\_\_\_\ \%$$

9. Application efficiency low 1/4 (Eq)

$$Eq(\%) = \frac{DU(\%) \times Ea(\%)}{100} = \frac{\_\_\_\_\_\_\_\_}{100} = \_\_\_\_\_\_\ \%$$

10. Average Net Application

$$= \frac{\text{Total irrigated volume (ac. in)} \times Ea(\%)}{\text{Act. strip area (ac)} \times 100} = \_\_\_\_\_\_\_\_ = \_\_\_\_\_\_\ \text{in.}$$

SURFACE SYSTEM EVALUATION WORKSHEET F

GRADED BORDERS
RECOMMENDATIONS & COST SAVINGS

Landuser ____________________ Date __________ Field Office ____________________

Time factors:

Required opportunity time to infiltrate soil water deficit of _______ inches:
To = ______________ min (____________ hr - ____________ min)

Estimated required irrigation inflow time from adv.-recession curves:
Tin = ______________ min (____________ hr - ____________ min)

At inflow rate of:
Q = ______________ cfs Per border strip

POTENTIAL WATER AND COST SAVINGS

Present management:

Estimated present average net application per irrigation ____________ inches

$$\text{Present gross applied per year} = \frac{\text{Net applied per irrig.} \times \text{No. irrig.} \times 100}{\text{Application Efficiency (Ea) 1/}}$$

= ______________________ = ____________ inches

Potential Management:

Annual net irrig requirement __________ inches, for ________________ (crop)

Potential application efficiency (Epa) ____________ percent (from irrigation guide, NEH or other source)

$$\text{Potential annual gross applied} = \frac{\text{Annual net irrigation requirement} \times 100}{\text{Potential application efficiency (Epa)}}$$

= __________ = __________ inches

Total annual water conserved

$$= \frac{\text{(Present gross applied - Potential gross applied)} \times \text{Area irrig. (ac)}}{12}$$

$= \frac{\rule{8em}{0.4pt}}{12}$ = ____________ acre feet

1/ Use the best estimate of what the application efficiency of a typical irrigation during the season may be. The application efficiency from irrigation to irrigation can vary depending on the SWD, set times, etc.

SURFACE SYSTEM EVALUATION WORKSHEET F (Continued)

GRADED BORDERS
RECOMMENDATIONS & COST SAVINGS

Landuser ____________ Date ________ Field Office ____________

Annual Cost Savings:

From pumping plant evaluation:

Pumping plant efficiency ________ Kind of fuel ____________

Cost per unit of fuel ________ fuel cost per acre foot $______

Cost savings = Fuel cost per acre foot x acre feet conserved per year
= ________________ = $________________

Water purchase cost

= Cost per acre foot x acre feet saved per year = $________________
= $____________

Cost savings = Pumping cost + water cost =
____________ = $________

RECOMMENDATIONS

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IRRIGATION TRAINING SERIES

MODULE 911

GRADED BORDER IRRIGATION EVALUATION

CERTIFICATION OF COMPLETION

This is to certify that ______________________________
(full name)

completed Module 911, Graded Border Irrigation Evaluation,

on ______________________ and should be credited with training hours

as follows:

______ Study Guide and Facilitator's Example Problem (12 Hours)

______ Field Evaluation (16 Hours)

Total Training:________ Hours

Signed ___________________________ ______________________________
Supervisor/Trainer Participant

Completion of Module 911, Graded Border Irrigation Evaluation (as recorded above) is acknowledged and documented in the above named employee's record.

Signed ___________________________ ____________________
Training Officer Date