TRAINING MANUAL FOR ON-FARM ANALYSIS OF IRRIGATION SYSTEMS

How-To-Do-It-Series

Volume II

By

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HOW-TO-DO-IT SERIES

Preface

Volume I of the Problem Identification Training Manual consists of a number of short, technical "How-To-Do-It" articles. The purpose of these articles is to provide specific instructions on how to carry out the tasks of problem identification. The How-To-Do-It series is merely a supplement to the problem identification process (Volume I) and therefore the skills presented here are some of the tools necessary to complete a problem identification study.

The format of this volume will be organized along the following major categories:

1) How-To-Do Methodologies related to the farmer's field;
2) How-To-Do Methodologies related to the irrigation water;
3) How-To-Do Methodologies related to the farmer's socio economic network.

This methodology series is meant to provide all trainees with methods of how to perform specific field tasks in problem identification. The actual execution of these methods, however, requires training for discipline members of field teams. The particular methods to be used depends on the actual field situation and type of problems being investigated. Each team member should keep in mind that this volume contains methods which will help team members in problem identification.

Additional How-To-Do Methodologies will be provided to the trainees during the Training Program.

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GROUNDWATER MONITORING TECHNIQUES

by Dan Sunada

INTRODUCTION

The most common method for obtaining groundwater levels are through the use of observation wells and piezometers. The observation wells are cased with either steel or plastic perforated pipe.

Usually the observation wells are installed on a grid system and usually in clusters at each location when the aquifer is stratified. The clusters of wells are installed at differing depths so that information on the individual stratum can be identified. When detailed information on water levels are needed (i.e. near canals and drains), a line of well may be installed to better define the hydraulic gradient. Detailed driller's logs should be obtained in order to identify the types and composition of the individual strata, their thickness, and the thickness of the total aquifer. Information from the driller's log will also provide information for the depths of the wells. Shallow wells (less than 5 meters) can also be installed by project personnel when the well casing can be driven using a well point of a small drilling rig. Of course, driller's log information may not be obtainable from this type of installation.

After the observation wells have been installed, much data can be collected on the hydraulic conductivity, specific yield, and storage coefficients, transmissibility, and other values. The water should be sampled for laboratory analysis once for reference and periodical field measurement of electrical conductivity should be made. The water table elevations should be periodically measured and recorded for each well with some wells measured continuously by recorders. Each well should be provided with a cap to keep debris and small children playing in the area from destroying the usefulness of the wells. In addition, the wells should be periodically flushed to insure representative flows and water quality information.

Piezometers are small diameter pipes perforated only at the descend depth. Piezometers are used to obtain a measure of the hydraulic potential of the aquifer at the depth corresponding to the perforation of the piezometer. Piezometers may also be used to collect water quality samples for laboratory analysis.

Piezometers are also installed on a grid systems (usually fairly close to the wells) and in a cluster arrangement. Under good conditions with few large rocks, piezometers can often be installed by project personnel by use of a jetting rig by which water is forced through the piezometer pipe as it is lowered into the ground (Mickelson et al., 1961); (Donnan and Bradshaw, 1952). The force of the water jet removes the unconsolidated particles. Piezometers are also often driven into place. Information on the installation and evaluation of piezometers is presented by the USDI-USBR (1964), Reeve and Jensen (1949), Bornstien and Alberts (1963), Myers and Van Bavel (1962), and Donnan and Bradshaw (1952).

When selecting the sites for observation wells and piezometer installations, they should be located where vehicular traffic, farming equipment, or road maintenance equipment will not disturb or remove the upper portions of the pipes.

The water level measurements for piezometers and wells are usually measured from the top of the pipe to the water level. Therefore, in order to relate all the data from all of the wells and piezometers in a grid system, it is necessary to determine the elevations of the tops of each well and piezometer casing, and thereby the respective water level elevations for each well and piezometer.

Equipment for water sampling and depth to water determinations are commercially available. However, it often becomes necessary to construct equipment to meet the specific requirements of the project installations.

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PROCEDURE FOR OBSERVATION WELL INSTALLATION

by Alan Early and Nasir Ahmed[*]

When plans are being formulated to provide the irrigation water during the growing season, a knowledge of the amount of water which might be available from the soil itself is valuable information. The possibilities that the water table rises so high as to reduce crop production should also be evaluated. Both the depth of the water table and its fluctuations during the growing season are important.

Instructions for the field engineer are outlined below which will aid in the installation of observation wells. These, in turn, provide the means for measuring water table levels and fluctuations, as necessary, beneath a watercourse system.

Procedure for Installation

1. Survey the hand pumps, open wells, ponds, etc. throughout the area involved. Note the depth to the water table of each, on the attached form. If the depth exceeds 20 feet, contributions from the water table to plant needs will be negligible.
2. Consult well drillers, water users, hydrologists, etc., acquainted with the area and get their opinions as to the normal annual fluctuation of the water table from the current levels. Design the observation wells tube at 2 feet (60 cm) deeper than the lowest water table level expected. The observation wells should, when possible, be placed at field intersections.
3. Auger the hole. (A screw type auger may be used for clay or silt soils. A bucket type auger is satisfactory for all soil textures.) Bore to a level at least two feet (60 cm) lower than

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[*] This article was taken from The Problem Identification Handbook (April 1, 1980). Developed by the CSU-Pakistan Water Management Project sponsored by U.S. Agency for International Development Contract No. AID/TAC-1100.

the expected lowest level of the water table. The diameter of the augered hold should match the outside diameter of the pipe.* Available augers larger than the pipe may be used, but the pipe will not be as firmly anchored and secured from theft.

4. If available, pour coarse sand or pea gravel into the hole in quantity sufficient to fill the bottom 6" (15 cm).
5. Excavate a collar-shaped area, 1 foot (30 cm) in diameter, around the pipe. Fill this excavation with concrete to the level of the surface of the surrounding soil. The primary purpose of this concrete collar is to reduce the possibility of theft, and it may be eliminated is the area is secure.

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*The top of the pipe should be about 4" (10 cm) above the surface of the ground and should be threaded to accept a cap which can be screwed on with pipe wrenches. When the well is not attended, the cap should always be screwed on with sufficient force that it cannot be opened manually by irresponsible persons who might drop soil and debris into the well.

SUGGESTED TABULATION FORM

WATERCOURSE

Date	Type of Observation	Depth of WT	Location	HMT

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MEASUREMENT OF HYDRAULIC CONDUCITIVITY
by The Auger Hole Method

adapted by I. Garcia

Object: To measure saturated hydraulic conductivity in the field using the auger-hole method.

INTRODUCTION

Hydraulic conductivity is defined as a measure of the ease with which water can be transmitted through a porous material. The hydraulic conductivity is also defined as the physical property which can be measured and expressed as a proportionality factor (K) in the Darcy equation,

$$q = - K \frac{\Delta H}{\Delta L} , \qquad (1)$$

where q is the volume flux $(L\ t^{-1})$ and $\Delta H/\Delta L$ which is the hydraulic gradient $(L\ L^{-1})$. In this equation, the hydraulic conductivity K $(L\ T^{-1})$ depends both on the nature of the porous medium (soil) and the physical properties of the fluid (water).

Measurements of saturated hydraulic conductivity are used in the analysis of any saturated soil water-flow system. These include drainage of soils for agricultural; drainage of highways, airports, and construction sites; and the determination of seepage below dams.

PRINCIPLES

The auger hole method of measuring the hydraulic conductivity of soil is illustrated in Figure 1. (1) A cylindrical hole is augered into a body of soil that is water saturated. (2) Water is allowed to seep into and fill the auger hole to the level of the water table. (3) The depth H of the hole below the water table is measured. (4) Some or all of the water in the auger hole is quickly removed to a distance y below the water table. Finally, (5) The rate of rise of water in the auger hole, which is related to the hydraulic conductivity of the soil, is measured.

In Figure 1, r is the radius of the auger hole and S is the distance from the bottom of the auger hole to the impermeable barrier.

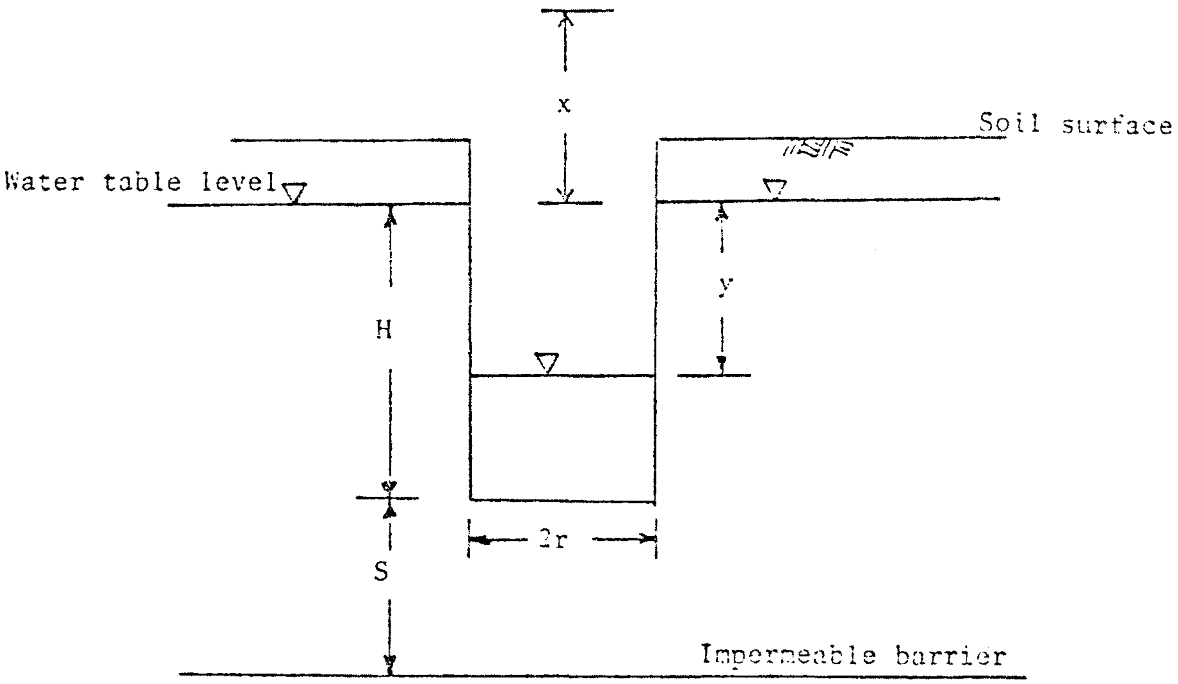

Figure 1. The auger hole method.

The relationship between the observed rate of rise of water in the auger hole and the hydraulic conductivity is expressed by

$$K = - C \frac{dy}{dt} , \tag{2}$$

where C is the shape factor (see below) of the auger hole, dy is the change in water height in the auger hole (cm) that occurs in time dt (sec) and K is the hydraulic conductivity ($m\ day^{-1}$). The mixed units m/day, cm and sec, in Equation 2 are used for practical work. If homogeneous units are used, then Equation 2 becomes

$$K = - \frac{C}{864} \frac{dy}{dt} , \tag{3}$$

where K and dy/dt have the same units and C/864 is dimensionless.

The values of C in Table 1 were obtained using auger hole seepage theory (Boast and Kirkham, 1971). The values of C are for a wide range of auger hole geometries. The shape of the auger hole is characterized by the ratio of the length of the auger hole below the water table H to the radius of the auger hole r. Table 1 contains C values for auger holes of seven values of H/r ranging from H/r = 1 to H/r = 100 (a quite small diameter auger hole). For each of the seven values of H/r, C is shown for

Table 1. Values of C for Equation 2 for auger holes underlain by impermeable or infinitely permeable material (Boast and Kirkham, 1971).

H/r	y/H	S/H								S/H
		0	0.05	0.1	0.2	0.5	1	2	5	∞
1	1	447	423	404	375	323	286	264	255	254
	0.75	469	450	434	408	360	324	303	292	291
	0.5	555	537	522	497	449	411	386	380	379
2	1	186	176	167	154	134	123	118	116	115
	0.75	196	187	180	168	149	138	133	131	131
	0.5	234	225	218	207	188	175	169	167	167
5	1	51.9	48.6	46.2	42.8	38.7	36.9	36.1		35.8
	0.75	54.8	52.0	49.9	46.8	42.8	41.0	40.2		40.0
	0.5	66.1	63.4	16.3	38.1	53.9	51.9	51.0		50.7
10	1	18.1	16.9	16.1	15.1	14.1	13.6	13.4		13.4
	0.75	19.1	18.1	17.4	16.5	15.5	15.0	14.8		14.8
	0.5	23.3	22.3	21.5	20.6	19.5	19.0	18.8		18.7
20	1	5.91	5.53	5.30	5.06	4.81	4.70	4.66		4.64
	0.75	6.27	5.94	5.73	5.50	5.25	5.15	5.10		5.08
	0.5	7.67	7.34	7.12	6.88	6.60	6.48	6.43		6.41
50	1	1.25	1.18	1.14	1.11	1.07	1.05			1.04
	0.75	1.33	1.27	1.23	1.20	1.16	1.14			1.13
	0.5	1.64	1.57	1.54	1.50	1.46	1.44			1.43
100	1	0.35	0.35	0.34	0.34	0.33	0.32			0.32
	0.75	0.38	0.38	0.37	0.36	0.35	0.35			0.35
	0.5	0.47	0.47	0.46	0.45	0.44	0.44			0.44

auger holes that are empty, one-fourth full and half full. For each of these 21 cases, C values are shown for auger hole with an impermeable barrier at various dimensionless distances S/H.

SPECIAL APPARATUS (Figure 2)

1. Soil auger or a commercial drilling rig.
2. Permeable material for casing the auger hole to prevent caving. Materials used for casing auger holes may be thin perforated sheet metal pipe, perforated stovepipe, drain til, thin perforated PVC Pipe, etc.
3. Water elevation indicator. The indicator device consist of a float lowered into the auger hole and connected to a counter weight with a tape. This tape is mared, at equal time intervals, as the water level rises in the auger hole.

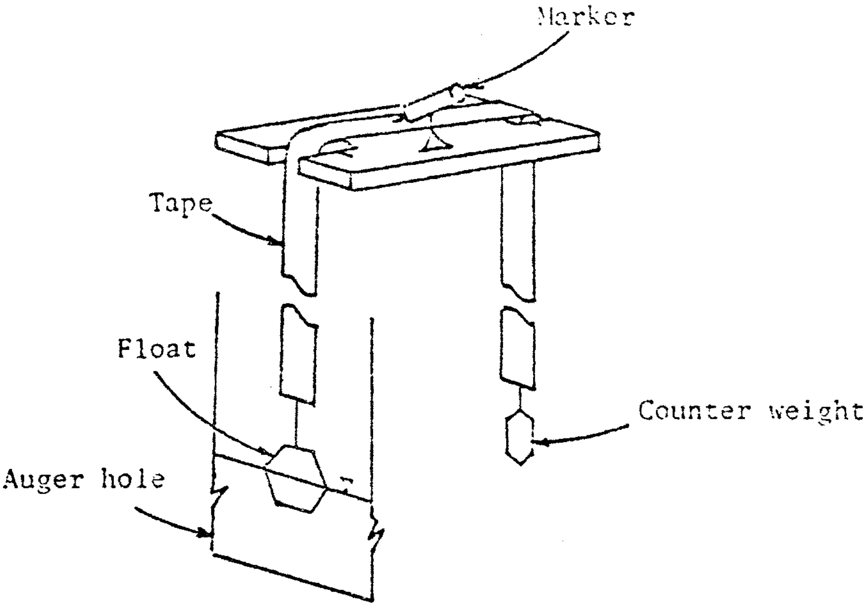

Figure 2. Water elevation indicator device.

4. Pump system to quickly removing water from the auger hole.

PROCEDURE

In the following discussion, the installation of the auger hole (Steps 1 through 4) is done before determining the hydraulic conductivity. Successive steps (5 through 9) are done several times so that more than one estimate of the hydraulic conductivity can be made.

1. A vertical hole is dug with a soil auger or by another method to the desired depth below the water table.
2. Install the permeable case in the hole, leaving the end of the case several centimers above the soil surface. The pipe or tile used as a casing should be back-filled properly to insure free flow of groundwater into and out of the auger hole. The proper way to install the casing is to place a small quantity of gravel on the bottom of the hole and set the open pipe on this gravel. Gravel is then back-filled around the pipe to a level above the water table. The original soil can be used to fill the remaining portion of the hole around the pipe to the soil surface. The auger hole should be capped for protection.
3. Pump the hole several times until clean water is obtained.
4. Allow the water to seep into and fill the auger hole to the level of the water table. This will require at least a day for heavy, tight soils. In the case of permeable sand soils, only a few minutes are needed.
5. When the water in the auger hole is at water table level, lower the float into the auger hole and mark a datum point on the tape.
6. Pull the float out of the auger hole.
7. Pump out or bail the water quickly.
8. Lower the float into the auger hole and mark the tap at frequent, equal, time intervals as the water level rises in the auger hole.
9. From the datum point, determine the distance y.

CALCULATIONS

Table 1 enables one to determine the hydraulic conductivity of a soil K, from measured values of the rate of water rising in the auger hole $-dy/dt$, and the relationship expressed in Equation 2. Intermediate values of C can be obtained by interpolation. For accurate work use logarithmic interpolation of C, and H/r at some known value of y/H, as explained below.

Sample calculation

To show the calculation, we present an example in Figure 3.

The readings of water level in the auger hole y as a function of time were:

Time (sec)	y (cm)
10	106
20	93
30	81
40	69
50	59
60	48
70	40
80	33
90	26
100	21

According to Figure 3a $H/r = 30$, y/H is taken at 0.5 and the depth to the impermeable barrier, S, is not known. We therefore estimate C for the two extreme cases i.e., $S = 0$ and $S = 00$. Since we do not have values of C corresponding to an H/r of 30 in Table 1 a logarithmic interpolation is required (Figure 4). It is found that the value of C corresponding to an H/r of 30 is between 3.21 ($S = \infty$) and 3.80 ($S = 0$). We therefore choose a value between these two extremes say, $C = 3.51$.

The rate of change in the height of water in the auger hole, obtained in Figure 3b was $-dy/dt = 1.22$ cm/sec. Thus, using the above values in Equation 2 we find the hydraulic conductivity.

$$K(\text{m/day}) = (1.22)(\text{cm/sec})(3.51) = 4.28 \text{ m/day}.$$

COMMENTS

The advantages of using the auger hole method for hydraulic conductivity determinations are as follows:

1. The soil is not disturbed (original conditions in the field).
2. The "sample" is large and takes into account many types of water channel in the soil.
3. The fluid used is the soil solution itself and not tap water or distilled water having unknown effects.
4. The method is not unduly time-consuming.

A series limitation inherent in the auger hole method is that the presence of a water table is required and preferably it should not be too low. This means that in most locations only a few opportunities for measurements are available each year, most probably in spring. In some locations the condition may be favorable all through the year; in others this method will never be applicable.

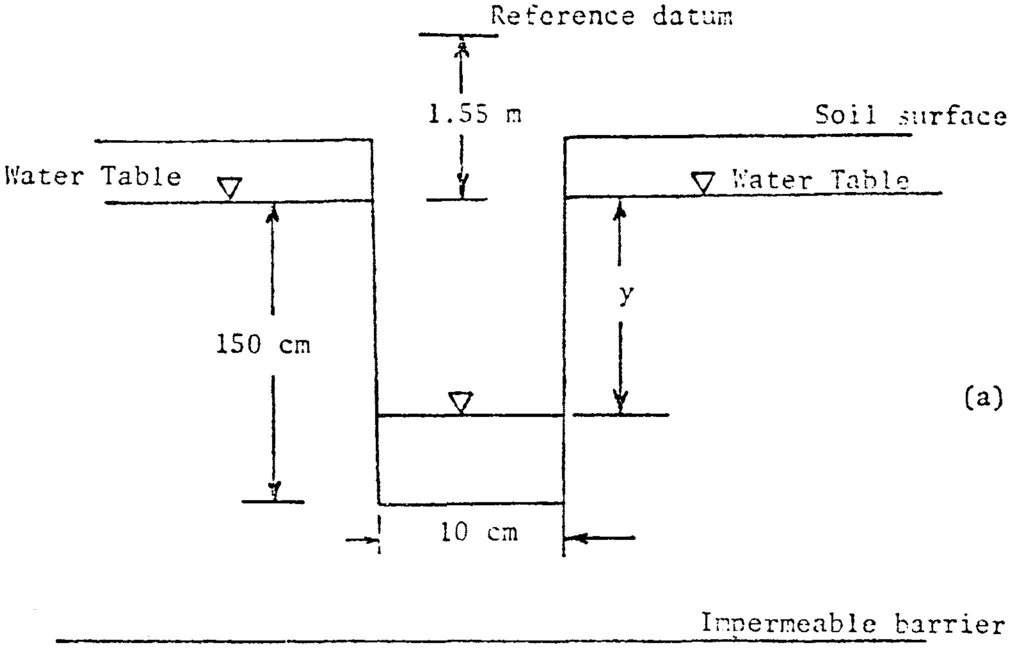

Figure 3a. Dimensions of the example auger hole.

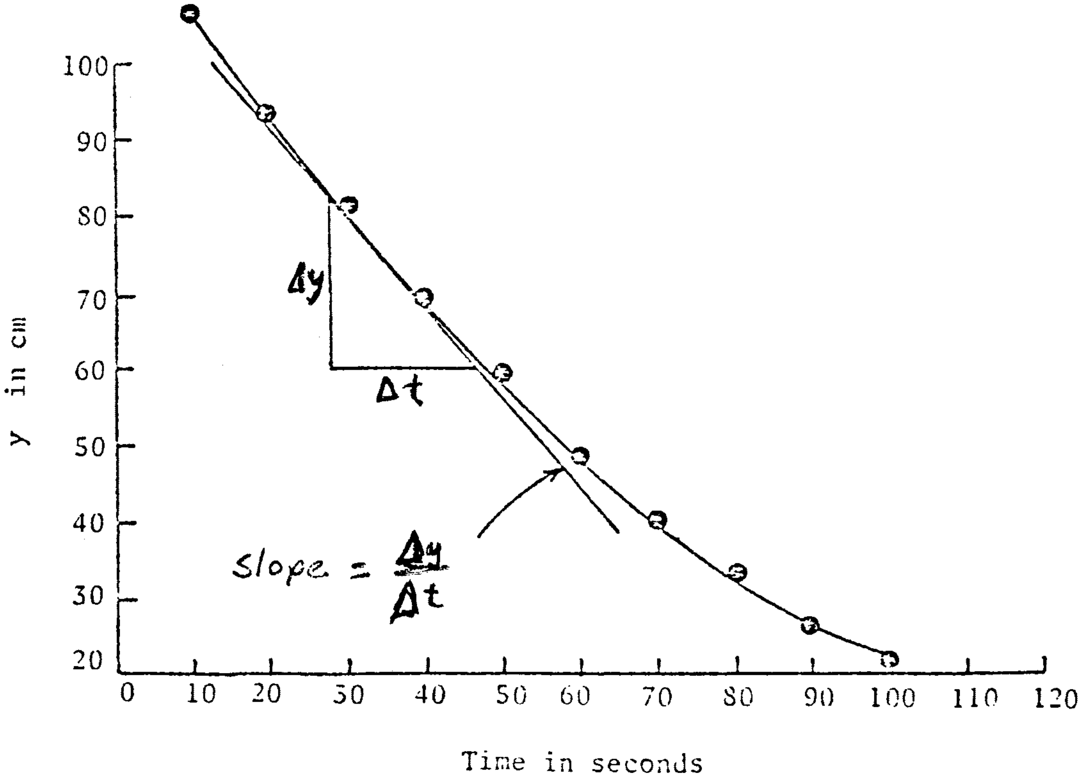

Figure 3b. Relationship between values of y and time.

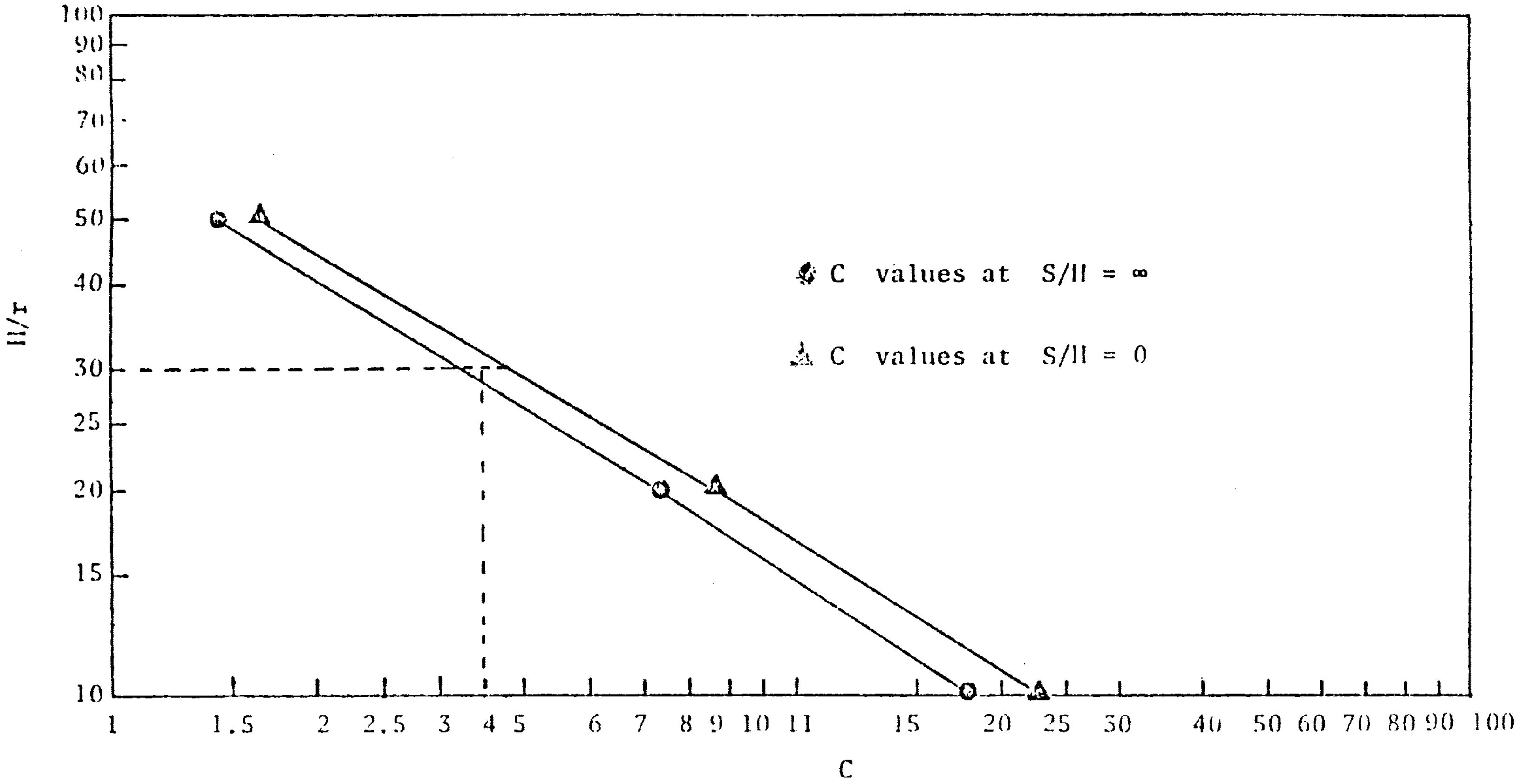

Figure 4. Logarithmic interpolation of C and H/r at y/H = 0.5.

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SOIL CLASSIFICATION

by L. Willardson and D. Sunada

INTRODUCTION

A bulk volume of soil may contain four major constituents, inorganic solids (minerals), organic solids, liquid (usually water), and air. Different soils contain varying amounts of each constituent and the nature of each constituent may vary. Soil classification is a systematic method of analyzing these constituents and describing the soil by use of standardized quantitative tests. Since the soil descriptions are based on definite tests, anyone using the classification systems should be able to arrive at the same soil classification.

Unfortunately, no single classification system is capable of describing all the significant aspects of a soil to every person who uses it. An adequate agricultural soil classification may present very little useful information to an agronomist of geologist. Therefore, each field of study involved with soils has its own (or several) classification system. The system presented here is that used by the United States Department of Agriculture, and is internationally used in agricultural studies.

SOIL TEXTURE

The USDA soil classification systems is based on soil texture, or the relative proportions of various size groups of mineral particles in a given soil. Inorganic soils may be divided into four components which are, in order of decreasing size, gravel, sand, silt, and clay. The limiting particle diameters for each of these components or soil separates is given in Table 1. The soil classification by finding the proportions by weight of sand, silt, and clay in the soil. Figure 1 is then entered and the intersections of the proper proportions determinates the soil textural classification.

Table 1. Particle diameter of soil separates.

Soil Separate	Particle Diameter (mm)
Gravel	2.0
Very Coarse Sand	2.0 - 1.0
Coarse Sand	1.0 - 0.5
Medium Sand	0.5 - 0.25
Fine Sand	0.25 - 0.10
Very Fine Sand	0.10 - 0.05
Silt	0.05 - 0.002
Clay	0.002

Adapted from p. 1-2, Section 15 - Irrigation, SCS National Engineering Handbook, USDA, 1964.

Example: A soil is found to have 12% sand, 53% silt, and 35% clay. The intersection of these proportions on Figure 1 lies in the zone marked silty clay loam.[*]

It is necessary to perform a grain size analysis on the soil to find its textural proportions. The simplest method of separating different sized particles is by passing them through a series of wire mesh sieves which are stacked in order of decreasing mesh openings. The soil is deposited on the top sieve and the stack is shaken. The particles smaller than the mesh opening will pass through and fall on the next finer mesh. When the soil has been properly shaken, the sieves may be taken apart and the amount of soil retained on each sieve may be weighed. Using this information, the percentages may be computed.

This system works satisfactorily for the coarse sized particles, the sands, and gravels. The weight of the finer particles is so small that they generally do not pass through the small mesh openings. The finest sieve that these particles will normally pass is the #200 sieve which has openings of 0.074 mm. They may also adhere to the sides of the coarse particles and can affect the accuracy of the weighings of that fraction. Ways have been developed to deal with both of these problems.

To make an accurate analysis of the coarse fraction, the fine portion of the soil may be washed away so that the coarse fraction is left. This is normally accomplished by placing the soil on a #200 sieve mesh and spraying water through the mesh and soil. The soil is then dried and a normal sieve analysis can be run on the remaining material.

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[*] The following two pages are from Chapter I--Soil-Plant-Water Relationship, Section 15 - Irrigation, Soil Conservation Service National Engineering Handbook, U.S. Department of Agriculture, 1964.

The grain size analysis is usually conducted on the fine fraction of the soil by means of a hydrometer analysis. In this test, the fine fraction of a soil is carefully mixed in a cylinder full of water and the mixture is allowed to settle with time. As the soil particles settle, the specific gravity of the mixture changes. The amount of material still in suspension can be estimated by the difference between the specific gravity of the mixture and the specific gravity of just the liquid without the soil particles.

The specific gravity is measured by a hydrometer, a glass bulb with a stem which has a calibrated scale inside it. The hydrometer is placed in the mixture and the scale in the stem is read. This reading gives an indication of the amount of soil in suspension. The diameter of the soil particles is approximated by use of Stokes Law which relates the velocity of a particle fall in a liquid to its diameter. Therefore, the test consists of taking measurements of the specific gravity to find the percent of material in suspension at particular times to determine the particle diameter.

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SOIL PARTICLE SIZE ANALYSIS BY THE HYDROMETER METHOD

by L. Willardson

Particle size analysis can be made by the hydrometer method for soils having particles smaller than a number 40 (0.425 mm) screen. Sieving is normally used if most of the particles are larger than a number 200 (0.075 mm) screen. The hydromer method is used if most of the particles are smaller than a number 200 screen.

General Procedure

A known weight of soil is thoroughly mixed and dispersed in a known volume of water. The specific gravity of the soil-water suspension is measured with a hydrometer. As the larger heavier soil particles settle out of the solution, the specific gravity of the suspension decreases. A correlation related to the settling velocity of particles is made between time and the specific gravity.

Equipment Needed

1. Stirring apparatus
   Mechanical device or air-jet device
2. Hydrometer - either type
   Type 151H - Calibrated to read specific gravity 1.000 in distilled water at 20 degrees C
   Type 151H - Calibrated in grains of soil per liter (-5 to +60 g/liter)
3. 1000 ml sedimentation cylinder
4. Thermometer accurate to 0.5 C
5. Water bath or constant temperature room

Detailed Procedure

For the hydrometer analysis the sample of all material passing the 2 mm sieve (No. 10) should be about 115 g for sandy soils and 65g for silt and clay soils. Determine the hygroscopic moisture correction factor by weighing out a 10 to 15g portion of the air dried soil and drying in a 110 C oven to a constant mass. The hygroscopic correction factor is the ratio of the mass of the oven dried sample and the mass of the air dried sample.

The remaining 50 to 100g of a carefully weighed air dried sample is placed in a 250 ml beaker and covered with 125 ml of recently prepared sodium hexametaphosphate solution buffered with sodium carbonate to a pH of 8 or 9 (40 g/liter). Stir and allow to soak 12 to 16 hours (sodium hexametaphosphate buffered with sodium carbonate is marketed as "calgon").

Transfer the soaked soil to the stirring apparatus. If the mechanical stirrer is used, additional distilled water should be added to the dispersion cup to fill it more than half full. Stir for one minute.

Care should be taken that all soil is transferred from the dispersion device to the sedimentation cylinder. Distilled water is added to bring the total volume in the sedimentation cylinder to 1000 ml.

The test is started by covering the end of the cylinder with the palm of the hand and tipping the cylinder upside down and back for one minute (30 times). Make sure that all the soil at the bottom of the cylinder is loosened and in suspension. Place the cylinder in a convenient place in the constant temperature room. Hydrometer readings taken at the following intervals of time: 2, 5, 15, 30, 60, 250, and 1440 minutes after the beginning of sedimentation. The hydrometer is slowly immersed in the soil suspension about 30 seconds before each reading to allow it to come to rest before the reading time. Read the hydrometer at the top of the meniscus formed by the suspension around its stem. The reading shall be made to the nearest 0.005 specific gravity for hydrometer type 151-H or the nearest 0.5g per liter for the type 152-H hydrometer. After each reading carefully remove the hydrometer and place it with a spinning motion in a graduate of clean water. Measure and record the temperature of the suspension after each hydrometer reading.

After making the final hydrometer reading, wash the suspension on a 0.075 mm (No. 200) sieve. Dry the fraction retained on the sieve and separate into fractions using 0.425 mm and 0.075 mm sieves and such additional sieves as required. Record the masses retained.

Calculations

Calculate the oven-dried mass of soil used in the hydrometer analysis by multiplying by the hygroscopic moisture correction factor.

Calculate the mass of the total sample represented by the mass of soil used in the hydrometer test by dividing the oven dry mass of the hydrometer sample by the percent of the total sample passing the 2 mm (No. 10) sieve and multiplying by 100. The mass obtained is W in the formulas for calculating the percent remaining in suspension at the level where the hydrometer measures the density of the suspension.

When the 151-H hydrometer is used, P is calculated from:

$$P = \left(\frac{100{,}000}{W}\ \frac{G}{G - G_1}\right)(R - G_1)$$

For the 152-H hydrometer the percentage in suspension is:

$$P = \frac{Ra}{W} \times 100$$

Where: a = correction factor for the 152-H hydrometer reading

P = percentage soil remaining in suspension at the level where the hydrometer measures the suspension density

R = hydrometer reading after subtracting the composite correction defined below

W = oven dry mass of soil in the total test sample represented by weight of soil dispersed (defined in previous paragraph)

G = specific gravity of soil particles

G_1 = the specific gravity of the liquid (G_1 = 1.00)

R = the hydrometer reading (i.e., 1.025)

To obtain the composite hydrometer correction prepare a 100 ml of distilled water and dispersing agent in the same proportion as in the sedimentation test. Place the hydrometer in this mixture and read the top of the meniscus. For the type 151-H hydrometer the composite correction is the difference between the reading and 1.000. For the 152-H hydrometer it is the difference between the reading and zero. The correction is temperature dependent and should be established for the range of temperatures expected in the sedimentation test.

The diameter of particle corresponding to the percentage P above is calculated using Stokes' Law for drag forces on a sphere settling under viscous conditions.

$$F_d = 3\pi\mu VD$$

where F_d is the drag force, μ is the viscosity of the fluid, V is the particle full velocity, and D is the diameter of the sphere. At the terminal velocity, F_d is the buoyant weight of the particle.

$$F_c = (\gamma_s - \gamma_w)\ \pi D^3/6$$

where γ_s and γ_w are the unit weights of the particles and water.

Solving for D,

$$D = \sqrt{\frac{18\mu}{\gamma_s - \gamma_w}} \sqrt{V} \quad \text{or}$$

$$D_{mm} = K \sqrt{L/T}$$

where L is the fall distance of the particle measured in centimeters from the water surface to the center of buoyance of the hydrometer (see Table 2) and T is the time of the reading in minutes (also the fall time). The factor, K, is a function of temperature and specific gravity of the particles. Values of K are tabulated in Table 3.

Table 1. Correction factor "a" for specific gravity (hydrometer 152H).

G	"a"	G	"a"	G	"a"
2.95	0.94	2.75	0.98	2.55	1.02
2.90	0.95	2.70	0.99	2.50	1.03
2.85	0.96	2.65	1.00	2.45	1.05
2.80	0.97	2.60	1.01		

Table 2. Effective depth (L) vs. hydrometer reading.

Hydrometer 151H		Hydrometer 152H			
Reading	L(cm)	Reading	L(cm)	Reading	L(cm)
1.000	16.3	0	16.3	32	11.1
1.002	15.8	2	16.0	34	10.7
1.004	15.2	4	15.6	36	10.4
1.006	14.7	6	15.3	38	10.1
1.008	14.2	8	15.0	40	9.7
1.010	13.7	10	14.7	42	9.4
1.012	13.1	12	14.3	44	9.1
1.014	12.6	14	14.0	46	8.8
1.016	12.1	16	13.7	48	8.4
1.018	11.5	18	13.3	50	8.1
1.020	11.0	20	13.0	52	7.8
1.022	10.5	22	12.7	54	7.4
1.024	10.0	24	12.4	56	7.1
1.026	9.2	26	12.0	58	6.8
1.028	8.9	28	11.7	60	6.5
1.030	8.4	30	11.4		

Table 3. Values of "K" for computing particle diameter in hydrometer analysis.

Temp °C	Specific Gravity - G			
	2.6	2.65	2.7	2.79
16	0.0146	0.0144	0.0141	0.0139
18	0.0142	0.0140	0.0138	0.0136
20	0.0139	0.0136	0.0134	0.0132
22	0.0135	0.0133	0.0131	0.0129
24	0.0132	0.0130	0.0128	0.0126
26	0.0129	0.0127	0.0125	0.0124
28	0.0126	0.0124	0.0122	0.0121
30	0.0124	0.0122	0.0120	0.0118

SIEVE ANALYSIS

Dry mass of sample after washing on 0.075 mm (No. 200) sieve __________ g

Size Opening mm	Sieve No.	Mass Retained g	Cumulative Mass Retained	Mass Passing	% Sediment Sample Passing	% Total Sample Passing

HYDROMETER ANALYSIS

Sample description ________________________________ Date ______________

______________________ Specific Gravity ________________ Tested by ____________

Location ________________ Hydrometer Correction ______________________________

Hydrometer Sample ________ % Finer than ______ sieve. Mass dry soil W = ______ g

Time	Elapsed Time t - min	Temp °C	Hydrometer Reading		% Finer P	L (Table 2) cm	K (Table 3)	D $K\sqrt{L/t}$ mm	% Finer in Total Sample
			Original	Corrected					

Project ____________________

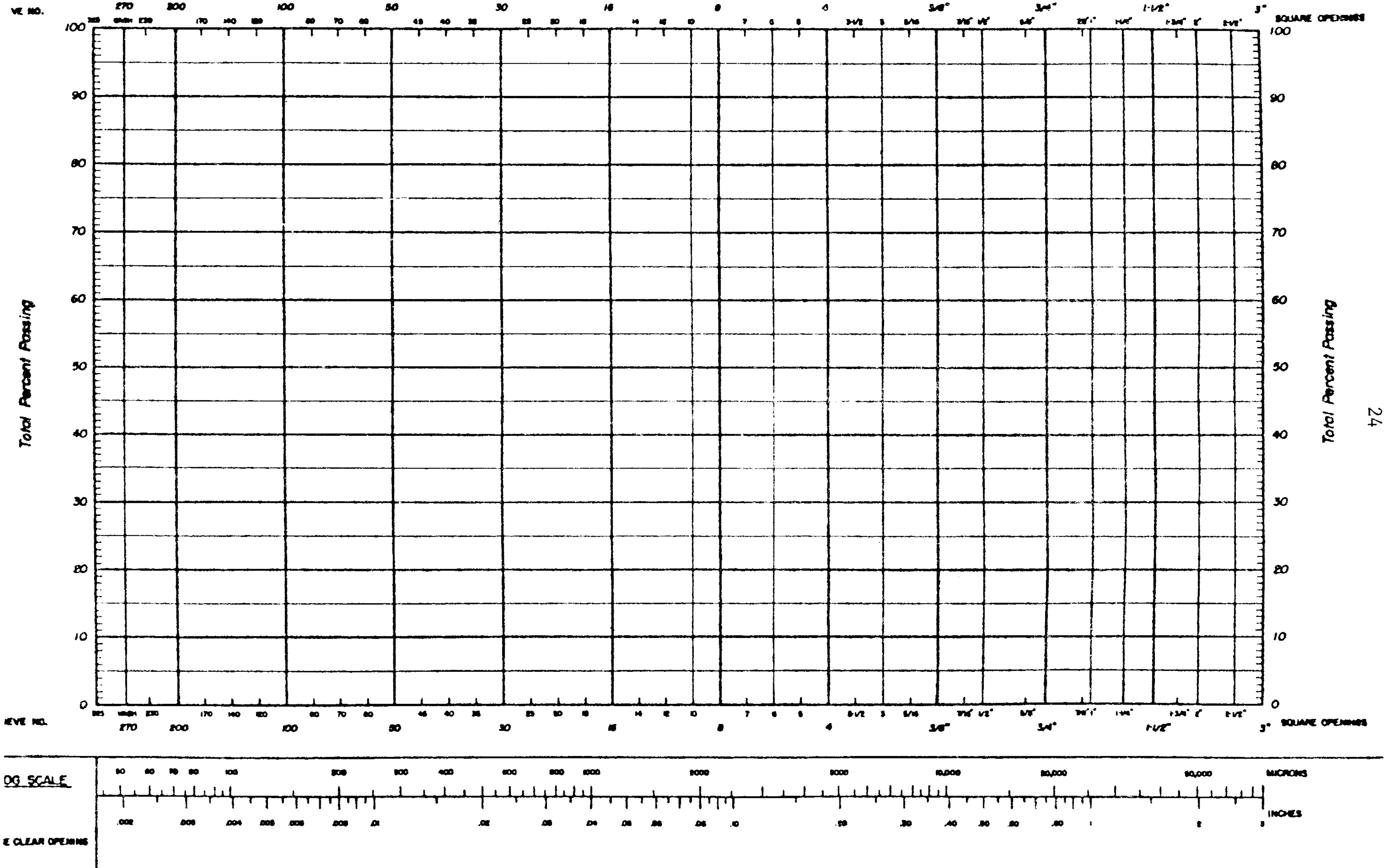
Location ____________________

Station ____________________

Material ____________________

Sample No. ____________________

SEMI-LOG CHART FOR GRADING CURVES



U.S. STANDARD SIEVES - A.A.S.H.O. METHOD T-27

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PARTICLE SIZE ANALYSIS BY SIEVING

by L. Willardson

Determination of the particle size distribution of soils and gravel or sand drain envelope materials is important in drainage design. The information is needed to protect drains from clogging by sediment.

Particle size analysis for fine soils is usually done by the hydrometer method. Particle size analysis for sand, gravel or a coarse soil is done by sieving.

General Procedure

A representative sample of the material is air dried. The material is weighed and then shaken through a series of standard sieves of progressively smaller sizes. The amount of material retained on each sieve is weighed and a particle size distribution curve is plotted for identifying the material.

Equipment Needed

1. A balance of weighing device sensitive to 0.01 grams. The balance should be able to weigh at least 500 grams of material.

2. A set of standard sieves of sizes numbers: 4, 10, 20, 40, 80, 100, 200, and PAN. The corresponding sieve openings are: 4.75, 2.00, 0.850, 0.425, 0.180, 0.150, and 0.075 mm, respectively. The pan catches all material finer than a number 200 sieve. Other sizes besides those listed can be used as long as they cover the range of sizes adequately.

3. A sieve shaker. The sieves can be shaken by hand or by means of a sieve shaker machine. A cover is needed to prevent loss of material during shaking.

Detailed Procedure

1. A representative sample of the material should be air dried. Care should be taken to avoid separation of the material during handling to avoid getting too many large or small particles from the sample.

2. The sample should be carefully split or divided to obtain an average sample weighing 300 to 500 grams. A sample splitter can be used or

the sample can be divided by hand on a paper or plastic sheet. Care should be taken to avoid losing small or large particles from the sample.

3. The sample is weighed to the nearest 0.01 gram.

4. The sample is put into the top of a stack of sieves that become progressively smaller toward the bottom. The coarsest mesh sieve should be on top and the pan to collect the finest materials should be on the bottom.

5. The sieves should be jarred and shaken vertically and horizontally until there is less than a one percent change in the weight of the material on a sieve during one minute of shaking.

Overshaking can grind to powder the material on the screens.

The material should not be rubbed to make it go through the screens.

6. When shaking is completed, the amount of material retained on each screen should be weighed. The sum of all the weights should be nearly equal to the weight of material placed in the sieves at the beginning.

7. When the sieves are cleaned by brushing, care should be taken to avoid damaging the fine sieves.

8. The results appear as in the following table.

Sieve Number	Opening mm	Weight Retained	Cumulative Retained
4	4.75	0	0
10	2.00	0	0
20	0.850	9.10	9.10
40	0.425	16.95	26.05
80	0.180	23.40	49.45
100	0.150	17.30	66.75
200	0.075	3.90	70.65
Pan	--	1.32	71.97
Total		71.97	
Original Weight		72.00	
Loss		0.03 grams	

The cumulative weight retained is found by adding the weights retained on each screen progressively.

9. The percent of material finer is calculated by subtracting the cumulative weight retained from the total and dividing by the total. For example, the percent of material finer than the number 80 screen is:

$$\frac{71.97-49.45}{71.97} \times 100 = 31\%$$

Following this procedure, a table can be prepared of opening sizes and percent finer.

Opening mm	Percent Finer
2.00	87
0.850	64
0.425	31
0.180	7
0.150	2
0.075	0

10. The data are plotted on semi-log paper with the vertical linear axis as percent finer and the horizontal logarithmic axis as particle size or sieve opening.

A very steep curve indicates a uniform material. A flatter curve indicates a graded material. The usual soil particle size distribution curve has an "S" shape.

11. A soil classification triangle can be used to classify the soil from the data.

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CROP SURVEY METHODS

by M. B. Lowdermilk*

Most agricultural field workers have had some experience in crop survey methods. The purpose as related to command areas of farm irrigation systems is to document over time the crops cultivated in each farmer's field for each cropping season. Where three or more crops are cultivated in succession under intensive methods, the task is more complex. Also the task becomes more complex when more than one crop is cultivated in a single irrigation basin or a farmer's field.

Procedures Involved

1. First obtain or develop a precise map of the command area and measure the irrigation basins for each farm. This can be done by actual tape measurements or by pacing the field boundaries. If the pacing method is used each field investigator will need to calibrate his particular pace in terms of feet and inches or meters and centimeters per pace.
2. Select a section of the command area and station a person with a map near the center and use two persons making measurements and calling out the particular crop or crops in each unit as the party moves down a command area in a systematic manner.
3. Use codes for each crop such as W for wheat, F for Fallow, etc. as shown in Figure C attached.
4. If the field work map is of adequate scale and there are several crops in a given unit the recorder should enter the dominant crop above the others such as

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*This How-To-Do-It was taken from The Problem Identification Handbook (April 1, 1980). Developed by the CSU-Pakistan Water Management Project sponsored by U.S. Agency for International Development, Contract No. AID/TAC-1100.

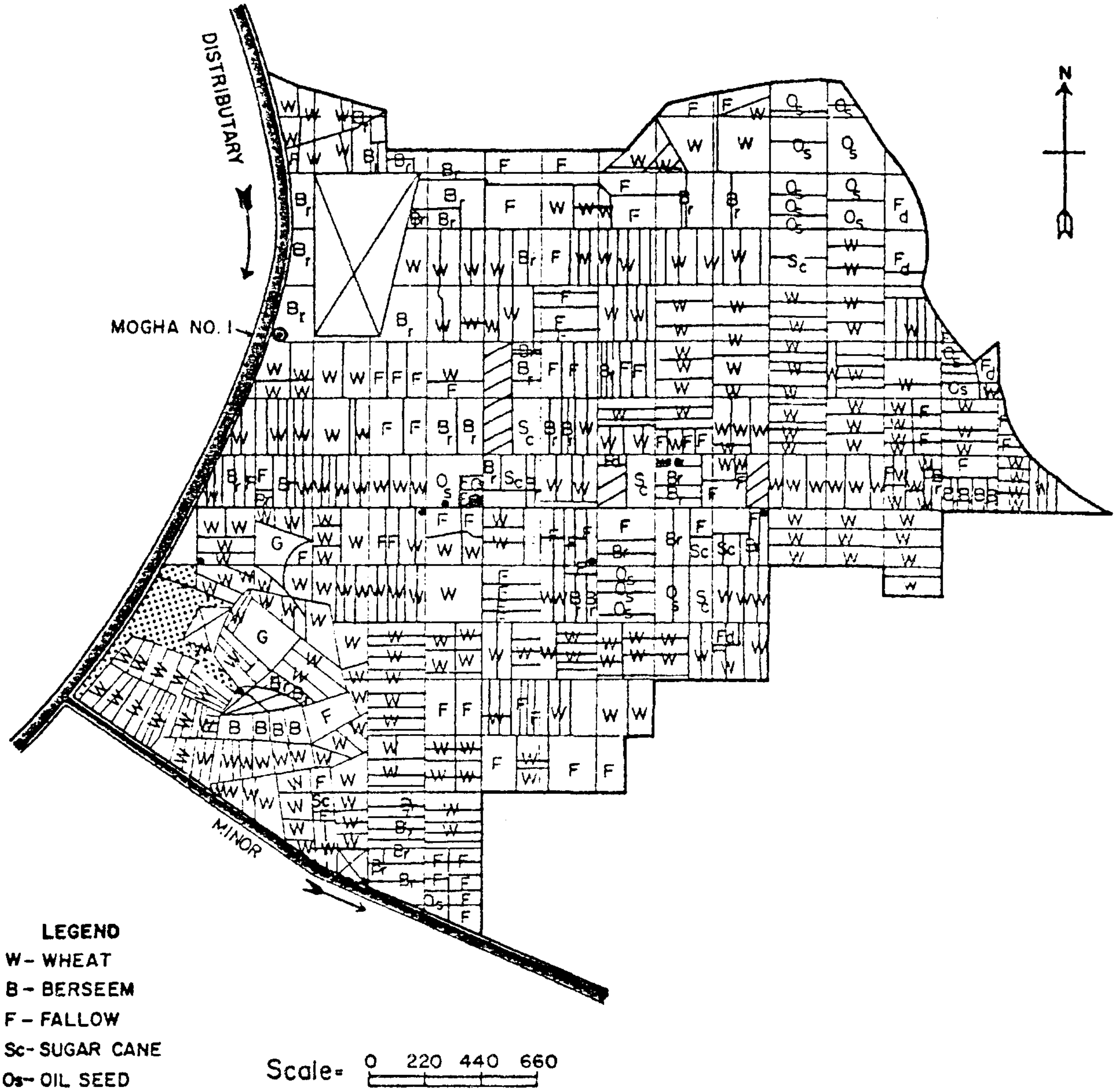
Ca = Cabbage
To = Tomatoes
W = Wheat

to indicate the dominant crop. If relay crops are used they can be noted as Co + Berseem to show that Berseem is interplanted in Cotton (Co).

5. The timing of crop surveys is important. For example, if the survey is done during the transition of crops invalid data will often occur because what appears fallow may be cultivated within a short period. In each area one must choose the best time for a particular crop survey.
6. Equally important is to return at the proper time in the crop cycle to record the next crop. If there are two distinct cropping seasons a decision can be made to enter the first crop as Co = Cotton/W = Wheat over the next crop. There is however often a problem because farmers change the size of their irrigation basins and fields often in relationship to the crops they cultivate at a given time. Also farmers rent-in and rent-out land from time to time.

Uses of Crop Survey Data

1. Providing a record of cropping intensities, patterns, and rotations over time.
2. Providing a record of intercropping and fallow over time.
3. Providing a record of shifts in field sizes and crops over time.



LEGEND

W - WHEAT
B - BERSEEM
F - FALLOW
Sc - SUGAR CANE
Os - OIL SEED
Br - BARREN
Fd - FODDER
G - GARDEN
▬ - DISTRIBUTARY
⊙ ● - MOGHA / TUBEWELL
☒ - HOUSE
▬ - MINOR
• - JHALAR
—— - BUNDED UNIT BOUNDARY
—— - AREA BOUNDARY

WATER MANAGEMENT RESEARCH PROJECT

WATERCOURSE SURVEY SAMPLE VILLAGE: NUMBER 103

DISTRICT LAHORE

WATERCOURSE COMMAND I

CROPS

EWUP
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MAPPING CROP STANDS

by Moslin Wahla and John Reuss*

Often data are required about the quality of crop stands. Usually these data are needed to determine the germination or emergence of a crop variety under different conditions such as fertility, salinity, moisture, composition, physical soil types, field levelness status, etc. depending on the specific purpose of the investigation.

Procedures to Use

1. Select the fields or irrigation basins according to some acceptable sampling method.
2. Decide on the areas within fields to be sampled on a random basis.
3. After the grid has been developed and the sampling frame, count the plants in the grided sample area. For example, if the unit is 20 feet by 20 feet count the plants in the 400 square foot area and record the data.

Example of Mapping Crop Stands to Determine the Influence of Field Levelness on Cotton Stands and Yields/Acre

The example given below is taken from a study to determine the effect of poorly leveled fields on crop productivity utilizing the elevation differences on stands and yields of cotton in 15 sample fields. The method and the results are presented from the work of Wahla and Reuss.

Fields were selected by Agricultural Extension workers during October 1975. Basis of selection was simply that the farmer was aware that a significant elevation difference existed within the field. Two plots, each twenty-foot square, were located so as to include the highest land within the field in one plot and the lowest land within the other. A middle elevation plot of the same size was selected between the high and low elevation

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areas. Extreme edges or dirt borrow areas were avoided and selection of the areas was made without regard to crop growth. In most cases elevation differences were determined by depth of water at the final irrigation. Where no irrigation was applied after plot selection, elevation differences were determined by means of dumpy level.

The number of stalks within each plot area was counted, and the cotton harvested from each plot at each picking date was weighed and recorded. To date most of the plots have been picked three times. Data collected to date are summarized in Table 1.

The low and mid elevation plots respectively averaged 4.6 and 2.2 inches lower than the high elevation plots. Thus, about 4.6 more inches of water were applied to the low elevation areas than the high areas. Yield data collection is not yet complete but preliminary analysis indicates a definite and major yield difference due to elevation within the field. Yields are generally very low, but in all cases, the yields from the low elevation plots are below those of the high and mid elevation plots. Average yield from the low elevation plots is only about one-half of that from the high and middle elevation plots. The probability that this difference is due to chance is less than 0.005. There is an apparent reduction in stands on the low lying plots, but this difference is less consistent than the yield difference.

The data will be subjected to additional analysis after the data collection is completed. However, the effect of excess water on the lowest areas appears unmistakable. Apparently major yield depressions on significant portions of these fields are being caused by lack of adequate leveling (see Table 1).

Such a method as described above can be used for several purposes as required by the investigator.

Table 1. Effect of elevation differences within fields on cotton stands and yields (3 pickings).

Plot	Elevation Difference			Stand			Yield		
No.	High	Mid	Low	High	Mid	Low	High	Mid	Low
		inches*			Stalks/400 ft^2			lbs/acre	
1	0	2.2	3.4	191	172	182	370	522	265
2	0	3.1	4.7	120	108	82	291	443	269
3	0	2.1	4.3	82	170	21	232	389	174
4	0	2.0	4.0				291	160	58
5	0	2.0	4.0				138	79	65
6	0	1.0	3.0				450	291	196
7	0	2.0	3.7	123	136	82	545	689	199
8	0	2.5	4.0	38	34	28	302	384	98
9	0	2.0	4.0	70	196	65	365	436	215
10	0	3.2	6.0	77	76	41	545	806	178
11	0	3.2	10.6	73	71	48	334	163	73
12	0	1.5	4.0	96	78	29	291	204	87
13	0	2.5	5.6	143	157	80	370	395	174
14	0	1.5	4.0	180	87	80	482	552	225
15	0	2.0	4.0	119	143	122	901	668	596
	Means	2.19	4.58	109	118	72	390	345	191

*Elevation below highest point.

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YIELD ESTIMATE METHODS

by M. B. Lowdermilk*

The following discussion will present a method of accounting for crop yield estimations. This format, though specifically designed for nonfodder crops such as rice, wheat, cotton, oats, etc., will put forth some generalized guidelines and procedures in which different types of crops can be measured in a manner that is relevant to them. In describing this format, three general dimensions making up the accounting format will be described and then how the yield per crop is calculated will be put forth.

To begin the process, the researcher will ask the farmer what he believes the estimated area under crop is and the estimated total units produced. These questions will provide a baseline figure from which to compare later calculations. The calculations are divided into three main categories: harvest costs, home consumption estimates, and the total quantity of units sold.

There are three types of harvest costs: direct costs, indirect costs, and other types of costs. Direct costs involve the costs that are placed on the activities that are an integral part of the immediate harvest; i.e. cutting, picking, threshing, winnowing/cleaning, bagging, transport, and storage. The indirect costs are payments to local artisans for services rendered in relation to the harvest. These payments will go to such people as the blacksmith, carpenters, shoemakers, barbers, religious leaders, laundryman, etc. Other costs involve payments for various reasons to local officers for services rendered during the harvest. Payments of this type go to agricultural officers, revenue agents, irrigation officials, and the like. These costs are in kind and they provide an indicator of what the farmer pays for the harvesting of the crop.

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The next dimension consists of the home consumption estimate. This entails what the home unit utilizes for its own subsistence plus any extra support that it may attain. Again the unit of measurement is in kind. A critical aspect of measuring this dimension is the establishment of the home unit. The researcher will have to include not only people, but also animals owned by the family who are fed by that family. In addition, a definition of what constitutes a full unit vs. a fractional unit must be ascertained. For instance are small children and the elderly equal to a middle aged adult in their consumptive patterns? Thus in defining a home consumption estimate, different sub-units in the household and on the farm must be delineated and then these units are added up and multiplied by a specific level of consumption per unit.

A third measurement involves the total quantity of units sold by the farmer. This measure, which is also labeled in kind, constitutes the total amount of crop sold by the farmer. This measure is then added to the other two measures to arrive at a total production figure.

Harvest Costs + Home Consumption Estimate + Total Quantity of Units Sold = Total Production (in kind)

After this figure is calculated, the researcher then checks this answer to the question asking the farmer to estimate the perceived total units produced. If the two answers vary by more than 5%, then the researcher should go through this accounting procedure again. If it continues to be that much different, an examination of why the farmer perceived what he did should follow. Dividing the total production by the area cropped will give the researcher the yield per unit area of a particular crop for a particular farmer.

$$\frac{\text{Total Production}}{\text{Area Cropped}} = \text{Yield/Unit Area}$$

Additional checks to this accounting procedure involve getting an estimate of production from several persons in the family and measuring the area cropped when possible. What is of critical importance is that the researcher must know the area and the crops raised and also he should be aware of the various inputs placed into the system in order to have that crop grow. This accounting method is only a rough procedure, but it does serve as a check to an individual's perceived estimate of what he is producing.

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CONSUMPTIVE USE

by William Franklin[*]

INTRODUCTION

The total evaporation occurring from soil and plant surfaces and the plant transpiration (evaporation from the pareachyma cells through stomatal cells) is called evapotranspiration (ET). In addition to ET, plants will use a small amount of water in tissue building. The sum of the ET and the water use in tissue building is called consumptive use. However, because the water removed in plant tissues is usually very small compared to ET, the terms consumptive use and evapotranspiration are commonly used interchangeably.

When the evapotranspiration rate of a particular crop is not limited by soil water availability, and when the crop is growing vigorously with full foliage, it is called potential evapotranspiration (E_{tp}). Potential evapotranspiration is usually defined for a "reference" crop and is regarded as a function of climatic factors only.

Evapotranspiration for a crop may be greater or less than that for the reference crop due to various environmental factors. This is referred to as actual evapotranspiration (Et). The ratio of Et/E_{tp} (when soil water is not a limiting factor) is called the crop coefficient. When soil water is limiting, the evapotranspiration will decrease, and a "stress" factor (Ks) term is introduced. An empirical equation to evaluate K_s has been proposed by Kincaid and Heermann (1974).

COMPUTING EVAPOTRANSPIRATION

A review of the alternative approaches to estimating the volume and rates of water evaporated from wet crop and soil surfaces or transpired by the plants can be found in several literature sources (Jensen, 1973;

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Doorenbos and Pruitt, 1977; Horton, 1973). As far as this technology is applicable to the management of irrigation return flow quality (through irrigation scheduling), Skogerboe et al. (1974b) and Jensen (1975) are good summaries.

There are many methods by which evapotranspiration can be calculated, however, the three most common approaches for estimating evapotranspiration are (1) the Blaney-Criddle method; (2) the Modified Jensen-Haise method; and (3) the Penman Combination method. These methods represent much of the range in sophistication available today, varying in detail from a temperature dependent analysis (Blaney-Criddle) to an analysis of energy balance and convective transport (Penman). It should be noted that both the Jensen-Haise and Penman equations are calculated in cal $cm^{-2}t^{-1}$ and can then be converted to an equivalent depth of evaporation by dividing by an assumed value for the latent heat of vaporization of 585 cal gm^{-1}, which yields units of length over time. This conversion is:

$E_{tp} \times 0.0017 \rightarrow cm\ t^{-1}$

$E_{tp} \times 0.000673 \rightarrow in\ t^{-1}$

The Blaney-Criddle Method

The Blaney-Criddle procedure for estimating evapotranspiration has the form (Blaney and Criddle, 1950):

$$E_t = \frac{k_t k_c\ t\ p}{100} \qquad (1)$$

where:

E_t = monthly evapotranspiration in inches;

k_t = 0.0.173t - 0.134 (2)

k_c = time distributed crop growth stage coefficient;

t = mean monthly temperature in °F; and

p = mean monthly percentage of annual daytime hours.

Crop curves and values for p can be found in Blaney and Criddle (1950) and USDA Soil Conservation Service, Technical Report 21. Estimates of E_t were originally intended on a seasonal basis, but work by numerous individuals have shortened this interval by interpolating values for p and k_c.

The Modified Jensen-Haise Method

The Jensen-Haise procedure is a temperature and solar reduction equation adjusted for location and elevation by vapor pressure functions (Jensen and Haise, 1963):

$$E_{tp} = C_t(T - T_x)\ R_s \qquad (3)$$

in which,

E_{tp} = average daily potential evapotranspiration of a well-watered alfalfa crop having 30 to 50 cm of top growth, mm/day;

T = mean daily temperature, °C;

R_s = total daily solar radiation in langleys multiplied by 0.0171 to get mm/day;

T_x = intercept of the temperature axis

$$= -2.5 - 0.14\ (e_2 - e_1)\ °C/mb - elev(m)/550 \qquad (4)$$

e_2, e_1 = saturation vapor pressures at the mean maximum and mean minimum temperature, respectively, for the warmest month of the year, in mb/

C_T = temperature coefficient

$$= \frac{1}{C_1 + C_2\ C_H} \qquad (5)$$

$$C_1 = 38 - (2°C \times elev/(m)/305) \qquad (6)$$

$$C_2 = 7.6°C \qquad (7)$$

$$C_H = \frac{50\ mb}{(e_2 - e_1)} \qquad (8)$$

In order to relate E_{tp} to evapotranspiration values for other crops, a crop growth stage coefficient was defined,

$$k_{co} - E_t/E_{tp} \qquad (9)$$

where

k_{co} = crop growth stage coefficient; and

E_t = potential evaporation for the specified crop

Kincaid and Heermann (1974) present polynomial regression equations for k_{co} based on the table of coefficients presented by Jensen (1973).

The Penman Combination Method

Penman (1948) first derived an equation for the evapotranspiration of a short, well-watered crop (generally assumed to be grass) based on a combination of energy balance at the crop surface and the heat-mass transfer processes due to air movements. The equation which resulted and is used today is written for alfalfa:

$$E_{tp} = [\frac{\Delta}{\Delta+\gamma}\ (Rn+G)+15.36\ \frac{\Delta}{\Delta+\gamma}\ (a+bU_2)(e_z{}^{\circ}-e_z)] - 0.0171 \qquad (10)$$

in which,

Δ = slope of the saturation vapor pressure curve at a specified temperature, d(mb)/d(°C);
γ = psychrometric constant, mb/°C;
R_n = net radiant energy, langleys/day (ly/day);
G = soil heat flux, ly/day;
U_2 = wind run at a height of 2 meters, km/day;
a,b = empirical regression coefficients requiring local calibration;
e_z^o = saturation vapor pressure at the surface of the crop, mb; and
e_z = vapor pressure at the crop surface, mb.

The data available at most irrigated sites employing the Penman approach include solar radiation (R_s), temperature, wind, and relative humidity or dew point temperature. In order to develop the parameters for Equation 10 a number of empirical functions can be used. In the Grand Valley of western Colorado, the approach that was used is described below.

Net radiation, R_n, was determined from relationships presented by both Jensen (1973) and Kincaid and Heermann (1974). This procedure begins by defining solar radiation on a clear, cloudless day by plotting a curve through the long-term maximal values:

$$R_{so} = 760 \exp - \left[\frac{\text{Day}-107}{167}\right]^2 \qquad (11)$$

where

R_{so} = clear day solar radiation, ly/day; and
Day 1 - March 1.

A more recent review of Equation 11 indicates the coefficient 760 should be increased about 10 percent, but the overall effect is negligible. In a similar view, it is necessary to define the clear day net outgoing longwave radiation:

$$R_{bo} = \varepsilon' \sigma T_k^4 \qquad (12)$$

where

R_{bo} = net clear day outgoing longwave radiation, ly/day;
$\varepsilon' = -0.2 + 0.261 \exp [-7.77 \times 10^{-4} (273-T_k^2]$ (13)
T_k = temperature in degrees Kelvin (°C + 273)
σ = Stefan-Boltzmann constant = 11.21×10^{-8} ly/°K

Based on Equations 11 and 12, the longwave radiation occurring on a particular day equals (Jensen, 1973):

$$R_b = [1.2 \frac{R_s}{R_{so}} - 0.2] R_{bo} \tag{14}$$

and

$$R_n = (1-\alpha) R_s - R_b$$

(15) in which α = crop albedo (generally taken to be 0.23).

The exchange in heat from the soil is based on two assumptions: (1) the soil temperature to a depth of 2 meters varies approximately with average air temperature; and (2) the volumetric heat capacity of the soil is 0.5 cal cm^{-3} $°C^{-1}$. The soil heat flux, G, is then written as (Jensen, 1973):

$$G = \frac{\bar{T}_{i-1} - \bar{T}_{i+1}}{t} \times 100 \tag{16}$$

where,

G = soil heat flux, ly/day;
$\bar{T}_{i-1}$ = mean temperature for the previous period, °C;
$\bar{T}_{i+1}$ = mean temperature for the following period, °C; and
Δt = days between the preceding and following periods (period interval).

Kincaid and Heermann (1974) use of comparison of current temperature with the average of the previous 3 days to calculate G for irrigation scheduling. They also present convenient expressions for $\Delta/\Delta+\gamma$, $\gamma/\Delta+\gamma$, and e_z^o as follows:

$$\gamma/\Delta+\gamma = 0.959 - 0.0125T + 0.00004534T^2 \tag{17}$$

$$\Delta/\Delta+\gamma = 1 - (\gamma/\Delta+\gamma) \tag{18}$$

$$e_z^o = -0.6959 + 0.2946T - 0.005195T^2 + 89 \times 10^{-6}T^{-3} \tag{19}$$

in which T represents the mean daily temperature in °F.

The elevation of the term $(e_z^o - e_z)$ in the Penman equation can be made in several ways. For the Grand Valley studies, the following expression was used:

$$(e_z^o - e_z) = \frac{e_2^o + e_1^o}{2} - e_1^o \times rh \tag{20}$$

in which

e_z^o, e_1^o = saturation vapor pressure at maximum and minimum temperatures, mb; and
rh = maximum relative humidity (usually taken as the 6-8 AM values) expressed as a fraction.

MEASUREMENT OF EVAPOTRANSPIRATION

Consumptive use of water in a water balance computation of an irrigated area is one of the major components of the budget. It is, therefore, necessary that this value be determined as accurately as possible, and it is imperative that the evapotranspiration estimating formulas be calibrated for local conditions. Attempts to base conclusions on uncalibrated consumptive use equations would be extremely presumptuous, as will be explained later in this section. Tanner (1967) and the World Meteorological Organization (WMO) Technical 1, Note No. 83 (1966) provide a very good review of the procedure and methodology used for the measurement of potential evapotranspiration in the field.

Measurement of evapotranspiration should include the means for the actual measurement of consumptive use and, in addition, a complete weather station to measure air temperature (plus data, maximum and minimum) dew point temperature, relative humidity, precipitation, wind run, solar and net radiation and evaporation (Class A pan). Doorenbos (1976) presents an excellent discussion on the establishment and operation of a weather station for agricultural studies and the calibration of empirical ET indexes to actual ET measurements. WMO (1971) and WMO (1970) also present much information on the collection and analyses of hydrometeorological data.

Lysimetry

Probably the most accurate measurement of ET is obtained by the use of lysimeters. Lysimetry is the only method of measuring evapotranspiration where the investigator has complete knowledge of all the terms of the water balance equation. Harrold (1966) presents a very good review of the use of lysimeters for measuring ET. Horton (1973) has compiled an annotated bibliography on Et which includes lysimetry.

A lysimeter is a device which is hydrologically isolated from the surrounding soil. This device contains a volume of soil (which is usually planted to vegetation) and some means to measure the consumptive use (described below). Lysimeters must be representative of the surrounding conditions if they are to provide useful ET measurements. They must be representative of the soil type.

Two types of lysimeters, which have worked quite well for calibration purposes, are the constant water table lysimeter and hydraulic weighing lysimeters. The constant-water table lysimeter are usually planted to grass (such as Kentucky Bluegrass) or other crops with shallow root systems. On the other hand, the hydraulic weighing lysimeters are usually planted in deeper rooted crops such as alfalfa or corn. The reference crops used in the calculations, which are usually planted in lysimeters, are generally considered to be well-watered grass or alfalfa.

Construction of a constant water table lysimeter is shown in Figure 1. They are usually about 1 meter square and about 60 cm deep. The amount of water use is calculated by using an area ratio of the lysimeter to the reservoir. The evapotranspiration rate is very sensitive to the depth of the water table in the lysimeter (usually kept at about 15 cm from surface for grass). In addition, the crop must be trimmed periodically to insure vigorous growth, and any vegetative growth extending beyond the sides of the lysimeter should be trimmed back.

Construction of the hydraulic weighing lysimeters are shown in Figure 2, and a typical calibration curve is shown short a time period does not give complete confidence in the resulting equations because temperature is only one of many climatic factors affecting evapotranspiration. A longer term analysis is needed before proposing a usable function for k_t beyond that expressed in Equation 2.

Jensen-Haise Calibration

In the Grand Valley, the mean minimum and mean maximum temperatures at the 1480 meter elevation are 346.°C and 18.1°C, respectively. At these temperatures, $e_2 = 55.29$ mb and $e_1 = 20.58$ mb so that $C_H = 1.44$. The data similarly result in C_T being equal to 0.0255 and $T_x = -10.05$. The Jensen-Haise equation for the Grand Valley is, therefore, (multiplied by 0.0171 to yield mm/day):

$$E_{tp} = 4.36 \times 10^{-4} (T + 10.05) R_s \qquad (23)$$

Equation 23 overestimates evapotranspiration as determined from the grass lysimeters (and divided by 0.87) by 4% to 5% over the accumulated irrigation season. However, during the windy periods of May and June, Equation 23 can underestimate E_{tp} by about 10 to 15%. By solving for C_T and T_x and correlating with the lysimeter data, Equation 23 was slightly modified as indicated below:

$$E_{tp} = 4.75 \times 10^{4} (T + 9.646) R_s \qquad (24)$$

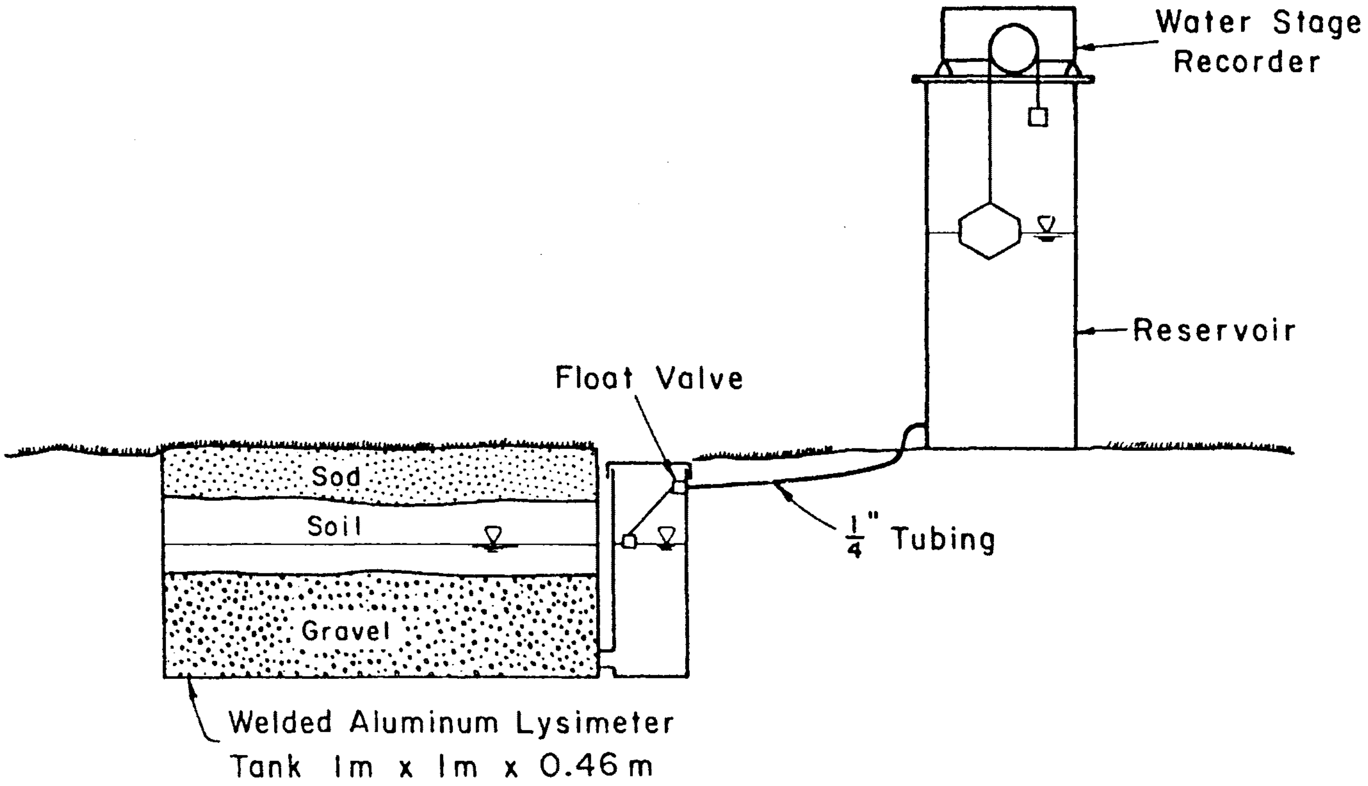

Figure 1. Constant water table lysimeter.

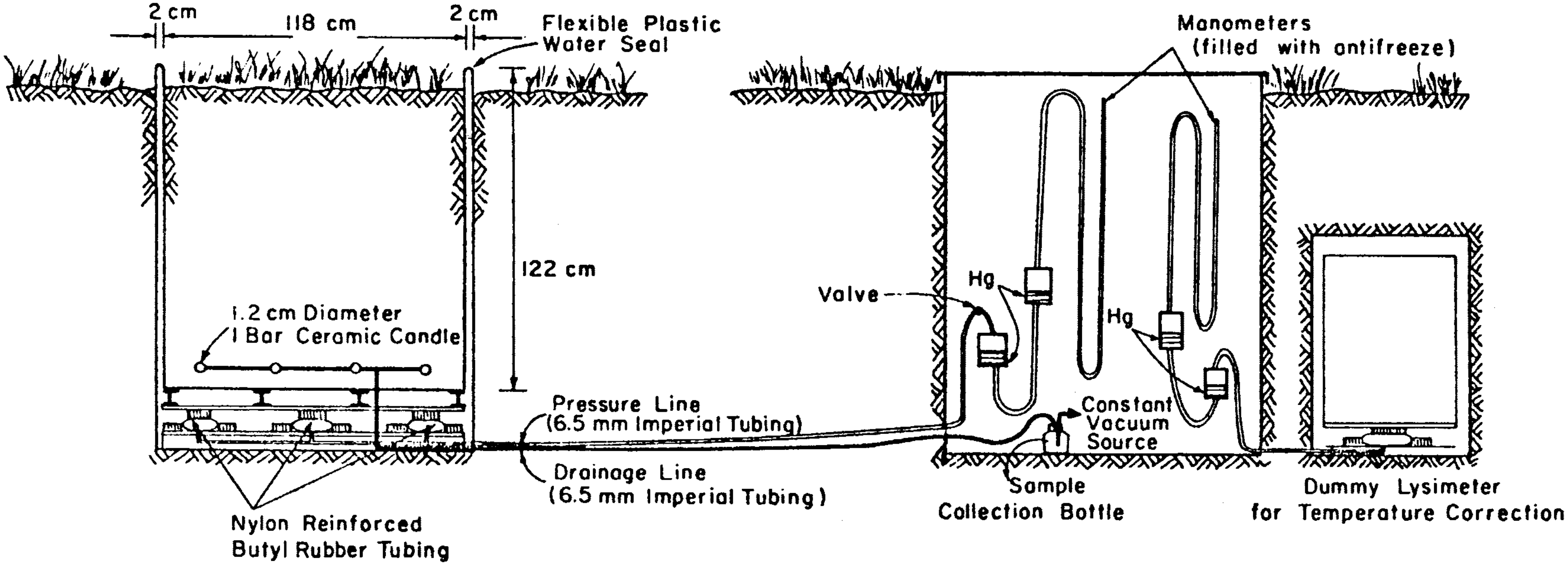

Figure 2. Hydraulic weighing lysimeter.

Penman Calculations

The Penman equation has several regression formulas implied in its form as listed in Equation 10. An evaluation of each of these was made, but the only effective correlation was between the wind term coefficients, a and b. Interestingly enough, the values determined for alfalfa ($a = 0.90$ and $b = 0.0062$) are not significantly different from the values Penman originally suggested for grass (Jensen, 1973). The resulting Penman formula for alfalfa (E_{tp}) is:

$$E_{tp} = 0.0171[C_1(R_n+G) + C_2(0.9+0.0062U_2)(e_z^o-e_z)] \qquad (25)$$

Comparison of Methods

The mean monthly measured values of the grass lysimeter evapotranspiration for the Grand Valley are plotted against both the calibrated and original Blaney-Criddle relationships in Figure 4. These data were collected in 1975. The other years do not differ markedly, however. The revised function allows a substantially better monthly estimate of consumptive use than the version suggested by Blaney and Criddle (1950). In fact, over the season the measured and predicted (by the adjusted equation) are identical. The Blaney-Criddle approach is satisfactory for time periods greater than or equal to one month, but not the daily or weekly periods needed for irrigation scheduling. It is also obvious that application of the original Blaney-Criddle approach can lead to significant errors if the method is not locally calibrated.

Figure 4 shows the comparison of measured and calculated E_{tp} values during the 1975 irrigation season in Grand Valley when the Jensen-Haise method is applied. The error introduced by simply using the reported function with the altitude correction is too small to be significant, although about a 4 to 5 percent improvement was achieved in Figure 3. These lysimeters are irrigated for the purpose of maintaining a low-tension soil moisture condition. A neutron access tube or other methods are installed to assist in monitoring soil moisture distribution. A method of extracting the surplus water and to provide a leaching mechanism should be installed. One bar ceramic candles connected to a vacuum system work well for this purpose.

Calibrating Estimating Formulas

Once a reliable measurement of evapotranspiration is obtained, it is then used to calibrate the evapotranspiration estimating formulas for the

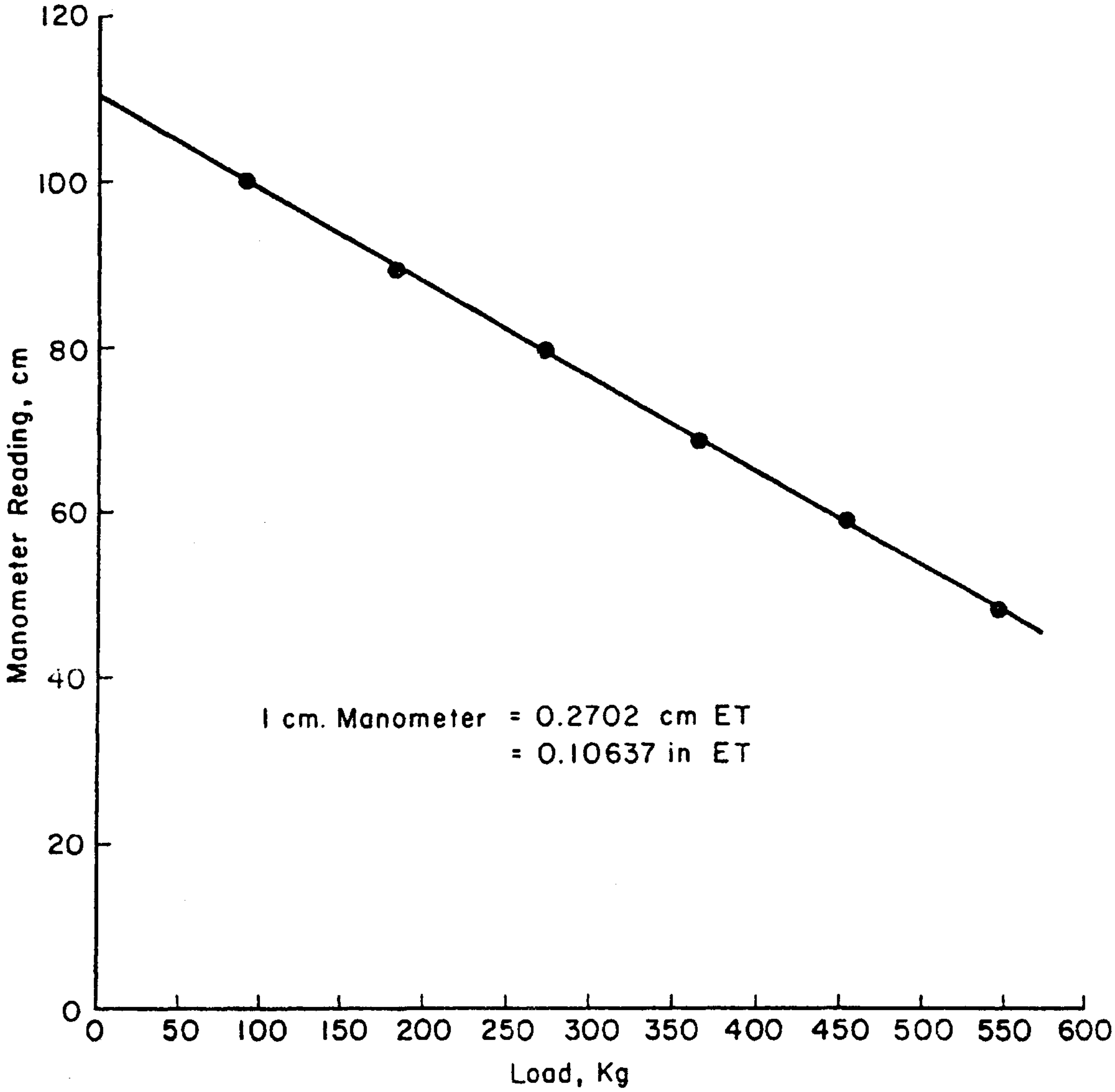
120
100
80
60
40
20
0
Manometer Reading, cm
0
50
100
150
200
250
300
350
400
450
500
550
600
Load, Kg
I cm. Manometer = 0.2702 cm ET
= 0.10637 in ET

Figure 3.

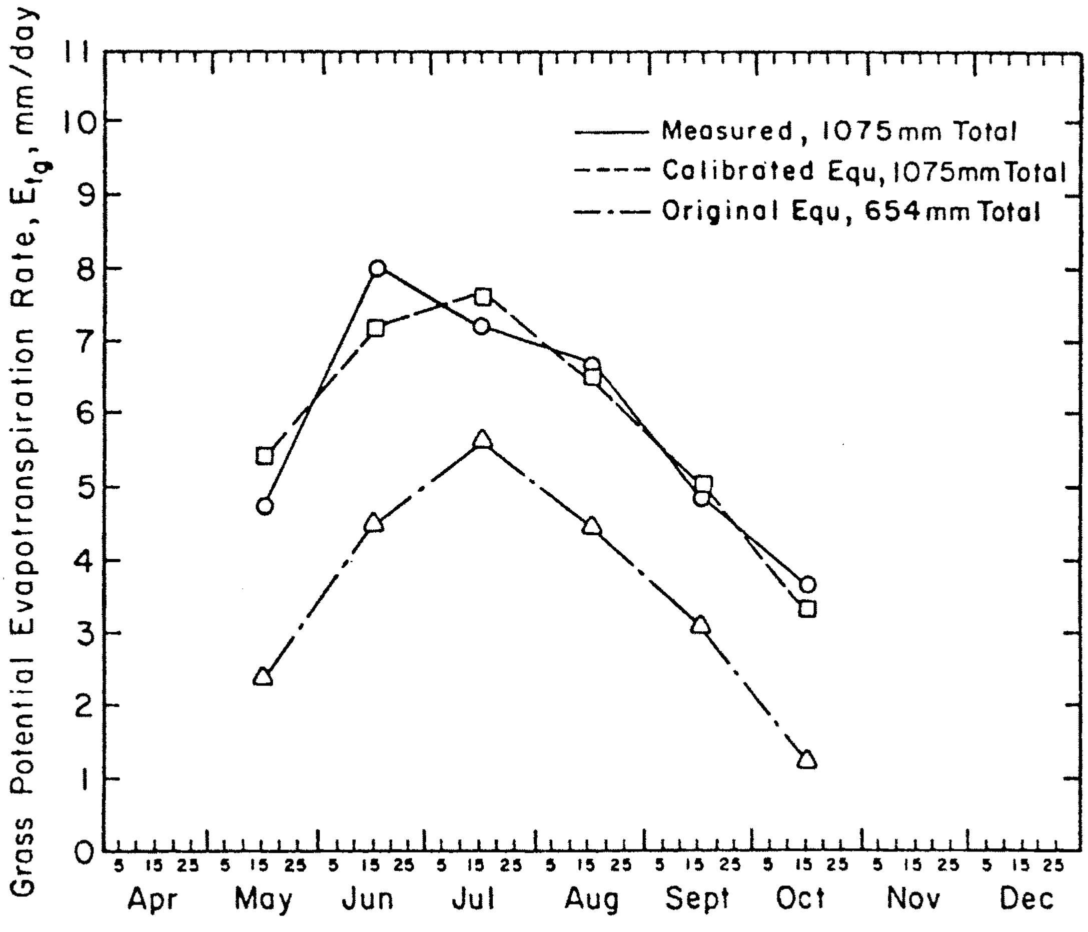

Figure 4. Comparison of lysimeter data with the Blaney-Criddle estimate for well-watered grass in 1975.

local conditions. For purposes of illustration, these formulas will be calibrated for conditions encountered in the Grand Valley of Colorado.

Blaney-Criddle Calibration

The uncalibrated Blaney-Criddle equation, as described earlier, underestimates E_{tp} in the Grand Valley by approximately 40 percent. Generally, in the windy months of spring the procedure underestimates E_{tp} by as much as 50%, whereas later results show substantial overestimation. The calibration of Equation 1 involved solving for the k_t term:

$$at - b = \frac{E_t \cdot 100}{p \cdot c \cdot k_t} \tag{21}$$

In this case, k_t was found to be:

$$k_t = -0.00268 + 1.49 \tag{22}$$

Even so, the month-to-month variations were large (i.e., Equations 1 and 22 overestimate E_{tp} in May, July and September, while it underestimates the values in June and August). It should be noted that calibration of the k_t parameter over so with local calibration. The Jensen-Haise method is often used in conjunction with the Penman equation in many irrigation scheduling services, primarily from July on when wind is less significant. The largest error in the time distributed estimates (5 to 6 day intervals) was less than 2 mm per day in the latter part of the Grand Valley's 1975 irrigation season. In June, a 5 mm error is noticeable.

Although the Penman equation shows more seasonal error than the Jensen-Haise approach (Figure 5), it follows the lysimeter data better over the season. In evaluating these results, it appears that time intervals less tha 3 to 5 days are not justified by the sensitivity of the approaches. In fact, the correlation between measured and predicted values on a daily basis was less than 70 percent, whereas it was approximately 90 percent for 5 to 6 day periods.

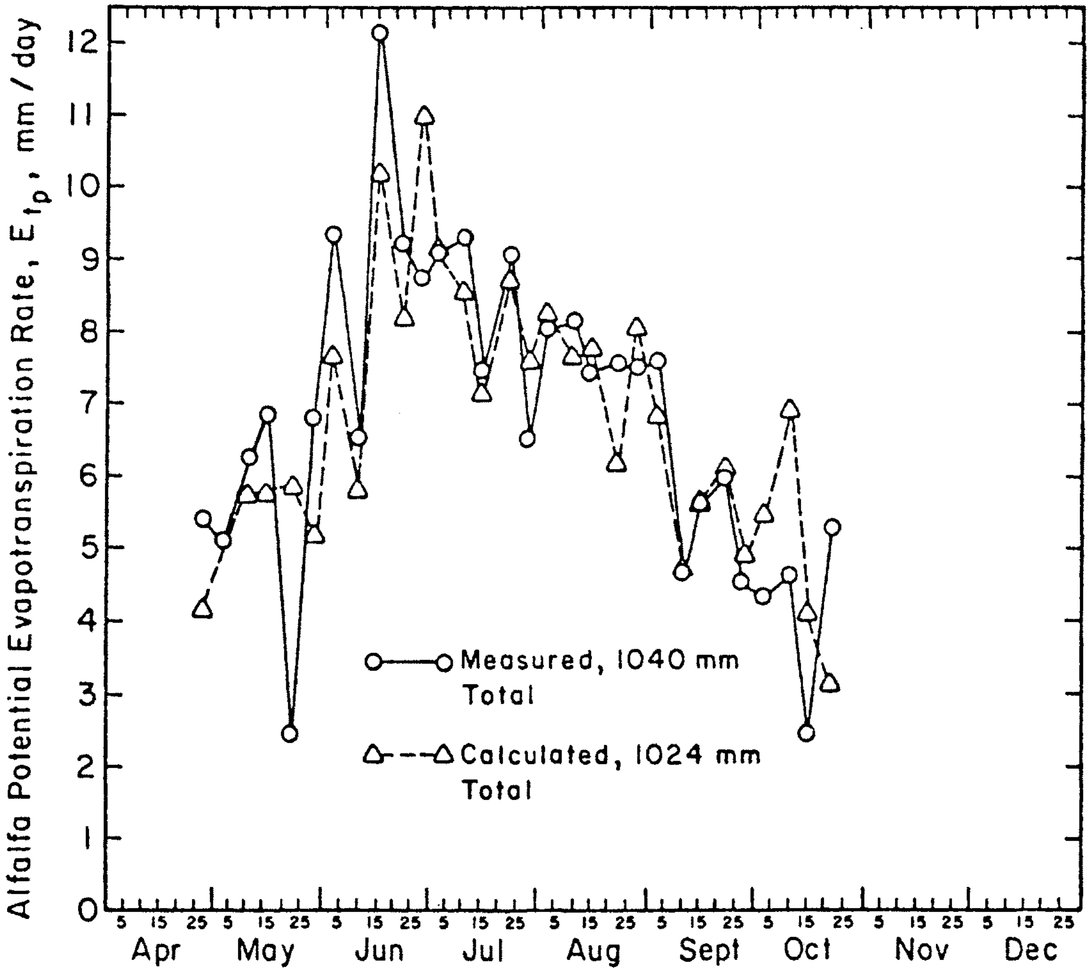

Figure 5. Comparison of lysimeter data and the Penman equation estimate for alfalfa in 1975.

EWUP
How to do it
Field Procedure

DIFFERENTIAL LEVELING FOR BENCH MARK SURVEY OF THE WATERCOURSE

by Wayne Clyma and Alan Early*

Differential leveling is the process of finding the differences in elevation of any two points. It usually requires several setups of the instrument along a general line between the two points. Each setup requires a rod reading on a point of unknown elevation. A bench mark survey is conducted to provide a widely spaced series of points (headgates, culverts, bridges, etc.) of known elevation from which a topographic survey is conducted at a later date.

THEORY OF LEVELING

Leveling is the process of determining the elevations of differences in elevations of points. Figure 1 illustrates the basic procedure.

A level is set up at a location approximately half-way between bench mark (B.M.) and a turning point (T.P.). A bench mark is relatively permanent, natural or artificial object bearing a marked point whose elevation is known or assumed. A turning point is a temporary bench mark for the purpose of continuing a line of levels. Portable turning points are provided for field watercourse surveys and topographic surveys.

For example, referring to Figure 1, if the elevation of the bench mark (B.M.$_1$) is assumed to have an elevation of 100.000 meters, the elevation of the turning point (T.P.$_1$) can be determined by leveling. First, the instrument is set up approximately half-way between B.M.$_1$ and T.P.$_1$ and is leveled. A rod reading is taken on B.M.$_1$ of 2.40. This rod reading is termed a backsight (B.S.). A backsight is a rod reading taken on a bench mark or turning point of known elevation. It is the vertical distance between the B.M. and the line of sight of the instrument. The line of sight

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* This How-To-Do-It was taken from The Problem Identification Handbook (April 1, 1980). Developed by the CSU-Pakistan Water Management Project sponsored by U.S. Agency for International Development, Contract No. AID/TAC-1100.

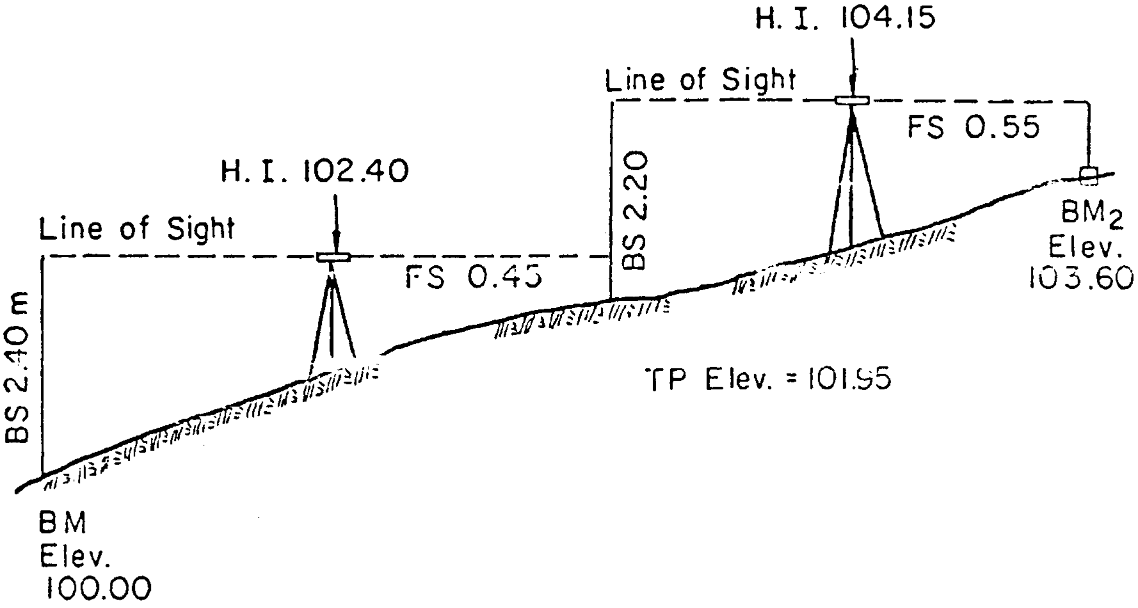

Figure 1. Theory of differential leveling.

of the instrument is almost always higher than the B.M. or the T.P. Therefore, the backsight is almost always positive and could be described as a plus sight.

The height of instrument (H.I.) is the elevation of the line of sight when the instrument is level. This corresponds to the line of sight of the instrument and is obtained by adding the backsight to the elevation of the B.M.$_1$, 100.00, to obtain the H.I., 102.40. Turning the telescope to bring into view the rod held on T.P.$_1$ a rod reading called a foresight is obtained. A foresight (F.S.) is a rod reading taken on a turning point of any other point of unknown elevation for which the elevation is to be determined. The foresight is almost always subtracted from the height of instrument and could be described as a minus sight. In the example of Figure 1, the F.S., 0.45, is subtracted from the H.I., 102.40, to obtain the elevation of T.P., 101.95. Thus, by a process known as leveling, we have determined the difference in elevation of two points. This methodology may now be used to check the elevations shown in Figure 1, and determine the elevation of T.P.$_2$.

From the above definitions, we can derive two equations that are quite beneficial in leveling. These equations will be repeated many times during a leveling exercise, so a person who is learning to use the level should become thoroughly familiar with them. They are:

Elev. + B.S. = H.I.

H.I. + F.S. = Elev.

Note that if a backsight is taken on a B.M. or T.P. located on the roof of a tunnel or the ceiling of a room with the instrument at a lower elevations, the backsight must be subtracted from the elevation to obtain the height of instrument. Also, if a rod reading is taken on a pipe or some other object higher than the instrument, the foresight must be added to the height of instrument to obtain the elevation.

PROCEDURE FOR DIFFERENTIAL LEVELING

Several procedures and precautions should be observed for accurate differential leveling. Refer to Figures 2 and 3 for sample rod readings and a sample set of notes for a differential leveling exercise.

To begin a differential survey, the rodman holds a rod on B.M.$_1$ while the levelman goes forward a convenient distance (not over 100 meters for a Bostrom-Brady farm level) and sets up the level. The levelman takes a

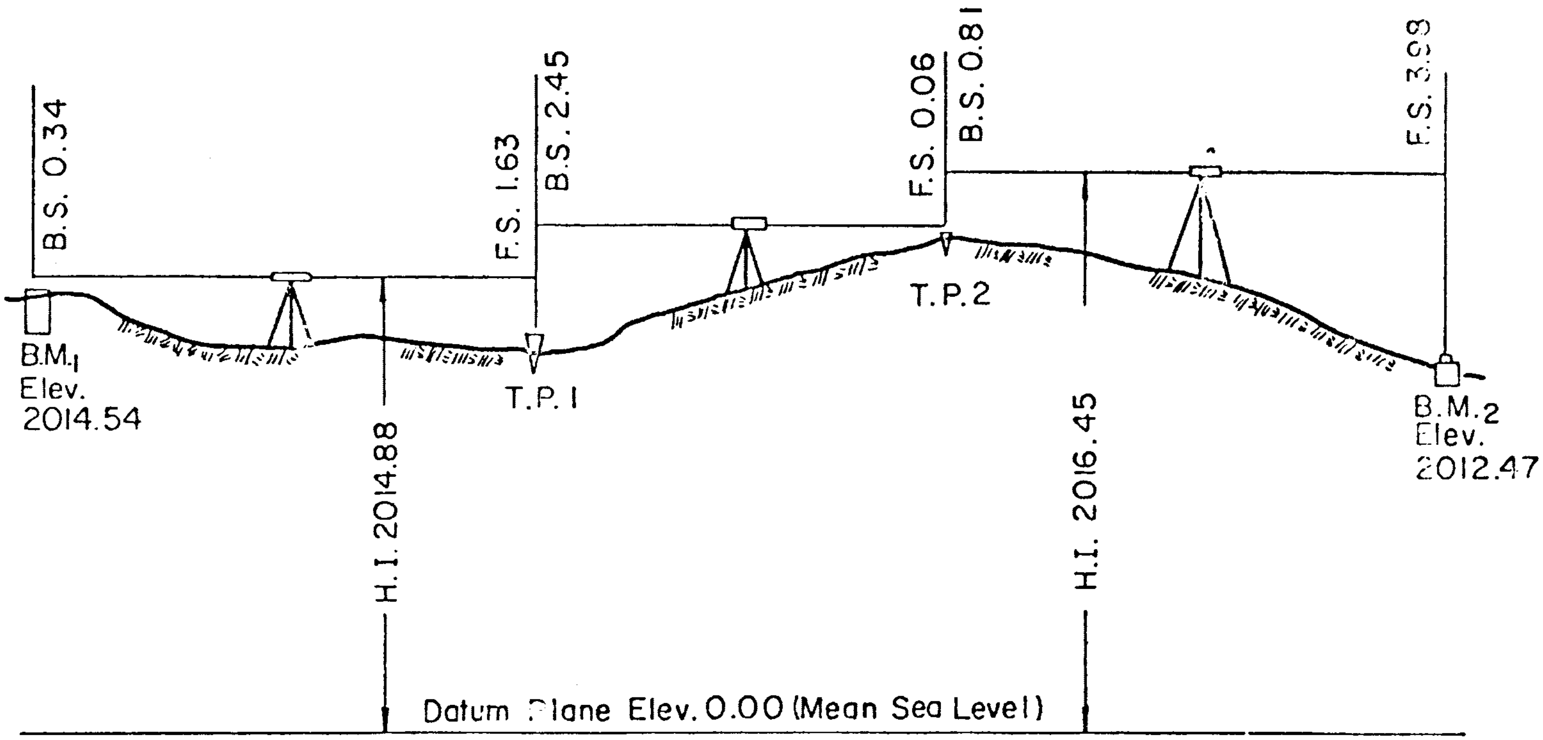

Figure 2. Illustrating the procedure for taking backsights and foresights of differential leveling.

DIFFERENTIAL LEVELING
FOR BENCH MARKS
Alemaya College Campus

Sunny, calm

Haily S. & N
Tewolde W.
Aug. 18, 1965

Sta	BS	HI	FS	Elev.		
BM_1	0.34	100.34		100.00	$B.M._1$:	the southern bolt on the pole
TP_1	2.45	101.16	1.63	98.71		nearest to the irrigation lab.
TP_2	0.81	101.91	0.06	101.10		about 5 m from eastern side
BM_2	3.98	101.91	3.98	97.93		door
TP_3	0.00	101.19	0.81	101.10		
TP_4	1.98	100.71	2.46	98.73	$B.M._2$:	Steel rod on the N.E. corner
BM_1			0.69	100.02		of the cattle guard into the
BS =	9.65	FS =	9.63	0.02		livestock area across from
						poultry.

Error of closure =

9.65 - 9.63 = 0.02 check

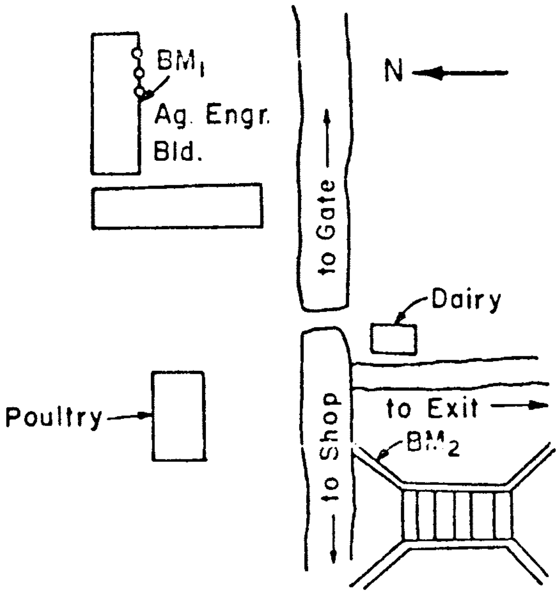

Figure 3. Sample differential leveling notes.

reading on the rod and determines where the middle cross hair strikes the rod, in Figure 2 at 0.34. This is a backsight and the notekeeper records 0.34 in the B.S. column of the notes. Now the H.I. is determined by adding the B.S. to the elevation of the B.M., (100.00 + 0.34 = 100.34), and is entered in the notes in the H.I. column. For the convenience of one who is learning this procedure, a plus sign can be placed above the B.S. column and a minus sign above the F.S. column to indicate how that column is used in note computations.

After the B.S. has been obtained, the rodman steps the distance from the B.M. to the instrument and then steps the same distance away from the instrument in the direction of $B.M._2$. This pacing is one of the acceptable methods of balancing the horizontal distances between the backsight and the foresight. This distance can also be measured by stadia, but the accuracy obtained by taping is not considered necessary. The effects of refraction, curvature of the earth, and lack of instrument adjustment are thereby eliminated. On slopes a zigzag path may be taken to utilize the longer rod length available on the downhill sights.

CLOSED SURVEYS

To verify the accuracy of the leveling, a return check must always be made. That is, the line of levels must be continued from $B.M._2$ back over a slightly different route to $B.M._1$, the initial starting point. To make the return check independent of the first line of levels, after the F.S. is taken on $B.M._2$, lift the level slightly and relevel it so that the H.I. will be at a slightly and relevel it so that the H.I. will be at a slightly different elevation. This results in a B.S. on $B.M._2$ different from the F.S. and should result in a better check of the line of levels. When the survey party has returned to $B.M._1$, a <u>closed survey</u> has been completed. All leveling exercises should be closed surveys so that a check of the accuracy of the survey can be made. Figure 4 gives a sample traverse for a benchmark survey of a watercourse. Note that all available permanent structures are used as bench marks. These bench marks must be marked with both a waterproof maker and with a nail or screwdriver scratch for permanence. Figure 5 provides the sample survey notes for the traverse of Figure 4. Note the double tabling of points which are both turning points (T.P.) and bench marks (B.M.). Portable turning points are labeled PTP.

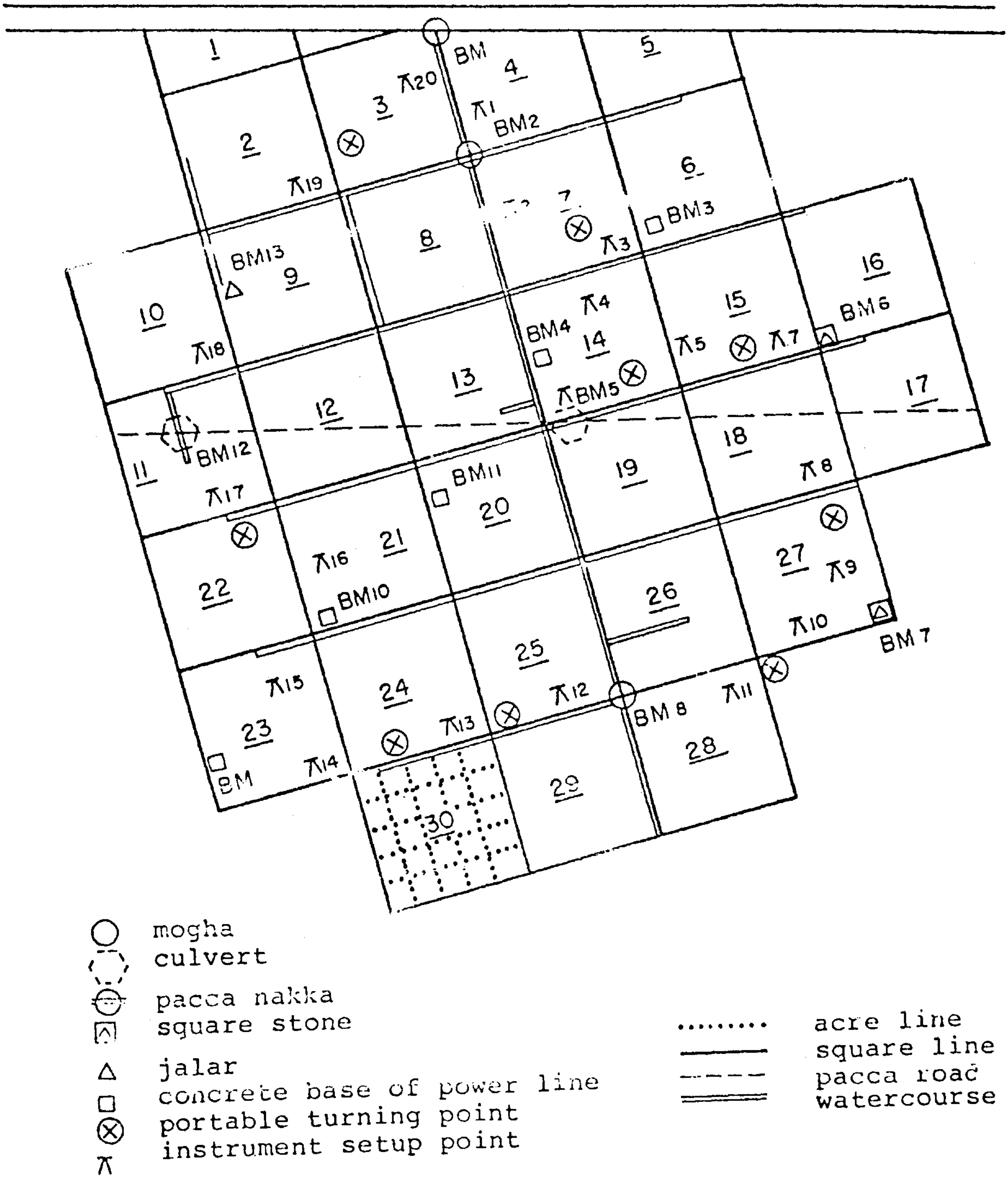

Figure 4. Sample traverse for bench mark survey of watercourse.

WATERCOURSE BENCH MARK SURVEY
BY DIFFERENTIAL LEVELING
Chak 110/JB, Lyallpur

Sunny Wanyam
Hot Zahid
Calm Aug. 18, 1975

Sta.		BS	HI	FS	Elev.	
	BM_1	3.02	103.02		100.00	Mogha Scratch Mark - Upstream Side
TP_1	BM_2	4.22	103.17	4.07	98.95	Pacca Kanna Corner of Squares 3, 4, 7 and 8
TP_2	TP_2	3.89	102.05	5.01	98.16	
TP_3	BM_3	6.87	104.85	4.07	97.98	Sq. 6: CBPL* - Scratch
TP_4	BM_4	4.48	102.44	6.89	97.96	Sq. 14: CBPL - Scratch
TP_5	BM_5	4.32	101.75	5.01	97.43	Sq. 13, 14: Concrete culvert - upstream
TP_6	TP_6	5.10	101.60	5.25	96.50	
TP_7	TP_7	4.88	101.50	4.98	96.62	
TP_8	BM_6	3.37	99.61	5.26	96.24	Sq. 15, 16, 17, 18: Square stone - scratch
TP_9	TP_9	3.85	99.28	4.18	95.43	
TP_{10}	BM_7	4.71	99.98	4.01	95.27	Sq. 25, 26, 28, 29: Square stone - scratch
TP_{11}	TP_{11}	4.85	99.56	5.27	94.71	
TP_{12}	BM_8	5.17	99.44	5.29	94.27	Pacca Nakka Corner of Squares 25, 26, 28, 29
TP_{13}	TP_{13}	4.37	98.81	5.00	94.44	
TP_{14}	TP_{14}	3.99	98.28	4.52	94.29	
TP_{15}	BM_9	4.00	98.37	3.91	94.37	Sq. 23: CBPL - scratch
TP_{16}	BM_{10}	6.02	100.77	3.62	94.75	Sq. 21: CBPL - scratch
	BM_{11}			/5.91/	94.86	Sq. 20: CBPL - scratch
TP_{17}	TP_{17}	6.27	101.77	5.27	95.50	
TP_{18}	BM_{12}	5.33	102.82	4.28	97.49	Sq. 11: Concrete Culvert: Scratch - Downstream
TP_{19}	BM_{13}	4.81	103.74	3.89	98.93	
TP_{20}	TP_{20}	4.68	104.72	3.80	99.94	Sq. 9: Steel frame on Jalar Base - scratch
	BM_1			4.51	100.11	Mogha

BS = 98.20 FS = 98.09 0.11 = Elev. Diff.

Error of closure = 98.20 - 98.09 = 0.11

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*Concrete Base of Power Line - CBPL

Figure 5. Watercourse benchmark survey notes by differential leveling.

ERROR OF CLOSURE

If there have been no errors made in a closed survey or if the errors have compensated, then the elevation determined for B.M.$_1$ by the return check will be the same as the original elevation of B.M.$_1$. Generally these elevations are not exactly the same due to errors in rod readings or instrumental errors. The amount by which the original B.M. elevation and the B.M. elevation observed upon the return check fail to agree is called the <u>error of closure</u>.

Allowable errors of closure for a survey is a function of the accuracy of the instrument and the length of the survey or the number of times the instrument is set up. For a Bostrom-Brady level, the allowable error of closure equals 0.01 meters per two instrument setups (0.01/2 setups). For the notes shown in Figure 3, there were four instrument setups so the allowable error of closure was 0.02. The actual error for the survey. For general leveling purposes with available equipment, the allowable error in English units (feet) is given by:

$$\text{Allowable error} = 0.000\sqrt{\frac{\text{length of traverse in feet}}{100}}$$

If the sample traverse for Figure 4 were 20,000 ft., then the allowable error is 0.0989 or 0.10 foot. Bench mark surveys which do not meet this standard must be completely resurveyed until the error of closure is less than the allowable error. The survey whose notes are provided in Figure 5 does not meet the standard and must be repeated.

CHECKING THE LEVEL NOTES

The computations of the level notes should always be checked by comparing the difference between the sum of the backsights (B.S.) and the sum of the foresights (F.S.) with the differences between the initial and final elevation of the B.M. and used to close the survey before leaving the field. This computation checks the notes for errors in arithmetic. The two differences <u>must</u> agree or an error in arithmetic has been made. No set of leveling notes is complete without an error of closure computation and check of the arithmetical accuracy of the notes, before leaving the field.

USE OF THE BENCH MARK SURVEY

The bench mark survey when completed to the required standard of accuracy becomes a basic for additional field surveys that are completed subsequently. The permanent benchmarks can then become starting points for any portion of the profile leveling survey of the watercourse and of the topographic survey of the watercourse. This set of benchmarks is then a set of known elevations to facilitate the completion of these other surveys.

PORTABLE TURNING POINTS

While profile leveling, benchmark or topographic surveying, the need for intermediate turning points arises frequently. The placement of the staff rod on the ground or on the bed of the watercourse can lead to errors of major magnitude, if when the rod is rotated in contact with the soil, changes in rod elevation occur. To avoid this problem and source of inaccuracy, portable, stable turning points are provided for field use. Figure 6 shows this simple surveying item. It is nothing more than a 4 inch square piece of #14 or #16 sheet metal with one-inch corners bent down at 90° from the face to form four legs. A rivet in the center holds a chain handle to the bottom side. The rod is rotated on the rivet after the turning point has been forced into the ground.

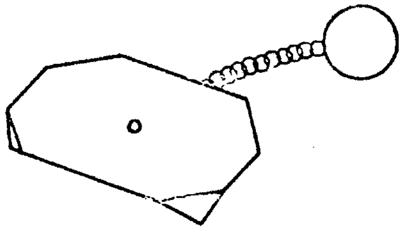

Figure 6. Portable pucca turning point.

EWUP
How to do it
Field Procedure

PROFILE LEVELING OF MAIN AND LATERAL CONVEYANCE CHANNELS

by Wayne Clyma and Alan Early[*]

GENERAL

Profile leveling is the process of determining the elevation of the ground surface at a series of points at measured intervals along a drainage ditch, terrace, waterway, road, or for any other purpose where it is necessary to consider changes in elevation of the ground surface.

TAPING PROFILES

It is necessary to tape or otherwise measure the horizontal distances for a profile. Vertical distances along the profile would have no meaning without the corresponding horizontal distances between changes in elevation.

Stakes or chaining pins are usually set along the fixed line for a profile survey. These stakes or chaining pins are usually set before the survey is made. Stakes are placed at fixed distances along a survey i.e., 25', 50', or 100', depending upon the detail required for the survey. In addition, stakes are set at points where the line changes direction and at every full station. For the profile survey of the watercourse main and the major branches, chaining pins should be used to mark the stations at 25' distance intervals.

A full station is 0 + 00, 1 + 00, 2 + 00, etc. Stakes set at any other point between the full stations are called plus stations and are designated, for example 1 + 25. Note that 0 + 00 designates the beginning of the line. Distances along the line indicate the full stations and the plus stations for instance 150 ft is written as 1 + 50 ft. Thus, the digits to the left of the + designate the distance in multiples of 100', while those to the right indicate less than 100'. The station number is usually marked upon

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[*] This How-To-Do-It was taken from The Problem Identification Handbook (April 1, 1980). Developed by the CSU-Pakistan Water Management Project sponsored by U.S. Agency for International Development, Contract No. AID/TAC-1100.

that side of the stake facing 0 + 00. Stakes are arranged, when possible, so that the wide part of the 2" x 5" stake points to the next station on the line.

A stake is driven at each station located on the profile. Each station will also be entered in the field notes. Pins will no longer be necessary to count tape lengths, since the length of the line will be recorded in the notes. For other than 100 ft tapes, two pins may be used to measure full tape lengths. When other than full tape length is measured, the rear chainman holds the partial tape length at the appropriate point. The stake is located for that station. The note keeper adds the partial tape length to his last station and records the new station. Since the head chainman has the zero end of the tape, the intermediate distances are read directly on the tape without subtraction.

Intermediate Sights

The purpose of the profile survey is to determine the true slope of the ground surface or watercourse bed surface. This means that where there is an obvious change in the slope of the ground or bed surface, a stake is placed and an intermediate sight (foresight or minus sight) is taken so that the elevation of the ground surface at that point can be determined. The foresights for a profile are called intermediate sights because they are foresights intermediate or between the foresights taken on T.P.'s for a continuing line of levels. The student beginning profiles has a tendency to take more intermediate rod readings than are necessary. The guide to remember so that none are left out is to take an intermediate shot wherever the ground surface changes slope. If in doubt, take the rod reading. It is simpler to have an extra rod reading than to leave out one that was necessary.

Procedure for Profile Leveling

The first step in profile leveling is to establish the centerline of the watercourse, terrace outlet channel, or road to be profiled and to measure the line accurately setting stakes at all points where rod readings are to be taken. Set the level up near the line to be profiled. It is normal to offset the instrument from the line so that more nearly equal horizontal distances from the instrument to the rod can be obtained. A rod reading is obtained on the bench mark and the height of instrument is determined. Frequently the bench mark is located so that more than one instrument setup is required before the rod can be read at the stakes located on the profile line. When this is necessary, the T.P.'s are selected and the notes are as for a differential survey. Rod readings are observed on the ground or bed with portable pucca turning point adjacent to the stake of chaining pin for the intermediate shots. For turning points, all rod readings are taken on top of a stake if the stake is used or on the portable pucca turning point if chaining pins are used. When placing the rod adjacent to a stake for an intermediate shot, the student should always try to select average ground. That is, the rod should not be placed in a hole, nor should it be placed on the top of a hill or clod. The location should represent the average of the ground surface immediately around the stake.

For an example of a ground surface profile and corresponding rod readings, see Figures 1 and 2. After the instrument has been leveled, a rod reading is obtained on the B.M. and the H.I. is computed. In the example, a B.S. of 1.02 gives an H.I. of 101.02, a rod reading is then obtained near 0 + 00 for the first shot, 0 + 38.03 for the second shot, and so forth until station 0 + 72.56 has been read. A turning point is then necessary, so a T.P. is selected and a foresight of 1.60 is obtained on the top of the stake. The instrument is carried to a new position along the line, releveled, a B.S. of 0.98 obtained on T.P., and a new H.I. computed. We are now ready to take additional intermediate shots along the profile line. This process is continued until the profile is completed. A complete set of profile leveling notes is shown in Figure 3.

Closed Surveys

In profile leveling, as in differential leveling, a closed circuit of levels must be made to check the accuracy of the survey. This is done, as in differential leveling by running a line of differential levels back to the bench mark from which the survey was begun.

Error of Closure and Checking the Notes

The method of checking the note computations and computing the error of closure is shown in Figure 4. Note that for a profile survey the foresight and the backsights used for computing the error of closure are only those which were taken on the B.M.'s and T.P.'s. The intermediate rod readings are not used in the computation for error of closure. The only method of checking the intermediate rod readings is to rerun the entire profile.

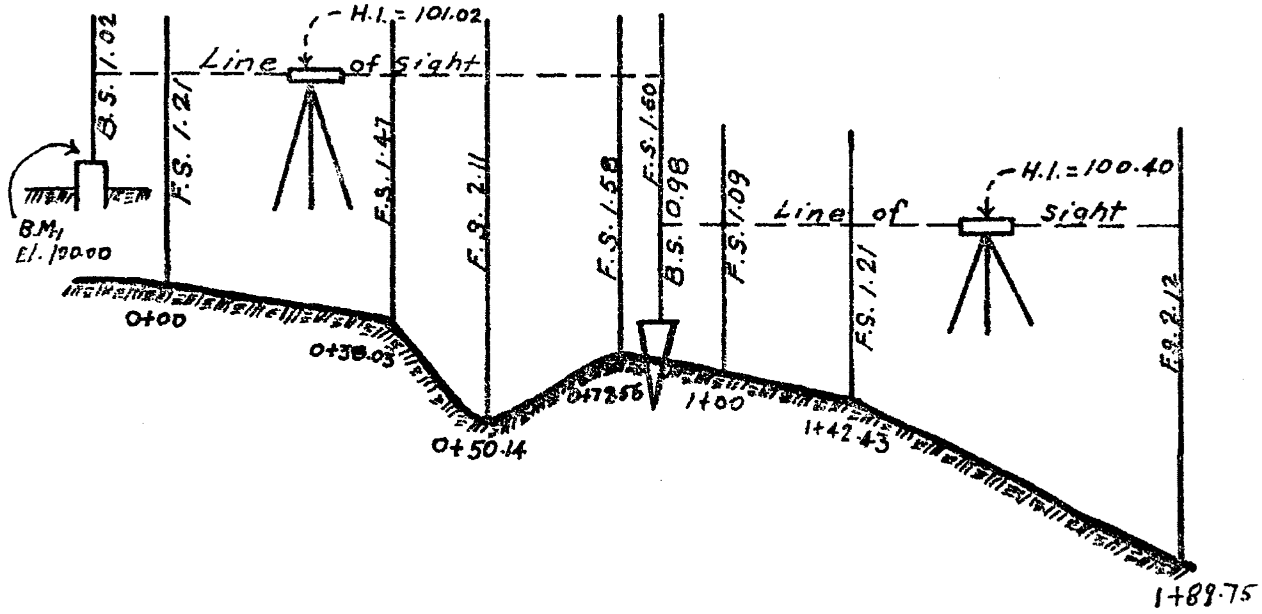

Figure 1. Rod readings for profile leveling.

PROFILE LEVELING

Sta.	ES	EI	ES	Elev.
BM_1	1.02	101.02		100.00
0 + 00			1.21	99.81
0 + 38.03			1.47	99.55
0 + 50.14			2.11	98.91
0 + 72.56			1.50	99.44
TP_1	0.98	109.40	1.69	99.31
1 + 80			1.09	99.31
1 + 42.43			1.21	99.19
1 + 89.75			2.12	98.28

Figure 2. Left side of notes for profile shown in Figure 1.

PROFILE FOR AG. ENGR. CULVERT

Tewolde W.R&N
Mehary T. ϕ

Sta.	BS	HI	FS	Elev.
BM_1	1.62	101.62		100.00
0+00			0.51	101.11
0+4.12			0.86	100.76
0+8.75			1.14	100.48
0+12.50			1.39	100.23
0+15.96			0.92	100.70
0+20.58			1.65	99.97
0+27.85			1.98	99.64
0+30.00			2.16	99.46
0+36.90			2.39	99.23
0+39.42			2.25	99.37
0+42.30			2.76	98.86
TP_1	0.23	99.70	2.15	99.47
0+48.4			1.26	98.44
0+58.56			1.91	97.79
0+60.00			1.95	97.75
0+65.83			1.93	97.77
0+69.90			3.05	96.65
0+72.18			3.44	96.26
0+72.65			3.60	96.10
0+73.19			3.48	96.22
0+76.49			3.30	96.40
0+81.55			3.50	96.20
TP_2	0.54	96.93	3.31	96.39
0+83.15		96.93	1.27	95.66
0+85.30			1.49	95.44
0+88.10			1.56	95.37
0+90.00			1.83	95.10
0+93.40			1.90	95.03
0+97.31			2.21	94.72
TP_3	3.32	99.70	0.55	96.38
TP_4	1.72	100.93	0.49	99.21
BM_1			0.92	100.01
ΣBS =	7.43	ΣFS =	7.42	100.00

Error of closure = ΣBS - ΣFS
= 7.43 - 7.42
= 0.01 0.01 check

Cloudy, shower
Oct. 7, 1965
BM: an x mark on the retention wall at the north side of the Agri. Engr. building, about 2.60 m above the first step, under a lamp post.

Figure 3. Sample notes for a profile leveling exercise.

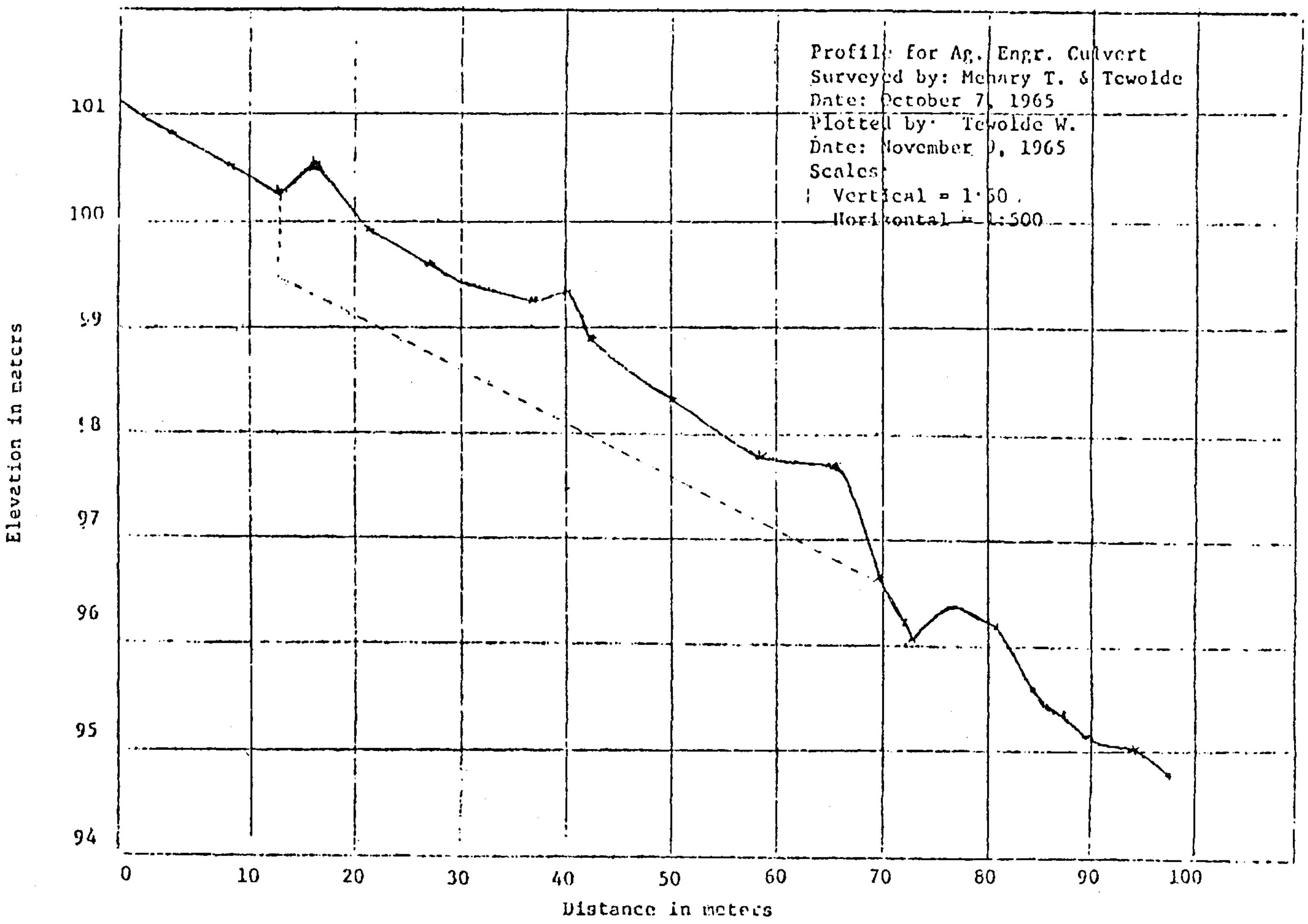

Figure 4. Cross section plot for a profile leveling exercise.

Plotting Profiles

Profiles are usually plotted on paper and the result called a cross section. Special profile paper can be obtained which simplifies plotting, but any ruled paper may be used.

The vertical scale of a profile is generally exaggerated with respect to the horizontal scale in order to make differences in elevation more pronounced. This is because the vertical distances in elevation are usually much less than the horizontal distance covered by the profile. The exaggeration is usually on a ratio of 10/1. That is, for a horizontal scale of 1:500, (i.e., 1 foot equals 500 ft) the vertical scale would be 1:50 (1 foot equals 50 ft). Since the points plotted on the paper from the profile represent "average ground" it is usually the practice to draw smooth lines (not straight lines) from point to point.

The plotted profile is used for many purposes, such as:

1. Determination of the depth of cut for a drainage or irrigation watercourse.
2. Determination of the fill for a farm pond.
3. Selection of the grades for a drainage ditch, irrigation watercourse or culvert.

Rate of grade, gradient, or just grade is the rise or fall in feet per 100 feet. Thus, a grade of 2.5 means that there is 2.5 ft difference in the elevation per 100 feet horizontally. Ascending grades are plus and decending grades are minus. The selection of a grade line for a project involves the principles of engineering desing.

The term "grade" is also employed to denote the elevation of the finished surface of an engineering project.

EWUP
How to do it
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VEGETATIVE LAND USE MAPPING

by M. B. Lowdermilk and A. Early[*]

INTRODUCTION

The inventory of land and water resources in an area is important for any hydrologic study. Significant agricultural land use surveys have been conducted by the U.S. Department of Interior, Bureau of Reclamation, and the U.S. Department of Agriculture, Soil Conservation Service for many irrigated areas in the United States. In addition, detailed soil survey information has been developed for almost all irrigated areas.

The quantity of water transpired by vegetation, and evaporative losses from various water surfaces account not only for the most significant phase of the hydrologic or water flow system, but also play an important role in the salt flow system. An understanding of water and salt budgets can be obtained only by careful study of the water and salt flow systems in the area utilizing recognized hydrologic techniques. This is usually done by extensively studying a small area and extending the results to the entire irrigated area. A budgeting process must be designed to account for the water as it moves about and changes use within the area, and it must also be designed to account for the salt and its relative flow system. Consequently, once such budgets have been prepared which define the system, it then becomes possible to test or delineate the effects of various changes or proposed water management alternatives upon the system. In order to extend the analysis to an area-wide basis, it is important that the land use be determined for the entire area.

The type of land use data required for the preparation of a budget consists of delineating the various types of vegetation and land uses utilizing water in excess of normal precipitation. This cataloging process

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[*] This How-To-Do-It was taken from The Problem Identification Handbook (April 1, 1980). Developed by the CSU-Pakistan Water Management Project sponsored by U.S. Agency for International Development, Contract No. AID/TAC-1100.

is an expensive and time consuming effort which includes separating the agricultural areas from the wetland phreatophytes, the urban areas and the industrial areas as well as the open water surfaces. These types of studies are not only necessary for budgeting procedures, but they also provide an excellent data base for future studies in an area for many disciplines. This data must be collected by field investigations.

Aerial photographs are an excellent tool to be used in vegetative land use mapping. The most current photographs available should be used since land use changes are usually minimal, field boundaries have not changed, ditches have not been relocated, farmsteads and urban areas are easily defined, and adjustments and updating are easily accomplished.

Aerial photographs having almost any scale can be ordered from the U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service, Aerial Photography Division, Wester Laboratory in Salt Lake City, Utah. It is important to select a scale for the photographs which corresponds to other base maps or design maps which exist or will be used for the project.

The range, township, and section numbers are marked on the photographs which are then taken into the field and the land use at the time is marked on the appropriate photographs for each field. A suggested land use mapping index is presented in Table 1. Other indexes are in use by the USBR, SCS, and other agencies, but whatever index is used for mapping purposes, it should be compatible with other studies which have been undertaken in the area or river basin. A typical photograph from which the land uses were labeled in accordance with the water related land use index is shown in Figure 1. For example, a field marked A1 on the aerial photograph indicates that during that year, corn was grown in that field. Although it is realized that certain changes will occur from year to year, it is usually safe to assume that the total acreages and the distribution of crop acreages varies slowly with time over a large area.

Due to the scale distortion, which is always present in aerial photographs, a effort should be made to prepare land use base maps with accurately placed section lines. To assist in accomplishing this, maps should be prepared using a grid based on geodetic coordinates. This is usually not a problem since most agricultural areas in the western United States have roads and field boundaries corresponding to these coordinates.

Table 1. Suggested land use mapping index.

A. Irrigated Cropland
    1. Corn
    2. Sugar beets
    3. Potatoes
    4. Peas
    5. Tomatoes
    6. Truck crop
    7. Barley
    8. Oats
    9. Wheat
    10. Alfalfa
    11. Native grass hay
    12. Cultivated grass and hay
    13. Pasture
    14. Wetland pasture
    15. Native grass pasture
    16. Orchard
    17. Idle
    18. Other

B. Dry Cropland
    1. Alfalfa
    2. Wheat
    3. Barley
    4. Beans
    5. Cultivated grasses
    6. Fallow
    7. Other

C. Other Land Use
    1. Farmlands
    2. Residential yards
    3. Urban
    4. Stock yards
    5. School yards

D. Industrial
    1. Power plants
    2. Refineries
    3. Meat packing
    4. Other

E. Open Water Surfaces
    1. Major storage
    2. Holding storage
    3. Sump ponds
    4. Natural ponds

F. Phreatophytes
    1. Cottonwood
    2. Salt Cedar
    3. Willows
    4. Rushes or cattails
    5. Greasewood
    6. Sagebrush and/or rabbitbrush
    7. Wildrose, squawberry, etc.
    8. Grasses and/or sedges
    9. Atriflex

P. Precipitation only

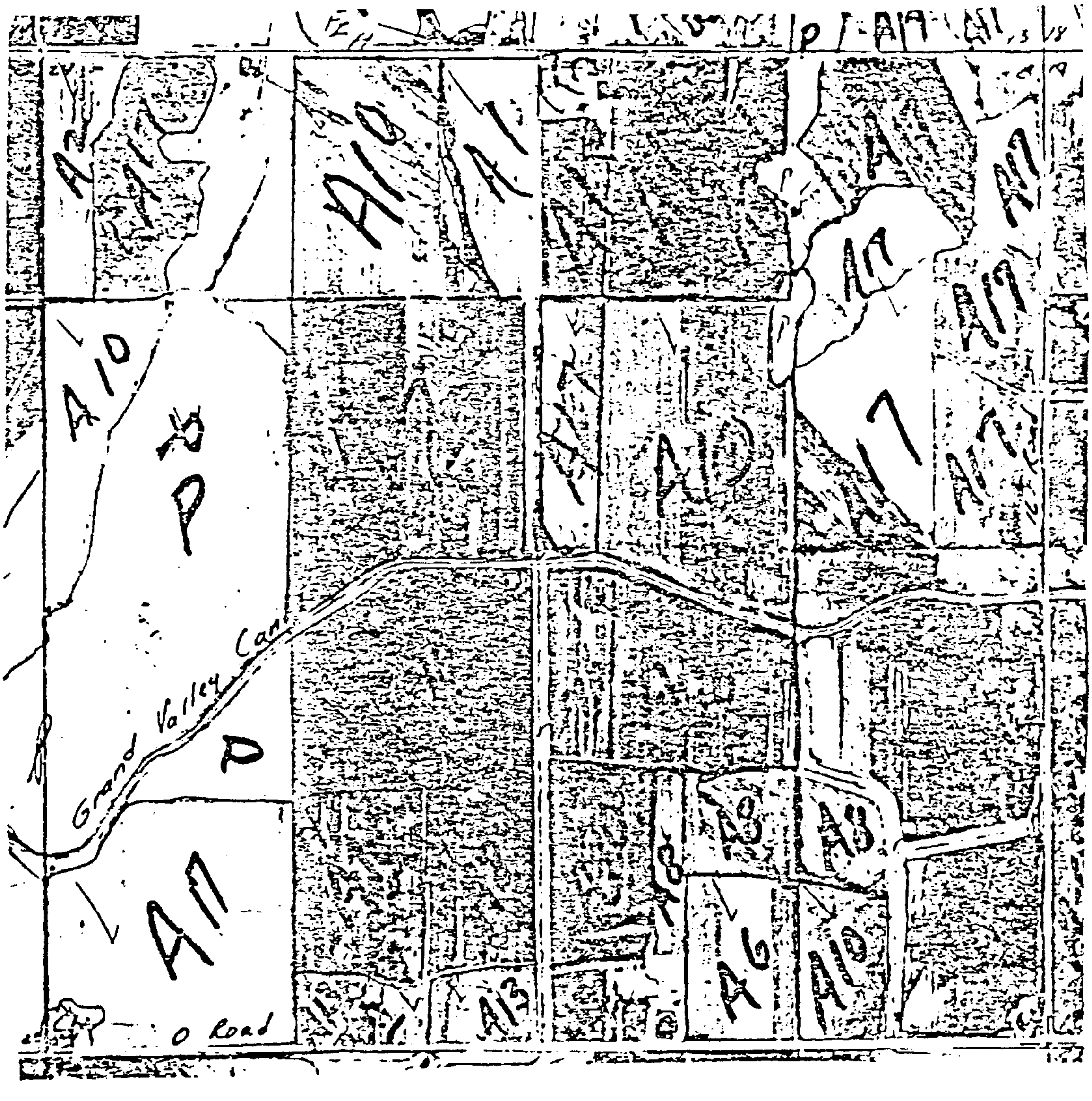

Figure 1. Typical areal photograph used for land use mapping showing the land use mapping index used in Table 9.

The scale of the base maps should correspond directly to the scale of the aerial photographs. U.S. Geological Survey quadrangle maps can be used for control where available. In addition, there are several computer techniques available to correct for distortion if adequate control is established.

The various water related land use areas are then transferred from the aerial photographs to the base maps which also depict the individual field boundaries (see Figure 2). The irrigation conveyance system should be added to the base maps in order that lands served by each canal or lateral could be established if desired.

In addition, many sections are not exactly 640 acres (259 ha), and they can often vary by as much as ± 10 percent of this value. It is therefore necessary to establish the area of each section. One method is to use graphical computer techniques or planimeter each section from the quadrangles to arrive at the correct acreage for that section. The acreage of each land use within that section must also be determined from the base maps by similar methods. The acreage of each and use is then summed for each canal, each lateral, or each watershed to arrive at the needed values.

The results of these investigations, including the base maps and/or tabulation of the data for each section or subgroup, should be organized and made available for public distribution. This type of information is very valuable and is needed by many state and local planning agencies, public interest groups, environmental impact assessments, etc. In addition, this information provides a very good basis for comparison in future land use related investigations. Examples of these types of publications are Walker and Skogerboe (1971) and Evans et al. (1973).

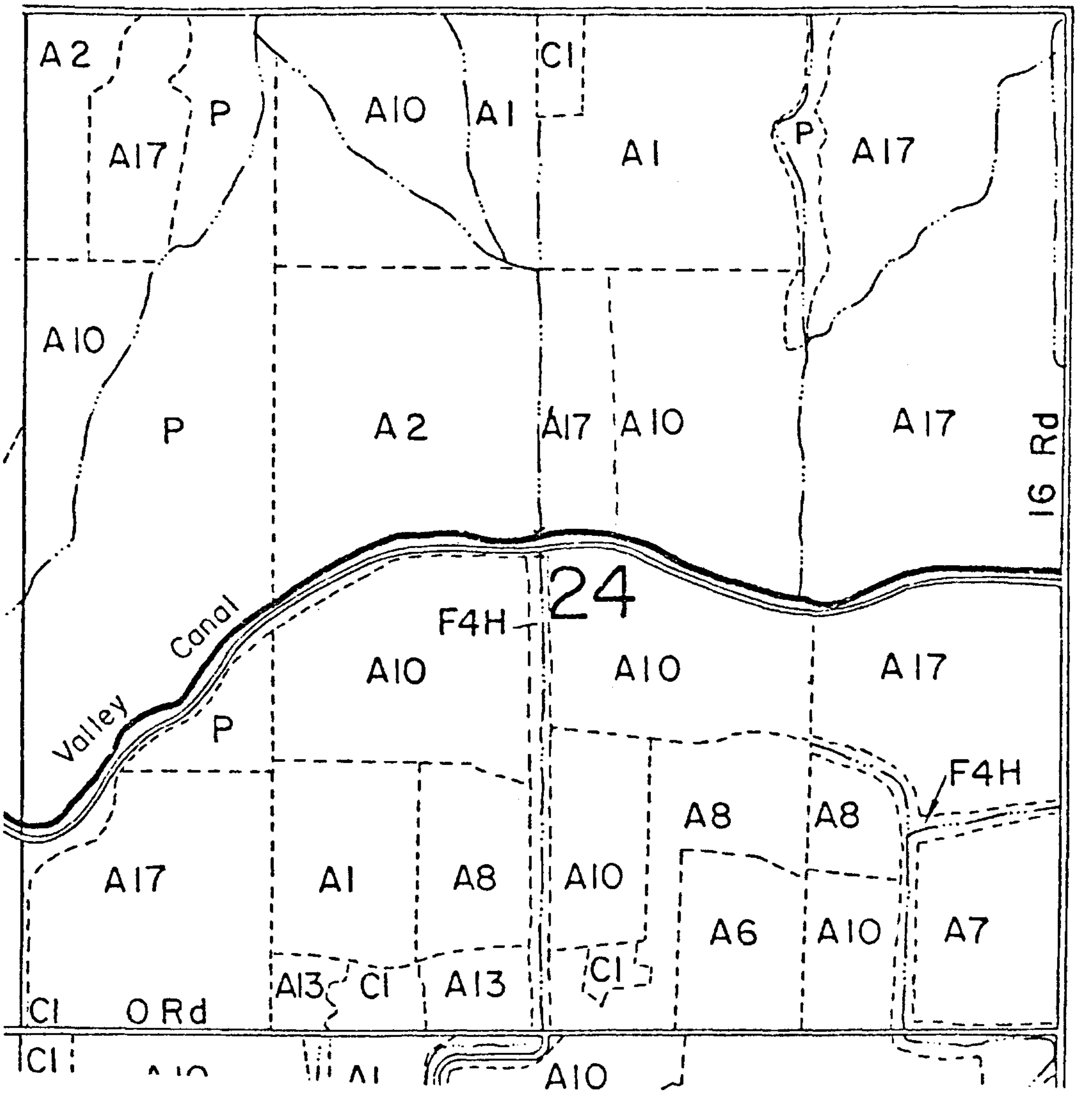

Figure 2. Finished map corresponding to the areal photograph shown in Figure 1.

EWUP
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SOIL MOISTURE DETERMINATION TECHNIQUES

by Alan Early*

Water management proficiency requires that the technician learn the water requirements of the plants to be grown and how much of that water can be furnished from soil stored moisture and how much and how often it must be applied through irrigation. Soil moisture determination, therefore, becomes important as soon as soil samples have been collected and prepared.

First, the sample must be protected against moisture loss from the time of collection until the initial weight has been recorded. Airtight metal or plastic containers are used for this purpose. Two types of moisture determination methods are used. The gravimetric (measurement by weight) determination involves the determination of weight differences at the time the sample is collected and after it has been dried to measure the amount of the water contained in the soil. The touch and feel (TAF) method is a field procedure which is utilized to make quick, practical estimates of moisture resources and requirements.

GRAVIMETRIC DETERMINATIONS

The Oven

The oven is the tool utilized by the laboratory to determine soil moisture analyses. It provides an exact analytical measurement of the amount of moisture contained in the soil, and through the combination of the results from samples representing various segments of the soil profile, the water content of the field within the root zone of the crop to be produced can be calculated. The exact requirements of the research scientist are provided for by this method.

Standard procedures in the use of the oven are:

a. Weigh and record the weights of the airtight containers and the soil they contain.

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*This How-To-Do-It was taken from The Problem Identification Handbook (April 1, 1980). Developed by the CSU-Pakistan Water Management Project sponsored by U.S. Agency for International Development, Contract No. AID/TAC-1100.

b. Open the containers and place in the oven which has been set at 105°C.

c. Dry for 24 hours.

d. Record the dry weight.

e. Subtract dry weight from the weight of the field-collected sample. The difference is water.

This procedure may be repeated as necessary until the weight becomes constant, since some soils dry more readily than others.

The Sun Drying Method

Since ovens are not generally available to the worker in the field, an alternate method has been developed which utilizes solar energy for the purpose of drying soil samples. In areas where the climate is warm and dry, results have been found to be very close to those obtained from oven-dried samples.

This procedure calls for the use of plastic sheets or of the same plastic bags in which the samples are stored to be exposed to the sun after the sample has first been weighed. Procedures utilized in the sun-drying of samples are:

a. Determine weight of sheet or bag by weighing 100 of them and determining the average weight.

b. Spread the sample out and break any clods present, thus providing maximum exposure of the soil to the sun.

c. Place the samples in a convenient, protected area where maximum exposure to the sun is available.

d. Exposure time

Time of year	Sheet	Bag
Hot Season	3 hours	5 hours
Cool Season	4 hours	7 hours

These tabulated times assume this number of hours of bright sunshine. Drying cannot be conducted during cloudy or partly cloudy weather.

Overnight drying is not recommended since wind or storms can ruin samples very quickly.

Note...these exposure times have been found to approach 1% of oven dry weights in Pakistan, where the climate is warm and dry and sun intensity is high.

Specifications of drying sheets or bags:

Sheets

a. Sheets should be 2 to 6 mil polyethelene plastic, 24 inches square.

b. Sheets need not be weighed if a special weighing dish is used.

Bags

a. If the same bag is used for drying as that in which the sample is collected, larger bags are needed. 15" x 15" plastic bags are recommended so that they may be folded to provide a two-inch rim around the exposed sample. The use of the bag provides somewhat more protection against spillage than the sheet, and requires fewer supplies and less handling.

The Touch and Feel Method (TAF)

The touch and feel method is not intended to replace field samplings and laboratory techniques. Rather, it is intended to enable the technician to develop a practical, quick estimate in the field when decisions relative to water use or irrigation planning are necessary.

The attached table presents descriptions of the appearance of the soil as it is examined. First, determine the texture of the soil:

Wet a small handful of the soil and work it into an uniform consistency by squeezing and kneading it.

A coarse soil when squeezed will leave moisture in the hand. The sample shows little cohesion and will not form a "ribbon" when squeezed between the thumb and forefinger.

A light soil leaves a wet outline on the hand when squeezed. Shows some cohesion when manipulated and will form only a very weak "ribbon" when squeezed between the thumb and forefinger.

A medium soil leaves a slightly wet outline when squeezed in the hand. It shows definite cohesion, and will form a moderate ribbon (up to 1 inch in length) between the thumb and forefinger.

A fine soil hardly leaves a moisture outline when squeezed in the hand. It is strongly cohesive, and will sometimes ribbon out to almost two inches between the thumb and forefinger.

Once the basic textural group has been determined and proper column in the table has been chosen, the samples in the field moisture condition is examined. The procedure is to squeeze the sample into a ball, about an inch in diameter. Test the ball for strength and compare its strength with the descriptions in the column of the table representing the textural grade of the sample. Estimate soil moisture deficiency in inches per foot of depth from the table...last column.

The chart assumes the average soil available soil moisture, at field capacity, for the four textural classes to be:

Coarse - 0.7 inches per foot
Light - 1.3 inches per foot
Medium - 1.8 inches per foot
Fine - 2.0 inches per foot

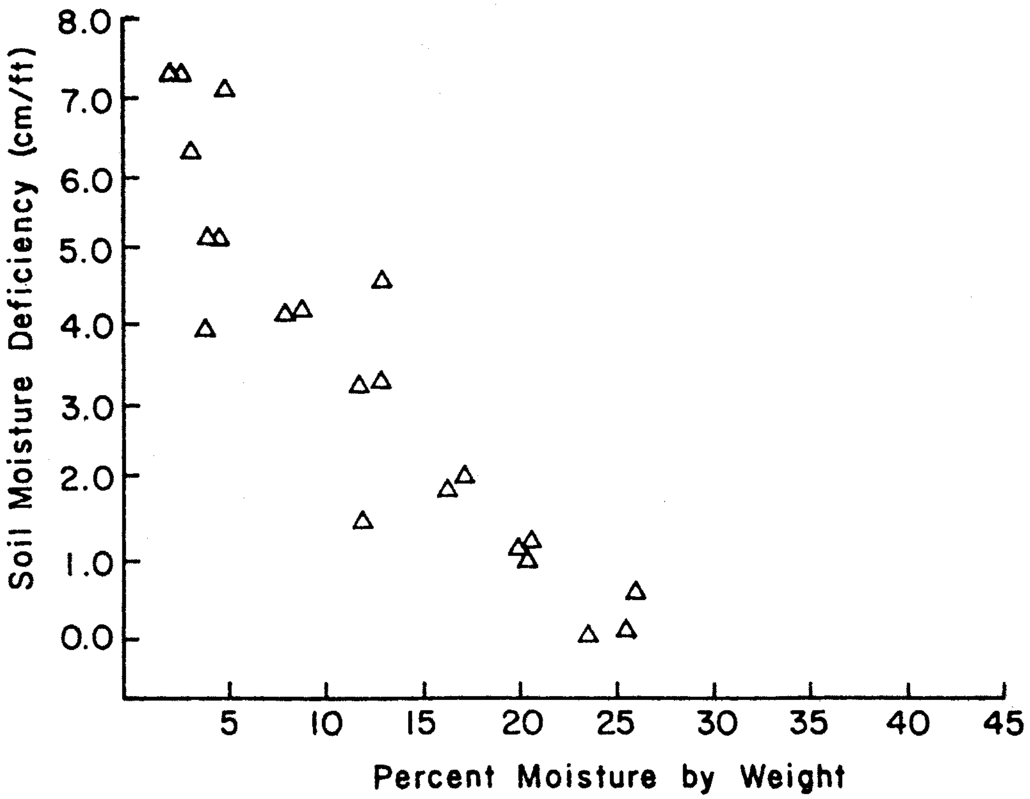
These values can be divided by 12 and multiplied by 100 to convert to available moisture on a volume basis. This figure divided by the bulk density of the soil will provide available moisture on a weight basis (which the gravimetric procedure provides).

Comparison of the Three Techniques

Actually the three techniques which are discussed here are not designed to replace one another. Rather, they are each utilized in that manner which will expedite the management program most efficiently.

The procedure which provides the true analytical analyses of soil moisture availability is the use of the oven. The other methods have been developed to supplement, not replace, this one. The accuracy of the sun-drying method is determined by the care with which the sample is handled; the temperature, humidity, and intensity of the sun. Its accuracy might not be dependable in cool or humid climates, but in warm, dry areas like Pakistan the results have been found to be practical and accurate when samples are properly handled and protected.

The TAF method is not intended to replace gravimetric procedures. It has been developed for use by the technician to make quick, practical field decisions. If this procedure is to be accurate and effective, the person using it should constantly calibrate his "feel" against gravimetric results. It is suggested that he develop a graph, similar to the following, on a regular basis.



One individual's calibration of his "feel" using the gravimetric method.

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SOIL MOISTURE SAMPLING AND CALCULATION USING A KING TUBE SAMPLER

by Alan Early*

The king tube sampler is a useful tool to the water management specialist. When properly constructed and correctly used it can provide volumetric samples of soil to calculate dry bulk density as well as soil moisture percentages and plant food analyses. However, extremes in soil moisture percentages may limit density accuracy. In very dry soil some of the sample may often be left at the bottom of the hole, on the other hand, very wet soil will stick to the sides of the tube. In either case lower than actual density values may result.

A few precautions and suggestions have been developed which will assist in avoiding these pitfalls.

1. Be sure the tube is clean and free of rust. Clean and polish the tube regularly. Cover with a light film of oil if tube is not used regularly.
2. Measure the inside diameter of the cutting edge of the tube and check the exterior depth calibrations above the cutting edge. Reject the tube if any of the measurements are not within 0.005 ft (.01 centimeter).
3. Select representative sites from the field to be sampled. Areas within the field which appear different from the "average" should be sampled separately.
4. Align the tube vertically and strike the tube vertically into the ground allowing the pointed edge of the hammer to move inside the tube in an up and down motion. Never swing the hammer as a driving device.
5. Place a straight edge on the ground next to the hole as a reference point to stop the sample tube at each depth graduation.

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6. Remove the hammer from inside the tube and orient it horizontally (perpendicular to the tube) passing the hammer slot over the end of the tube. Rotate the hammer 90° in a horizontal plane and lift the tube slowly, vertically from the soil.
7. Place your left index finger over the cutting edge of the tube as it emerges from the surface of the soil to prevent sample spillage.
8. Invert the tube with top of tube over the container (moisture can with tight fitting lid or plastic bag) which is to keep the sample in proper moisture condition until weights have been determined. Force the sample loose by pushing it loose with the index finger. A clean, polished tube, properly constructed will easily release the sample into the container. Close the container immediately to prevent the loss of moisture. Do not allow unweighted sample to be exposed directly to the sun, especially samples collected in plastic bags.
9. Repeat steps 4 through 8 for as many different depth increments as needed.
10. Repeat steps 3 through 9 for at least two replicates in other representative sites of the field being sampled.
11. Weigh and record the weight of the wet sample in the field. Samples placed in plastic bags should be weighed immediately.
12. Dry the sample.
13. Reweigh the sample after predetermined drying time. (The sample is considered dry when no further weight changes occur.)
14. Make necessary calculations using the following procedures.
    a. Volume = $3.14\ (D/2)^2H$.
    b. Water Weight = (wet weight of sample and container) - dry weight of sample and container).
    c. Net dry weight of sample = dry weight (sample and container) - weight of container.
    d. Percent moisture by weight = net $\frac{\text{weight of water}}{\text{dry weight of soil}} \times 100$
    e. Field dry bulk density = $\frac{\text{net dry weight of soil}}{\text{volume of sample (cc)}}$ (gm)
    f. Percent moisture by volume = field dry bulk density x percent moisture by weight or $\frac{\text{weight of water}}{\text{volume of sample}} \times 100$

g. Approximate available moisture (inches per foot) ASM = 12 x % MC Volume - Volume at wilting point where % MC-Vol at the wilting point is to come from laboratory analysis of soil moisture characteristic.

SOIL MOISTURE SAMPLING REPORT

Observers __________ and __________ Weight of plastic bag __________ g
Date __________ Hours Drying Time __________
Date Last Irrigation __________ Diameter of king tube __________ cm
Date of next irrigation __________ Volume of sample 6" = ______ cc 12" = ______ cc

Rep	Trtmt	Depth	WetWt(g)	DryWt(g)	WtH_2O	NetDryWt	%MC-Wt	DBD	%MC-Vol	ASM(in/ft)
		1(0-6")								
		2(6-12")								
		3(12-24")								
		4(24-36")								
		5(36-48")								
		6(48-60")								
		7(60-72")								

Rep	Trtmt	Depth	WetWt(g)	DryWt(g)	WtH_2O	NetDryWt	%MC-Wt	DBD	%MC-Vol	ASM(in/ft)
		1(0-6")								
		2(6-12")								
		3(12-24")								
		4(24-36")								
		5(36-48")								
		6(48-60")								
		7(60-72")								

Rep	Trtmt	Depth	WetWt(g)	DryWt(g)	WtH_2O	NetDryWt	%MC-Wt	DBD	%MC-Vol	ASM(in/ft)
		1(0-6")								
		2(6-12")								
		3(12-24")								
		4(24-36")								
		5(36-48")								
		6(48-60")								
		7(60-72")								

Rep	Trtmt	Depth	WetWt(g)	DryWt(g)	WgH_2O	NetDryWt	%MC-Wt	DBD	%MC-Vol	ASM(in/ft)
		1(0-6")								
		2(6-12")								
		3(12-24")								
		4(24-36")								
		5(36-48")								
		6(48-60")								
		7(60-72")								

Rep	Trtmt	Depth	WetWg(g)	DryWt(g)	WgH_2O	NetDryWt	%MC-Wt	DBD	%MC-Vol	ASM(in/ft)
		1(0-6")								
		2(6-12")								
		3(12-24")								
		4(24-36")								
		5(36-48")								
		6(48-60")								
		7(60-72")								

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SOIL PROFILES AND WATER TABLES

by Doral Kemper*

The position of the water table is an indication of whether or not a drainage problem exists. A high water table means that something has to be done to reduce the amount of water in the soil. Under ordinary conditions in arid regions, the water table should not be occasionally higher than 1.2 meters below the soil surface, and most of the time it should be 2.0 meters or more below the soil surface. A shallow water table will cause salt to accumulate on the soil surface from direct evaporation. A high water table will also cause poor aeration conditions in the root zone of the plants.

If the water table is too high under irrigated conditions, some form of artificial drainage must be provided.

Where aritificial drainage is required, it is important to know the location and position of the water table. It is also important to know the texture characteristics of the soil profile.

General Procedure

A hand auger, a power auger or a soil coring device is used to make a hole in the soil to a depth of two meters or more. The depth and texture of the various soil layers should be recorded. The depth at which free water is noticed should also be recorded. Observations of the position of the water table in the hole should be observed over a period of days or weeks or months, depending on the need. If the water table is too high, a drainage system should be considered.

Equipment Needed

Hand auger or power soil sampler capable of making a hole 5 cm or larger in diameter to a depth of two meters or more.

Surveying equipment and stakes for locating the water table holes both for surface position and elevation.

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Measuring tape to determine depth from the soil surface to the water table.

Detailed Procedure

In the area selected for study of a water table problem, lay out a regular grid location for the water table observation holes. The spacing may be 1 or 2 kilometers in large areas or as little as 50 meters in a normal spacing.

Make a vertical hole in the soil, keeping notes of the soil texture, structure, color changes, soil conditions and wetness for each of the layers. A special note should be made of the depth for the first appearance of visible water in the soil being removed.

The completed hole should be covered or protected so that animals will not step in it and the hole can be left for observation. Observations of the water level in the hole should be made periodically. Observations may be made hourly, daily, weekly, monthly or annually, depending on the need. For farm drainage design, daily observations are usually required. The observations consist of measuring and recording the distance from the soil surface to the water table using tape or a chain or a rod.

If elevation changes and slope of the water table are important, elevations of the soil surface should be determined at each auger hole for reference. Data from the observation holes can be used to make maps of depth to water table and water table contours.

If the hole is unstable or if long-term observations are needed, a perforated pipe surrounded with coarse sand can be used to line the hole.

EWUP
How to do it
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GUIDELINES FOR CUTTHROAT FLUME INSPECTION

by Alan Early*

Precise water measurement is necessary if good water management is to be realized. A useful saying is, "How can you on a farm manage water if the amount of water to be managed is not known?" Measuring water is the most basic requirement for developing an understanding of any irrigation system. First of all, the precision of water measurement is dictated by the accuracy with which the flow measuring device is constructed. Exact tolerances in fabrication are therefore required.

The following is a guideline, fill-in table, and check list for inspecting cutthroat flumes. All measurements of flume dimensions must be met within 1/16 in. (0.005 ft or 1.5 m) of the specified length, or within 0.5 degrees of the specified angle, if the flume is to be acceptable for field use. Flumes which do not meet these standards should be rejected.

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TABLE OF LINEAR DIMENSIONS Tolerance (0.005 ft)

	Specification	Top	Middle	Bottom	Other
W					
L					
B_1=W + L/4.5					
B_2=W + L/4.5					
L_1=L/3					
L_2=2L/3					
L_a=2L/9					
L_b=5L/9					
H					
H_a					
H_b					

TABLE OF ANGLES MEASURED

Angles are measured from the vertical wall (or staff gauge) to the floor of the flume in the direction corresponding to the arrows in the attached diagram.

Tolerance: 0.5 degree

	Spec.	Measured		Spec.	Measured		Spec.	Measured
1.			6.			11.		
2.			7.			12.		
3.			8.			13.		
4.			9.			14.		
5.			10.			15.		

GENERAL QUALITATIVE MEASURES AND OBSERVATIONS

_____1. Staff gauges should be located precisely at distances L_a and L_b from the throat, respectively, with these distances being measured to the center of the staff gauge markings.

_____2. Staff gauges installed perpendicular to the floor of the flume.

_____3. When installed with stilling wells, the centerline of the piezometer holes for water entry must be precisely at distances L_a and L_b from the throat (tolerance: .005 ft).

_____4. When installed with stilling wells, the staff gauge in each stilling well must start at exactly the same datum (floor of the flume) in the stilling well as in the respective converging and diverging sections.

_____5. Sides must be perpendicular to the floor throughout the converging inlet and diverging outlet sections.

_____6. Sides must be plane number surfaces, free of buckles and bulges.

_____7. The bend of the walls in the throat section must be sharp and perpendicular to the floor along the direction of the flow.

_____8. A cross brace should be placed across the top of the flume at the center of the converging inlet section and at the center of the diverging outlet section with these cross braces being parallel to the flume floor.

_____9. Metal strips should be placed on top of the flume walls on both sides of the flume and near the center of both the inlet converging section and outlet diverging section, with all four metal pieces being parallel to the floor of the flume.

_____10. The floor of the flume should be a flat plane surface and free of bulges.

_____11. Bolts or other means of attaching the staff gauges to the flume walls (if stilling wells are not used) should not result in any protrusion into the flow.

EWUP
How to do it
Field Procedure

HOW TO READ STAFF GAUGE ON FLUMES AND HOW TO DETERMINE DISCHARGE FROM THE READING

by Alan Early and Wayne Clyma*

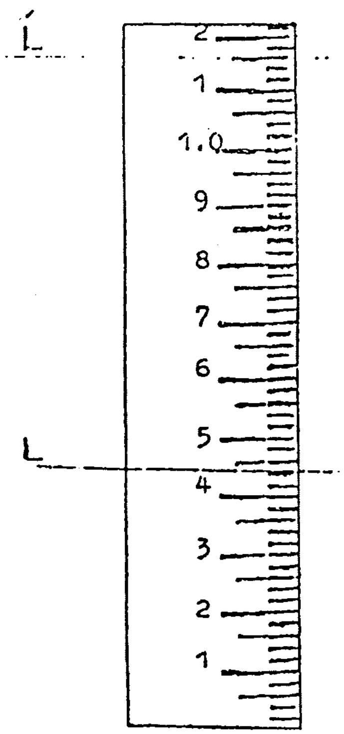
STAFF GAUGE

The staff gauge is usually a metallic scale to measure the water surface level from a fixed reference point. It tells the depth of water or the static head acting at any point.

On this gauge, one foot is divided into 10 equal divisions and each division is labelled. (1, 2, 3, etc. ...up to 9). These divisions are made with black lines on white paint. After each ten divisions, foot marks are also labelled, 1.0, 2.0, etc., up to the maximum desired depth. The 1/10th ft divisions are further divided into 10 divisions each (1/100 ft), as shown on the diagram.

HOW TO READ THE GAUGE

Suppose that the water surface level is "L" as shown in the diagram. The reading is between 0 and 1.0 ft, and calibrations 0.4 and 0.5 ft. In this illustration, the water level (L) is above the 0.4 ft division and below the 0.5 ft and below the 1.0' reading on the gauge. The first recording, therefore, is 0.4 ft. The final recording then is obtained by adding the 1/100 ft calibrations which are found between 0.4 ft and the water level, L. The 1/100 ft calibrations are alternately black and white. Reading downward from 0.5 to 0 they are black/1, white/2, black/3, white/4, black/5, white/6. When they are read from the 0.4 calibration upward, they are white/1, black/2, white/3, black/4. Thus the water level L is 0.4 ft + 4/100 ft = 0.44 ft, or 0.5 ft - 6/100 ft = 0.44 ft.



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*This How-To-Do-It was taken from The Problem Identification Handbook (April 1, 1980). Developed by the CSU-Pakistan Water Management Project sponsored by U.S. Agency for International Development, Contract No. AID/TAC-1100.

Similarly, if the water level is above the 1.0 ft division upon the gauge, the steps are the same except that the reading is 1.0 ft + the tenths + the 1/100ths. Thus as illustrated, if L' is the water level, then the reading is:

	a.	1.00 ft
plus	b.	.10 ft
plus	c.	.06 ft
total	d.	1.16 ft

Gauge readings above the 2, 3, 4, etc. calibrations are computed in the same manner.

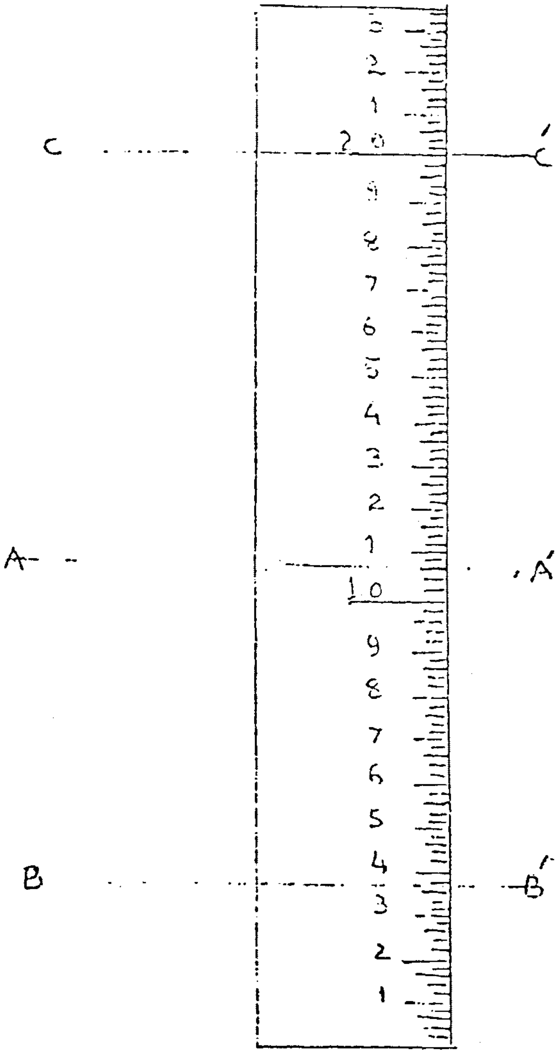
Note that all labels are at the top of each black line so that the top of each black line indicates an even number and the bottom of that line indicates an odd number.

Example:

(1) Reading at Section AA' is 1.06 (Figure 2).

(2) Reading at Section BB' is 0.37 (Figure 3).

(3) Reading at Section CC' is 2.00 (Figure 4).



DETERMINING THE DISCHARGE

To determine the discharge with flumes, water levels at both the upstream and downstream wells are measured with staff gauges fixed on the flumes. The reading of the upstream gauge is h_a and that of the downstream gauge is h_b. When h_a and h_b are known, the discharge can be determined from the flow calibration tables which are provided with the equipment.

There are two types of flow calibration tables, one for free flow and the other for submerged flow conditions.

If h_b/h_a is less than 65%, the free flow calibration table will be used and if h_b/h_a is greater than 65% then the submerged flow calibration table must be used.

For example, in an 8" x 3' cutthroat flume, if h_a is 0.50 and h_b is 0.25, $h_b/h_a = 0.25/0.50 = 50\%$. 50% is less than 65%, so the free flow calibration table will be used and one can easily determine the discharge of 0.83 cubic feet per second (CFS) in the flow calibration table written in front of 0.50 h_a. If h_a is 0.48 and h_b is 0.36, then $h_b/h_a = 0.36/0.48 = 75\%$ which is more than 65% so the submerged calibration table will be used and the discharge of 0.7 cfs can be observed in front of 0.48 h_a under 12 (h_a-h_b).

The flow calibration tables used in this example are attached and the concerned readings are shown underlined.

PRECAUTIONS FOR USE OF STAFF GAUGE

1. Make sure that the gauge is installed vertically.
2. All gauges of the flume should give the same reading in standing water, with the flume properly leveled. Incorrect installation of gauges or the flume will result in wrong measurements.
3. While reading the gauge, there should be no disturbance in the water surface near the gauge.
4. If there is disturbance, that should be removed by placing the hand parallel to the vertical side of the flume.
5. If a disturbance in the surface is not easily removed, then the average of minimum and maximum readings should be taken.
6. Pull out all the mud and dirt from the stilling wells.* It can affect your reading by blocking the inlet ports.

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*To avoid error due to disturbance in the water surface level near the gauges, flumes are usually provided with stilling wells in which gauges are installed and readings of h_a and h_b in the stilling well gauges are used for discharge calculations.

Table 1. Free flow calibrations for selected cutthroat flumes (values listed are discharge in cfs).

$^{a}\mathrm{ft}$	41NX3FT	81NX3FT	121NX3FT
0.10	0.02	0.04	0.07
0.20	0.08	0.15	0.23
0.30	0.16	0.32	0.49
0.40	0.27	0.55	0.83
0.50	0.41	0.83	1.26
0.60	0.57	1.16	1.76
0.70	0.76	1.54	2.33
0.80	0.97	1.97	2.98
0.90	1.20	2.45	3.71
1.00	1.46	2.97	4.50

Table 2. Submerged flow calibrations for 8" x 3' cutthroat flume (values listed are discharge in cfs).

h_a							
ft	0.10	0.12	0.14	0.16	0.18	0.20	0.22
0.50	0.8	0.8	0.8	0.8	0.8	0.8	0.8
0.52	0.8	0.9	0.9	0.9	0.9	0.9	0.9
0.54	0.9	0.9	0.9	0.9	0.9	1.0	1.0
0.56	0.9	1.0	1.0	1.0	1.0	1.0	1.0
0.58	1.0	1.0	1.1	1.1	1.1	1.1	1.1
0.60	1.1	1.1	1.1	1.1	1.1	1.2	1.2
0.62	1.1	1.1	1.2	1.2	1.2	1.2	1.2
0.64	1.2	1.2	1.2	1.3	1.3	1.3	1.3
0.66	1.2	1.3	1.3	1.3	1.4	1.4	1.4
0.68	1.3	1.3	1.4	1.4	1.4	1.4	1.4
0.70	1.3	1.4	1.4	1.5	1.5	1.5	1.5
0.72	1.4	1.5	1.5	1.6	1.6	1.6	1.6
0.74	1.5	1.5	1.6	1.6	1.7	1.7	1.7
0.76	1.5	1.6	1.7	1.7	1.7	1.8	1.8
0.78	1.6	1.7	1.7	1.8	1.8	1.8	1.9
0.80	1.7	1.7	1.8	1.8	1.9	1.9	1.9
0.82	1.7	1.8	1.9	1.9	2.0	2.0	2.0
0.84	1.8	1.9	2.0	2.0	2.0	2.1	2.1
0.86	1.9	2.0	2.0	2.1	2.1	2.2	2.2
0.88	1.9	2.0	2.1	2.2	2.2	2.3	2.3
0.90	2.0	2.1	2.2	2.2	2.3	2.3	2.4
0.92	2.1	2.2	2.3	2.3	2.4	2.4	2.5
0.94	2.1	2.3	2.3	2.4	2.5	2.5	2.6
0.96	2.2	2.3	2.4	2.5	2.6	2.6	2.6
0.98	2.3	2.4	2.5	2.6	2.6	2.7	2.7
1.00	2.4	2.5	2.6	2.7	2.7	2.8	2.8

EWUP
How to do it
Field Procedure

COLLECTING SOIL SAMPLES FOR SOIL FERTILITY AND SALINITY ANALYSES

by Bill Stewart*

The analyses of the soil sample provides a quick, practical way for the farmer and the field supervisor to obtain advanced information about the fields with which they will be working during the following production season. Cultural decisions can be made in advance, thus allowing for more efficient planning for time and supplies when the soil is prepared for planting.

If the tests are to be of value to the farmer, he must be able to associate each of them with a particular set of field conditions. Familiarity with the fields and with the situations which the tests represent will enable him to formulate his production plan ahead of time. The purpose of the sample manner in which the soil sample is collected and prepared, therefore, becomes very important. Rather precise techniques have been developed which, when followed, will provide accurate information about the fields under the conditions which the soil sample represents--it must be emphasized that samples which are not representative, or which are improperly handled are worthless.

Tools

The sample can be collected with the shovel or spade, normally used on the farm for other work. Soil sampling augers and tubes, however, simplify the collection. In Pakistan, the King Tube Sampler is widely used. Sampling equipment must be clean and free from rust to eliminate pollution--clean, well-kept equipment is also easier to use. If micronutrient analyses are to be performed, stainless steel and plastic tubes and buckets are recommended to eliminate any possibility of introducing iron and zinc into the sample from the equipment.

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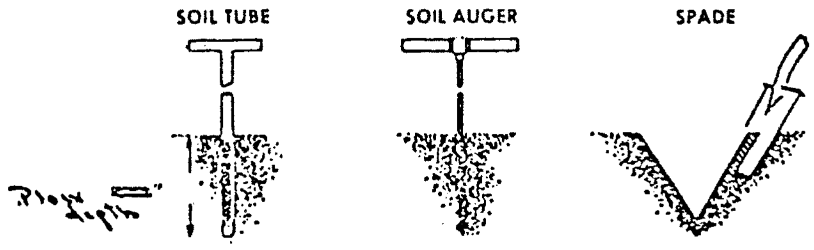
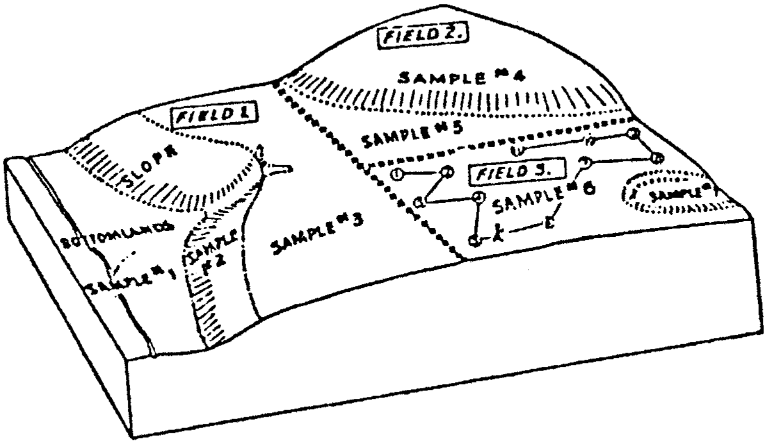
*This How-To-Do-It was taken from The Problem Identification Handbook (April 1, 1980). Developed by the CSU-Pakistan Water Management Project sponsored by U.S. Agency for International Development, Contract No. AID/TAC-1100.

1. USE ANY OF THE TOOLS SHOWN BELOW TO TAKE SAMPLES. TAKE SAMPLE TO THE PLOW DEPTH ~~(USUALLY [illegible])~~.



The field supervisor who is responsible for sampling procedures will gradually develop a "routine" which simplifies the sampling procedure and reduces the time involved. A rather definite procedure is followed:

First: The person who is sampling the field must become familiar with the various situations within the field and sample accordingly. Each sample must represent a specific field situation and condition, and be labeled, bagged, and packaged accordingly.



EACH SAMPLE SHOULD REPRESENT A UNIFORM AREA. SIZE UP THE AREA AND OBSERVE THESE VARIATIONS:

DIFFERENCES IN TEXTURE (SAND, SILT, CLAY), COLOR, SLOPE, DEGREE OF EROSION, DRAINAGE, PAST MANAGEMENT (FERTILIZATION, ROTATION, ETC)

Second: Using clean equipment, collect 10 to 20 cores from each selected area. (If the spade is used, the "core" is a sample of the furrow slice, 1 inch wide, from the center of the blade.) Most of the fertility elements are normally contained in the upper six inches of the soil, so sample to the depth of the "plow slice"--usually 6 to 8 inches. Additional samples may be taken at intervals from the entire root zone for salinity analyses, when necessary.* If subsoil samples are to be taken, either for fertility or salinity analyses, collect a second sample from the same bore from the 6" to the 12" level, etc., until the desired depth is reached. Label and submit these samples separately.

Third: Thoroughly mix the sample, breaking up any clods which might be present. Dry the sample (air dry, do not heat). Spread the sample upon a flat, clean surface and "quarter" the sample until about a quart (about 1 liter volume) of soil remains for fertility analyses. Samples about twice this size should be collected for complete salinity analysis.

Fourth: Package the sample in a strong, clean container.

Fifth: Be sure to fully identify each sample and record the information needed to identify it with the field situation from which it was collected.

Sixth: Submit complete information to the laboratory. (Their information can only represent that which they are given.) Package the samples and deliver them to the laboratory with that information.

This completes the sampling process for 1 field condition. Repeat for each segment of the field which is sampled.

Be sure that samples are protected against breakage and mixing on their way to the laboratory.

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*For salinity analyses, subsoil samples are always required.

EWUP
How to do it
Field Procedure

INSTALLATION AND USE OF CUTTHROAT FLUMES FOR WATER MEASUREMENT

by W. A. Moskin, W. Clyma, and A. Early*

A considerable amount of work has been done on the development of water measuring equipment including flumes, weirs and flow meters. The cutthroat flume is the latest development in this series. It has specific advantages:

1. Satisfactory water measurements can be made under both free and submerged flow conditions.
2. Head loss through this flume is low, even lower than the Parshall flume which has been used for many years.

In summary, this flume provides accurate water flow rate measurement in the flat gradient channels commonly encountered in irrigation systems. The cutthroat flume is easily constructed due to its flat bottom and consistent wall geometry. Its advantages have resulted in wide acceptance by many involved in water management work in flat gradient channels, such as irrigation and drainage channels.

THEORETICAL CONSIDERATIONS

A. Flume Selection

A flume with the proper throat size must be selected. Flow measurement is not as accurate at low heads or at very high heads. Tables 1 and 2 may be utilized as a guide to selection of flume throat width for the flume lengths of 3 feet or 1 meter, which are commonly used in on-farm water management research (see Tables 1 and 2).

B. Flume Dimensions Checkup

All flume dimensions must be measured to be sure that the flume has been constructed properly. If dimensions of the throat vary more than 1/16 in., reject the flume. Check also for general appearance of the flume. The

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Table 1. Free flow calibrations for selected cutthroats flumes (values listed are discharge in cfs).

h_a	41NX3FT	81NX3FT	121NX3FT	161NX3FT	8INX6FT	16INX5FT	24INX6FT
0.10	0.02	0.04	0.07	0.09	0.06	0.11	0.17
0.20	0.08	0.15	0.23	0.31	0.17	0.35	0.54
0.30	0.16	0.32	0.49	0.66	0.34	0.69	1.05
0.40	0.27	0.55	0.83	1.12	0.55	1.11	1.69
0.50	0.41	0.83	1.26	1.68	0.79	1.60	2.44
0.60	0.57	1.16	1.76	2.36	1.07	2.16	3.29
0.70	0.76	1.54	2.33	3.13	1.37	2.79	4.24
0.80	0.97	1.97	2.98	4.00	1.71	3.47	5.28
0.90	1.20	2.45	3.71	4.97	2.08	4.21	6.41
1.00	1.46	2.97	4.50	6.03	2.47	5.01	7.62

Table 2. Free flow calibrations for selected cutthroat flumes, metric units (Q*, cms).

h_a^* meters	10X90CM	20X90CM	30X90CM	20X180CM	40X180CM	60X180CM	30X270CM	60X270CM	100X270CM
.025	.000	.001	.001	.001	.002	.003	.002	.004	.007
.050	.001	.003	.004	.003	.007	.011	.006	.012	.020
.075	.003	.006	.009	.007	.014	.021	.011	.022	.038
.100	.005	.011	.016	.011	.022	.033	.017	.035	.059
.125	.008	.016	.024	.015	.032	.048	.024	.049	.083
.150	.011	.023	.034	.021	.043	.064	.032	.066	.111
.175	.014	.031	.045	.027	.055	.083	.041	.083	.141
.200	.018	.039	.057	.034	.068	.104	.051	.103	.174
.225	.023	.049	.071	.041	.083	.126	.061	.123	.209
.250	.028	.059	.086	.049	.099	.150	.072	.146	.246
.275	.033	.070	.102	.057	.116	.175	.083	.169	.285
.300	.039	.082	.120	.066	.134	.202	.095	.193	.327

walls should be vertical and perpendicular to the flat bottom. The converging and diverging sections should be fabricated according to specifications. Check all welded joints. If welds are found improper, the flume should be rejected.

C. Gauge Installation

Check the gauges. Gauges and inlets to the stilling wells reading the upstream head (h_a) as well as the downstream head (h_b) should be check against the specifications. If the flume is equipped with stilling wells, check the water level next to the staff gauges as compared to the level in the stilling wells in standing water with the flume properly leveled. Incorrect installation will cause erroneous discharge readings.

D. Orientation for Leveling

If the flume must be installed in a channel with water flowing in it, make sure that two longitudinal and transverse locations on the flume top are parallel with two similar locations on the flume bottom. As close to the flume throat as possible, preferably on the converging section of the flume, place a short (about 6 in. long) carpenter's level in the transverse direction of the floor of the flume and bring the bubble to the level position. Likewise, bring the flume to a level position in the longitudinal direction. Find the same transverse level position somewhere on the top of the flume, either in the throat region, on the crosspiece at the start of the converging section, or on the crosspiece at the start of the converging section. Mark this position for later leveling the flume in flowing water. Likewise for longitudinally leveling, place the level on top of the walls of the converging or diverging section of the flume. Wherever the bubble comes to the center, mark that position on the top of the walls. Always use these two marked positions to level the flume if it must be installed in flowing water, otherwise always use the floor of the flume to insure that the flume is installed in a level position.

Check these predetermined positions occasionally with reference to the flume bottom, as the flume may become deformed with long continued use.

INSTALLATION AND OPERATIONAL CONSIDERATIONS

Experience reveals that installation of a flume in the channel for flow measurement does not always make a farmer happy. His complaint is that the flume has "eaten" much of his water. If the channel has a flat gradient with very little freeboard, and the flume has been installed for free flow conditions, considerable water will be stored in the irrigation (or drainage) channel above the flume. This creates an uncontrollable situation for the farmer as well as the person making discharge measurements. The upstream section of the channel may overtop, causing spillage, and great concern on the part of the farmer. Until steady state conditions are achieved, the measured discharge is much less than that passing through that point prior to flume installation. These difficulties, and others, force the development of proper installation techniques, which in turn facilitate measurements and minimize the farmers complaints about our friend, Mr. C. T. Flume for "eating" his water.

Helpful suggestions:

1. Establish an amiable acquaintence with the farmer. Explain your mission to him, completely.
2. Never approach the farmer bureaucratically. Treat him as the important person he is.
3. Develop friendly relationships with all farmers concerned.
4. Remember, the farmer in whose channel the flume is installed is very important to us, without his cooperation our work is meaningless.
5. Attempt to convince the concerned farmer that our mission is to help <u>him</u> achieve better water management.
6. Never make false promises to win favors (getting his water supply increased, etc.). Adverse relationships in the future will result.
7. If we fail to make a farmer understand the program, it is better not to argue. Wait for another cooperative farmer to irrigate. Make measurements there.
8. Always remember that most irrigation channels have flat gradient beds with very little freeboard. Take some time to decide about the site for flume installation. With the cutthroat flume, good discharge measurements can be made, even under submerged flow conditions. However, submergence should not exceed 90% if possible. Higher submergence will reduce energy loss, but the problem of the upstream section being overtopped could be minimized alternatively through careful installation and/or by building up the banks of the upstream channel. However, where conditions permit (steep-gradient conditions with more freeboard) installation should be for free flow conditions.

9. The flume should be placed in the center of the channel. It should be parallel to the direction of water flow in the channel.
10. The sides and bottom and around the flume walls should be properly sealed so that there are no leaks beside nor under the flume. Sandy soil conditions impose serious leak problems. Plastic sheets or cloth used as a cutoff wall in the surrounding soil can be used to overcome this problem.
11. The flume should be properly leveled both in the longitudinal and in the transverse direction. For this purpose, the flume bottom can be used while installing it in a dry channel. For installation in flowing water, the two reference points already marked on the topside of the flume walls can be used.
12. Before recording readings of the upstream and downstream gauges, always check for leaks along the sides and underneath the flume. The inside bottom of the flume should be checked and cleaned of any sediment or trash as this will cause h_a to increase and result in an erroneous reading. Also, make sure that the flume is still in a level position both longitudinally and traversely. If leaks are observed, stop them, and if the level is disturbed, relevel the flume. Repeat this process before recording each reading of the gauges.

INTERPRETATIONAL CONSIDERATIONS

Recording the gauge readings and determining the discharge from the rating tables is the easiest step in the flow measurement process. Who can answer with full confidence that flow measured with this flume is quite correct? To answer this question confidently requires more than simply recording gauge readings.

Experience has shown that on flat-gradient channels the flume has to be installed much longer before it reaches a steady-state flow condition than is necessary for steep-gradient channels. Short period installations may often lead to wrong conclusions. The section through which the water flows is restricted to a much smaller width through the flume as compared to that upstream from the flume. This imposes a problem of water storage in the upstream section of the channel and a smaller volume of flow through the flume during the initial period of flume installation. Sufficient time should be given to allow the channel storage to stop increasing, and the flow through the flume to equal the steady state flow in the channel. In short, one must wait long enough after the flume is installed so that equilibrium conditions between inflow above the flume and outflow through the flume are established. This can be noted easily with the volume of flow becoming constant (the h_a gauge reading doesn't change with time) as the water level in the upstream section of the channel ceases to increase.

A. Water Measurement Applications

The cutthroat flume is a flow measuring device. It is simple in construction, easy to install and gives reasonable accuracy in flow measurement, both under free flow and submerged flow conditions. Proper water management plans a vital role in the economic utilization of water resources. For better water management, it is essential to know the rate of flow through any water flow system and to know how much water actually enters a specific field. These questions are best answered by using a cutthroat flume at various locations in a water conveyance channel. Select any convenient length of the conveyance system. Install the flume at the starting point and another flume at the end of that selected length. The ratio of the second flow volume to the first flow will provide us with the conveyance efficiency of that portion of the water delivery subsystem. Use the second flow volume to determine the depth of water applied to a specific field. In the above example, the first flume is installed as close to the channel inlet as possible and the second as close to the field as possible. From the depth of water applied, calculations of the water application efficiency can be made. Suggestions are given below on evaluation of delivery and application efficiencies.

B. Measurement Installation

The first flume should be installed close to the irrigation channel inlet. The most important point abou the first flume installation is whether or not submergence of the inlet occurs. By inlet submergence is meant the reduction in inlet discharge due to water backup in the channel because of flume installation. The effect can be noted by installing another flume about 1,000 feet below the first one. If, after pulling out the first flume, no change in flow is observed at the second, then one can be confident that the first flume is not submerging the inlet. If some increase in flow occurs at the second flume, then a location at a slightly greater distance from the inlet must be used for the first flume. Continuous adjustment in the position of the first flume is necessary until no change occurs in the flow through the second flume after removing the first one. Before installing the flume near the inlet, record the water surface elevations in the irrigation canal upstream from the inlet and in the channel just below (downstream from) the inlet. If these two elevations differ by less than half a foot (15 cm), one should check as described above to see if flume installation has submerged the inlet. Afte the flume installation, there should be no change in the water surface elevations of the upstream canal. The upstream section of the flume should show some increase in elevation. The flume should be installed in such a position that the increase in water level in the irrigation channel is as small as possible when there is a danger of submerging the inlet. In doing all this, highly submerged flow conditions which would endanger our measurement accuracy should not result. The flume should not be installed at more than 90 percent submergence. If the channel downstream from the inlet has a steep gradient, then the chances of the inlet being submerged with flume installation are small, but if the channel has a flat gradient, then inlet submergence must be given serious consideration.

The volume of flow which passes through the inlet or through the flume installed close to the inlet has to go somewhere through the conveyance system to be utilized for irrigation purposes. How much of this discharge is being effectively used for irrigation purposes is another area of interest for the water management specialist. If some of this inlet discharge does not reach the fields, then we must ask "Where does it go?" These and many other questions force a person who is interested in better water management to further investigate the situation.

Determination of volume of flow through a certain length of conveyance system requires installation of another flume. This flume must be installed as close to the fields being irrigated as possible, making certain that no spillage losses are caused in the upstream section of the channel. The discharge measurement made by this second flume will serve five purposes:

1. Determine the conveyance efficiency of the water delivery subsystem.
2. Determine the overall water losses of the system.
3. Evaluate the depth of application of irrigation to a specific field.
4. Evaluate the application efficiency to specific fields (with additional measurements).

5. Evaluate the overall irrigation efficiency of a particular irrigation system.

All of the above listed evaluations make this water measurement the most important element of the entire study. Erroneous measurement will jeopardize the whole water management investigation.

The following steps will help to a great extent to get this measurement with reasonably accuracy.

1. After the second flume is installed, make sure that one person is designated to walk along the channel back to the first flume which has been installed near the inlet. This person should make note of spills, stealing bank leaks, trading between the farmers, bank failures, water diversions into other branches, and anything special which might affect the discharge measurement at the second flume. He should be intructed to keep a record of all these happenings with time.
2. When the second flume is installed, the flow is reduced for the initial periods following installation. In flat gradient channels, a lot of water is stored in the upstream section of the channel. Sufficient time should be allowed to dissipate this storage, otherwise false conclusions are likely. Wait long enough after flume installation to achieve steady flow conditions. This can be noted when the flow rate becomes constant (the h_a gauge reading does not change with time) if there are no changes in the upstream section of the channel.

C. <u>Water Delivery Efficiency</u>

Water delivery efficiency is the ratio of flow at the second flume to the flow at the first. For example, if the discharge at the second flume is 1.2 cubic feet per second (cusec) and that for the first flume is 1.8 cusecs, the deliver efficiency is:

$$E_d(\%) = \frac{100\ (\text{flume } 2)}{(\text{flume } 1)} = \frac{1.2}{1.8} \times 100 = 67\%$$

D. <u>Irrigation Channel Losses</u>

Irrigation channel losses consist of seepage from the channel into the underlying groundwater and of spills which occur from leaky banks, overtopping the banks of the channel, etc. Losses may be measured or reported in several ways. One method of reporting the loss is the percent loss which is:

$$\text{Loss (\%)} = 100\text{-E}_d\text{(\%)} = \frac{\text{flume 1-flume 2}}{\text{flume 1}} \text{ x } 100 = \frac{0.6}{0.8} \text{ x } 100 = 33\%$$

Another method is a discharge rate per unit length of channel. Assume the distance between the above flumes is 2400 ft:

$$\text{Loss} = \frac{\text{flume 1-flume 2}}{\frac{\text{length of channel}}{\text{100 feet}}} = \frac{0.6}{2.4} = \text{0.25 cubic feet per second per 1000 feet}$$

Using cusecs/1000 feet as a measure of loss permits the direct comparison of the loss rate for different channels and lengths of channel. The channel loss rate does appear to increase with increasing discharge and decrease with increasing length of watercourse, so this method of reporting loss may also be considered.

Probably the most correct method for reporting loss is in terms of a seepage rate. The loss between two locations along the irrigation channel is measured. The length of the section and the wetted perimeter at several locations in the channel is measured. The average wetted perimeter is calculated and the loss may be reported as: (using 5 feet as an assumed average wetted perimeter)

$$\text{Loss} = \frac{\text{flume 1-flume 2}}{\text{(length)(wetted perimeter)}} = \frac{0.6}{(2400)(5)} = \text{51.84 in./day} = \text{2.16 in./hr}$$

E. Water Application

The water application to a field is determined by the flow rate, the time of application, and the area of the field, as follows:

$qt = dA$

q = flow rate in cusecs

t = time in hours

d = depth of application in inches

A = area of field in acres

If the flow at flume 2 near the field averages 1.2 cusecs during the time period of 2.25 hours, and the water is being applied to a field of 150 ft x 200 ft, which is approximately 0.69 acres, then the water application is:

$$d = qt/A = \frac{(1.2)(2.25)}{0.69} = 3.9 \text{ in.}$$

The amount of water applied is 2.9 acre inches per acre.

F. Application Efficiency

The application efficiency is computed as the amount of water stored in the soil, or the soil moisture deficiency, divided by the amount of water applied to the field. Determination of soil moisture deficiency may be accomplished by several procedures, the most simple of which is soil moisture sampling. If the soil moisture deficiency was 2.3 inches, then the applications efficiency for this example equals:

$$EA = \frac{\text{(amount of water stored in the soil)}}{\text{(amount of water applied to the field)}} = 100\ \frac{(2.3)}{(3.9)} = 59\%$$

G. Irrigation Efficiency

The irrigation efficiency is determined as the product of the deliver efficiency and the application efficiency. It is a measure of the effectiveness of the water used that is available at the inlet. For the examples already cited, the irrigation efficiency is calculated as:

$$E_i = E_d \times E_a = 67 \times 59 = 40\%$$

Additional information may also be derived from these basic flow measurements, but these are some important examples.

EWUP
How to do it
Field Procedure

FIELD AND WATERCOURSE ORIENTATION MAPPING USING PLANE TABLE AND PEEP-SIGHT ALIDADE

by Wayne Clyma and Alan Early*

The plane table and alidade, Figure 1, are frequently used instruments where layout maps are needed of irregular field and watercourse orientations. This offers the advantages of preparing the map while surveying is done and permits checking the watercourse and field layout as shown on the map with the actual layout. Also, where the design of, for example, a farm pond, is completed as soon as a map has been prepared, the design can be completed and staked all in one operation. No return trip to an office to prepare the map, make and design, and then another trip to the field to stake the dam, pond, and spillway is necessary. The principal disadvantage of using the plane table and alidade is the extra field time necessary. When bad weather occurs, no work is possible.

The basic equipment for the plane table and alidade method of mapping consists of a tripod, drawing board, alidade equipped with peep-sight alignment hairs, rod, tape, and pencil, paper and scale for preparing the map. Paper is fastened to the board and positions are plotted on the paper by sighting through the alidade for direction, and determining the distance by taping.

THE PLANE TABLE

The plane table (Figure 1) is a rectangular board (1) usually 18 x 31 inches. (46 x 79 cm) with a means for attaching it to a tripod. The top surface of the board is provided to attach a sheet of mapping paper.

The table is leveled by changing the position and the lengths of the legs. A small spirit level is provided for leveling the table (2).

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* This How-To-Do-It was taken from The Problem Identification Handbook (April 1, 1980). Developed by the CSU-Pakistan Water Management Project sponsored by U.S. Agency for International Development, Contract No. AID/TAC-1100.

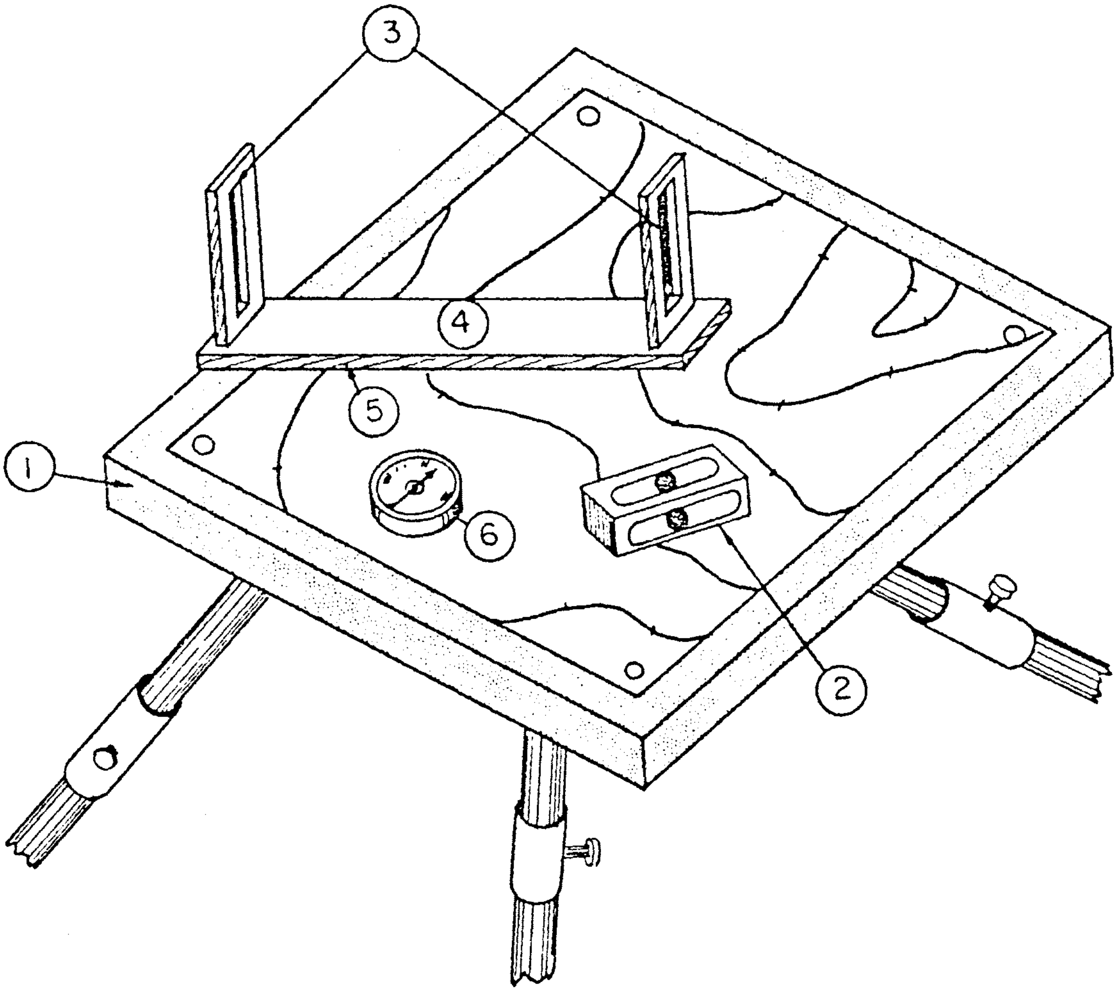

Figure 1. The plane table and alidade.

THE ALIDADE

The alidade in Figure 1 has two peep-sight brackets (3) with the vertical hairs separated by a distance of 18 inches. The alidade has a linear, usually brass, base (4) that supports it when resting on the table. One edge of the support (5) is usually leveled and this is the sighting edge. A separate, small magnetic compass (6) is provided for proper orientation of the plane table.

SETTING UP THE PLANE TABLE

The tripod and plane table are set up at an appropriate central location with respect to the line of sight for field layout or watercourse to be mapped. Using the level bubble on the separate level provided, the table is leveled. Leveling the table is sometimes difficult. The table is then rotated in a horizontal plane until magnetic north is the top of the map, or until another reference direction has been selected. The location of the instrument is designated on the map either arbitrarily or by using other known points to determine instrument location. A map can then be prepared using the alidade to sight locations and the tape to determine distances.

Alidades of other types can be used to determine both elevation and stadia distances. Because of the difficulties of maintaining a precisely leveled table, the surveyor may find it advantageous to use the plane table for locations and the farm level for elevations. This procedure may seem unnecessary (duplication of equipment). However, use of the level eliminates most of the difficulties of keeping the table level for good elevation control. Where a plane table and alidade are available, a level is usually available. One experienced surveyor for both level and table can usually keep two experienced rodmen busy.

ORIENTING THE PLANE TABLE

Location of the instrument on the map that is to be made is usually accomplished by two methods: (1) compass and (2) backsighting.

To orient the table by compass, the alidade is placed in the direction that is desirable for a north-south line. The table is then rotated until the compass needle points to magnetic north. The board is clamped and a line is drawn on the paper for future reference and to periodically check the orientation of the board.

Orientation of the board by backsighting requires that two points be located in the field. They may or may not be located on the map. If not located on the map, the orientation of the line is assumed for best use of the paper for construction of the map, then the orientation of the line is assumed for best use of the paper in constructing the map. Distances in all directions may be estimated and scaled to make sure that the scale selected will permit all the area to be mapped to be included.

If two points (A and B) are already located on the map, the instrument can be located at either point. The alidade is then pointed along the A-B line and the table is rotated until A (or B) is sighted and aligned with the vertical hair.

If point A is located on the map and point B is a more desirable instrument location, then the instrument is set up at point A. The table may be initially oriented by compass or by some other known line. The instrument is then sighted at point B and a line is drawn. The distance to B can be measured by pacing or taping, depending upon the accuracy required. B is then marked. The instrument is moved to point B, set up, and the alidade pointed along line B-A on the map. The table is rotated until the vertical hair is aligned on point A.

After the table has been oriented by either of the methods, several distance objects should be located and short lines identified at the edge of the map with a description of what the objects are. The orientation of the table can then be checked periodically without having the rodman return the point A. By carefully selecting well-defined objects on the skyline, reorientation of the table is more accurate. The large distances require minute adjustments for proper orientation. A straight pin is usually placed in the table at the point representing instrument location. The alidade is then kept against the pin when sighting locations. Even with the pin, care is required in keeping the line of sight of the alidade radiating from the station.

Points on the map that require precise locations may be located by intersection or triangulation. With the instrument at one location, lines are drawn that represent the line of sight to the desired points. The instrument is relocated by carefully taping the distance to the new location. Line of sight lines are drawn from the location to the desired points. Where two lines intersect, this is the location of the point. By using three instrument locations, a triangle of error is formed around each point. These methods are indicated in Figure 2.

A sample field and watercourse layout survey and map are illustrated in Figure 3. Points A and B are points of known location. The distance between these points has been taped. The plane table is set up over point A and the mapping sheet has been set up with the points A and B separated by the scaled length (usually 1' = 220'). The alidade is aligned to sight from A to B and the dotted line rays are then made to the corners of the field (1, 2, 3, and 4), the centerline of the watercourse (5 and 6) and the boundaries of the next field (7 and 8), centerline of the bund.

The plane table is moved and set up over point B and oriented to point A, as shown in Figure 4. The points 1, 2, 3, 4, 5, 6, 7, and 8 are resighted and appropriate dotted line rays are drawn as illustrated. Once the intersecting rays have been obtained the field boundaries can be drawn, as shown, with solid lines. In a like manner, points C and D are chosen in the next field, as shown in Figure 4. The distances from B to C and C to D are taped and the procedure continues for mapping the entire area.

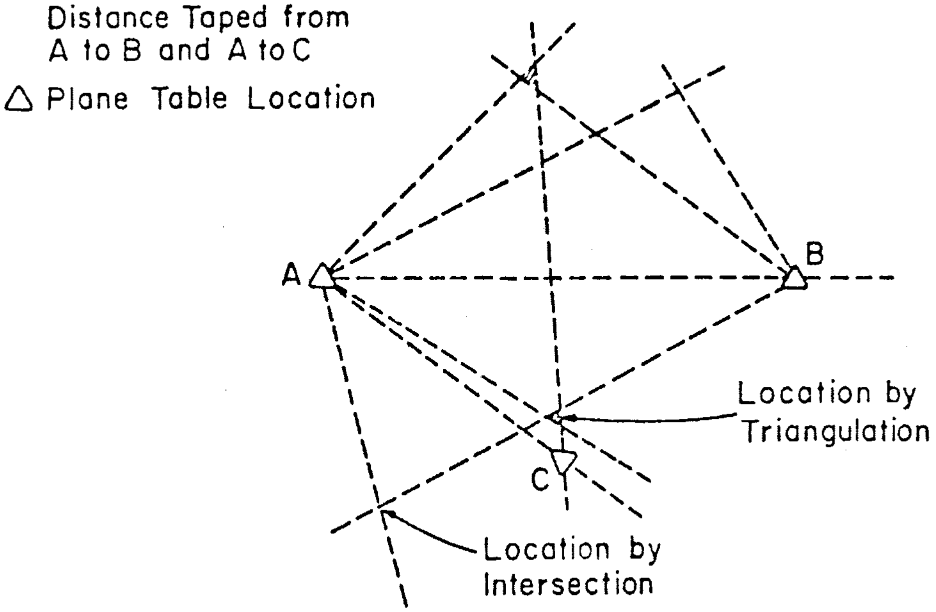

Figure 2. Illustration of the intersection and triangulation methods of locating points.

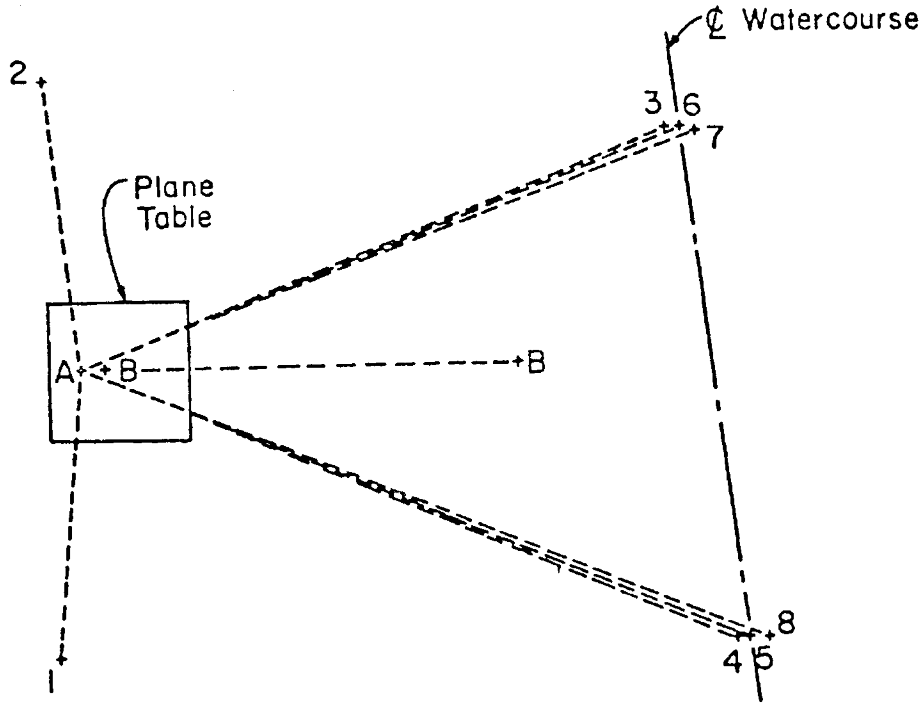

Figure 3. Step 1 in plane table mapping (plane table over point A).

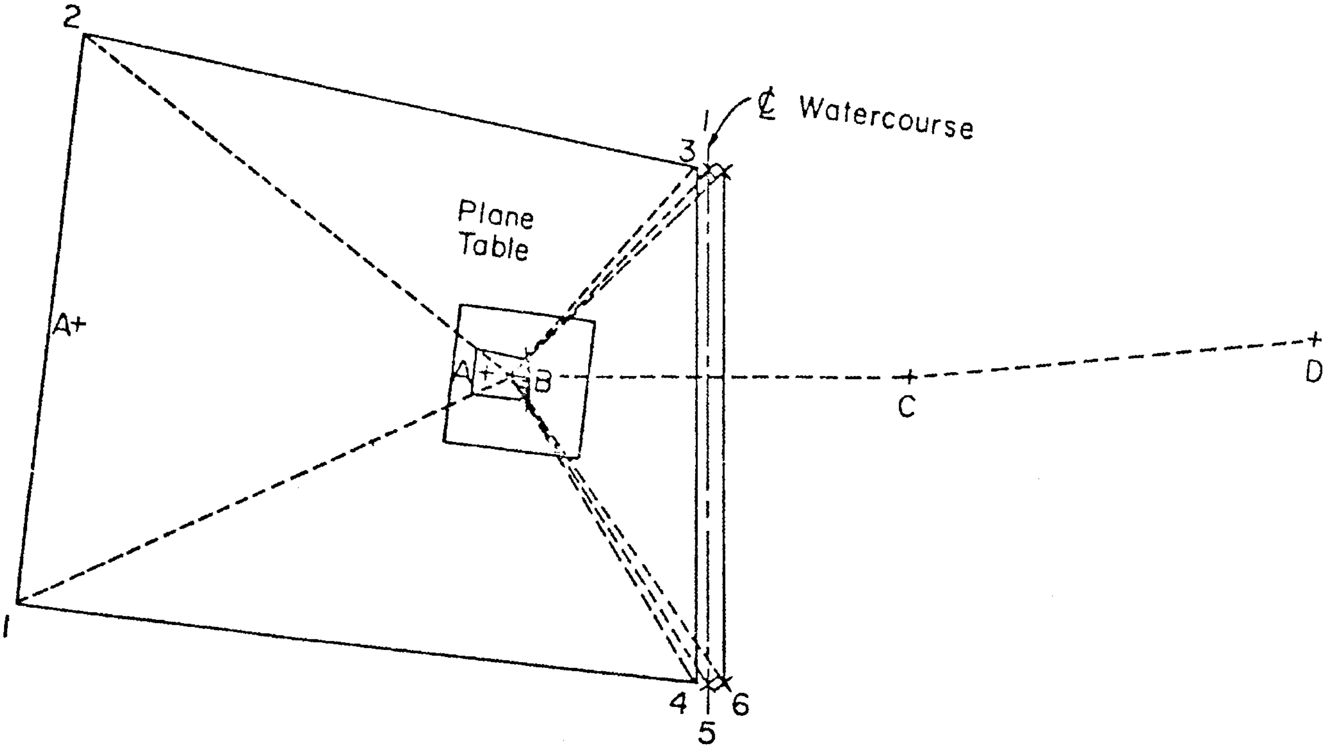

Figure 4. Step 2 in plane table mapping (plane table over point B).

EWUP
How to do it
Field Procedure

TOPOGRAPHIC MAPPING USING GRID METHOD AND LEVEL

by Wayne Clyma and Alan Early*

Maps are essential to the best farm planning. In addition, maps are frequently the basis for engineering design of farm layouts and soil and water conservation structures and facilities. Experience indicates a definite shortage of maps which provide adequate background for farm planning and engineering design (scale 1:5000 or less). Field technicians, no matter where, have encountered a need for adequate maps to assist in the application of engineering techniques.

TOPOGRAPHIC MAPS

A map which shows horizontal distances, horizontal angles, and elevations is called a topographic map. The addition of elevation to a map results in the map showing topography, or relief of the land surface. The contour map is the simplest method of showing elevation on an otherwise two-dimensional sheet of paper. A contour is an imaginary line of constant elevation on the surface of the earth. The shoreline of a lake is a contour frequently seen in nature as the waterline is a line of constant elevation. A contour line is a linear connecting points on the map which represents points on the surface of the ground having the same elevation. The elevation of the contour line is usually indicated by numbers on the line.

The following characteristics of contour lines are useful guides in drawing and interpreting maps:

1. Evenly spaced contours show a uniform slope.
2. The distance between contours indicates the steepness of the slope. Wide spacing denotes flat slopes: close spacing, steep slopes.

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*This How-To-Do-It was taken from The Problem Identification Handbook (April 1, 1980). Developed by the CSU-Pakistan Water Management Project sponsored by U.S. Agency for International Development, Contract No. AID/TAC-1100.

3. Contours which increase in elevation represent hills. Those which decrease in elevation portray valleys. Contour elevations are shown at breaks in the contour to avoid confusion.
4. Irregular contours signify rough, rugged country.
5. Contour lines tend to parallel each other on uniform slopes.
6. Contours never meet except on a vertical surface such as a wall or cliff. They cannot cross except in the unusual case of an overhanging shelf. Knife-edge conditions are seldom found in natural formations.
7. Valleys are usually characterized by V-shaped contours, ridges by U-shaped contours.
8. The V's formed by contours crossing a stream point upstream.
9. The U's made by contours crossing a ridge line, point down the ridge.
10. All contour lines must close upon themselves either within or without the borders of the map.

METHODS OF MAPPING

There are three methods of making topographic maps for agricultural engineering surveying, they are:

1. Grid method
2. Angle and stadia method
3. Plane table and alidade method (telescope alidade with stadia hairs)

The particular method used depends upon several factors. These are:

1. The use of the man
2. The kind of equipment available
3. The kind of personnel available
4. The topography of the land to be mapped
5. The size of the area to be mapped

Another method of mapping in use, which has agricultural application, is aerial photography. The aerial photograph furnishes details of topography, unavailable in other methods of mapping. In addition, by the use of stereoscopes, contours can be added to the aerial photograph with a minimum of field surveying for horizontal and vertical control. Aerial photographs may, or may not, be available in the areas where work is to be done.

THE GRID METHOD

The grid method of topographic mapping has several advantages. It can be done with a farm level and a steel tape, equipment which are readily available. It lends itself to topographic mapping of individual fields and farms where the ground surface is relatively flat. The amount of effort spent in the field doing the survey is about equal to the effort spent in the office preparing the map. The running of contour lines across very flat ground is difficult. Therefore, the taking of elevations at regularly spaced intervals should result in a better topographic map. The grid method is the most widely used method of surveying for land leveling, since the relocation of each point is simple. This relocation of each point is essential to checking elevations as the leveling progresses.

PROCEDURE FOR THE GRID METHOD OF MAPPING

Where possible, the area to be mapped should have two sides that intersect at right angles (90°) with each other. This is particularly applicable to the uniform layout of the kila-bundi pattern of Pakistan. If this is not possible, then the diagonals and all four sides of the field need to be measured, or if the fields are irregular in shape, a plane table survey of field boundaries is necessary before location of the grid points is possible. Two sides of the field can then be staked at regular intervals for the grid and the surveying done in the same manner as for two sides that intersect at 90 degrees. After a preliminary survey of the area to be mapped, two sides are selected to establish the grid. Each side is then staked with tall stakes at regular intervals. The length of the interval depends upon the use of the map. General topographic maps are frequently staked at 25 or 30 meter intervals. Maps for land leveling design and computations are usually staked at 10 to 15 meter intervals.

One side of the area is then numbered at each stake location from 0 to the end of the stakes. The other side is lettered at each stake location from A to the end of the stakes. The stakes used at each grid point should be a minimum of 1 meter high and 2 meters is preferred.

After the two sides have been staked, then two additional sides are staked. The stakes start at 1 and continue to the end of the lettered points. The other row starts at B and continues to the end of the numbered stakes. The rodman can then locate himself at any grid point by sighting along the four stakes that form' the two lines that intersect at his particular grid point.

After the 4 rows of stakes have been established at the grid points, then the elevation of each grid point is established by profile leveling.

Each grid point is designated by the appropriate letter and number as shown in the sample notes in Figure 1. The survey is closed by returning to the BM after the elevation of each grid point has been determined. It is important that the arrangement of the grid be shown in the notes on the right side of the page. This will assure that the map is properly oriented when it is prepared in the office.

For watercourse survey purposes taking is not necessary. General watercourse surveys require the use of a one-acre grid. For this purpose the approximate location of the center of an acre can be obtained visually or by pacing, but without taping or staking the location. A portable turning point is merely used at this location to give a representative elevation for that acre. Surveying begins and ends at a bench mark determined in the initial bench mark survey of the watercourse area.

For the detailed survey of sample farmers' fields, a more intensive data collection scheme is required. Four elevation determinations per irrigation unit are required for this purpose. Each acre might possibly have 2 to 10 of these smallest irrigation units. The intensity thus increases to 8 to 40 shots on a per acre basis, depending on the number of bunded units per acre.

MAP PREPARATION

The topographic map is prepared from the field notes. A map prepared from the field notes shown in Figure 1 is shown in Figure 2. For relatively flat areas, a contour interval of 0.25 meters should be used. For a more rolling topography 0.50 meter or 1.00 meter intervals can be used.

For watercourse mapping a contour interval of 0.25 feet is required for general use. For land leveling design a grid spacing of 50 feet is desirable on small leveling jobs and 100 feet is acceptable on large-scale leveling jobs. The required precision of leveling is ± 0.05 feet (0.10 maximum difference across the irrigated unit). Thus if topographic maps are to be used for land leveling design work the contour interval should be a maximum of 0.5 feet, with 0.25 feet the preferred interval.

Note that certain information is included on the topographic map. A title, location of the mapped area, survey personnel, date of the survey, scale, person preparing the map, date of map preparation, legend, north arrow, and important natural and manmade topographic features should always be included on the map.

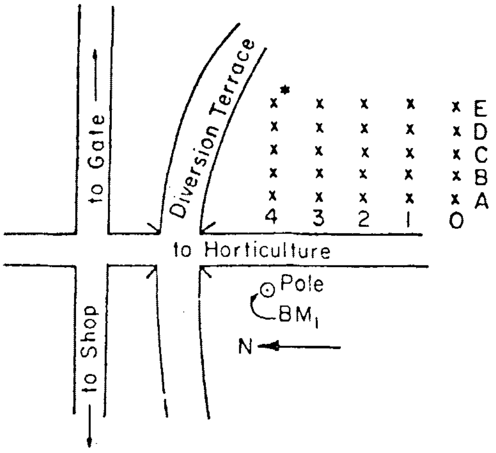
TOPOGRAPHIC LEVELING

No.	BS	HI	FS	Elev.
BM_1	1.20	101.20		100.00
A_0			2.21	98.99
A_1			2.47	98.73
A_2			2.11	99.09
A_3			1.38	99.82
B_3			1.44	99.76
B_2			1.86	99.34
B_1			2.08	99.14
B_0			2.21	98.99
C_0			2.09	99.11
C_1			2.00	99.20
C_2			1.65	99.55
C_3			1.25	99.95
C_4			0.53	100.67
D_4			0.53	100.67
D_3			1.06	100.14
D_2			1.27	99.93
D_1			1.77	99.43
D_0			1.85	99.35
E_0			1.44	99.76
E_1			1.04	100.16
E_2			0.90	100.30
E_3			0.60	100.60
E_4			0.26	100.94
TP_1	2.51	102.42	1.29	99.91
B_4			1.14	101.28
A_4			0.70	101.72
BM_1			2.44	99.98
BS =	3.71	FS =	3.73	100.00

Error of closure = FS - BS
= 3.73 - 3.71
= 0.02 0.02 Check

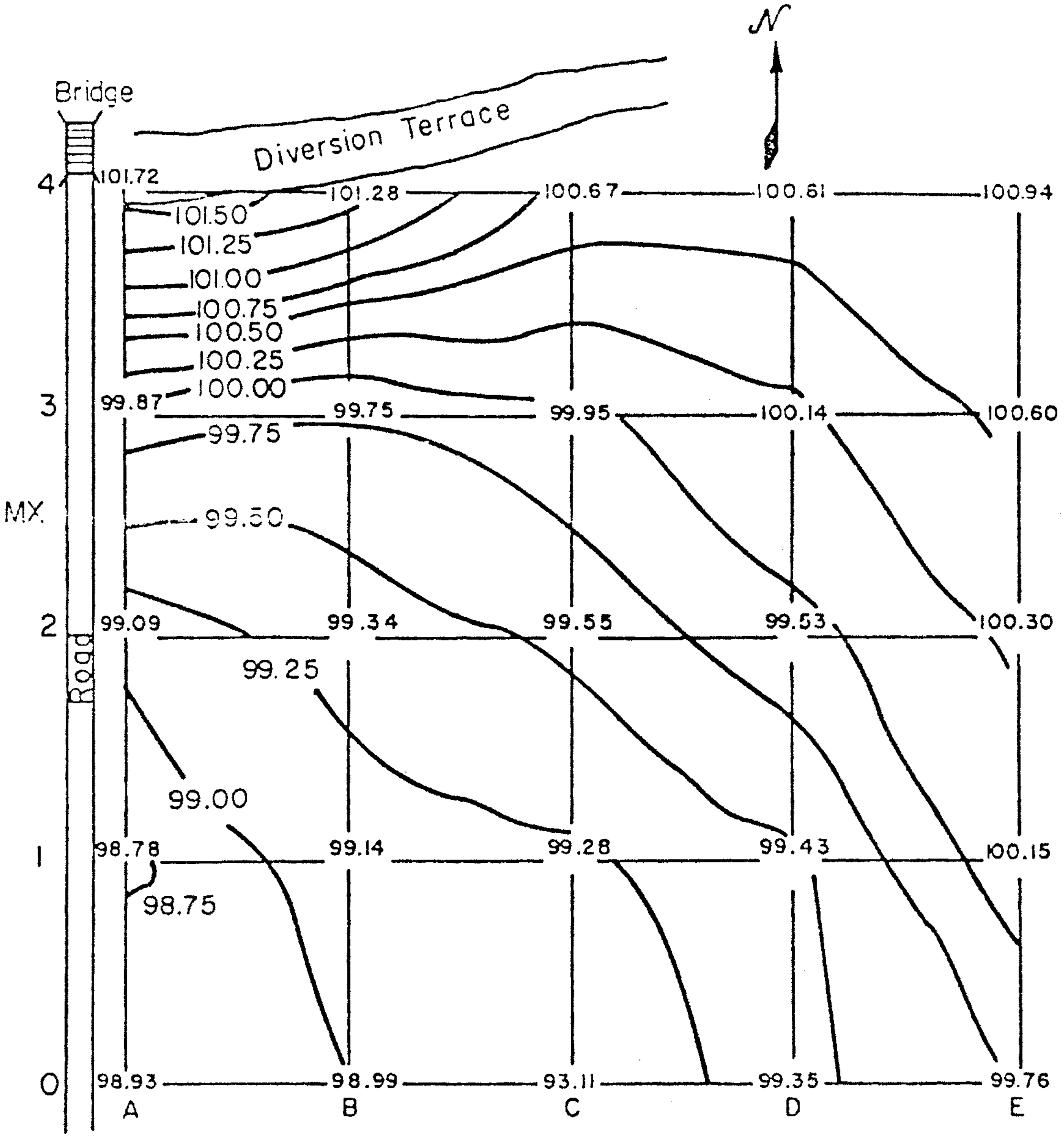
Cloudy, windy Tewolde W.
Aug. 19, 1965 Hailu S.

BM_1 - A point x, marked on the pole stand on the pole next to the bridge on the road to the Horticulture area about 4 meters from the road and 52 meters from the south west end of the bridge.



*x Denotes Grid Station

Figure 1. Field notes for topographic map using grid method of mapping.



TOPOGRAPHIC MAP
College Farm
Surveyed by Tewelderbrhan W.M. & Hailu S.
Date: August 19, 1965
Scale: 1:750
Plotted: by Hailu S.
Date: August 23, 1965

Figure 2. Topographic map from field notes in Figure 1.

Maps are frequently prepared with one contour more heavily than the others. Notice in Figure 2 that the even meter contours, 99.00, 100.00 and 101.00 are more heavily accentuated. This is done to provide better contrast between the general relief and the detailed topography of the area.

The contours are entered on the map by placing a triangular scale or ruler between grid points of known elevation. The point of even numbered contour is proportioned between the two points, a procedure which assumes a uniform topography or slope in the vicinity.

EWUP
How to do it
Field Procedure

EVALUATION OF FURROW IRRIGATION SYSTEMS[1]

by Thomas W. Ley and Wayne Clyma[2]

INTRODUCTION

Evaluation of the performance of furrow irrigation systems requires the collection and analysis of data relating to both the operation and management of the water application subsystem. The procedures suggested for the collection and analyses of data which follow can be used at two levels depending on the amount of detail desired. The less detailed approach provides satisfactory evaluation of system performance utilizing a suggested minimum number of analyses. The more detailed approach adds information on the operating aspects of the hydraulics of the system. Most often, the more detailed measurements are desired for an evaluation of some aspect of system design hydraulics. The less detailed approach provides fully the benefits of an evaluation of farmer practice. Discussion of the procedures for collecting and analyzing the more detailed types of data is provided in a later section. An equipment list and suggested data forms are provided later. The following subsections discuss the data to be collected, the chronological evaluation procedure and suggested analyses of the data for the evaluation of farmer practices.

REQUIRED DATA

Preliminary Data

There is a large amount of preliminary site data which should be collected and analyzed before the evaluation of an irrigation occurs.

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[1] Prepared under the support of the U.S. Agency for International Development, Contracts AID/NE-C-1351 and AID/DSAN-C-0058. All reported opinions, conclusions or recommendations are those of the authors and not those of the funding agency of the U.S. Government.

[2] Research Associate and Associate Professor, respectively, Dept. of Agricultural and Chemical Engineering, Colorado State University, Fort Collins, Colorado.

These data include physical information of the site and information from the farmer concerning his irrigation system and its operation. A list of suggested questions to direct to the farmer in order to obtain information in each of the following categories is included in Appendix A. Other more site specific questions should arise from the farmer's answers to these general questions.

1. Farmer operation and management.--Understanding why or how a farmer does certain things in managing and operating the irrigation system is vital. Often this aspect of evaluating irrigation performance may be overlooked and incomplete knowledge of the irrigation system state results. Farmer management may be constraining the level of performance which can be attained. The general level of knowledge of the farmer concerning irrigation principles and practices is evaluated. Other information discussed later will aid in determining if system management can be improved.

2. Water supply.--The farmer will know the available water supply, source, delivery, frequency, etc. He may have only a general knowledge of the flow rate and quality. These should be measured during the course of an evaluation. On-farm conveyance losses may be a big problem. The farmer may or may not know. Measure the losses if necessary.

3. Crop characteristics.--The crops grown and the planting dates of each must be known. Available data in the literature on crop seasonal water requirements, rates and stages of growth, maximum potential rooting depths, time from planting to effective cover, etc. This information along with climate data is used to estimate crop water use through the irrigation season. The crop root zone should be measured at each irrigation for crops with expanding root systems. The measured root zone for a perennial crop (such as alfalfa) can often be assumed valid for the entire season unless a highly fluctuating water table is encountered. The crop root zone at each irrigation determines the available soil water reservoir at that time and is necessary to determine the soil water deficiency, the stress at the time of irrigation and performance parameters such as water application and water requirement efficiencies.

4. Physical characteristics.--Measure and record the field dimensions. Stakes should be driven into the ground at 25-m intervals along the length (adjust for size of field as necessary). Measure and record surface elevation at each stake (station) using a field rod and level. Plot

the surface profile (elevation vs. length). Measure and record furrow spacings at several locations in the field. Determine if the downstream boundary condition is ponded or free outflow. Determine where and how to measure furrow inflow and runoff.

5. Soil survey.--If available, obtain information on soils in the area (on the farm), such as maps and classifications from a local or regional office (e.g., USDA Soil Conservation Service or similar government agency). Such information is very useful and aids the design of data collection procedures. Soil types and textures are known and maps usually depict the variation of surface textures in a field. If this information is not available, a soil survey is necessary to determine the soil types and uniformity in the field being studied. Soil samples should be collected in a minimum of ten locations in the field (i.e., at five locations along the length and two along the width). Samples should be taken from a minimum of four depths within the expected root zone, i.e., every 30 cm in an expected 1.2 m root zone (adjust as necessary). These samples should be analyzed to determine soil types.

Once soil types and variations through the field are known the apparent specific gravity of the soil (bulk density) and the field capacity and wilting point of the soil must be determined. Garcia (1978) presents procedures for these measurements. Depending on the results of the soil survey the sample collection procedure is defined. For a field with uniform soils it is necessary to collect data on the above soil properties in a minimum of three locations in the field to obtain a good average. For a field with nonuniform soils the above soil properties must be determined for each major soil type. A minimum of three replication of samples is necessary to obtain an average. In all cases, it is necessary to sample with depth. See Appendix B for further discussion.

Accurate definition of the above soil properties is necessary. The time and effort necessary to achieve this are well worth it and will eliminate having to repeat any sampling. These data are most easily collected before the crop is planted. Some change of apparent specific gravity of the plow layer with time may be expected. Sampling plans for soil water content and infiltration tests will be functions of soil type and uniformity. The results of the soil survey should thus be available in advance of the initial irrigation evaluation.

If soil salinity/alkalinity is expected to be a problem (indicated by maps, previous surveys, information from the farmer), samples should be analyzed to determine the salinity/alkalinity. Such a problem may also indicate the presence of a high water table.

6. Water table.--The farmer should have general knowledge of water table conditions in the area. Soil survey results may indicate a high water table. If the water table is high or expected to fluctuate considerably (i.e., within the maximum potential root zone), it is desirable to monitor the ground water level through the irrigation season. This can be done with a series of grid of observation wells (EWUP, Vol. II, 1979).

A high water table can limit crop growth through water-logging. The groundwater quality can also seriously affect crop growth and should be measured.

Crop water use from the capillary fringe or the water table is possible. Estimates of crop consumptive use by evapotranspiration modeling techniques will not correspond with measured soil water deficits (by soil water content sampling) when the crop is using groundwater, assuming either method is yielding accurate results. This is significant if the water table rises during the season due to early overrigation. Water table fluctuations due to overririgation may also contribute to crop consumptive use and can affect root zone expansion.

On The Day Before Irrigation

Infiltration Data.--Blocked furrow infiltration tests should be conducted in at least four locations along the irrigated run when the field has a uniform soil. When nonuniform soils are present, a minimum of three replications of a test should be conducted on each soil type. There should be enough labor available so that each infiltrometer (Figure 1) is manned throughout the test. The tests should last not less than seven to eight hours, and in some cases, as long as the duration of irrigation. Garcia (1978) presents procedures for the assembly and operation of the infiltrometers. Infiltration tests should be conducted in furrows other than those in which advance and recession data will be collected, but must be in furrows which will be irrigated. Further discussion of considerations of where to sample and how often is included in Appendix B.

Preirrigation Soil Water Content Data.--Garcia (1978) presents procedures for the collection and analysis of soil samples for determination of soil water content by the gravimetric method. In furrow irrigation, it is difficult to determine average water contents in the soil profile since the entire soil surface is not covered with water during irrigation and there may be significant lateral movement of water in the soil. In all instances, samples should be taken from each of several layers of the measured or expected maximum rooting depth of the crop (i.e., for a 1.2 m root zone, sample each 30-cm layer, and in the top 30-cm layer, collect samples from each 15-cm increment). If the water table is higher or near the expected maximum rooting depth, samples should be collected to near the water table. Each individual sample should be 150 grams or more. A problem arises in determining where to sample at each location. When every furrow is irrigated, it is suggested that samples be taken from the bottom of the wet furrow and the middle of the furrow ridge (plant row) between furrows to get a representative average (Figure 2a). When every other furrow is irrigated, it is suggested to take samples from the bottom of the irrigated furrow, the middle of the furrow ridge (plant row), and from the bottom of the nonirrigated furrow, in order to get a representative average of the water content below the ground surface and between wet furrows (Figure 2b). For this case, an average water content for each layer sampled could be defined as:

$$P_{w,avg} = \frac{P_{w,1} + 2P_{w,2} + P_{w,3}}{4} \qquad (1)$$

where $P_{w,avg}$ = average water content for the layer,
$P_{w,1}$ = water content for the layer in area 1 (see Figure 2b),
$P_{w,2}$ = water content for the layer in area 2 (see Figure 2b),
$P_{w,3}$ = water content for the layer in area 3 (see Figure 2b).

It is pointed out that area 2 (Figure 2b) receives twice the weight of the others in computing the average, since this area does in fact occur twice in the soil volume being represented.

Soil sampling locations in the field are determined by the results of the soil survey. If soils in the field are found to be uniform a minimum of three sampling locations in different parts of the field (along the furrow) should be selected to obtain an average for the field. If soils are nonuniform or if nonuniform water applications are expected, a minimum of

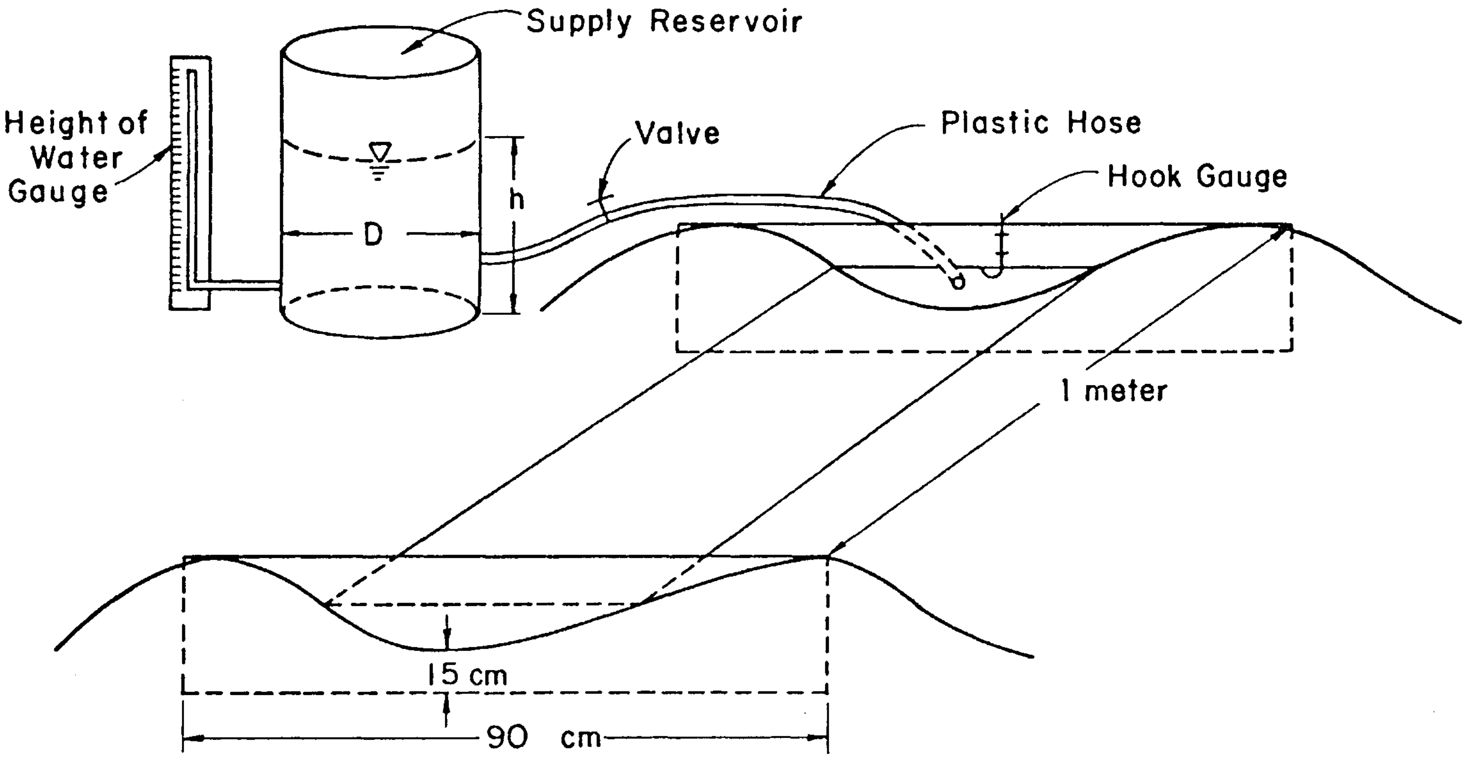


Figure 1. Blocked furrow infiltrometer.

three replications of samples in each representative area are necessary for computing an average. For instance, the distribution of applied water in many fields is nonuniform. A sampling scheme to delineate the differences along the length might be three replications of samples at the head, middle and tail ends of a field. See Appendix B for further discussion of the considerations of sampling plans, numbers of samples to collect, etc.

It is recommended that evaluation data (inflow/runoff, advance/recession, etc.) be collected on a minimum of three furrows. Flumes or other flow measuring devices should be installed at the head and tail ends of each furrow to be evaluated. Care must be taken to ensure that the flumes (if used) are level, have no leaks around them, and that the furrow sides are built up in the approach to the flume to prevent overtopping. Since the flume, being a critical depth flow measurement device requiring a loss of head, water in the approach section of the furrow will back up. This effect is more pronounced on smaller slopes than steeper ones. Flow measuring devices should be installed on the day before irrigation.

On the Day of Irrigation

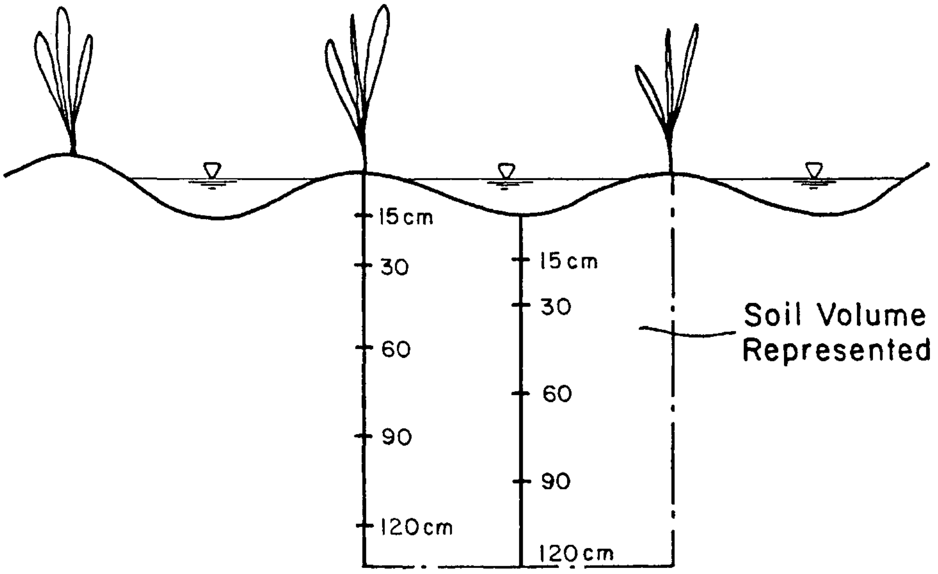
The following data are taken on a minimum of three furrows as the irrigation progresses. The clock time when water is introduced to each furrow being studied should be recorded.

Advance Data.--Record the clock time at which the water arrives at each station (i.e., every 25 m) as the waterfront moves down the furrow.

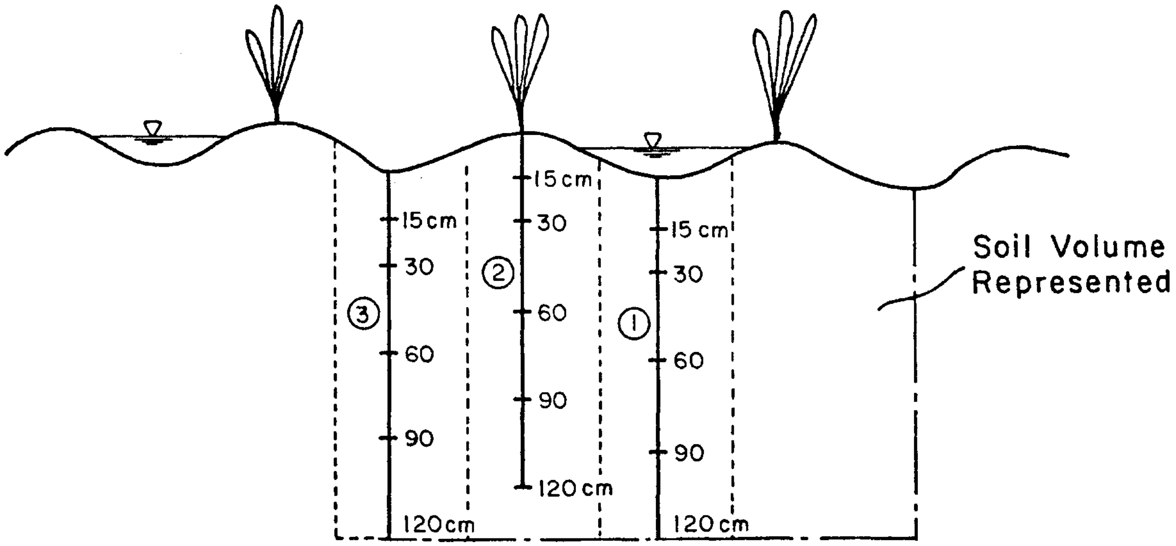
Inflow Data.-Periodically record the clock time or elapsed time from the beginning of irrigation and reading for each inflow rate measuring device.

Runoff Data.--Record the clock time when water reaches the point (usually near end of field) where the runoff rate measuring devices are located. It is suggested that runoff data be collected at 30 sec, 1 min, 2 min, 4 min, 8 min, 15 min, 30 min and then every 1/2-hour from the time when runoff begins.

Recession Data.--Towards the end of irrigation, remove the flow measuring devices from the furrows. Record the clock time when water is shut off. Record the clock time at which water recedes from each station. The receding water edge is hard to define. Recession at a particular point is assumed to have occurred when approximately two-thirds of the furrow wetted perimeter is free of water. Very shallow flow conditions exist



a) Suggested Sample Holes when Every Furrow is Irrigated



b) Suggested Sample Holes when Every-other Furrow is Irrigated

Figure 2. Suggested soil water sampling locations across an irrigated furrow spacing.

during recession. Small puddles and ripples in the furrow bottom further compound the problem. Consistency is of prime importance when taking recession data.

All flow measuring devices should be checked during the irrigation for leaks and proper operating conditions. During the course of the evaluation any unusual factors or conditions should be noted. For instance, cracks in the soil significantly affect advance rate. Any erosion and sedimentation should be noted. Crop conditions (i.e., relative size, color, stand, wilting, etc.) throughout the section of the field being irrigated should be noted. Stunted growth may indicate salinity problems, poor infiltration rates (i.e., change in soil texture of plow pan layer which reduces infiltration) or other problems.

After Irrigation

Post-irrigation soil water content samples should be collected anywhere from 1-1/2 days to 3 days after irrigation. This depends on the soil type and the time required for the soil to drain to field capacity. Garcia (1978) presents a field procedure for estimating when (after wetting) a soil has drained to field capacity. The same collection procedures as previously discussed apply.

DISCUSSION AND RECOMMENDATIONS

It is important to convey to the farmer what will be done during the evaluation. Crop damage and soil disturbance should be minimized. Cooperation of the farmer in all aspects of the evaluation is a necessity. It is important that nothing the investigators do before or during the evaluation cause the farmer to deviate from his normal irrigation practices.

It is important that preliminary data collected early in the season be good data. A careful, coordinated, determined effort here will save much time and eliminate problems and headaches later in the season. For instance, the soil water content of a field before the initial irrigation of the season may generally be assumed as uniform. Much effort in careful soil sampling and in collection of more samples (to increase the precision with which the mean soil water content is estimated) is recommended. The establishment of this initial condition serves an important purpose. It is the starting point for a root zone soil water budget.

From this initial condition, water added to the root zone of the crop by precipitation (measured by rain gages set up in several locations at the site) and by irrigation (measured by irrigation evaluations) is known. Crop use is estimated using climate data and crop stage and growth data in an accurate, calibrated evapotranspiration model. A root-zone soil water budget can thus be calculated through the season. Soil water content data collected at succeeding irrigations of the season are used as a check on the predicted soil water status when calibration of the ET model is necessary.

If there is a high water table in the area, crop use from the capillary fringe or the water table itself can be estimated. The difference between the calculated crop use and the measured soil water deficit (by sampling) during an irrigation interval is an estimate of the crop use from the water table during that interval. If there is no reason to believe that the crop is using water from a water table, then the computed difference indicates the accuracy of each method and possibly needed action to improve sampling or predictive techniques.

In some instances, collection of advance/recession data may not be necessary at each irrigation. For instance, a uniform application of water may be expected on a field with shorter lengths of run on a heavier soil. In this case, the distribution is assumed uniform and all that is required is the water on and water off to determine the water added to the soil. While this case may occur, it is advisable to collect advance and recession data when any nonuniformity of water application is suspected due to poor irrigation practices, nonuniform soils, nonuniform field slopes, etc. in order to know the distribution of applied water.

During the course of an actual irrigation evaluation, it is recommended that a partial evaluation of the data being collected be conducted. This is accomplished best by processing the data as it is collected in the field and interpreting the results. For instance, it is easy to evaluate inflow and runoff data and an obvious error is determined if the runoff is greater than the inflow. This check on data provides the investigator a means of eliminating wasted time and effort in the collection of erroneous data.

FIELD DATA ANALYSIS

Field data analysis provides a basis for understanding the performance of the irrigation system and how the system is being operated. The data may be analyzed through a number of procedures. Those presented here represent the minimum of analyses required to formulate an understanding of the system's performance resulting from a particular management scheme.

Infiltration Data.--The data collected during blocked furrow infiltration tests are generally of the form: total volume infiltrated per unit length vs. elapsed time. The data are plotted on log-log or rectangular grid paper. Garcia (1978) presents methods of analyzing the data such that an infiltration relationship of either of the following forms can be determined:

$$z = kt^a , \tag{2}$$

or

$$z = Kt^A + Ct \tag{3}$$

where z = cumulative volume infiltrated per unit length (L^3L^{-1}),

t = elapsed time (T),

C = steady-state or large-time infiltration rate ($L^3T^{-1}L^{-1}$),

k, a, K, A = empirical constants.

An infiltration function of either form (Eq. 2 or 3) should be found, and usually it is determined for the mean of the infiltration data collected at particular locations in a field. For instance, the mean would be determined for infiltration data on each major soil type or for each area where a sampling plan called for tests to be made.

Soil Water Content Data.--Procedures for determining the water content (dry weight basis) of each of the soil samples collected are presented by Garcia (1978). The depth of water in the soil profile is found using the following relationship:

$$d_m = \sum_{i=1}^{n} (P_{w,i} \times \gamma_{b,i} \times Y_i) \tag{4}$$

where d_m = water depth in the soil profile (L),

$P_{w,i}$ = water content (dry weight basis) of the ith layer of the profile (MM^{-1}),

$\gamma_{b,i}$ = soil bulk density in the ith layer of the profile [$ML^{-3}(ML^{-3})^{-1}$],

Y_i = thickness of the ith layer (L).

n = number of root zone layers sampled.

The preirrigation water depths at each sampling location (i.e., position in the field) are averaged and compared to the water depth when the soil is at field capacity. This gives an estimate of the amount of water which needs to be applied during irrigation to bring the root zone to field capacity. This method for determining the soil water deficit at irrigation time is subject to the large degree of variability observed in soil water content sampling studies, and may give unreliable results. When reliable crop data and, climate data are available, another estimate of the soil water deficit can be obtained through the use of an evapotranspiration modeling procedure and soil water budgeting as discussed earlier.

Pre and postirrigation water depths can be compared to obtain an estimate of the depth of water infiltrated (assuming there is no deep percolation of water past the lowest sampling depth) at each of the sampling locations. This is, of course, subject to the comment made previously concerning the reliability of soil sampling to determine water contents. The temporal and spatial variability in soil properties can be magnitudes and even orders of magnitude in just a small area of a field. Thus, the limitation on the reliability of results is imposed.

Advance/Recession Data.--Normally, these data are plotted on a rectangular grid with time as the ordinate and distance along the furrow as the abscissa (Figure 3). The difference in time between the two curves is the infiltration opportunity time. The infiltration opportunity time at each station along the filed should be determined. Often, the surface elevations are also plotted on the same sheet. Nonuniformity of slope along the run will usually show up in the advance and recession curves. A plot of the surface profile may often be very useful in helping to explain variations in advance and recession rates.

Inflow/Runoff Data.--The inflow and runoff data should be plotted vs. time (with inflow and runoff rates as the ordinates and time as the abscissa) on the same rectangular grid. These are the inflow and runoff hydrographs. The inflow hydrograph is plotted up to the time of shut off. Graphical integration of the area under this curve represents the volume of water applied, W_a (L^3). The runoff hydrograph is also plotted up to the time of shutoff. After shutoff, the runoff rate is assumed to decrease linearly from the runoff rate at the time of shutoff to zero at the end of recession. Graphical integration of the entire area under this curve represents the total runoff volume, W_u (L^3). The difference between the volume of applied water and volume of runoff, as determined by this method, is the volume of water remaining in the field, or the total volume infiltrated during the irrigation, i.e.,

$$W_i = W_a - W_u \tag{5}$$

where W_i = total volume infiltrated (L^3).

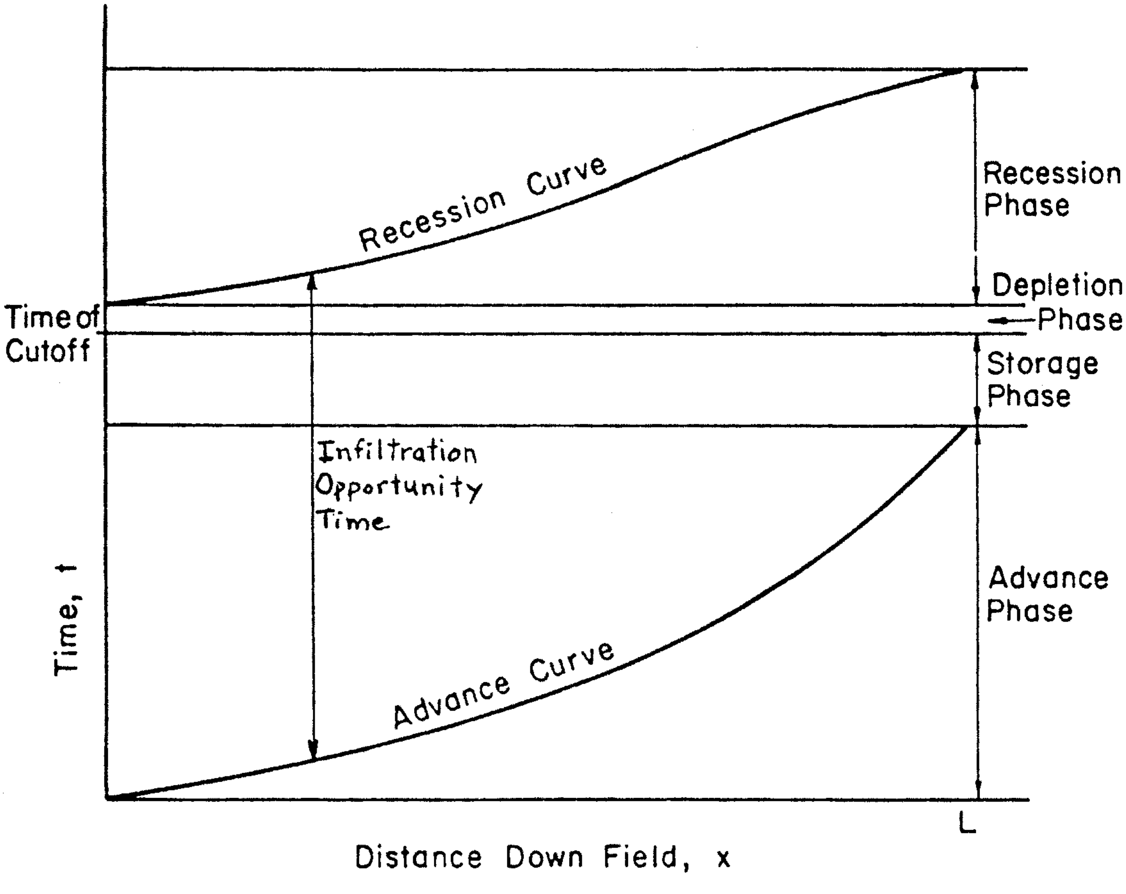


Figure 3. Simplified representation of advance and recession curves and phases or irrigation.

The inflow-runoff method is assumed to be the most accurate for determining the total volume of infiltration. This is because it gives the average infiltration for the entire furrow length (as opposed to "point" type measurements from infiltration tests or soil water data), and because flow rates can usually be measured more accurately than infiltration or soil water content.

Subsurface Distribution of Applied Water.--The subsurface distribution of applied water in furrow irrigation can be determined when the following information is known.

1. A representative infiltration function(s) as determined above.
2. Infiltration opportunity times along the irrigated run, i.e., advance and recession times at points along the run.

Upon construction of the subsurface profile, it is possible to characterize the performance of a particular irrigation. However, before irrigation performance parameters are defined it is necessary to define several related quantities upon which they depend.

Figure 4 represents an idealized profile of infiltrated water as a result of a furrow irrigation. The distance AB is the field length, and the line DFG is the boundary of the infiltrated water. If the downstream boundary condition is one of free outfall, then runoff water from the field can be assumed to extend to the imaginary field length C, and to infiltrate according to the profile CD. The water requirement depth at the time of irrigation is assumed uniform along the field length and is represented by line EFH. With these concepts in mind the following quantities with appropriate units shown in Figure 4 are defined.

1. Total volume of applied water, W_a (area ACDGA). This is the total volume of water introduced per furrow.

2. Total volume of water required in the root zone to reach field capacity, W_r (area ABEHA). This is the volumetric soil water deficit.

3. Total volume of water stored in the root zone, W_{rz} (area ABDFHA). This volume of water is dependent upon the field capacity of the soil and the available storage at the time of irrigation. The total volume of water available for plant use after the irrigation and drainage period equals the difference between the field capacity (FC) and the permanent wilting point (PWP) of the soil, assuming the root zone is completely filled from the

permanent wilting point to field capacity during irrigation [i.e., the total available water expressed as a depth, TAW = (FC - PWP) x (bulk density of the soil) x (rooting depth)].

4. Total volume of deep percolation, W_p (area FGHF). The volume of water which infiltrates past the lower boundary of the root zone. W_p may equal zero in some cases.

5. Total volume of tailwater or runoff, W_u (area BCDB). The volume of water which runs off the end of the field if free outfall conditions exist.

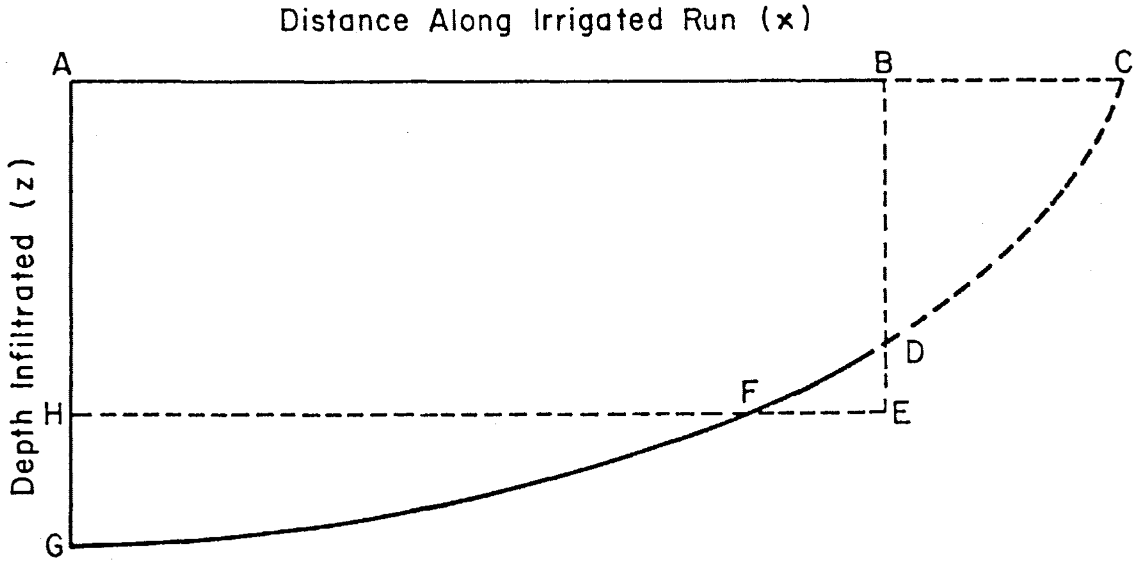
6. Total volume of root zone deficit after irrigation, W_{df} (area DEFD). W_{df} equals zero if the root zone is completely filled.

The infiltration relationship(s) as determined from infiltration tests and the infiltration opportunity times from advance/recession data are used to plot the subsurface distribution. The total infiltrated volume as predicted by the infiltration function(s) should be determined from this plot. Comparison of this value with that determined by the inflow/runoff hydrograph analysis is a check on the adequacy of the infiltration function(s) in predicting the total infiltrated volume. If there is significant deviation, the multiplicative constants of the infiltration function(s) should be adjusted by a trial and error volume balance procedure until the two values coincide. Once this is finished, the subsurface distribution, as predicted by the "adjusted" infiltration function(s), is plotted. The soil water deficit as estimated through soil water content analyses or evapotranspiration studies is also plotted on the same sheet.

Efficiency and Performance Parameters.--Graphical integration of each of the representative areas of the subsurface distribution is used to find each of the volumes as previously discussed. Values of volume applied, volume infiltrated and volume of runoff as determined by both the inflow/runoff analyses and by the subsurface distribution should correspond (assuming the infiltration function used to construct the subsurface profile is representative, i.e., yields good prediction of total infiltration water volume).

Four irrigation performance parameters are defined as follows:

1. Water application efficiency, E_a, is the percent of the amount of water applied which is stored in the root zone for future use.



AB	length of furrow (L)
ACDGA	total volume of applied water per furrow, $W_a(L^3)$
ABEHA	total volume of requirement per furrow, $W_r(L^3)$
ABDFHA	total volume of actual root zone storage per furrow, $W_{rz}(L^3)$
FGHF	total volume of deep percolation per furrow, $W_p(L^3)$
BCDB	total volume of runoff water per furrow, $W_u(L^3)$
DEFD	total volume of root zone deficit after irrigation per furrow, $W_{df}(L^3)$

Figure 4. Idealized subsurface profile of applied water in furrow irrigation.

$$E_a = \frac{W_{rz}}{W_a} \cdot 100 \tag{6}$$

where

$$W_{rz} = W_i - W_p \tag{7a}$$

$$= W_r - W_{df}. \tag{7b}$$

2. Water requirement efficiency, E_r, indicates the percent of the amount of water required to refill the root zone which is supplied by an irrigation.

$$E_r = \frac{W_{rz}}{W_r} \cdot 100 \tag{8}$$

3. Runoff (or tailwater) ratio, R_t, represents the fraction of the total amount applied which is lost as runoff from the end of the field.

$$R_t = \frac{W_u}{W_a} \tag{9}$$

4. Deep percolation ratio, R_p, represents the fraction of the total amount applied which is lost as deep percolation past the bottom of the root zone.

$$R_p = \frac{W_p}{W_a} \tag{10}$$

The sum of the deep percolation ratio, the runoff ratio and the water application efficiency (expressed as a fraction) is unity. Each of the above volumes can be treated as average depths when divided by the product of furrow length and irrigated furrow spacing.

EXAMPLE SYSTEM EVALUATION

The following discussion presents the results of an evaluation of a furrowed irrigation system using the procedures just discussed. A design of this field was formulated using the SCS furrow irrigation design procedure (USDA, 1978 draft). The results of this design are presented in a separate analysis of the design procedure (Ley and Clyma, 1980). Thus, it is possible to compare the current system operation and performance with the suggested design operation and performance. Ultimately, this allows for determination of possible system redesign and management changes such that improved system performance results. Recommended design parameters are repeated here for the reader's convenience.

$Q = 0.57 - 0.76$ ℓps/furrow (9-12 gpm/furrow)

$T_1 = 720$ min

irrigated furrow spacing = 1.12 m (3.67 ft)

design depth = 61 mm (2.4 in.)

The crop irrigated was sugar beets planted on a 0.56 m (1.84 ft) row spacing. Pre and postirrigation soil water content samples were collected, however, analysis has proven them to be inadequate. At any rate, an average evapotranspiration rate for sugar beets was determined to be near 6 mm/day (0.24 in./day) in the general area. The elapsed time from the previous irrigation (when the root zone was last completely filled) to the time of the irrigation being evaluated was 12 days. The soil water deficit was thus estimated to be approximately 72 mm (2.8 in.).

The farmer was irrigating the furrows from a concrete-lined head ditch using 1 1/4-in. siphon tubes. Every other furrow was being irrigated so the irrigated furrow spacing was 1.12 m. The average furrow grade is 0.0098 m/m. The furrow length is 365 m. Inflow and runoff measurements were taken at the head of the furrow and at $x = 350$ m, respectively. Soils were found to be uniform already, although there was some variation in texture with depth.

Five blocked furrow infiltration tests were conducted the day before irrigation at five locations along the length of run. The data, reduced to the form of volume infiltrated per unit length vs. time, are plotted in Figure 5. The mean infiltrated volume per unit length vs. time was found and is also plotted in Figure 5. A least squares regression procedure, outlined in Garcia (1978), was used to determine an empirical infiltration function of the form of Eq. (3) for the mean:

$$z = 2369.4\, t^{0.37} + 70\, t \tag{11}$$

where z = cumulative volume infiltrated (cm^3/m),

t = time (min).

This function is also plotted in Figure 5.

Advance and recession data and surface elevation data are plotted in Figure 6. Infiltration opportunity times at stations along the furrow are included. The time of advance to the runoff measuring device ($x = 350$ m) was 180 min. The plot of the surface profile slope (Figure 6) indicates the uniformity of slope is acceptable.

Normally, the farmer operates using a 12-hr inflow or set time. For this particular irrigation, however, a power failure caused pump shutdown and interrupted the irrigation. The inflow time over which measurements were taken was 7.5 hr. Inflow and runoff data for this time duration are plotted in Figure 7. Graphical integration of the area enclosed by each of these curves resulted in the following volumes:

Total volume applied, $W_a = 22.86\ \text{m}^3$
Total runoff volume, $W_u = 6.68\ \text{m}^3$
Total infiltrated volume, $W_i = W_a - W_u$
$= 16.18\ \text{m}^3$

An average infiltrated depth can be found by dividing by the furrow length and irrigated furrow spacing. In this case, a furrow length of 350 m is used since this is the distance over which infiltration occurred. The average infiltrated depth is:

$$\frac{16.18\ \text{m}^3}{(350\ \text{m})(1.12\ \text{m})} \left(\frac{1000\ \text{mm}}{\text{m}}\right) = 41.3\ \text{mm}$$

Infiltration opportunity times (from Figure 7) are used in Equation (11) to plot the subsurface distribution (see Figure 8). The ordinate in Figure 8 is actually an average infiltration depth in cm which is obtained by converting values obtained in Equation (11) from cm^3/m to m^3/m, then by dividing by the irrigated furrow spacing (m) and multiplying by 100 to obtain cm. Graphical integration of the area enclosed by this curve results in an estimate of total volume infiltrated per unit width as predicted by the blocked furrow infiltration function (Equation 11). This estimate is:

$W_i')_{\text{pred.}} = 15.19\ \text{m}^3/\text{m}$ of width

where $W_i')_{\text{pred.}}$ = estimated total volume infiltrated per unit width (L^3L^{-1}).

Multiplying by the furrow spacing (1.12 m) yields an estimate of the total volume infiltrated. Hence,

$$\begin{aligned} W_i)_{\text{pred.}} &= W_i')_{\text{pred.}} \times 1.12 \\ &= (15.15)(1.12) \\ &= 17.02\ \text{m}^3 \end{aligned}$$

where $W_i)_{\text{pred.}}$ = estimate of total infiltrated volume (L^3).

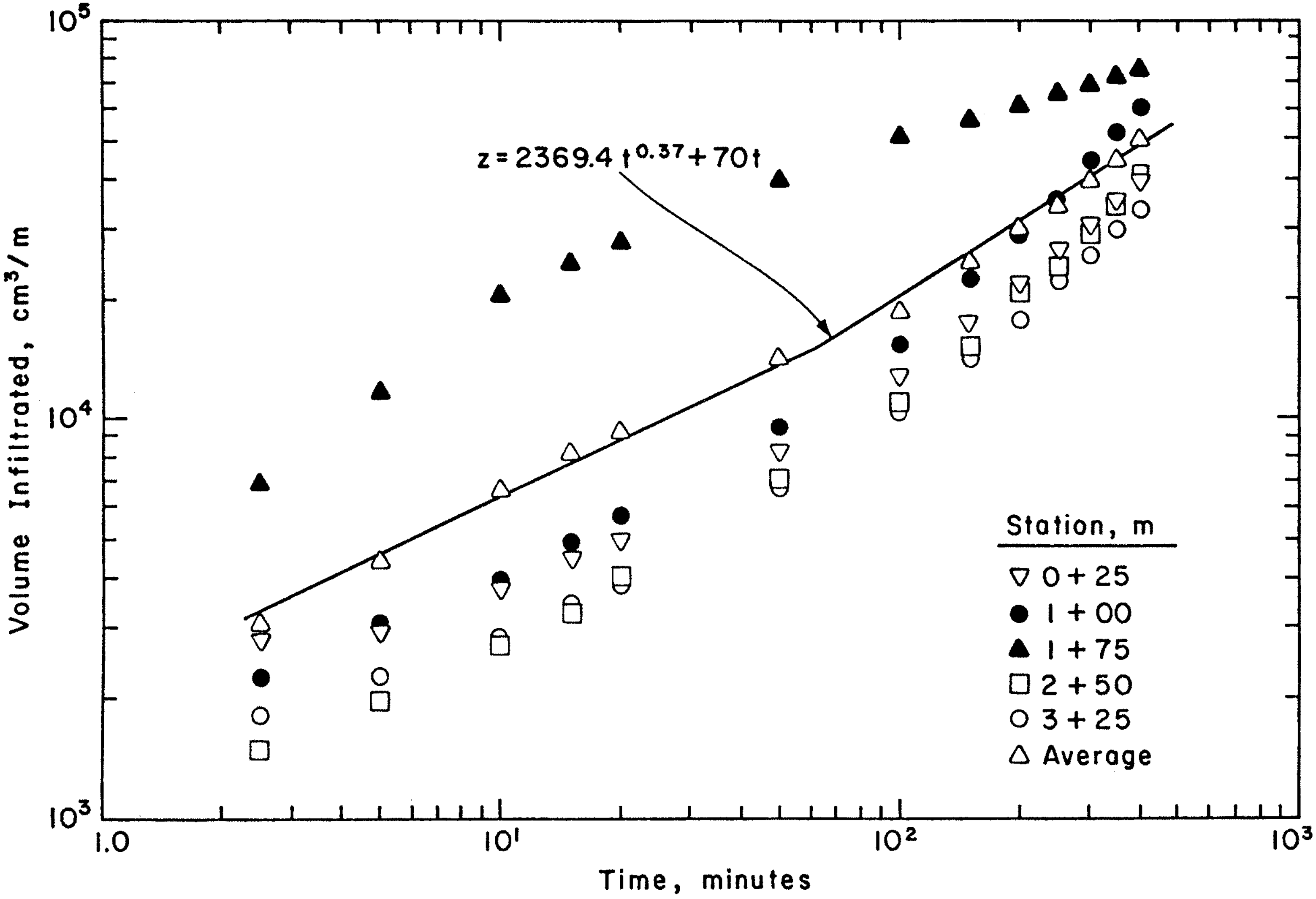
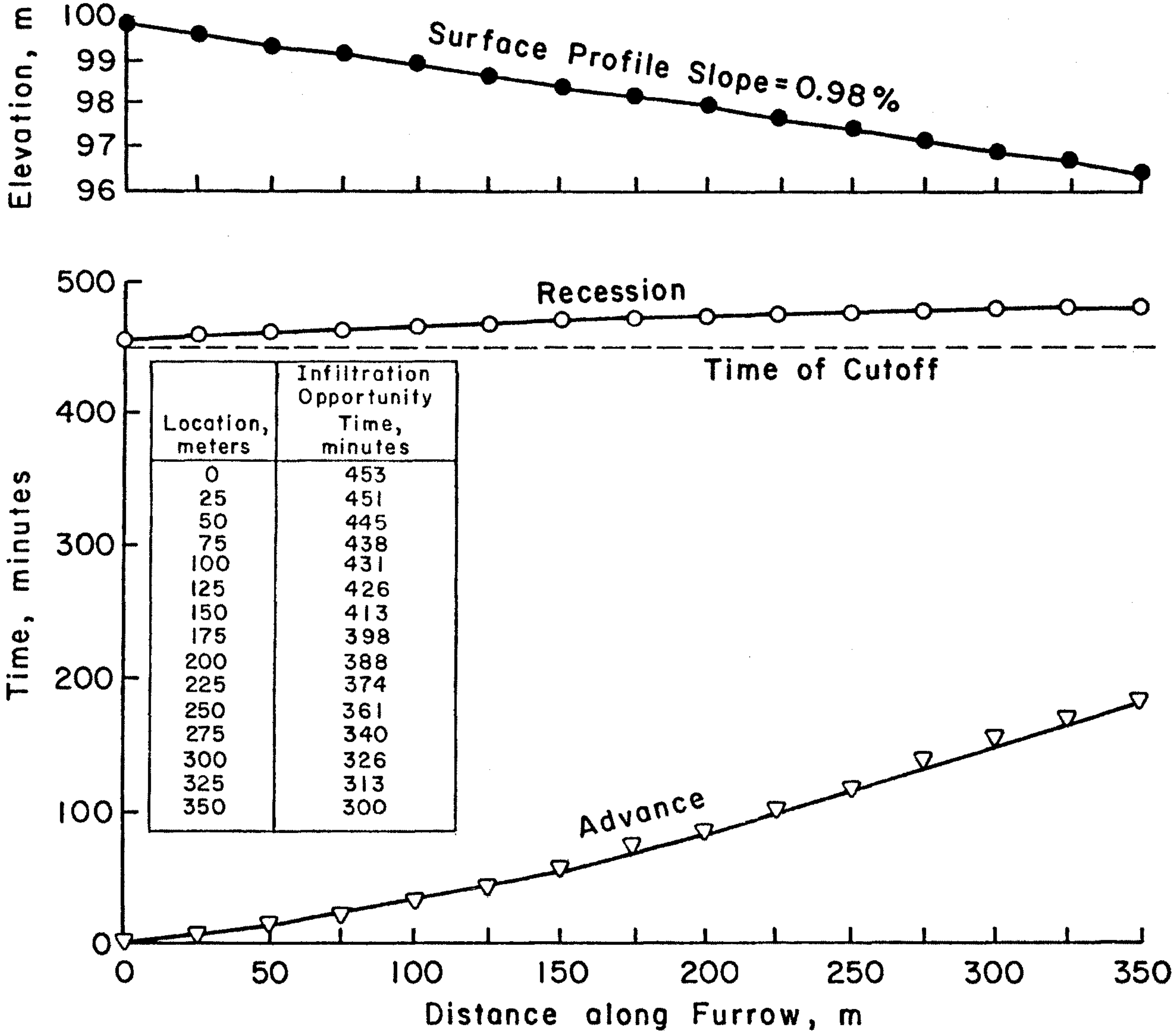


Figure 5. Blocked furrow infiltration test data.



Location, meters	Infiltration Opportunity Time, minutes
0	453
25	451
50	445
75	438
100	431
125	426
150	413
175	398
200	388
225	374
250	361
275	340
300	326
325	313
350	300

Figure 6. Advance/recession curves, surface profile slope and infiltration opportunity times.

An estimate of the average infiltrated depth as predicted by the blocked furrow infiltration function is:

$$\frac{17.02\ \text{m}^3}{(350\ \text{m})\ (1.12\ \text{m})}\ (\frac{1000\ \text{mm}}{\text{m}}) = 43.4\ \text{mm}$$

Comparison of the prediction of total infiltrated volume as obtained using the blocked furrow infiltration function with the value obtained by inflow/runoff hydrograph analysis shows the following deviation:

$$(\frac{17.02 - 16.18}{16.18})\ 100 = +\ 5.2\%$$

This deviation is acceptable, considering the accuracy with which data can be collected in the field. Had the deviation been unacceptable (i.e., greater than 10 - 15 percent), then adjustment of the multiplicative constants in the infiltration function would have been necessary (by a volume balance trial and error procedure or graphical procedure, see example border irrigation evaluation by Ley and Clyma, 1980) until the deviation was within an acceptable range.

Results.--Each of the volumes associated with performance parameters can be determined with the results of the inflow/runoff hydrograph analysis and the subsurface distribution plot. For this case, the inflow/runoff hydrograph results are used. The volumes are as follows:

Total volume applied, $W_a = 22.86\ \text{m}^3$

Total runoff volume, $W_u = 6.68\ \text{m}^3$

Total volume infiltrated, $W_i = 16.18\ \text{m}^3$

Total volume required, $W_r = (72\ \text{mm})\ (\frac{1\ \text{m}}{1000\ \text{mm}})(350\ \text{m})(1.12\ \text{m})$

$= 28.22\ \text{m}^3$

Total volume stored, $W_{rz} = 16.18\ \text{m}^3$

Total volume deep percolated, $W_p = 0.0\ \text{m}^3$

Total deficit volume, $W_{df} = 28.22 - 16.18$

$= 12.04\ \text{m}^3$

Each volume can be converted to an average depth by dividing by the product of furrow length and irrigated furrow spacing. The performance parameters for this irrigation are determined using Equations (6) through (10).

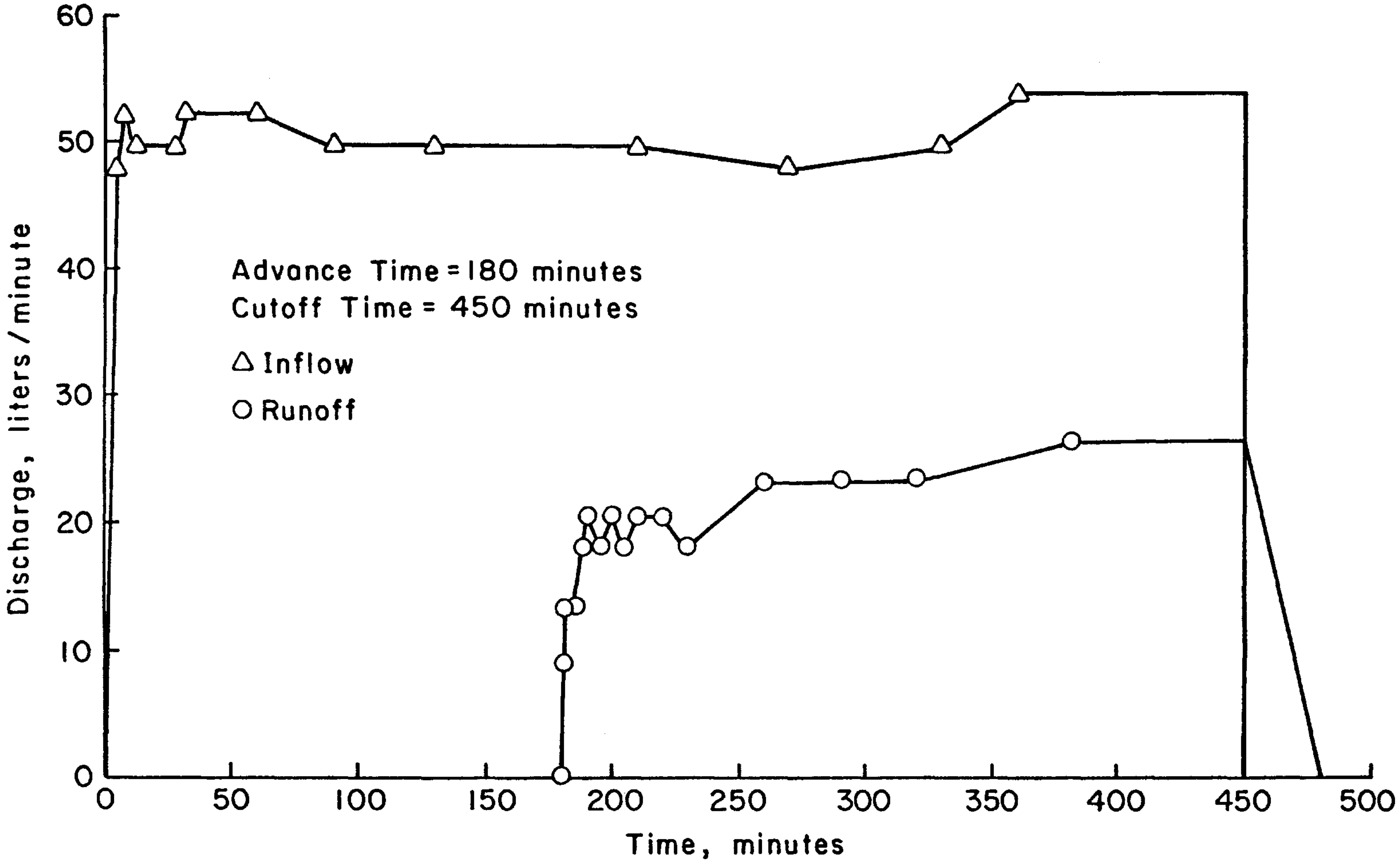


Figure 7. Inflow and runoff hydrographs.

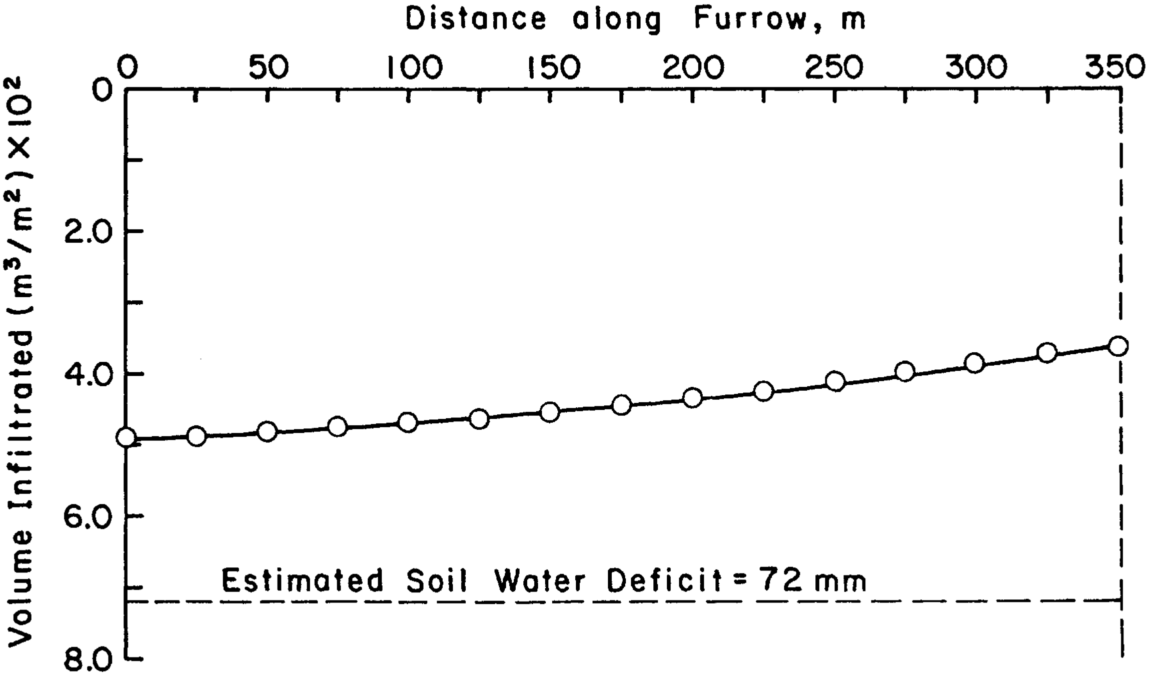


Figure 8. Subsurface distribution of applied water estimated from blocked furrow infiltration function, $z = 2369.4t^{0.37} + 70.0t$ (z-cm^3/m, t-min).

Water application efficiency, $$E_a = \frac{W_{rz}}{W_a} \cdot 100 \qquad (6)$$

$$= \frac{16.18}{22.86} \cdot 100$$

$$= 70.8\%$$

Water requirement efficiency, $$E_r = \frac{W_{rz}}{W_r} \cdot 100 \qquad (8)$$

$$= \frac{16.18}{28.22} \cdot 100$$

$$= 57.3\%$$

Tailwater ratio, $$R_t = \frac{W_u}{W_a} \qquad (9)$$

$$= \frac{6.68}{22.86}$$

$$= 0.292$$

Deep percolation ratio, $$R_p = \frac{W_p}{W_a} \qquad (10)$$

$$= \frac{0.0}{22.86}$$

$$= 0.0$$

Since the irrigation was interrupted by a power failure, it is not possible to compare the design with the results of this evaluation. However, it is known that the farmer normally uses a 12-hr set time and that he makes no adjustment to the furrow inflow rate once the siphon tubes are set. Hence, referring again to Figure 7, it is possible to estimate what the volumes for a 12-hr inflow time would have been. This is done by extrapolating both the inflow and runoff curves out to 720 minutes at a discharge rate equal to their averages for the last half of the 450 minute irrigation. Changes will occur in W_a, W_u, W_i, W_{rz} and possibly W_p. Estimates of what the volumes and performance parameters for the 12-hr set might have been are as follows:

$W_a = 36.40\ m^3$

$W_u\ \ 13.32\ m^3$

$W_i = 23.08\ m^3$

$W_{rz} = 23.08\ m^3$

$W_p = 0.0\ m^3$

$E_a = 63.4\%$

$E_r = 81.8\%$

$R_t = 0.366$

$R_p = 0.00$

Table 1 provides a summary of the evaluation and a comparison with the design.

Table 1. Summary of evaluation and comparison with design.

Parameter	Evaluation (measured)	Evaluation (estimated)	Design[1/]
Inflow time, min	450	720	720
Average furrow inflow rate, ℓps	0.847	0.843	0.57-0.76 (9-12 gpm)
Design depth or requirement, mm	72	72	61 (2.4 in.)
Average depth applied, mm	58.4	93.0	70.0 (2.76 in.)
Average infiltrated depth, mm	41.4	58.9	56.5 (2.22 in.)
Water application efficiency, %	70.8	63.4	81.4
Water requirement efficiency, %	57.3	81.8	92.7
Tailwater ratio, dec.	0.292	0.366	0.186
Deep percolation ratio, dec.	0.00	0.00	0.00

[1/] Values for average depth applied, average depth infiltrated and design performance parameters are averages for the 0.57-0.76 ℓps (9-12 gpm) range of furrow inflow rates.

CONCLUSIONS

1. It is obvious that the interrrupted irrigation was inadequate. However, the uniformity of application was good.

2. Extrapolation of flow rates on the inflow/runoff hydrographs (to 720 min) yields an estimate of what the system performance would normally be under the farmer's current (12-hr set) operation. Assuming these results valid, the farmer would be doing only a fair job of replenishing the needed soil water and would have a large amount of runoff loss. Comparison with

the suggested design parameters indicates why this happens. First, the farmer's average furrow inflow rate for the irrigation is well above the suggested range. This would be a major reason for the high amount of runoff losses as compared to design. Second, the farmer irrigated at a higher soil water deficit than suggested by design analyses. This factor contributes to the under-irrigation which is occurring with his current management.

3. The initial design for this field was formulated for a design depth of 72 mm (2.8 in.), the approximate operating soil water deficit for the farmer. Only marginally acceptable levels of design performance could be obtained for these design conditions. Iterations of the design procedure for smaller design depths were carried out and a feasible design determined for a design depth of 61 mm (2.4 in.). The farmer could significantly improve system performance by altering his system management to apply a smaller amount (61 mm) on a more frequent basis. i.e., reducing the design depth from 72 mm (2.8 in.) to 61 mm (2.4 in.) shortens the irrigation interval by 1 to 2 days.

RECOMMENDATIONS

1. The farmer should consider altering his system management to the smaller design application depth as discussed. Given the range of furrow inflow rates suggested from the design, 0.57 to 0.76 ℓps (9 to 12 gpm), acceptable levels of system performance can be achieved.

2. Further evaluations of the irrigation system are necessary. If the farmer accepts the above design parameters then an evaluation of the new design and management is desired. Also, seasonal changes in factors and conditions which affect the system performance must be evaluated so that an efficient operation can be implemented throughout the season. The example presented has only illustrated the many factors and conditions to be considered for one irrigation of the season.

COLLECTION AND ANALYSIS OF MORE DETAILED DATA

Data Collection

When it is desirable to obtain more detailed information on the physical operating aspects of the irrigation system, the following measurements should be made in sequence with the procedures described previously.

Furrow Cross Section Data.--An estimate of the furrow cross-sectional area can be obtained through the use of the device shown in Figure 9. The furrow profilometer is placed in the furrow with the sliding rods just resting on the furrow bottom. An identification marker of the location is placed next to the profilometer and a photo of them is taken. This should be done in several (at least three) preselected points along each of the furrows in which other measurements are made (i.e., advance/recession, inflow/runoff, etc.). Furrow cross section data should be collected both before and after the irrigation; it is suggested that these data be collected at the same time soil water content samples are collected. Care and good judgement should be exercised in the placement of the profilometer, making sure to place it in a representative section of the furrow without disturbing the soil.

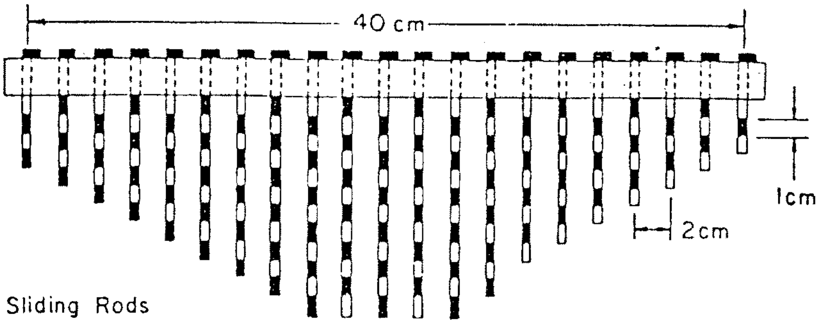


Figure 9. Furrow profilometer.

Flow Depth and Top Width Data.--The flow depth and top width are measured in each of the furrows in which inflow/runoff and advance/recession data are taken. Measurements should be made at several points along these furrows several times during the irrigation. These measurements should be taken at approximately the same location each time. When these data are collected, it is desirable to make the measurements as often as possible during the advance, and may be spaced out at 30 to 60-minute intervals during the rest of the irrigation.

Furrow Infiltration Data.--Another method for determining infiltration during furrow irrigation is the inflow-outflow method presented by Criddle, et al. (1956). Small flumes or other flow measuring devices are placed in the furrow at some spacing, i.e., anywhere from 25 m to 75 m. The inflow and outflow rates vs. time are recorded for each section. Flow depth and top width measurements are also taken in these sections. A volume balance procedure (discussed shortly) is used to determine an infiltration relationship. When these data are collected the measurements should be made in furrows other than those in which advance and recession data are collected.

Data Analyses

Furrow Profiles and Surface Storage.--Once the furrow cross section photos are ready, the data is transcribed to the appropriate data form. These data can then be analyzed, and in general, an empirical power relationship between center depth and cross-sectional area found:

$$A_f = ARy^{BR} \tag{12}$$

where A_f = furrow cross-sectional area (L^2),

y = center depth (L),

AR, BR = empirical constants.

The constants AR and BR can be found using a least squares technique. Usually a mean relationship for the entire furrow length is determined as follows:

a. Graphically estimate the area of each cross section at depths of 1, 2 and 3 cm from the furrow bottom at the furrow centerline.
b. Calculate the mean area for the furrow sections of each furrow at each depth.
c. Perform a logarithmic transformation of Equation (A-1) and a least squares regression of the transformed variables to determine the constants AR and BR.

Assuming the empirical relationship for the furrow cross-sectional area (as just derived) is valid for the entire furrow length; flow depth data are used to find flow areas at each of the points where the flow depth is measured. Since flow depth data are available through the advance phase and the remaining phases of irrigation, an average cross-sectional flow area for the entire furrow length can be found for each of these phases. In turn, an estimate of the total volume of water in the furrow (surface storage) for a particular length, can be found by multiplying the average flow area by the furrow length being considered. The volume of surface storage may be necessary in certain volume balance analyses.

The cross-sectional flow area relationship and flow depth data are also used in estimating the furrow roughness in a relationship such as Manning's formula:

$$Q = \frac{C_u}{n} S_o^{1/2} R^{2/3} A_f \tag{13}$$

where Q = flow rate at a particular section (L^3T^{-1}),

n = Manning's roughness factor,

S_o = bed slope $(L\ L^{-1})$,

R = hydraulic radius (L),

A_f = cross-sectional flow area (L^2),

C_u = constant dependent on units (1.0 for metric, 1.486 for English).

For such an analysis steady uniform flow in a prismatic channel of uniform slope is assumed. This allows usage of Manning's formula with the energy gradient equal to the furrow bed slope. The condition of steady uniform flow in furrow irrigation is approximated at the time when the soil has reached its basic intake rate. Thus, flow depth data only for about the last half of the irrigation should be used. The flow rate at any particular section along a furrow is assumed to decrease linearly from the inflow rate to the runoff rate when the soil is at its basic intake rate. Hence, Equation (A-2) can be solved for Manning's n since the other variables can be estimated (i.e., R and A_f are found from the furrow cross section relation and flow depth data). Point estimates of n will result, which are averaged to find the mean furrow roughness.

Furrow Infiltration by Inflow-Outflow.--Criddle, et al. (1956) present a complete method for analyzing data collected in the inflow-outflow procedure. It involves a volume balance procedure using the inflow-outflow rate measurements to determine the furrow infiltration vs. time. Since flow depth data are available for the sections of furrow being evaluated, the volume of surface storage for those sections can be found as described previously. These estimates of surface storage volume are time distributed as are the inflow rate and outflow rate measurements. A volume balance as follows results in a time distribution of the volume infiltrated.

$$VINF(t) = VIN(t) - [VOUT(t) + VSS(t)] \qquad (14)$$

where

$VINF(t)$ = total volume infiltrated at time t, (L^3),

$VIN(t)$ = total volume of inflow to furrow section at time t, (L^3),

$VOUT(t)$ = total volume of outflow from furrow section at time t, (L^3),

$VSS(t)$ = volume of water in surface storage at time t, (L^3).

In general, a functional relationship for infiltration can be determined for the data: volume infiltrated vs. time. More complete discussion of the method is found in Criddle, et al. (1956).

EQUIPMENT LIST AND SUGGESTED DATA FORMS

Equipment

The following list of equipment necessary for the evaluation of three furrows is suggested.

1. Six flow measurement devices (i.e., small cutthroat flumes with 1-in. throats).
2. Engineer's level, field rod, chain or tape, orange flagging.
3. Wood stakes and lathe for station markers, crayon for marking and hatchet for driving them into ground.
4. Soil sampling equipment:
    a. soil auger or tube sampler
    b. soil sample cans with tight fitting lids (up to 200, 2-in. diameter cans)
    c. box for carrying cans
5. Small carpenter's levels for leveling flumes, etc.
6. Blocked furrow infiltration equipment (up to 10 sets, see Figure 1) plus plastic sheeting.
7. 50 small wire stakes with orange flagging.
8. Bulk density equipment.
9. Instruments for measuring time (stop watch, wrist watch with second hand).
10. Buckets for hauling water.
11. Shovels, sledge hammers.
12. Soil uniformity box (partitioned box).
13. Pencils, clipboards and data forms.

For the more detailed measurements include:

14. Device for measuring flow depth and top width.
15. Furrow profilometer (see Figure A1).
16. Camera, film and identification marker.
17. Small flow measurement devices for furrow infiltration by inflow-outflow method.

Data Forms

Data forms for the following data sets are provided:

- Soil Water Content Data
- Bulk Density Data
- Blocked Furrow Infiltration Data
- Water Advance/Recession Data
- Flow Rate Data
- Farm and Field Data
- Flow Depth and Top Width Data
- Furrow Cross-sectional Area Data
- Furrow Infiltration Data (Inflow-Outflow Method).

Each form includes a special code for identification of the evaluation site:

Ident (R_E, F_A, F_I, I, F_u),

where the data are identified by the letters in parenthesis.

R_E--Region
F_A--Specific Farm
F_I--Field Number on Farm
I--Irrigation Number (starting from the first irrigation at that location)
F_u--Furrow Number

SOIL WATER CONTENT DATA

Ident (R_E, F_A, F_I, I): ____________ Observer: ____________ Date: ____________

Soil Type: ____________ Crop: ____________ Before / After Irrigation

Remarks: F - Furrow
R - Row

Stn.	R/F	Depth cm	Can No.	Wt. Can Tare g	Wt. Can & Soil Wet g	Wt. Can & Soil Dry g	Wt. Soil Dry g	Wt. Water g	Water Content % by Weight	Bulk Density γ_b	Water Content % by Volume	Water depth d mm

BULK DENSITY DATA

Ident (R_E,F_A,F_I,F_u): ____________ Observer: ____________ Date: ____________

Crop: ____________

R - Row
F - Furrow

Remarks:

Stn.	$\frac{R}{F}$	Soil Depth cm	Can No.	Wt. Can Tare g	Wt.Can & Soil Moist. g	Wt.Can & Soil Dry g	Wt. Soil Dry g	1st Read. Inst.	2nd Read. Inst.	Soil Vol. cm^3	Bulk Density γ_b

BLOCKED FURROW INFILTROMETER

Ident (R_E, F_A, F_I, I, F): ______________________ Observer: ______________________ Date: ______________________

Crop: ______________ Infiltrometer No. ______________

Remarks: A - Cross-sectional area of cylindrical supply reservoir. WP - Furrow wetted perimeter

A = _____ Station = _____ WP = ________ ________ ________

Time*			Infiltration			Time			Infiltration			Time			Infiltration		
Clock	Diff.	Cum	Depth	Diff.	Cum	Clock	Diff.	Cum	Depth	Diff.	Cum	Clock	Diff.	Cum	Depth	Diff.	Cum

*All clock times are on 24-hour basis.

WATER ADVANCE/RECESSION DATA

Ident (R_E,F_A,F_I,I): ______ Date: ______ Crop: ______ Irrigation Start: ______

Soil: ______ Observer: ______ Finish: ______

Comments Total Time: ______

Furrow: ______ Furrow: ______ Furrow: ______

Stream Size: ______ Stream Size: ______ Stream Size: ______

Station (m)	Advance		Recession	
	Time*			
	clock	cum	clock	cum

Station (m)	Advance		Recession	
	Time			
	clock	cum	clock	cum

Station (m)	Advance		Recession	
	Time			
	clock	cum	clock	cum

*All clock times are on 24-hour basis.

FLOW RATE DATA

IDENTIFICATION______________ OBSERVER________________ DATE_________

CROP_________ LENGTH__________ INFLOW_________ or RUNOFF___________

FURROW/BORDER NO._______ FURROW SPACING/BORDER WIDTH_______________

MEASURING DEVICE______________ START TIME_________ STOP TIME_______

COMMENTS:

Clock* Time (1)	Elapsed Time (min) (2)	ΔT (min) (3)	Reading ( ) (4)	Flow Rate ( ) (5)	Average Flow Rate ( ) (6)	Volume ( ) (6) x (3) (7)	Σ Volume ( ) Σ (7) (8)
		▨			▨	▨	▨

*All clock times are on 24-hour basis.

FARM AND FIELD DATA

IDENTIFICATION________________ OBSERVER_______________ DATE____________

FARMER__________________________ ADDRESS___________________________________

(Sketch the farm and on-farm water delivery system noting pertinent roads, boundaries, field boundaries, locations of pumps, open drains, etc.)

FLOW DEPTH AND TOP WIDTH DATA

Ident (R_E,F_A,F_I,I,F_u):_____ Length:______ Observer:_________ Date:______

Crop:______________________ Furrow Spacing (m):_________________________

Remarks:

d - Flow depth (cm)
w - Top width of flow (cm)

Time	Start	End	Start	End	Start	End	Start	End
Station d/w								

Time	Start	End	Start	End	Start	End	Start	End
Station d/w								

APPENDIX A RECONNAISSANCE QUESTIONNAIRE

1. Farmer operation and management

How does the farmer decide when to irrigate?
What is his irrigation frequency? How does it change during the season?
How does he decide how to irrigate?
How does he decide how much water to apply?
Does the farmer know the total flow rate available to him?
What are the farmer's operating hours?
Does he irrigate at night?
How does he decide how long to irrigate a field?
How long does he irrigate a field?
Does the farmer have any problems with the system?
What are his cultivation and tillage practices?
Does he irrigate every furrow or alternate furrows?
How many furrows does he irrigate in one set?
How many sets does it take to irrigate the field?
Does he try to compact the furrows equally?

2. Water supply

What are the sources of available water?
Is the delivery station (point of diversion to farm) a problem, i.e., high losses, etc.?
Is the on-farm distribution system a problem (i.e., too many in-field channels, high losses, etc.)?
What is the flow rate of each source of water?
When is each source available and for how long?
Is the frequency of delivery and available head a problem?
What is the water quality?
How is the water delivered to each field?

3. Crop characteristics

What are the crops being grown?
What are the respective planting dates?
What cropping patterns, if any, have been followed?
Does the farmer have any major problems in crop production?
What are the major inputs? Potential yield?
What is his expected yield? Average yield in area?
Any obvious physical symptoms of problems?

4. Physical characteristics

Does the farmer know the field dimensions?
Does he know the slope and cross-slope (if any)?
Has the field been leveled to a uniform slope?
If yes, when? If no, why not?
What provisions, if any, are made for surface runoff?
Does runoff leave the farm or is it used again somewhere on the farm?
What is the border spacing and how did the farmer decide on that spacing?
What is the furrow spacing?
What is the method of diverting water into each furrow?

5. Soil survey

Does the farmer know the soils on his farm?
Does he know of any trouble spots (i.e., very light or heavy soils or salinity problems)?

6. Water table

Does the farmer know the groundwater level?
Does he feel it is a problem?
Is surface/subsurface drainage provided? If so, where?

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EWUP
How to do it
Field Procedure

EVALUATION OF GRADED BORDER IRRIGATION SYSTEMS[1/]

Thomas W. Ley and Wayne Clyma[2/]

INTRODUCTION

Data collection and analysis procedures for evaluating the performance of graded border irrigation systems are presented. Information is collected on both the physical and managerial aspects of operational systems. Basic data reduction procedures define the state of the irrigation system. A list of suggested equipment and data forms are included.

REQUIRED DATA

Preliminary Data

The evaluation of any irrigation system necessarily requires the collection and analysis of a large amount of data. Not the least of which are basic preliminary site data which can be obtained through interviews with the farmer and by performing several basic physical measurements. Basic site information must be known before the evaluation of an irrigation occurs. It is also desirable to obtain as much information as possible from the farmer concerning his operation and management of the irrigation system before an irrigation is evaluated. A list of suggested questions is found in Appendix A for each of the following categories of information. The list, is by no means exhaustive, and often the farmers answers to some of the questions will lead the trained person to other more site specific questions.

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1. Farmer operation and management.--Understanding why or how a farmer does certain things in managing and operating the irrigation system is vital. Often this aspect of evaluating irrigation performance may be overlooked and incomplete knowledge of the irrigation system state results. Farmer management may be constraining the level of performance which can be attained. The general level of knowledge of the farmer concerning irrigation principles and practices is evaluated. Other information discussed later will aid in determining if system management can be improved.

2. Water supply.--The farmer will know the available water supply, source, delivery, frequency, etc. He may have only a general knowledge of the flow rate and quality. These should be measured during the course of an evaluation. On-farm conveyance losses may be a big problem. The farmer may or may not know. Measure the losses if necessary.

3. Crop characteristics.--The crops grown and the planting dates of each must be known. Available data in the literature are needed on crop seasonal water requirements, rates and stages of growth, maximum potential rooting depths, time from planting to effective cover, etc. This information along with climatic data is used to estimate crop water use through the irrigation season. The crop root zone should be measured at each irrigation for crops with expanding root systems. The measured root zone for a perennial crop (such as alfalfa) can often be assumed valid for the entire season unless a fluctuating water table is encountered. The crop root zone at each irrigation determines the available soil water reservoir at that time and is necessary to determine the soil water deficiency, the stress at the time of irrigation and performance parameters such as water application and water requirement efficiencies.

4. Physical characteristics.--Measure and record the field dimensions. Stakes should be driven into the ground at 25-m intervals along the length (adjust for size of field as necessary). Measure and record surface elevations at each stake (station) using a field rod and level. Plot the surface profile (elevation vs. length). Measure and record the cross-slope and border spacing at each station. Determine if a ponded or free outflow boundary condition exists at the downstream end. Determine where and how to measure border inflow and runoff.

5. Soil survey.--If available, obtain information on soils in the area (on the farm), such as maps and classifications from a local or

regional office (e.g., USDA Soil Conservation Service or similar government agency). Such information is very useful and aids the design of data collection procedures. Soil types and textures are known and maps usually depict the variation of surface textures in a field. If this information is not available a soil survey is necessary to determine the soil types and uniformity in the field being studied. Soil samples should be collected in a minimum of ten locations in the field (i.e., at five locations along the length and two along the width). Samples should be taken from a minimum of four depths within the expected root zone, i.e., every 30 cm in an expected 1.2 m root zone (adjust as necessary). These samples should be analyzed to determine soil types.

Once soil types and variations through the field are known the apparent specific gravity of the soil (bulk density), the field capacity and wilting point of the soil must be determined. Garcia (1978) presents procedures for these measurements. Depending on the results of the soil survey the sample collection procedure is defined. For a field with uniform soils it is necessary to collect data on the above soil properties in a minimum of three locations in the field to obtain a good average. It is necessary to sample with depth. For a field with non-uniform soils the above soil properties must be determined for each major soil type. A minimum of three replications of samples is necessary to obtain an average. Sampling with depth is required. See Appendix B for further discussion.

Accurate definition of the above soil properties is necessary. The time and effort necessary to achieve accurate data will eliminate having to repeat any sampling. These data are most easily collected before the crop is planted. Some change of apparent specific gravity of the plow layer with time may be expected. Sampling plans for soil water content and infiltration tests will be functions of soil type and uniformity. The results of the soil survey should thus be available in advance of the initial irrigation evaluation.

If soil salinity/alkalinity is expected to be a problem (indicated by maps, previous surveys, information from the farmers), samples should be analyzed to determine the salinity/alkalinity. Such a problem may also indicate the presence of a high water table.

6. Water table.--The farmer should have general knowledge of water table conditions in the area. Soil survey results may indicate a high water

table. If the water table is high or expected to fluctuate considerably (i.e., within the maximum potential root zone), it is desirable to monitor the ground water level through the irrigation season. This can be done with a series or grid of observation wells (EWUP, Vol. II, 1979).

A high water table can limit crop growth through water-logging. The groundwater quality can also seriously affect crop growth and should be measured.

Crop water use from the capillary fringe or the water table is possible. Estimates of crop consumptive use by evapotranspiration modeling techniques will not correspond with measured soil water deficits (by soil water content sampling) when the crop is using groundwater, assuming each method is yielding accurate results. This is significant if the water table rises during the season due to early overirrigation. Water table fluctuations due to overirrigation may also contribute to crop consumptive use and can affect root zone expansion.

On the Day before Irrigation

Preirrigation Soil Water Content Data.--Garcia (1978) presents procedures for the collection and analysis of soil samples for determining water content by the gravimetric method. Depending on the results of the soil survey (which should be available by this point in time), the sampling plan is devised. If the soil survey results show the soils to be uniform, a minimum of three locations in different parts of the field are selected for sampling to obtain an average for the field. However, if certain variations are expected (non-uniform water applications, etc.) or if soils are non-uniform a minimum of three replications of samples should be collected where the non-uniformities are or where variations are expected. For instance, non-uniform water applications along the length of run is common and collection of a minimum of three replications of samples at a minimum of three representative locations along the length is suggested. See Appendix B for further discussion on sampling and how often to sample.

In all cases, samples should be collected from each of several layers of the measured or expected maximum rooting depth of the crop (i.e., for a 1.2 m root zone, sample each 30-cm layer, and in the top 30-cm layer collect samples from each 15-cm increment). If the water table is higher than the expected maximum rooting depth, samples should be collected to the water table. Each individual sample should be 150 grams or more.

Other preparations for the evaluation should be made on the day before irrigation such as installation of flow measuring devices and cylinder infiltrameters. Contact the farmer and find out the time he expects to start irrigating. Plan to arrive in sufficient time to complete all preparations for the evaluation(s) such as preparation of data forms and assignment of duties.

On the Day of Irrigation

Infiltration Data.--For uniform soils at least three and preferably a total of six cylinder infiltration tests should be conducted in three locations along the length. For non-uniform soils three replications of tests should be made in each area where a different soil texture exists. If non-uniformity in distribution along the length of run is anticipated, then three replications for each representative length of the field is necessary to delineate these differences. During the season differences in soil water content will accentuate the differences in infiltration and the distribution of water. See Appendix B for further discussion of considerations of where to sample and how often.

The infiltrometer measurements should be started as the water arrives at each infiltrometer and the ponded depth maintained the same as the depth of flow of the irrigation water. If the tests cannot be conducted during irrigation, they should be conducted on the day before irrigation and a buffer ring should be used. Garcia (1978) presented procedures for installing the infiltrometers and conducting the tests.

Inflow/Runoff Data.--Flow measurement devices to determine inflow to and runoff from the border should be properly installed before the irrigation. The clock time[1/] at which water is first introduced to the border should be recorded. A measurement of the initial inflow rate should be taken. Periodically during the irrigation record the inflow rate and clock time of the observation. When the water reaches the runoff measurement device begin making runoff rate vs. time measurements. A suggested pattern for taking runoff data from the time runoff starts is to take a reading at 30 sec, 1 min, 2 min, 4 min, 8 min, 15 min, 30 min, and then every 1/2 hour. Record the clock time when water entering the border is terminated.

[1/] Clock times should be on a 24-hour basis (military time).

Advance/Recession Data.--The rate of waterfront advance should be observed and recorded. When the moving stream front is irregular, record the time when an "average" front reaches each station (see Fig. 1). After the inflow is terminated, record the rate of recession. Ideally, this would be the time when water disappears from each station. It is difficult to determine the location of the receding water edge. When water has disappeared from 50 percent of the grid surface area represented by each station, recession is assumed to have occurred at that station. Consistency is of primary importance in taking recession data.

After Irrigation

Postirrigation soil water content samples should be collected anywhere from 1-1/2 days to 3 days after irrigation. This depends on the soil type and the time required for the soil to drain to field capacity. Garcia (1978) presents a field procedure for estimating when (after wetting) a soil has drained to field capacity. The same collection procedures as previously discussed apply.

DISCUSSION AND RECOMMENDATIONS

To ensure cooperation of the farmer during the evaluation, describe exactly what will be done. Minimize crop damage and soil disturbance. Be sure the farmer will operate his system as he usually does. Avoid remarks which may influence his management decisions. The purpose of the evaluation is to determine the system performance and evaluate the system operation as the farmer currently manages it.

It is important that preliminary data collected early in the season be good data. A careful, coordinated, determined effort here will save much time and eliminate problems and headaches later in the season. For instance, the soil water content of a field before the initial irrigation of the season may generally be assumed as uniform. Much effort in careful soil sampling and in collection of more samples (to increase the precision with which the mean soil water content is estimated) is recommended. The establishment of this initial condition serves an important purpose. It is the starting point for a root zone soil water budget.

From this initial condition, water added to the root zone of the crop by precipitation (measured by rain gages set up in several locations at the site), and by irrigation (measured by irrigation evaluations) is known. Crop use is estimated using climate data and crop stage and growth

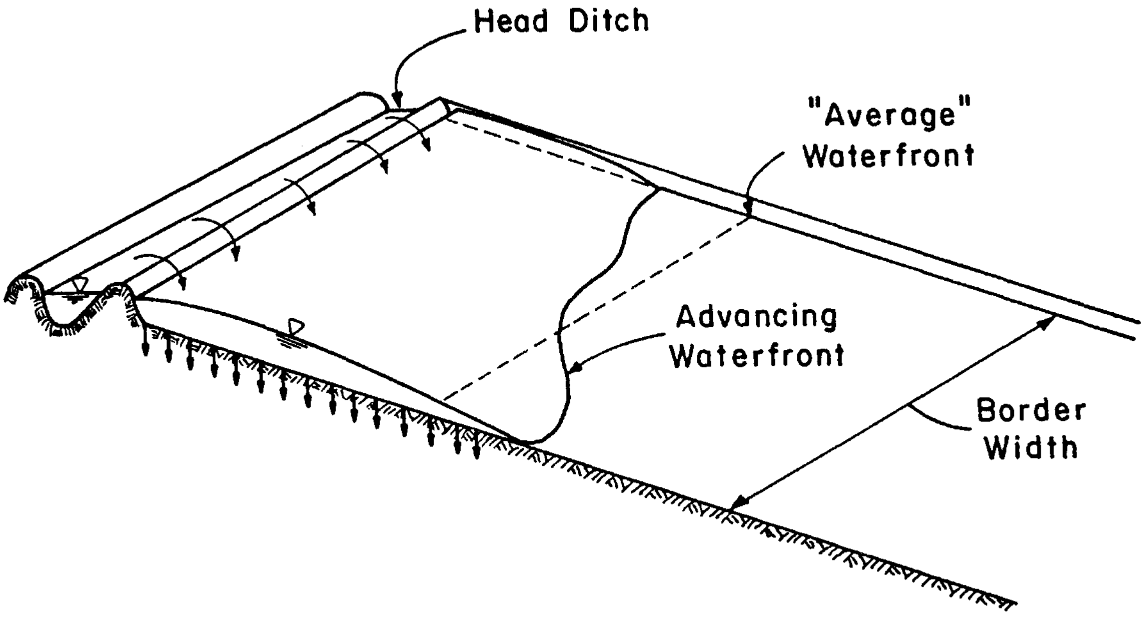


Figure 1. Illustration of irregular waterfront advance and location of "average" waterfront.

data in an accurate, calibrated evapotranspiration model. A root zone soil water budget can thus be calculated through the season. Soil water content data collected at succeeding irrigations of the season are used as a check on the predicted soil water status when calibration of the ET model is necessary.

If there is a high water table in the area, crop use from the capillary fringe or the water table itself can be estimated. The difference between the calculated crop use and the measured soil water deficit (by sampling) during an irrigation interval is an estimate of the crop use from the water table during that interval. If there is no reason to believe that the crop is using water from a water table, then the computed difference indicates the accuracy of each method and possibly needed action to improve sampling or predictive techniques.

In some instances, collection of advance/recession data may not be necessary at each irrigation. For instance, a uniform application of water may be expected on a field with shorter lengths of run on a heavier soil. In this case, the distribution is assumed uniform and all that is required is the water on and water off to determine the water added to the soil. While this case may occur, it is advisable to collect advance and recession data when any non-uniformity of water application is suspected due to poor irrigation practices, non-uniform soils, non-uniform field slopes, etc. in order to know the distribution of applied water.

During the course of an actual irrigation evaluation, it is recommended that a partial evaluation of the data being collected be conducted. This is accomplished best by processing the data as it is collected in the field and interpreting the results. For instance, it is easy to evaluate inflow and runoff data. An obvious error is determined if the runoff is greater than the inflow. This check on data provides the investigator a means of eliminating wasted time and effort in the collection of erroneous data.

FIELD DATA ANALYSIS

Field data analysis provides a basis for understanding the performance of the irrigation system and how the system is being operated. The data may be analyzed through a number of procedures. Those presented here represent the minimum of analyses required to formulate an understanding of the system's performance resulting from a particular management scheme.

Soil Water

The soil water content may be estimated by two methods: 1) gravimetric method, and 2) feel method. The soil water content expressed as a depth of water per unit depth of root zone can be estimated using the results of the gravimetric soil water analyses in the following equation:

$$d_m = \sum_{i=1}^{n} (P_{w,i} \cdot \gamma_{b,i} \cdot y_i) \qquad (1)$$

where d_m = the soil water content expressed as a depth (L) for the entire depth investigated,

$P_{w,i}$ = dry weight soil water content for the ith layer of the root zone (MM^{-1}),

$\gamma_{b,i}$ = soil bulk density in the ith layer $[(ML^{-3})(ML^{-3})^{-1}]$,

y_i = thickness of the ith soil layer (L),

n = number of layers in the root zone which were sampled.

The pre-irrigation soil water content data are checked with the soil field capacity to estimate the soil water deficit (available root zone storage) at the time of irrigation. As previously discussed, crop water use and root zone soil water budgeting also provides a check on the soil water deficit at irrigation time. The pre- and post-irrigation soil water data can also be useful in analyzing depths infiltrated and adequacy of irrigation along the border assuming there is no deep percolation of water below the lowest depths investigated.

The feel method for estimating soil water content is largely subjective since it is dependent upon visual inspection of certain characteristics of the soil sample. The method should be used only when the investigator has a large amount of experience and even then only for a rough estimate of soil water content. Table 1 describes the relationship between soil physical appearance and soil water content for varying soil types.

Advance and Recession

The advance and recession data are plotted on coordinate paper as shown in Figure 2. The advance curve is a plot of the time the waterfront advances along the border vs. the length of the border. The recession curve is a plot of the time the waterfront recedes from the surface vs. the border length. The intake opportunity time is the difference between the advance and recession time as shown in Figure 2. Intake opportunity times represent the amount of time water has the opportunity to infiltrate at points along the border. Surface elevation data are often plotted on the same graph as an aid in explaining variations in advance and recession rates, and resultant effects on infiltration opportunity time.

Infiltration Relationship

The data from cylinder infiltration rests are reduced to the form of cumulative depth of infiltration vs. time. The reduced data are then plotted on log-log paper (Garcia, 1978). In general, the data plot as straight lines, but may slightly curve and often will "dogleg." Some curves steepen after a few minutes either because of release of trapped air (usually in sandier soils) or because the cylinders were not driven deeply enough. Soils which have cracks, into which water disappears quickly, often exhibit curves which are initially steep and then flatten. Plow plans may cause a similar, but usually delayed effect. The average infiltrated depth vs. time should be computed using the data from each area where soil properties were found to be uniform (Merriam and Keller, 1978). The average infiltrated depth vs. time should then also be plotted on the same log-log graph as the individual data sets for these areas. A least squares regression technique (see Garcia, 1978) is often used to find an infiltration function of the following form for the average infiltrated depth vs. time:

$$z = kt^a \tag{2}$$

where z = cumulative depth infiltrated (L),

t = time (T)

k, a = empirical constants.

This type of infiltration function is usually considered representative in border irrigation. In most cases, the infiltration relationship resulting from ring infiltration tests is inadequate in predicting the actual infiltration which occurs during the irrigation. The *actual average* infiltrated depth can be found using inflow and runoff data (discussed later) for the irrigation. The following procedure is used to find the *predicted average* infiltrated depth (as predicted by the infiltration relationship).

1. Using intake opportunity times (from advance/recession data) for stations along the border and the infiltration relationship, find the predicted infiltrated depth at each station.

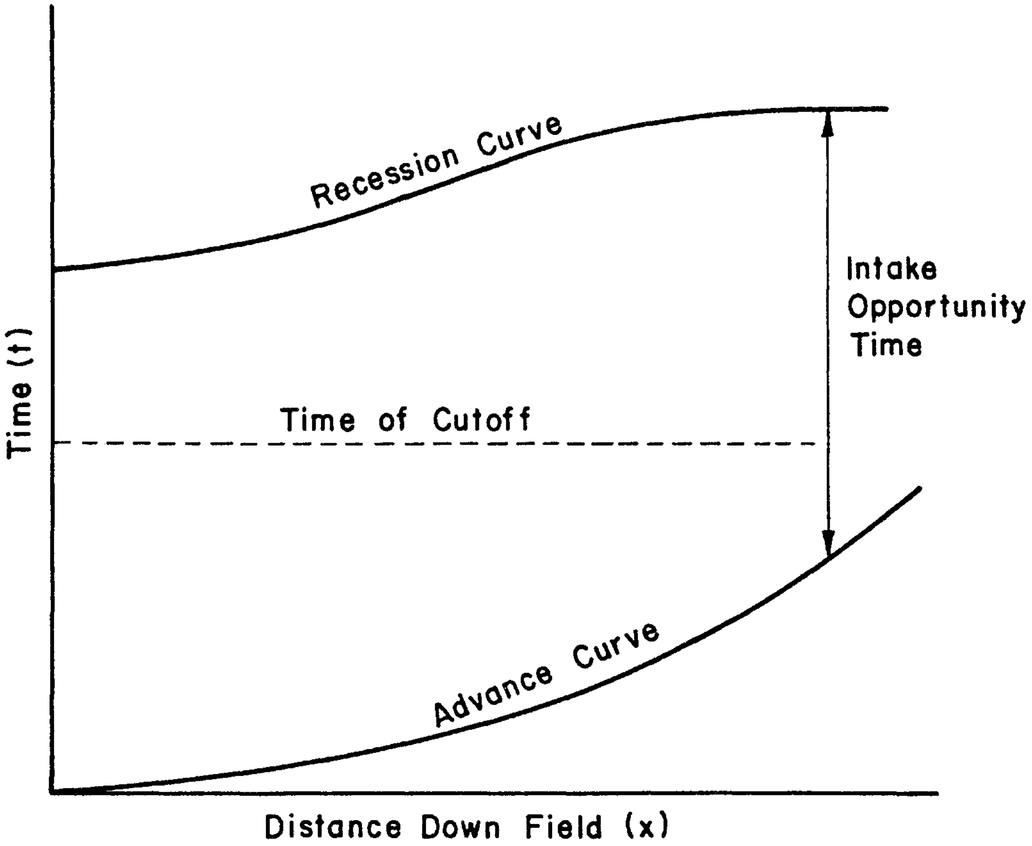


Figure 2. Typical advance and recession curves for border irrigation.

Table. 1. Soil moisture deficiency and appearance relationship chart (after Merriam and Keller, 1978). (This chart indicates approximate relationship of soil moisture deficiency between field capacity and wilting point. For more accurate information the soil must be checked by drying samples.)

Moisture	Soil Texutre Classification				Moisture
Deficiency (in./ft)	Coarse (loamy sand)	Sandy (sandy loam)	Medium (loam)	Fine (clay loam)	Deficiency (in./ft)
0.0	Leaves wet outline on hand when squeezed	Appears very dark, leaves wet outline on hand, makes a short ribbon	Appears very dark, leaves wet outline on hand, will ribbon out about one inch	Appears very dark, leaves slight moisture, on hand when squeezed, will ribbon out about two inches	0.0
0.2					0.2
0.4	Appears moist makes a weak ball	Quite dark color, makes a hard ball	Dark color, forms a plstic ball, slicks when rubbed		0.4
0.6	Appear slightly moist sticks together	Fairly dark color, makes a good ball		Dark color, will slick and ribbons easily	0.6
0.8	Dry, loose, flows thru fingers. (wilting point)		Quite dark, forms a hard ball	Quite dark, will make thick ribbon, may slick when rubbed	0.8
1.0		Slightly dark color, makes a weak ball	Fairly dark, forms a good ball		1.0
1.2	Lightly colored by moisture, will not ball	Slightly dark, forms weak ball		Fairly dark, makes a good ball	1.2
1.4		Very slight color due to moisture (wilting point)		Will ball, small clods will flatten out rather than crumble	1.4
1.6			Lightly colored, small clods crumble fairly easily		1.6
1.8			Slight color due to moisture, small clods are hard (wilting point)	Some darkness due to unavailable moisture, clods are hard, cracked (wilting point)	1.8
2.0					2.0

Field Method of Approximating Soil Moisture (Deficiency) for Irrigation; Transactions of the American Society of Agricultural Engineers, Vol. 3, No. 1, 1960; John L. Merriam, Professor, California Polytechnic State University, 1975, San Luis Obispo, California.

2. Determine the average infiltrated depth for each reach (distance between stations) by averaging the predicted infiltrated depths of successive stations.
3. Determine the predicted average infiltrated depth for the entire border by summing the reach averages (found in 2) and dividing by the number of reaches. Keep in mind that this value is an estimated or predicted value resulting from the use of the empirical infiltration function.

Inflow and Runoff

Inflow and runoff data provide a simple means of determining the actual average infiltrated depth. The inflow and runoff hydrographs are constructed on the same rectangular grid by plotting inflow and runoff rates vs. time. An estimate of the total volume of water applied, $W_a (L^3)$, is found by graphically integrating the area under the inflow hydrograph. An estimate of the total runoff volume, $W_u (L^3)$, is found by graphically integrating the area under the runoff hydrograph. An estimate of the total infiltrated volume, $W_i (L^3)$ is found by taking the difference as follows:

$$W_i = W_a - W_u \qquad (3)$$

The actual average infiltrated depth can then be determined by dividing W_i by the product of the border width and length.

Adequacy of Infiltration Relationship

Once both the predicted average infiltrated depth and the actual average infiltrated depth have been found they are compared. This is a check on the adequacy of the empirical infiltration function in predicting the average infiltrated depth. If the two values are not approximately equal (i.e., less than 5 to 10 percent difference), then the infiltration relationship should be adjusted accordingly until the predicted value is approximately equal to the actual value. The adjustment procedure is done either graphically or numerically and involves finding a new value for the multiplicative constant in Equation (2), while the value of the exponent remains the same (Merriam and Keller, 1978). On the log-log plot, this implies the slope of the curve remains constant and the curve is either shifted upwards or downwards. Both the graphical and numerical procedures are much more fully and easily explained in the example evaluation presented later.

Runoff Data Not Available.--When runoff data are not available, then the adequacy of the infiltration function must be checked using a different method (Merriam and Keller, 1978). In this case, the checkpoint is the actual average applied depth rather than the actual average infiltrated depth. The method requires the extrapolation of the advance and recession curves to their intersection. This provides an estimate of how far the water would have spread if the downstream boundary condition at end of the border was an imaginary extended border length, and is a means of accounting for all of the water applied. The predicted average applied depth is found by utilizing intake opportunity times in the infiltration relationship as previously discussed. Now, however, the opportunity times for the imaginary extended length must be included in the anaylsis. The actual average applied depth is found by dividing the total applied volume by the imaginary wetted area (i.e., the product of border width and total imaginary extended length). Comparison of the predicted average and actual average applied depths indicates if adjustment of the infiltration relationship is necessary. This procedure is obviously not as accurate as that used when runoff data are available due to the errors introduced in extrapolation of the advance and recession curves.

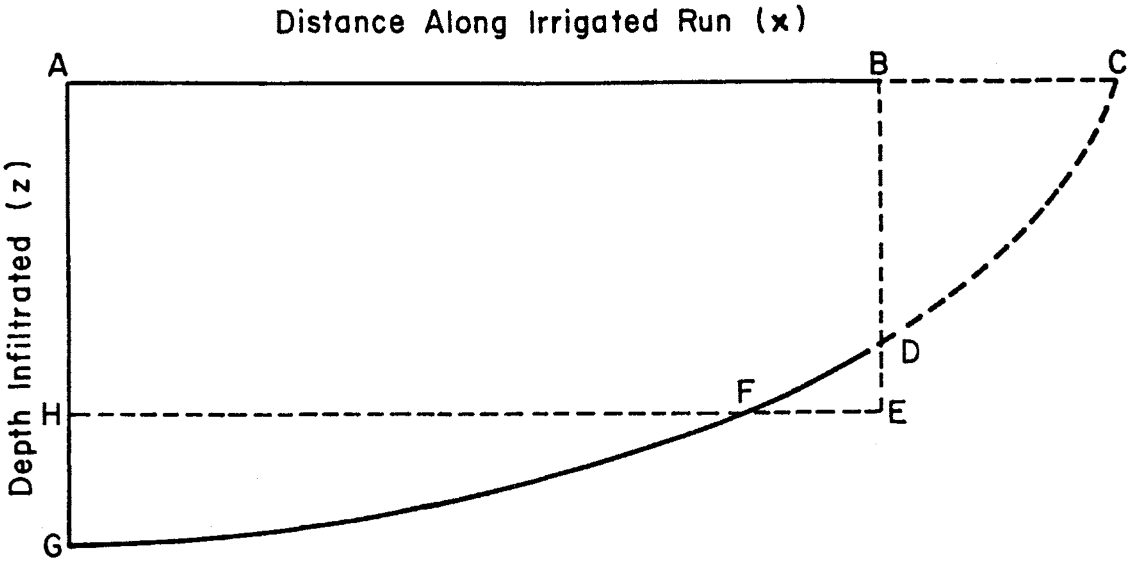
Subsurface Distribution

The subsurface distribution of applied water in border irrigation can be determined when the following information is known.

1. A representative infiltration function (as determined above).
2. Infiltration opportunity times along the irrigated run, i.e., advance and recession times at points along the run.

Upon construction of the subsurface profile, it is possible to characterize the performance of a particular irrigation. However, before irrigation performance parameters are defined it is necessary to define several related quantities upon which they depend.

Figure 3 represents an idealized profile of infiltrated water as a result of border irrigation. The distance AB is the border length, and the line DFG is the boundary of the infiltrated water. If the downstream boundary condition is one of free outfall, then runoff water from the field can be assumed to extend to the imaginary field length C, and to infiltrate according to the profile CD. The water requirement depth at the time of irrigation is assumed uniform along the border length and is represented by



AB	length of border (L)
ACDGA	total volume of applied water per unit field width, $W_a(L^3L^{-1})$
ABEHA	total volume of requirement per unit field width, $W_r(L^3L^{-1})$
ABDFHA	total volume of actual root zone storage per unit field width, $W_{rz}(L^3L^{-1})$
FGHF	total volume of deep percolation per unit field width, $W_r(L^3L^{-1})$
BCDB	total volume of runoff water per unit field width, $W_u(L^3L^{-1})$
DEFD	total volume of root zone deficit after irrigation per unit field width, $W_{df}(L^3L^{-1})$

Figure 3. Idealized subsurface profile of applied water in border irrigation.

line EFH. With these concepts in mind the following quantities with appropriate units are defined in Figure 3.

1. Total volume of applied water, W_a (area ACDGA). This is the total volume of water introduced per unit width of border.
2. Total volume of water required in the root zone to reach field capacity, W_r (area ABEHA). This is the volumetric soil water deficiency.
3. Total volume of water stored in the root zone, W_{rz} (area ABDFHA). This volume of water is dependent upon the field capacity of the soil and the available storage at the time of irrigation. The total volume of water available for plant use after the irrigation and drainage period equals the difference between the field capacity (FC) and the permanent wilting point (PWP) of the soil, if the root zone is completely filled during irrigation [i.e., the total available water expressed as a depth, TAW = (FC - PWP) x (bulk density of the soil) x (rooting depth)].
4. Total volume of deep percolation, W_p (area FGHF). The volume of water which infiltrates past the lower boundary of the root zone. W_p may equal zero in some cases.
5. Total volume of tailwater or runoff, W_u (area BCDB). The volume of water which runs off the end of the field if free outfall conditions exist.
6. Total volume of root zone deficit after irrigation, W_{df} (area DEFD). W_{df} equals zero if the root zone is completely filled.

The total volume of water applied and the total volume of runoff an be cross-checked with the hydrograph analyses discussed earlier, when such data are available. Volumes can be converted to average depths by dividing by the product of border width and border length.

Irrigation Performance Parameters

Four irrigation performance parameters are discussed and may be defined using either volumes or depths.

1. Water application efficiency, E_a, is the percent of the amount of water applied which is stored in the root zone for future use.

It is a measure of the effectiveness of the irrigation in storing water.

$$E_a = \frac{W_{rz}}{W_a} \cdot 100 = \frac{D_{au}}{D_a} \cdot 100 \qquad (4)$$

where W_{rz} and W_a are as defined previously, and D_{au} and D_a are the corresponding average depths (L) associated with these volumes, respectively.

2. Water requirement efficiency, E_r, indicates the percent of the amount of water required to refill the root zone, which is supplied by an irrigation. It is a measure of the effectiveness of the irrigation in meeting the crop requirement.

$$E_r = \frac{W_{rz}}{W_r} \cdot 100 = \frac{D_{au}}{D_u} \cdot 100 \qquad (5)$$

where W_{rz} and W_r are as defined previously, and D_{au} and D_u are the corresponding average depths (L) associated with these volumes, respectively.

3. Tailwater ratio, R_t, represents the fraction of the total amount applied which is lost as tailwater or runoff from the end of the border.

$$R_t = \frac{W_u}{W_a} \qquad (6)$$

where W_u and W_a are volumes (L^3) as previously defined.

4. Deep percolation ratio, R_p, represents the fraction of the total amount applied which is lost as deep percolation past the bottom of the root zone.

$$R_p = \frac{W_p}{W_a} \qquad (7)$$

where W_p is as previously defined.

It is pointed out that the sum of the water application efficiency (expressed as a fraction), the tailwater ratio, and the deep percolation ratio is unity.

Another performance parameter often used describes the uniformity of water application. It may be unnecessary, however, when a plot of the subsurface distribution of applied water (as discussed earlier) is available. This parameter is a measure of the uniformity of the spatial distribution. Several techniques for characterizing the spatial distribution of infiltrated water have been developed. One of the more common and more easily calculated parameters is UCH, the Hawaiian Sugar Planter's Association uniformity coefficient (Hart, 1961):

$$UCH = 1 - \sqrt{\frac{2}{\pi}}\ \frac{s}{\bar{x}} = 1\text{-}0.798\ \frac{s}{\bar{x}} \qquad (8)$$

where $\bar{x}$ = the mean infiltrated depth (determined from several observations),
s = the standard deviation of the observations.

EXAMPLE SYSTEM EVALUATION

The following discussion presents the results of an evaluation of a graded border irrigation system as the farmer was currently operating it. The original data are taken from Merriam and Keller (1978). The value of being able to describe system operation and performance through an evaluation, and then comparing the results to an appropriate design is illustrated. A design for the field was formulated using the SCS border irrigation design procedure (USDA, 1974). The results of this design are presented in a seperate analysis of the design procedure (Clyma, 1980). Changes in system operation and management for improved water application are more easily recognized when compared to the design.

Unfortunately, for this particular evaluation, runoff data and postirrigation soil water content data are not available. The preirrigation soil water status was evaluated using the feel method previously discussed. Recommended design parameters are repeated here for the reader's convenience.

Q_u = 4.31 ℓ/s-m (0.0464 cfs/ft)
T_a = 118 min
strip width = 7.9 m (26 ft)
design depth = 114 mm (4.5 in.)

The farmer was operating the system using the full available stream of 34 ℓps (1.2 cfs) on a border strip width of only 7 m (23 ft) and border length of 210 m (700 cfs). This gives a unit width stream of 4.83 ℓ/s-m (0.052 cfs/ft) (which is larger than the design value due to smaller border width). Due to harvest operations, the farmer scheduled a more frequent water application. The application time was 88 minutes and the soil water deficit at the time of irrigation was estimated to be 74 mm (2.9 in.).

Four cylinder infiltration tests were conducted during the evaluation in four locations along the length since the soil was found to be fairly uniform. These data, in the form of cumulative depth infiltrated versus time, are plotted in Figure 4. A wide range of initial intake rates is observed. However, after approximately 30 minutes, the data curves have nearly the same slope. The average cumulative intake vs. time was determined from the four sets of data and is also plotted in Figure 4 (as the curve labeled "average"). As can be seen, there is a significant dogleg in this curve (Merriam and Keller, 1978). Since all of the data plots exhibit nearly the same slope after 30 minutes, it was decided a straight line typical of this condition but also typical of the wide range of initial rates was most representative. The curve labeled "typical" is the result. It is felt that the "typical" curve provides adequate representation of the intake data, and is easier to describe functionally. The infiltration function defining the "typical" curve is:

$$z = 4.27\ t^{0.64} \quad , \qquad (9)$$

where z = depth infiltrated (mm)

t = intake opportunity time (min).

Equation (9) was also used to develop the initial design results presented earlier.

Advance and recession data were collected at 30-m stations along the irrigated run. These data along with infiltration opportunity times and the surface profile slope are presented in Figure 5. Since runoff data are not available, the advance and recession curves were extrapolated to their intersection in Figure 5. The imaginary extended length is seen to be about 260 m. Intake opportunity times for the imaginary extended length are included. An estimate of the actual average applied depth can now be determined. The inflow rate of 34 ℓps (1.2 cfs) was constant for the entire 88-min. duration. Therefore:

$$D_a = \frac{W_a}{WL} = \frac{QT}{WL} \qquad (10)$$

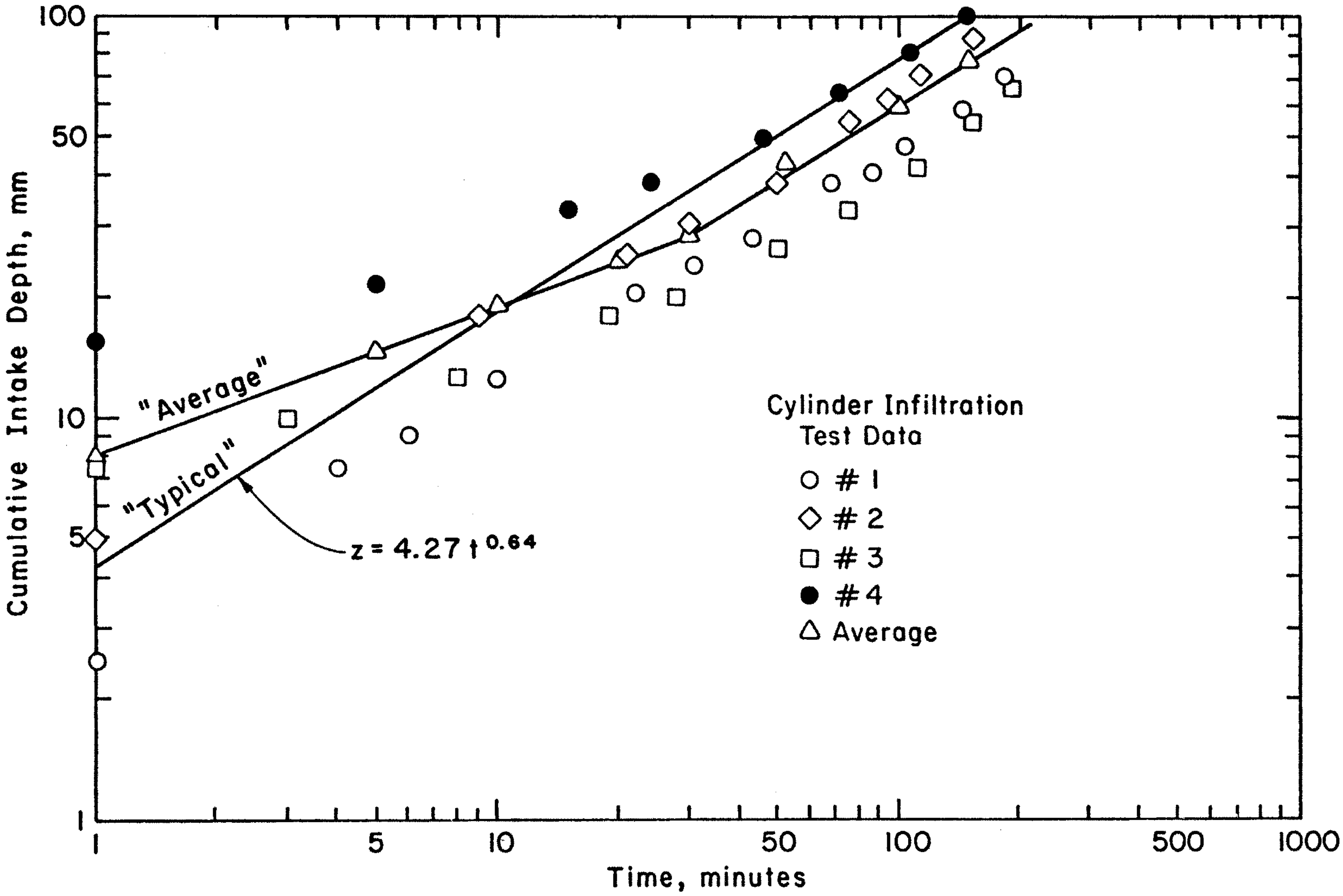
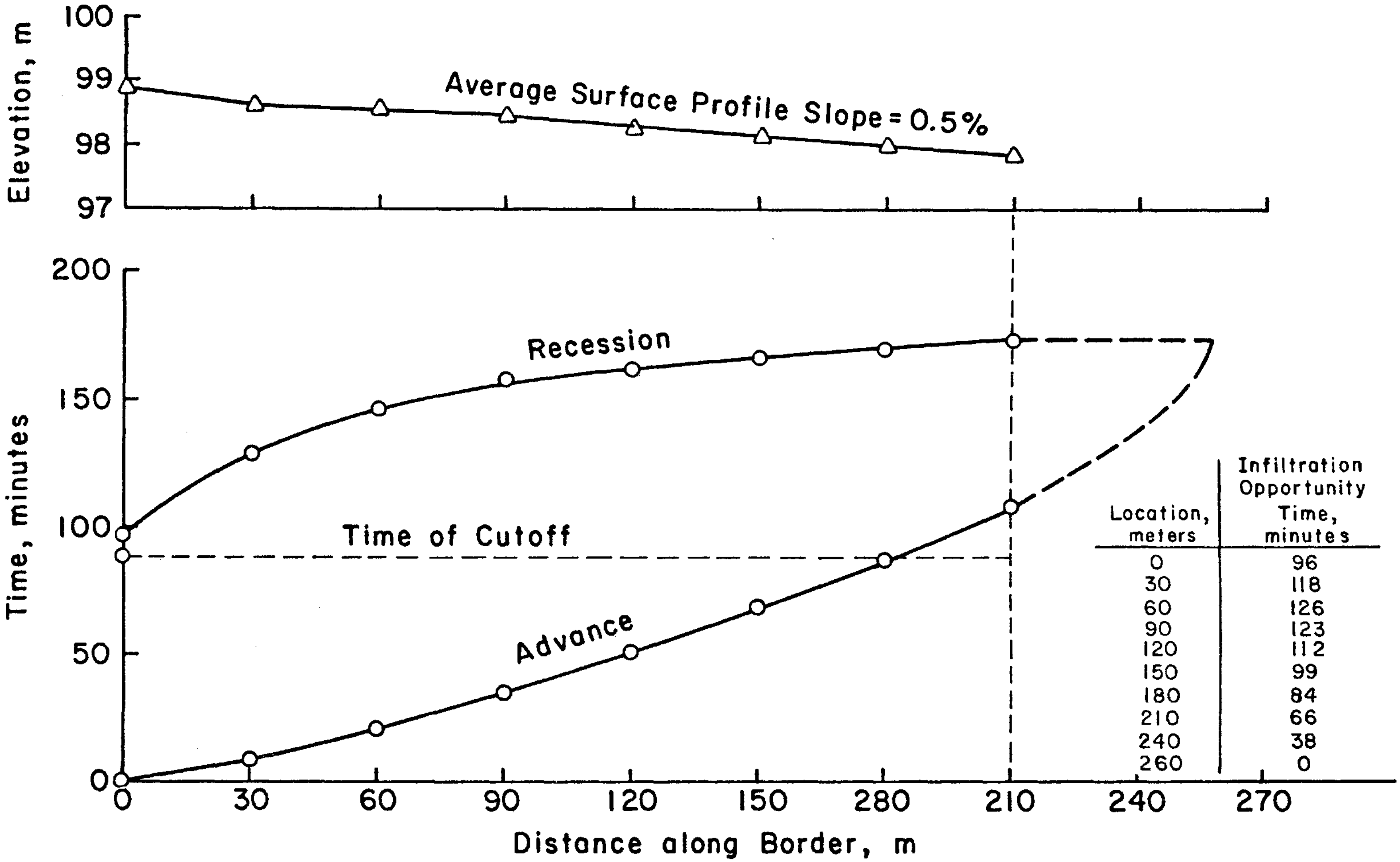


Figure 4. Cylinder intake data.



Location, meters	Infiltration Opportunity Time, minutes
0	96
30	118
60	126
90	123
120	112
150	99
180	84
210	66
240	38
260	0

Figure 5. Advance/recession, surface profile curves and infiltration opportunity times.

$$D_a = \frac{(34\ \ell ps)(88\ min)(60\ x/min)(\frac{1\ m^3}{1000\ \ell})}{(7\ m)\ (260\ m)}\ (\frac{1000\ mm}{1\ m})$$

$$D_a = 99\ mm$$

This value can be used as a checkpoint for testing the adequacy of the infiltration function previously determined in predicting the average applied depth. The procedure is illustrated in Table 2. Equation (9) and infiltration opportunity times from Figure 6 are used to find infiltrated depths at stations along the run (actual plus extended length). The average depth for each 30-m reach is found. The last reach was only 15 m, thus the average depth there was determined proportionately to its length. The average applied depth for the entire wetted length as predicted by Equation (9) is calculated as 76.9 mm. This does not correspond with the actual average depth applied of 99 mm, as found earlier.

Adjustment of the infiltration function is necessary. The procedure for doing this is illustrated graphically in Figure 6. The "typical" curve represented by Equation (9) is shifted upwards in Figure 6 keeping the slope of the curve constant. The "adjusted" curve should have a slope equal to the "typical" curve and should pass through the point, where the depth equals 99 mm and the time equals the time at which the "typical" curve has a depth of 76.9 mm infiltrated. This time (using Equation (9)) is approximately 92 minutes. The intercept at unit time for the adjusted curve is approximately 5.48 mm. A numerical procedure for determining the functional relationship of the "adjusted" curve involves finding a new value for k in Equation (2), such that with $a = 0.64$ and $t = 92$ min, z will equal 99 mm:

$$k = z \div t^a$$

$$k = 99 \div 92^{0.64}$$

$$k = 5.48$$

Thus, the "adjusted" infiltration curve is represented by:

$$z = 5.48\ t^{0.64} \qquad (11)$$

where z = cumulative infiltrated depth (mm)

t = time (min).

Table 2. Check on infiltrated depths and total applied depth predicted by "typical" infiltration function and "adjusted" infiltration function (after Merriam and Keller, 1978).

Station (m)	0	30	60	90	120	150	180	210	240	260
Opportunity Time (min)	96	118	126	123	112	99	84	66	38	0
Infiltration Depths (using Equation (9))										
Depth (mm)	79.3	90.5	94.3	92.9	87.5	80.8	72.8	62.4	43.8	0.0
Average Depth (mm)		84.9	92.4	93.6	90.2	84.2	76.8	67.6	53.1	0.5 (21.9)
Average Depth on 260 mm = 653.7/8.5 = 76.9 mm										
Infiltration Depths (using Equation (11))										
Depth (mm)	101.7	116.1	121.1	119.2	112.3	103.7	93.4	80.0	56.2	0.0
Average Depth (mm)	108.9	118.6	120.2	115.8	108.0	98.6	86.7	68.1	0.5(28.1)	
Average Depth on 260 mm = 838.8/8.5 = 98.7 mm										

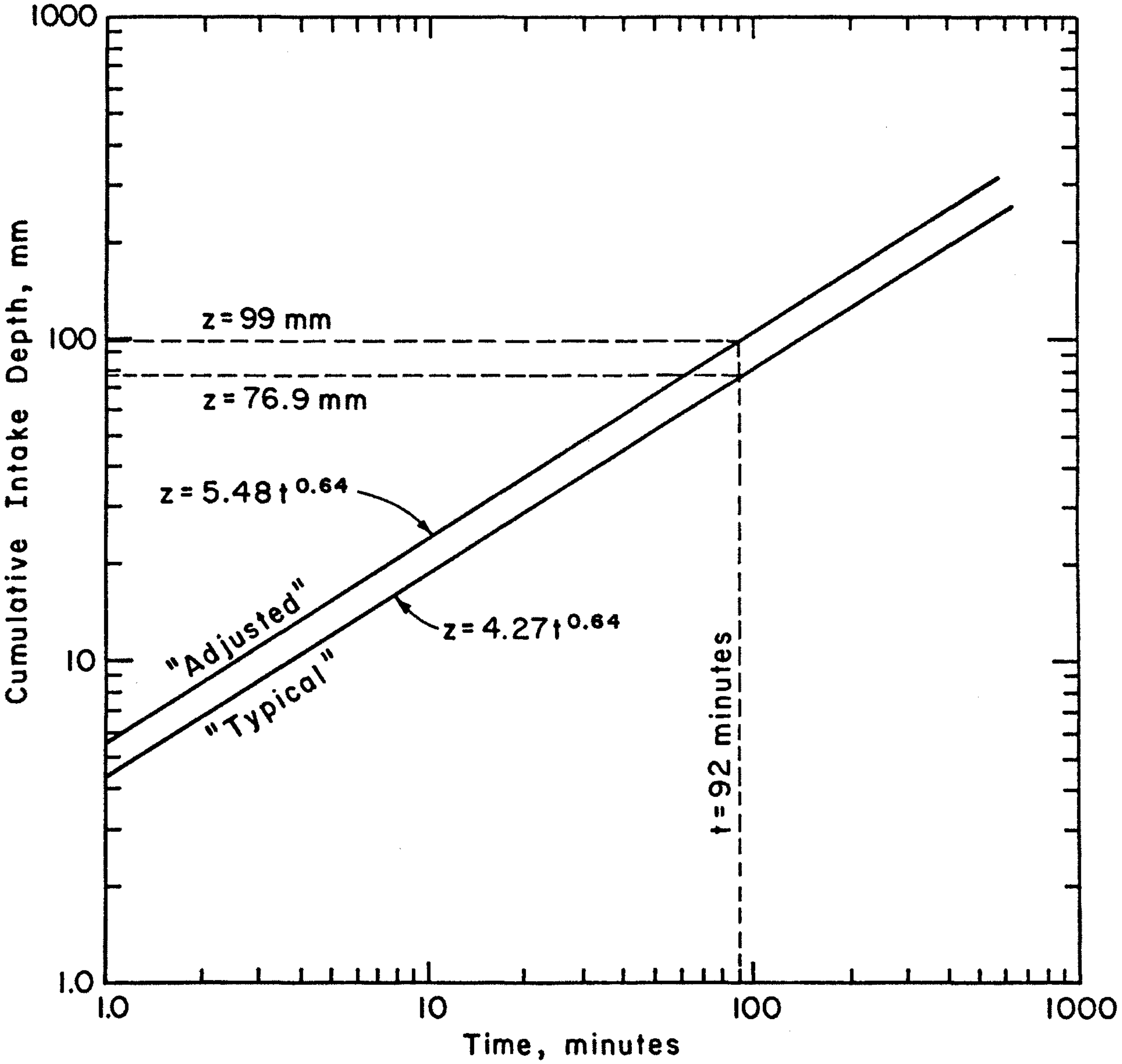


Figure 6. Illustration of adjustment of infiltration function.

A check on the adequacy of the "adjusted" curve is provided in the lower section of Table 2 using the same procedure as before. It is seen that Equation (11) adequately predicts the total average applied depth.

Results

The subsurface distribution of applied water as predicted by Equation (11) is plotted in Figure 7.

Each of the volumes associated with Figure 7 (as previously discussed) can be found by graphical integration of related areas of Figure 7. On a unit width basis (for border width of 7 m), they are as follows:

Volume applied, $W_a = 25.6\ m^3/m$
Volume runoff, $W_u = 2.7\ m^3/m$
Volume infiltrated, $22.9\ m^3/m$
Volume required, $W_r = 15.7\ m^3/m$
Volume stored, $W_{rz} = 15.7\ m^3/m$
Volume deep percolated, $W_p = 7.2\ m^3/m$
Volume deficit, $W_{df} = 0.0\ m^3/m$

Each of these volumes can be converted to an average depth by dividing by the border length of 240 m. Utilizing the above volumes, the performance parameters for this irrigation are determined using Equations (4) through (7).

Water application efficiency,
$$E_a = \frac{W_{rz}}{W_a} \cdot 100 = \frac{15.7}{25.6} \cdot 100 = 61.4\% \qquad (4)$$

Water requirement efficiency,
$$E_r = \frac{W_{rz}}{W_r} \cdot 100 = \frac{15.7}{15.7} \cdot 100 = 100\% \qquad (5)$$

Tailwater ratio,
$$R_t = \frac{W_u}{W_a} = \frac{2.7}{25.6} = 0.11 \qquad (6)$$

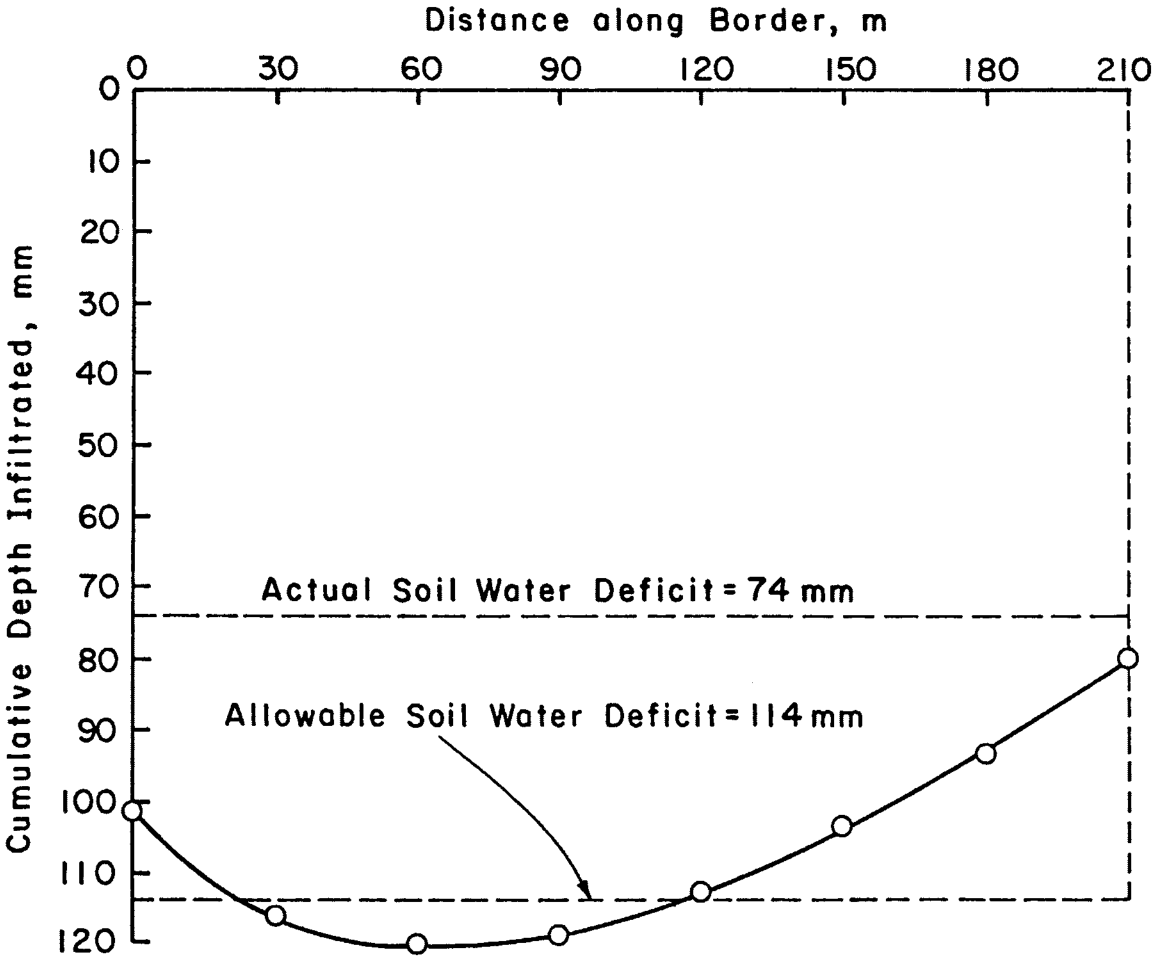


Figure 7. Subsurface distribution of applied water.

Deep percolation ratio, $$R_p = \frac{W_p}{W_a} = \frac{7.2}{25.6} = 0.28 \qquad (7)$$

The uniformity of water application is illustrated in Figure 8.

Table 3 presents a comparison of the suggested design with the system as it was operated for this irrigation. The expected runoff and deep percolation for the design are not available.

Table 3. Comparison of design and current operation.

Parameter	Design	Current Operation
Unit width stream, ℓ/s-m	4.31 (0.0464 cfs/ft)	4.83
Time of application, min	118.0	88.0
Border strip width, m	7.9 (26.0 ft)	7.0
Design depth or requirement, mm	114.0 (4.5 in.)	74.0
Average depth applied, mm	142.5 (5.61 in.)	119.9
Water application efficiency, %	80.0	61.4
Water requirement efficiency, %	--	100
Tailwater ratio, dec.	--	0.11
Deep percolation ratio, dec.	--	0.28

CONCLUSIONS

As a result of the evaluation, and comparison of the results to the suggested design, the following conclusions are made:

1. Obviously, the farmer irrigated too soon, i.e., at a smaller requirement than suggested. Although he was aware of this and was trying to apply a lighter amount, he still overirrigated the entire field.

2. Using the entire available flow on a smaller strip width, the farmer was using a larger unit width stream. The smaller application time used must be an attempt at reducing the amount applied. At 80% design efficiency and a requirement of 74 mm (2.9 in.), design equations yield an application time of approximately 68 minutes for this larger unit width stream. For the given field length this may be too short, since the distance of advance for this time if about 150 m (Figure 5). Poor distribution and underirrigation of the lower end would probably result.

3. The anticipated advance curve for the design should be only slightly steeper than in Figure 5 due to the offsetting effects of greater application time, but higher initial intake rate of the drier soil. The anticipated recession curve should be slightly steeper at the lower end and shifted upwards by an amount equal to the increase of application time, compared to Figure 5. Thus, the expected result if the system were operated according to design would be a more uniform application of water, with the upper end being slightly overirrigated and the lower end being slightly underirrigated.

4. For the border strip width currently in use, the farmer could use the larger unit width stream and decrease the application time to around 106 minutes and expect a value of E_a near 80%. The resulting irrigation would most likely be less uniform, however.

5. The nonuniformity in slope for the first 90 m probably causes the recession curve to be steeper in that section. The first 30 m, being much steeper, would cause a short lag time; and then the next, flatter 60-m section would cause the recession to slow down. The advance is also slowed down in the 30-m station to 90-m station section (refer to Figure 5). If this section were graded to the slope of the remainder of the field, the advance and recession curves should be more "parallel" and the amount of overirrigation in that section reduced.

6. The large amount of deep percolation is a result of irrigating too soon. The amount of runoff is about right, however, indicating the farmer had about the correct inflow time. An efficient irrigation would most likely be impossible for the 210 m border, the given soil water deficit and the available stream. Either a very non-uniform irrigation would result, with the requirement at the upper end just being met; or there would be a large amount of runoff on what have to be very narrow borders (so that the unit width stream would be large enough for the desired advance time).

RECOMMENDATIONS

1. The farmer should attempt to adhere to an irrigation schedule in which the design depth of 114 mm (4.5 in.) is applied at each irrigation. Obviously, however, seasonal changes in crop requirement and infiltration rate would have to be taken into account.

2. Land leveling to obtain a more uniform grade in the direction of irrigation would increase the uniformity of the water application. In

particular, the overirrigation occurring at the upper end of the border would be reduced.

3. The combined effects of the first two recommendations would yield high values for E_a and E_r. Also, it is pointed out, that runoff losses from the border could be effectively reduced through the use of a tailwater reuse system.

4. The farmer should not deviate from an irrigation schedule in which he applies 114 mm (4.5 in.) at each irrigation. The implication of operating at lower values of design depth for the given available flow rate and border dimensions is that the efficiency and uniformity of water application would be reduced. Otherwise, increased flexibility in the timing and rate of water delivery is necessary to obtain a specific unit width stream for a particular design depth, design efficiency and application time.

5. Using the 7-m (23-ft) width borders rather than the design recommended 7.9-m (26-ft) width results in a larger unit width stream when the full available flow is utilized. This reduces the application efficiency. Assuming the other design parameters had been used with this unit width stream, a reduction in efficiency from the design efficiency is expected. The farmer could use a slightly smaller application time than the design and still achieve good results since the deviation in border widths was small. The best alternatives are to reduce the supply rate to the field or increase the width to 7.9 meters.

EQUIPMENT LIST AND SUGGESTED DATA FORMS

Equipment

The equipment needed for a detailed evaluation of a border irrigation system is:

1. Engineer's level and rod for reading ground surface elevations.
2. A measuring tape for locating stations and measuring border dimensions.
3. Laths or stakes, hatchet and crayon for marking stations.
4. Instrument for measuring time (wristwatch with a second hand).
5. Equipment for collecting soil samples to determine water content.
    a. Soil auger or probe to take soil samples.
    b. Soil cans with tight-fitting lids.
6. Equipment for determining bulk density.
7. Cylinder infiltrometers (up to 6 sets).

8. Device for measuring the water level in cylinder such as a hook or staff gauge.
9. Equipment for installing cylinders.
   a. Metal plate or a heavy timber.
   b. Sledge hammer.
10. 3-mil plastic sheeting or other waterproof membrane.
11. Buckets for hauling water.
12. Shovels.
13. Devices for measuring flow such as Parshall or cutthroat flumes, calibrated siphons, weirs or flow meters.
14. Pencils, clipboards and data forms.

Data Forms

Data forms for the following data sets are provided:

Soil Water Content Data
Bulk Density Data
Cylinder Infiltrometer Data
Water Advance/Recession Data
Flow Rate Data
Farm and Field Data

SOIL WATER CONTENT DATA

Identification:________________ Observer: ________________ Date: ________________

Soil Type:________________________ Crop:____________________ Before / After Irrigation

Remarks:

Station	Depth cm	Can No.	Wt. Can Tare g	Wt.Can & Soil Wet g	Wt.Can & Soil Dry g	Wt. Soil Dry g	Wt. Water g	Water Content % by Weight	Bulk Density γ_b	Water Content % by Volume	Water depth d mm

BULK DENSITY DATA

Identification:________________ Observer:________________ Date:________________

Crop:____________________________

Remarks:

Station	Soil Depth cm	Can No.	Wt. Can Tare g	Wt. Can & Soil Moist. g	Wt. Can & Soil Dry g	Wt. Soil Dry g	1st Read. Inst.	2nd Read. Inst.	Soil Vol. cm^3	Bulk Density γ_b

CYLINDER INFIL[redacted]METER

Identification: ____________________ Observer: ____________________ Date: ____________________

Crop: ____

Remarks:

Station: __________

Infiltrometer No.					
Time*			Infiltration		
Clock	Diff.	Cum	Depth	Diff.	Cum

Station: __________

Infiltrometer No.					
Time		Infiltration			
Clock	Diff.	Cum	Depth	Diff.	Cum

Station: __________

Infiltrometer No.					
Time			Infiltration		
Clock	Diff.	Cum	Depth	Diff.	Cum

*All clock times are 24-hour basis.

WATER ADVANCE/RECESSION DATA

Identification: ____________ Date: ____________ Crop: ____________ Irrigation Start: ____________

Soil: ____________________ Observer: ____________________ Finish: ____________

Comments: Total Time: ____________

Border: ____________________ Border: ____________________ Border: ____________

Stream Size: ____________________ Stream Size: ____________________ Stream Size: ____________

Station (m)	Advance		Recession	
	Time*			
	clock	cum	clock	cum

Station(m)	Advance		Recession	
	Time			
	clock	cum	clock	cum

Station (m)	Advance		Recession	
	Time			
	clock	cum	clock	cum

*All clock times are on 24-hour basis.

FLOW RATE DATA

IDENTIFICATION__________ OBSERVER__________ DATE__________

CROP__________ LENGTH__________ INFLOW__________ or RUNOFF__________

FURROW/BORDER NO.__________ FURROW SPACING/BORDER WIDTH__________

MEASURING DEVICE__________ START TIME__________ STOP TIME__________

COMMENTS:

Clock* Time (1)	Elapsed Time (min) (2)	ΔT (min) (3)	Reading ( ) (4)	Flow Rate ( ) (5)	Average Flow Rate ( ) (6)	Volume ( ) (6) x (3) (7)	Σ Volume ( ) Σ (7) (8)
		▨			▨	▨	▨

*All clock times are on 24-hour basis.

FARM AND FIELD DATA

IDENTIFICATION__________ OBSERVER__________ DATE__________

FARMER__________ ADDRESS__________

(Sketch the farm and on-farm water delivery system noting pertinent roads, boundaries, field boundaries, locations of pumps, open drains, etc.)

APPENDIX A

RECONNAISSANCE QUESTIONNAIRE

1. Farmer operation and management

How does the farmer decide when to irrigate?
What is his irrigation frequency? How does it change during the season?
How does he decide how to irrigate?
How does he decide how much water to apply?
Does the farmer know the total flow rate available to him?
What are the farmer's operating hours?
Does he irrigate at night?
How does he decide how long to irrigate a field?
How long does he irrigate a field?
Does the farmer have any problems with the system?
What are his cultivation and tillage practices?
Does he irrigate more than one border strip at once?

2. Water supply

What are the sources of available water?
Is the delivery station (point of diversion to farm) a problem, i.e., high losses, etc.?
Is the on-farm distribution system a problem (i.e., too many in-field channels, high losses, etc.)?
What is the flow rate of each source of water?
When is each source available and for how long?
Is the frequency of delivery and available head a problem?
What is the water quality?
How is the water delivered to each field?

3. Crop characteristics

What are the crops being grown?
What are the respective planting dates?
What cropping patterns, if any, have been followed?
Does the farmer have any major problems in crop production?
What are the major inputs? Potential yield?
What is his expected yield? Average yield in area?
Any obvious physical symptoms of problems?

4. Physical characteristics

Does the farmer know the field dimensions?
Does he know the slope and cross-slope (if any)?
Has the field been leveled to a uniform slope?
If yes, when? If no, why not?
What provisions, if any, are made for surface runoff?
Does runoff leave the farm or is it used again somewhere on the farm?
What is the border spacing and how did the farmer decide on that spacing?
What is the method of diverting water into each border?

5. Soil survey

Does the farmer know the soils on his farm?
Does he know of any trouble spots (i.e., very light or heavy soils or salinity problems)?

6. Water table

Does the farmer know the groundwater level?
Does he feel it is a problem?
Is surface/subsurface drainage provided? If so, where?

APPENDIX B

SOIL MOISTURE MEASUREMENT CONSIDERATIONS

Basic guidelines to aid the evaluator in establishing procedures for sampling (where to samples, how many samples, etc.) are discussed. Plans will be needed to determine when, where and how much to sample for soil parameters such as field capacity, wilting point, bulk density, water content and infiltration as discussed in the text. It ic recalled that a minimum of three replications of samples is called for in all cases to obtain a simple average. The following discussion is intended to provide a means of determining when more samples should be collected (and how many more) to increase the precision of the results and also to illustrate simple tests which can be used to interpret the results. Garcia (Appendix A, 1978) has presented a basic treatment of the statistical analyses of measurements. These include measures of central tendency, such as mean; measures of variability, such as the standard deviation; and simple statistical inference based on these population parameters such that for a given level of probability an interval of values which encloses the true value of a parameter is estimated.

Several studies have focused on determining the variability of soil sampling for water content (Black et al., 1965; Reuss et al., 1975; Staple and Lehane, 1962; Hewlett and Douglass, 1961). Each of these studies presents results of site studies including means and standard deviations of sampling and extrapolation of these results to methods of estimating numbers of samples required for given levels of precision. The problems with such approaches is that it is necessary to know beforehand the variability of water contents to be expected in a field such that the number of samples or replicated samples to collect to obtain a confidence interval for the mean at a given precision (level of probability) can be determined. It is difficult to estimate the combined effects of sampling errors, possible sampling bias, and the variation of soil properties in a field (let alone the individual effects). At any rate, generalizations are made such as: requiring 30 or more samples per treatment to provide fair assurance that the least significant difference between the means of two treatments be less than 0.5 inch of water (Staple and Lehane, 1961). It should be obvious that given a certain level of variability in a given sampling plan, the precision with which a true value is estimated will increase as the number of samples taken increases. However, this is even further magnified where one is trying to estimate the difference between two true values. For instance, Reuss et al. (1975) presented results which showed that 95% confidence intervals for before and after irrigation water contents in a profile could be estimated as 9.50 ± 0.37 inches and 12.00 ± 0.61 inches, respectively. These were quite acceptable for the number of cores taken: five. However, for the difference of 2.5 inches the precision is ±0.71 inches or approximately ±28% of the value which was being estimated. This was unacceptable, and to increase the precision with which the difference is estimated the number of samples to collect both before and after irrigation is more than 60. This assumes the variability or error variance of sampling is a constant.

Two useful tools for analyzing sets of samples for significant differences are one-way and two-way analysis of variance tests. For instance, if a soil survey shows nonuniform soils in the field being studied, but significant differences in infiltration rates through the field are not suspected, a one-way analysis of variance of several sets of replicated tests would statistically determine if significant differences between locations are present. Similarly, a two-way analysis of variance can be used to check on differences between replications at a sampling location and on differences between sampling locations.

In all instances, it should be remembered that replications (minimum of three) are required to establish an average. If soils are uniform, three cores in the entire field may be all that are necessary, however, more may be desired to increase precision. When soils are nonuniform, replications (minimum of three) in each major soil type are necessary to establish the mean for that soil type. More samples will increase the precision. A one-way analysis of variance will determine if significant differences between the estimated means exist. Tradeoffs in precision and costs (time and effort of the evaluator) occur. In general, the best design to use is the one that provides the maximum precision at a given cost (effort) or that provides a specified precision (error) at the least cost (Black et al., Chapter 5, 1965).

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EWUP
How to do it
Field Procedure

GUIDELINES FOR IRRIGATION EVALUATIONS

by Wayne Clyma and Alan Early*

Good water management requires that irrigation schedules be planned in advance in order to best utilize water at the time and in the amounts available. The specialist can perform valuable service for his cooperators by encouraging the adoption of those practices which have resulted in sucess for the best irrigators. Irrigation schedules should be developed to: (1) provide for the best use of the water available; (2) supply each crop during its critical demand period; (3) apply in a manner which maintains root-zone moisture in the right amount but which avoids waste; and (4) allows for the flexibility needed to meet differences in seasonal climatic variations. The following suggestions can be used to assist in meeting these needs.

A. PLAN AHEAD

Contact farmers at least a day in advance to confirm his schedule and plans. Recontact and reconfirm early the day of the scheduled evaluation.

B. SOIL MOISTURE SAMPLING . . . be certain of:

1. exact depths used with king-tube
2. covering the cutting end of the tube with one hand as soon as possible after removing the tube from the hole.
3. closing plastic bag as soon as sample is inside
4. weighing the sample on the evening of the same day the sample is taken
5. estimating moisture content of the sample by the "feel" method immediately after weighing it

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*This How-To-Do-It was taken from The Problem Identification Handbook (April 1,1980). Developed by the CSU-Pakistan Water Management Project sponsored by U.S. Agency for International Development, Contract No. AID/TAC-1100.

6. exposing the sample to the sun only after weighing and estimating soil moisture
7. reweighing the sample immediately after exposure to the sun
8. collecting samples together to composite sample to have mechanical and soil moisture characteristic analyses completed at a later date
9. taking care of weighing scale
10. cleaning king-tube periodically.

C. WATER MEASUREMENT

Be certain that:

1. flume is leveled and remains so at all readings
2. time of each reading is recorded
3. notes are made of all changes in area irrigated and the time the changes were made
4. breakages of watercourse and bunds are noted with time of occurrence and duration of leakage and actions taken by the farmer to correct the problem.

D. FIELD BOOK AND NOTES

Be certain to include the following in the booklet completed of every farmers evaluation:

1. Date
2. Observer(s)
3. Time - start and stop
4. Location (sq. no. and acre no.)
5. Sketch map
6. H_a and H_b and discharge. (Calculate discharge at mogha and at nakka before leaving field in order to know if values are reasonable.)
7. Crop and height
8. Mogha number
9. Distance from mogha
10. Farmer's name
11. Date of last irrigation
12. Acre of field or its dimensions
13. CTF dimensions

E. INQUIRY

Question person irrigating with regard to:

1. How did he decide to irrigate the crop today?

   For instance:

   a. Appearance of the crop?

   b. Appearance of the soil?

   c. Time of last irrigation?

   d. Digging in the soil?

   e. Weather and season?

   f. Etc.? (note)

2. How did he choose this field and crop today when he has many fields to irrigate and a limited supply of water? Why?
3. What are his watercourse losses?
4. What are his field losses?
5. How deep does the water go? Roots?
6. How much water is he putting on the field?
7. How did he decide when to shut off water to the field?

IRRIGATION EVALUATION SUMMARY SHEET

Collected: ____________________

Copied: ____________________

Checked: ____________________

Mogha # ____________________

T/W # ____________________

Chak 1=%C
Village: ____________________ Ea

Distributary: ____________________

Canal: ____________________

District: ____________________

No.	Date	Farmer S/O	C/B	Field Location Ac/Sq	H/T	Crop & Height	Field Size	Area (AC)	Time of Irrigation			Doli	ChD (in)	Average Q Sakka (cfs)	Water Applied (in)	Average Q megha (cfs)	Distance Chg CTF$_2$ (ft^2)	Cd	CA %	$\frac{1}{2}$	
									Start	End	Hrs.										

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IRRIGATION EVALUATION PROCEDURE FOR FLOODED RICE CROPS

by Alan Early[*]

INTRODUCTION

Pakistan has abundant natural resources in the form of water, soil, people and favorable climate for food production, yet the agricultural yields are far below their potential when compared with world yield statistics. There are various causes and certainly poor water management practices are a major factor in this situation. The common concern in considering low yields in Pakistan is that a shortage of water exists while field experience shows that under-irrigation sometimes occurs and over-irrigation frequently occurs. The objective of an irrigation evaluation is to determine the water use efficiency of the irrigation application. The concept of irrigation efficiency is not the ultimate measure of irrigation effectiveness (the crop yield is the ultimate measure) but it is a useful measure of how the water is being used and can be helpful in identifying specific problem areas where water losses may be reduced.

Rice is one of Pakistan's major cash crops. Farmers generally do not know how much water should be given to their rice fields. They just irrigate so that the fields are ponded with the full supply of water. In this way much water is wasted due to over-irrigation. Accurate measurements are important to determine how much water is used in the rice fields, and how much could be saved and utilized for other crops.

This methodology paper is designed to delineate the unique considerations for lowland rice water requirements, to indicate the

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[*] This How-To-Do-It was taken from The Problem Identification Handbook (April 1, 1980). Developed by the CSU-Pakistan Water Management Project sponsored by U.S. Agency for International Development, Contract No. AID/TAC-1100.

procedure for irrigated lowland rice water use efficiency evaluations, and to specify the equipment required to complete the evaluation. A blank data form is attached and the methodology for computation is presented.

METHODOLOGY

Flooded (lowland) rice irrigation evaluations are unlike other (upland) crop water use determinations because the soil moisture reservoir is vastly different. In lowland rice land preparation the soil is puddled to destroy the soil structure and to decrease the moisture infiltration and transmission rates within the soil. The soil itself remains close to saturated conditions and under only rare circumstances should the moisture content fall as low as the field capacity where serious stress is imposed on the plant. Thus the only reservoir considered for the lowland rice evaluation is the water stored on the soil surface.

Since moisture movement within the soil laterally as seepage and vertically as percolation has been minimized by puddling, those further uncontrolled losses of seepage and percolation (S&P) are considered to be a soil requirement for water and a necessary part of the entire irrigation requirement for lowland rice. The general efficiency concept is the quotient of output (in this case useful water consumption as evapotranspiration, percolation and seepage) and input (rainfall and irrigation) as

$$E = \frac{\text{output}}{\text{input}} \times 100$$

For lowland flooded rice this irrigation application efficiency is generally known as the water use efficiency (WUE) and is defined as:

$$WUS = \frac{ET + S\&P}{RN + IR} \times 100$$

where

ET is the evapotranspiration of the crop, depth/unit time,

S&P is the seepage and percolation of the soil, depth/unit time,

RN is the rainfall depth/unit time, and

IR is the irrigation depth/unit time.

Since flooded rice is often continuously irrigated over the entire season, the time base for an irrigation evaluation is not the usual short term irrigation as for other crops. The water use efficiency is generally expressed on the minimum time period of one week to adequately represent the field conditions. More often it is expressed for the two general stages of rice growth, vegetative stage before panicle initiation and the reproductive stage of growth. It is generally not applied to the drying-off stage when irrigation is stopped and drainage of fields is completed as maturation occurs.

In the case of the upland crop evaluation the unit on which measurement and results were expressed was the bunded unit. When the continuous flow irrigation method of lowland rice evaluations and frequent paddy to paddy flow occurrence with attendant difficulty in flow measurement, the basis of the irrigation evaluations is generally a larger block of land from the irrigation inlet to the drainage outlet. It can include any suitably bounded unit from 1 acre to 25 acres, depending on the flow pattern. Suitable boundaries are cultivated or uncultivated land to which flow does not occur, highway or railroad right-of-ways or irrigation conveyance structures. If drainage occurs to or through any of these boundaries, that flow must be measured and accounted for in the overall moisture balance.

The overall basis on which lowland flooded rice irrigation evaluations are made is the water balance or otherwise known as the continuity relationship. Stated simply, the inflow minus outflow must equal the change in storage for complete accounting.

Water supplied to lowland rice fields as irrigation (IR) and rainfall (RF) can be accounted for by evapotranspiration (ET) into the atmosphere, by surface drainage (DR) from the fields, and by seepage and percolation (S&P) into the soil plus change in water stored on the soil surface. ET cannot easily be measured in the field, but relatively accurate methods have been developed for estimating potential ET, from open pan evaporation. Evaporation, water depth change, surface drainage, rainfall and irrigation can be readily measured. Surface drainage can be measured by use of cutthroat flumes although usually with difficulty.

Water balance accounting allows the estimation of S&P as a residual weighted average over a larger area. Point measurements of S&P are useful in finding the effects of local soil or topographical conditions, but they are difficult to integrate into a mean value representative of large areas. Collecting data for the complete water balance, is however, very arduous and expensive, since one must account for all water entering and leaving a site. The wide and unpredictable fluctuations in flow of the many irrigation sources and drains serving typical lowland areas make these measurements difficult and inaccurate. Furthermore, S&P values are sometimes less than 5 percent of the total water accounted for, so that inaccuracies in the irrigation or drainage measurement could easily result in individual S&P values being too high or too low by an order of magnitude.

PROCEDURE

There are six components which must be considered in estimating the complete water balance for flooded rice crops:

(i) Irrigation (IR)
(ii) Rain (RN)
(iii) Potential evapotranspiration (PET)
(iv) Drainage (DR)
(v) Change in surface storage (AS)
(vi) Seepage and Percolation (S&P)

These are considered sequentially as follows:

(i) Irrigation

This can be measured by various methods. The easiest method is by the installation of cutthroat flumes (CTF) at the field entrance of water, to measure the commonly referred to Q nacca in previous irrigation procedures.

(ii) Rain

A nonrecording rain-gauge can be used at the field site or data from a meterological center of less than 1 mile distance can be used only in case of emergency lack of a rain gauge.

(iii) Potential Evapotranspiration

PET cannot easily be measured in the field, but relatively accurate methods have been developed for estimating PET from a U.S. Weather Bureau Class A evaporation pan. This can be done by installing an evaporation pan in the field with the difference in daily readings recorded as ET, and a good estimate of PET, of a flooded rice crop, irregardless of the stage of crop growth.

(iv) Drainage

Drainage can be measured by installing flumes at the outlets of the rice fields, from which direct readings are taken periodically. Drainage water outflow is far more variable than the irrigation water in flow and becomes much more difficult to measure. If drainage is to be measured, hourly readings of flow should be recorded, or flumes with water level recorders should be used to provide a continuous record.

(v) Change in Surface Storage

Each paddy included in the block of land should be equipped with a staff gauge for direct reading of the daily water surface elevation difference or with a suitably stabilized reference stake from which water surface elevation differences can be read using a standard hook gauge. From the daily difference and the area of the paddy, the total volume and hence mean depth change of storage for the entire area can be calculated as AS.

(vi) Seepage and Percolation[*]

Methods of measuring seepage and percolation include laboratory permeability analysis and field pumping analysis to determine hydraulic conductivity, lysimeters and field water surface level recession. This latter method requires the use of a water level recorder on a stilling well on the paddy under observation. The stilling well is generally an empty oil drum with both ends open, buried with an open end approximately 1 foot into the soil. The drum is independently supplied with water from the paddy and the surface recession is recorded continuously.

This total recession includes ET, hence the pan evaporation rate must be subtracted to provide this estimate of seepage and percolation.

The major problems with the lysimeter and water recession methods are due to the discontinuities caused by the tank walls, the disturbed and unrepresentative conditions of the soil after filling the tank or permeameter and the tendency to measure only the percolation, vertical water movement to deeper depths. Seepage, the lateral movement of water in the soil is often more important than percolation, but depends on many environmental factors which are site specific.

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[*] If S&P can be adequately measured by water surface recession, then drainage measurement is not necessary and can be estimated by the residual.

The most common field method of estimating seepage and percolation in irrigation evaluations is by the use of the water balance. S&P are then estimated as the residual after all other factors are accounted.

EQUIPMENT

The equipment needs for flooded rice irrigation evaluations are as follows:

(i) irrigation - as many cutthroat flumes equipped for continuous flow recording for inflow measurements as there are inflow sites for the block of land under evaluation.

(ii) rainfall - one standard nonrecording rain gauge

(iii) evaporation - one standard U.S. Weather Bureau Class A pan and hook gauge

(iv) drainage - as many cutthroat flumes equipped for continuous flow recording for outflow measurement as there are outflow sites for the block of land under evaluation

(v) change in surface storage - as many staff gauges for water surface elevation or hook gauge bases as there are paddies in the area being studied

(vi) seepage and percolation - lysimeter, water surface recession or residual as discussed earlier.

DATA RECORD

The attached data sheet provides the format for the detailed accounting of water in the moisture budget and as a weekly and fortnightly summary. All measurements are in the units of inches water depth. The water use efficiency results are expressed as a dimensionless percentage.

Location ____________________

Start Date ____________________

Finish Date ____________________

SUMMARY SHEET FOR FLOODED RICE IRRIGATION EVALUATION[1/]

WATER BALANCE COMPONENTS IN INCHES ON AN ACRE BLOCK OF LAND

Day	Depth of Irrig. IR	Depth of rainfall RN	Depth of drainage DR	Initial Depth of Surface IS	Final Depth of Surface Storage FS	Depth Change of Surface Storage AS = IS-FS	Pan Evaporation depth ET	Residual* seepage & percolation depth residual S&P	Water use efficiency** WUE %
1									
2									
3									
4									
5									
6									
7									
Week summary									
1									
2									
3									
4									
5									
6									
7									
Week summary									

Basic efficiency relationship

$$\text{Eff.} = \frac{\text{output}}{\text{input}}\ 1\ 100$$

* S&P residual calculation

INFLOW - OUTFLOW = change in storage
INFLOW = IR + RN
OUTFLOW = S&P + ET + DR
CHANGE IN STORAGE = IS-FS = AS
IR + RN - S&P - ET - DR = AS
IR + RN - ET - DR - AS = S&P

** Water use efficiency

$$\left(\frac{ET+S\&P}{IR+RN}\right) 100 = 100 \left(\frac{-DR}{IR+RN}\right) + 100$$

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ESTIMATION OF WATER LOSSES WHICH OCCUR IN DELIVERY SYSTEMS BEFORE THE WATER REACHES THE FIELD

by Alan Early[*]

Most water delivery efficiency studies, to date, have been conducted under controlled, "steady state" conditions. For practical purposes, however, the actual delivery of water to the farmer's fields almost never takes place under standardized situations. Rather, the factors which control delivery efficiency constantly change. The actual delivery, therefore, becomes an "average" which is determined by the capability of the system and by the extent to which dilution factors can be controlled.

In Pakistan, any or all of the following factors may be involved before water is finally delivered to the farmer's fields.

1. Dead storage
   a. Watercourse channels are deeper than the fields. This is especially true within the village area (abadi) where the people remove mud from the channel for construction purposes.
   b. Buffalo wallows . . . areas where the animals walk and cool themselves in the muddy watercourse.
   c. Wide, shallow sections used by animals and people as crossing areas.
   d. Negative gradient areas within the channel itself . . . usually created when the channel is cleaned without proper leveling equipment.
2. Infiltration

   The rate of infiltration into the ditch bank is at its highest when the soil is dry, when the water is first turned on. This rate may

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[*] This How-To-Do-It was taken from The Problem Identification Handbook (April 1, 1980). Developed by the CSU-Pakistan Water Management Project sponsored by U.S. Agency for International Development, Contract No. AID/TAC-1100.

exceed that of filed soils by as much as 500 percent, due to the regularity of the capillary system within the compact bank soil.

3. Rodent holes

   Inspection and excavation of the banks reveals many holes created by insects, rodents, and plant roots. The highly porous nature of these banks is one reason for accelerated infiltration. Most of these holes originate in the sides of the channels and do not penetrate the entire ditch bank. They may penetrate downward and into the subsoil. Coarse textured subsoils then will further increase water loss.

4. Nakka leaks

   Most of the water wasted is through kacha nakkas due to less soil compaction in the newly cut field outlets. Water is adsorbed in the watercourse bunds as well as wasted through leakage of the nakkas. Every irrigation evaluator is cautioned to estimate this kind of loss before doing steady state flow measurements.

The losses involved in filling dead storage and infiltration consumption in the early period of the run can be estimated as a function of mogha discharge and time required to fill dead storage.

For measurement of discharge, mogha CTF readings during this period should be taken, time should be noted when the water is diverted into the watercourse and again when water reaches the field. This time also includes the time that would have been required had a good cross section of the watercourse been maintained through head and tail. Therefore, we must also estimate this necessary time and subtract from the time noted in the field. This can be estimated as follows:

1. Select a very good section of the watercourse. There would be no dead storage nor overtopping and no erosion in that section. Such a section is usually found near the mogha.
2. Measure the area of cross section with the help of a staff gauge. Use the average depth of flow and the average width of the cross section evaluated.
3. Calculate the time required had the ideal cross section been maintained throughout the watercourse length. Use the formula below:

$$Tn = \frac{A \times L}{Q \times 60 \times 60}$$

where Tn is the time necessarily required (hours)

A = areas of ideal cross section (square feet)

L = length of the watercourse filled

Q = average mogha discharge (cubic feet per second)

Suppose the total time taken by the water to reach the field is T. Then, the time required to fill the dead storage is T-Tn. Hence, the volume (acre inches) wasted through dead storage and infiltration is Q(T-Tn).

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SUBMISSION DELIVERY EFFICIENCY (Es)

by Doral Kemper*

$$Es = \frac{\text{Total volume of water delivered to the fields}}{\text{Total volume from mogha flow}}$$

The summation delivery efficiency can be calculated from the time discharge curves, which can be plotted by taking the mogha discharge (CFS), and the nakka discharge (CFS) on a vertical scale and time (day-hours) on a horizontal scale (Figure 1).

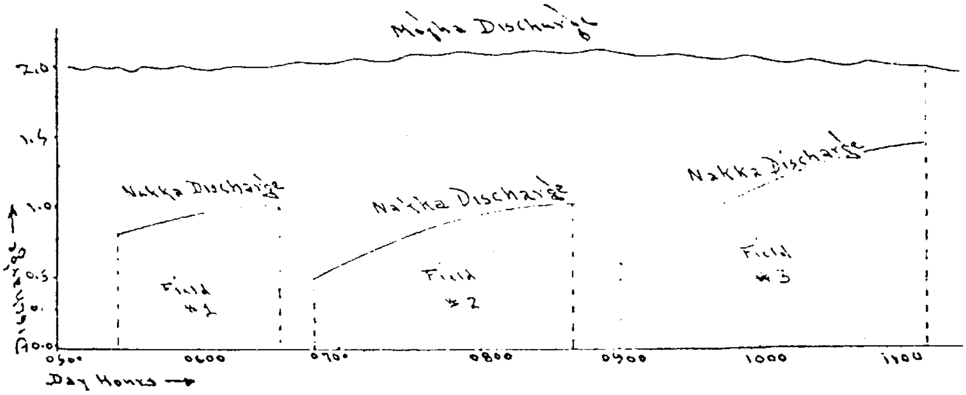

Figure 1. Time discharge curve.

The area under the mogha discharge will give the total mogha flow volume, while the total of the areas under the nakka discharge curves will sum up the total volume of water delivered to the fields, where appropriate conversion factors are applied.[1]

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[1] Kemper, W. D. et al., 1975. Annual Report, Water Management Research Project, Colorado State University.

The following form is provided in the Irrigation Evaluation Field Book to record the data.

Dead Storage in Watercourse

Date	Q Mogha	Time Water Diverted into Watercourse	Time Water Reached Field	(T) Hours	(A) Cross section Area of dead section	(L) Length of Watercourse	$T_n = \frac{AL}{Q}$ Actual time Required	Time for dead storage T-Tn	Volume Wasted Acre In. Q(T-Tn)	Remark

Figure 2. Record of wastage of full or a part of the mogha discharge.

Responsibility: The Agricultural Assistant is responsible for collecting this kind of data with the help of his field assistant. He will have to measure the discharge which is being wasted with the help of a cutthroat flume. If the full mogha supply is being wasted, the readings of the mogha flume will serve the purpose. If a part is being wasted, then he will have to install a flume at the point where it is being wasted.

The data will include the following:

1. Water delivered to a drain

   When it rains, water of the mogha is frequently turned into a drain, or the mogha is shut off.

2. Water delivered to a pond

   The pond may be a traditional village pond, or a fish pond.

3. Brick making or other nonagricultural uses

   Generally for construction purposes.

4. Accidental failure of nakka or watercourse bank upstream

   If frequently happens causing the farmer to suffer accidental losses due to inundation of his crop. The data is recorded on this form:

RECORD OF WASTAGE OF FULL OR PART OF MOGHA DISCHARGE

Mogha Number ____________________ Month ____________________

Distributary ____________________ Chak/Village ____________________

Canal ____________________ District ____________________

Field Office ___________

Date	Average discharge	Time			Volume wasted (Qxt) acre inches	Remarks
		start	end	hours		

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METHODS OF MEASURING SEEPAGE RATES

by Doval Kemper[*]

INTRODUCTION

There have been numerous methods developed for measuring seepage from canals and laterals involving both field and laboratory investigations. Each has its own unique characteristics which make it useful under certain conditions. The objective of this discussion is not only to describe different methods of measuring seepage rates, but to provide a review of several methods which could be used for developing water budgets, as well as provide references for further information.

The factors which influence seepage rates are many and complex. Among the more important ones are soil characteristics of the canal bed, length of time the canal has been operating, depth to groundwater, sediment load in the water, depth of water in the canal, temperature of both the water and soil, barometric pressure, biological factors, and salts contained in both the water and soil (Robinson and Rohwer, 1959; USDI, USBR, 1952; USDI, USBR, 1963; Rohwer and Stout, 1948; Brockway and Worstell, 1968). Although the technical literature contains much information about the relationship between these parameters and seepage rates, the seepage process is so complex that individual tests are often necessary for either research studies, developing water budgets, or prior to and after construction of channel improvements. Worstell (1976) provides an excellent review of seepage measurement techniques.

The most common methods of measuring seepage can be categorized as those that yield results indicating an average seepage from a length of channel and those in which information simply gives the permeability of a sample of the canal bed. If the latter type of measurement is employed,

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additional information on hydraulic gradients is necessary in order for the actual seepage to be computed. In most salinity related investigations, those methods which indicate actual seepage rates prove to be of most worth. Three of the most employed methods include the inflow-outflow method, ponding method, and seepage-meter method.

Inflow-Outflow Method

When the seepage rates from relatively long lengths are to be measured, the inflow-outflow method is a reliable and commonly used technique. The method consists of measuring the inflow and the outflow to the canal section under investigation, including all the diversions from and return flows to the canal. By computing the net loss in the canal, the actual seepage rate can be determined. Since the usual units of seepage rate are feet per day ($ft^3/ft^2/day$), the conversion from the total loss in the section requires a knowledge of the length and wetted perimeter (average) of the canal. The seepage rate can thus be expressed as:

$$SR = \frac{(\text{Inflow-Outflow}) \times 8.64 \times 10^4}{A} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; (1)$$

in which SR is the seepage rate in cfs (average for canal section), 8.64×10^4 is the number of seconds per day, A is the wetted area of the canal in square feet, and the difference between the inflow and outflow is expressed in cfs (ft^3/sec). Use of this method is discussed by Bourns (1955).

Although this method does give an indication of seepage rates under actual operating conditions, there are several factors which should be carefully observed, or large errors will be introducted into the results. The maintenance of constant flow depths in the canal during the tests is essential to eliminate the effects of bank and channel storage. Also, an accounting of all return flows from higher lands and diversions or leaks from the canal must be made. Occasionally, if the seepage rates are small, it may be useful to note rainfall and evaporation, although these latter factors are generally inconsequential. Finally, but probably most importantly, is the consideration of flow measuring devices to be employed. In the absence of measuring structures in the system, the flows can generally be measured by small flumes or weirs when flows are small and current meter measurements in the larger flow situations. Most calibrated devices can be expected to measure water within at least 5 percent if operated correctly, but current meter measurements require careful attention by experienced personnel to maintain accuracies below 5 percent.

Ponding Method

Although an objection is often raised that still water may seep at a different rate than flowing water, the difference is probably small in comparison to errors associated with other measurement methods regarding seepage. Basically, the ponding method involves measuring the rate of fall of the water surface in the pool created in the canal section. Then, by knowing the geometric properties of the section, it is possible to compute the seepage rate according to the following formula:

$$SR = \frac{\Delta E \times SW_a \times 24}{WP_a \times T} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

where ΔE is the drop in water surface elevation in feet, SW_a is the average surface width in feet, WP_a is the average wetted perimeter in feet, and T is the time of the run in hours. Some of the steps in conducting ponding tests are shown in Figure 1, and further information on the analysis can be found in Skogerboe and Walker (1972).

The ponding method usually provides the basis for comparison and other methods because it usually can be expected to yield the best results (Robinson and Rohwer, 1959; USDI, USBR, 1968). However, it does have certain disadvantages that should be pointed out. To begin with, the construction of the dikes is often expensive and must be completed during periods when the canal is not in use of during periods of interrupted canal operation. Furthermore, providing water to fill the pools or ponds may represent a significant problem. However, if the canal discharges are very large in relation to the seepage rates, then the ponding method is the best method by which the seepage rates can be determined. In fact, under such conditions, the errors expected in other methods (i.e., the inflow-outflow method) may completely mask the seepage loss.

Seepage-Meter Method

Seepage meters determine seepage rates under normal operating conditions, but only for a small area at a time. Nevertheless, by taking readings at several points along the canal section, a fair average value can be determined. The measurements involve pressing a cylindrical bell into the canal bed. Attached to the bell via plastic hose is a plastic bag filled with water and submerged in the canal. The water which seeps into the canal bed is replaced by water in the bag which is under the same pressure as the canal flows and thus represents the same head against the

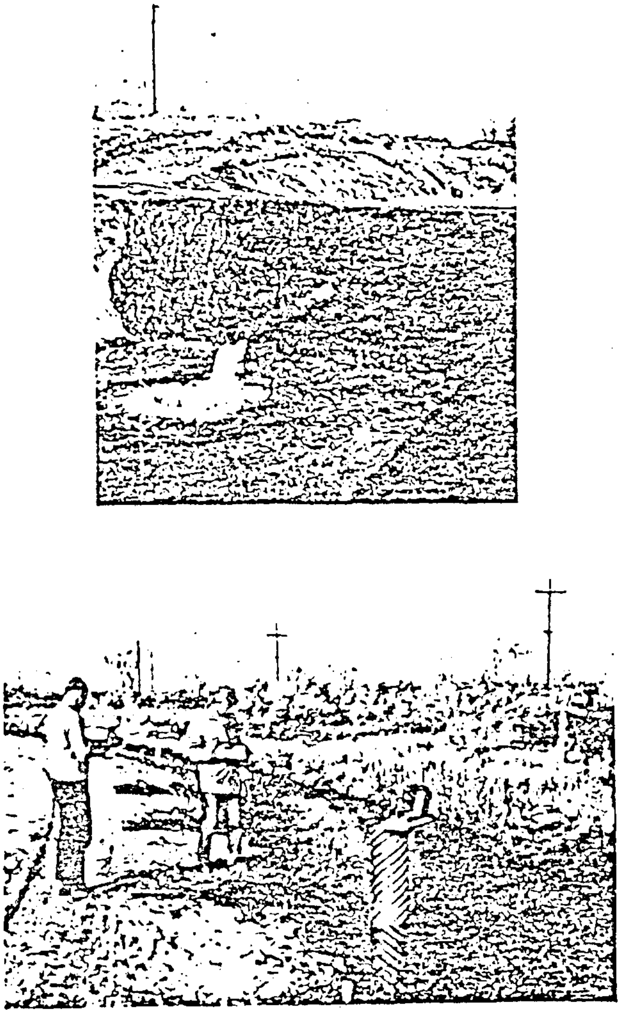

Figure 1. Illustration of the ponding method for evaluating seepage rates from canals.

canal surface. The seepage rate can be computed from a knowledge of the area of the bell, the seepage from the bell as determined by weighing the plastic bag before and after the test, and the elapsed time of the test. The seepage rate then may be determined by:

$$SR = \frac{Q}{A \times T} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

in which Q is the amount seeped through the canal bank in ft^3, A is the area of the bell in ft^2, and T is the elapsed time in days.

The seepage meter may be expected to work well unless the bed material is badly disturbed causing the meter to overestimate the seepage rates. The seepage meter method is difficult to apply under conditions in which the flow depths are too great or the channel velocities are too fast. In addition, gravel, moss, or highly vegetated channels also present difficulties in properly evaluating seepage rates.

Other Methods

There are numerous other techniques which yield useful seepage rate results in certain conditions. The first group of these may be classified as measurements of soil permeabilities which can be used to compute seepage rates. These include the well-permeameter method, variable head permeameter method, and the laboratory permeameter method (Robinson and Rohwer, 1959). The second group are those that use trace materials to determine seepage loss. These include the salt-penetration technique and the radioactive isotopes technique and fluorescent dyes (Robinson and Rohwer, 1959; and Liang and Richardson, 1971).

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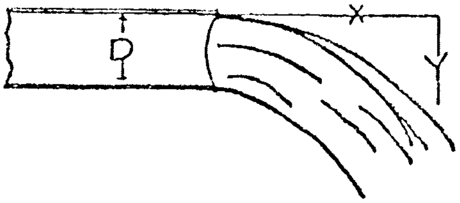
MEASURING TUBEWELL DELIVERY
(Purdue Coordinate Method)

adapted by Tom Trout*

The amount of water being discharged from many tubewells can be estimated using the Purdue Coordinate Method. This method has proven to be a practical, quick method of flow measurement and it can be utilized quickly and simply. The method utilizes the fall of a stream of water flowing from the mouth of a round, horizontal pipe, the inertia of the water from the tube determining the rate of fall.

Coordinates have been determined which can be utilized to make this determination. They are:

1. The inside diameter of the pipe . . . . . "D"
2. The measured distance from the end of the pipe, predetermined at 0", 6", 12", and 18" . . "X"
3. The fall of the stream in that distance, measured in inches . . . . . ."Y"



Method

1. Check the pipe for level and be sure that the pipe length is straight for 6 diameters or more above the mouth.
2. Determine "D" by measuring horizontal and vertical inside diameter. "D" is the mean of the measurements.

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3. Using a carpenter's square or a folding rule, measure the drop, "Y" at the given distance, "X" from the mouth of the tube. If the pipe gauge is heavy enough to be significance, subtract it from "Y".

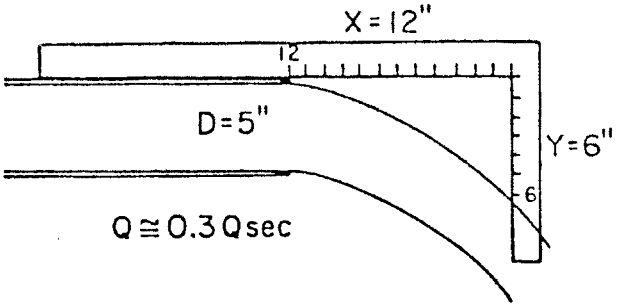

Figure 2. Coordinate method measurements using carpenters square.

4. Using the attached table, determine the rate of flow to the nearest 1/16 of a second foot.

Illustration--If D equals 5 inches, X equals 12 inches and y equals 6 inches, then from the table we read that the delivery is 0.8 second feet.

Note: If the water depth inside the pipe is less than 0.8D, measure Y at the mouth of the pipe and use X value 0.

LIMITATIONS

1. Pipe must be straight for a distance of 6 times D.
2. Accurate only when the pipe is level. For approximate results if the pipe is slightly inclined upward, subtract 1/10 second foot from "Y". If it is slightly inclined downward, add 1/10.

CHECK

This method is designed to provide a practical estimated measurement. An accurate method of measuring the discharge such as a propeller (Sparling) meter may be used to check the results. For research purposes, use the method which coincides with the experimental data.

For measuring delivery of tubewells of diameters other than those provided for in the tables, use the same coordinates and the formula.

$$0.0063^2 \times \sqrt{1/Y}$$

Table 1. Discharge from horizontal round pipes (cfs) after U.S.B.R. Water Measurement Manual (1967), Figure 92, p. 202 and 203.

	Horizontal Coordinate							
Vertical Coordinate Y (in)	X = 0"				X = 6"			
	Dia. 3"	4"	5"	6"	3"	4"	5 "	6"
0.5	.13							
1.0	0.12	0.29	0.59	0.94	0.40	0.76	1.27	1.78
1.5	0.08	0.22	0.49	0.81	0.33	0.65	1.07	1.56
2.0	0.04	0.17	0.38	0.71	0.29	0.56	0.91	1.36
2.5	0.02	0.11	0.30	0.56	0.26	0.49	0.81	1.24
3.0		0.05	0.20	0.45	0.22	0.45	0.74	1.11
3.5			0.12	0.33	0.20	0.40	0.67	1.00
4.0			0.07	0.27	0.19	0.37	0.61	0.95
4.5					0.17	0.33	0.57	
5.0					0.16	0.30		

	X = 12"				X = 18"			
	3"	4"	5"	6"	3"	4"	5 "	6"
1.0	0.71	1.27	2.23	3.12				
1.5	0.61	1.05	1.80	2.67	0.84	1.56	2.56	3.68
2.0	0.53	0.92	1.56	2.34	0.75	1.34	2.12	3.12
2.5	0.47	0.85	1.38	2.09	0.67	1.20	1.92	2.79
3.0	0.42	0.78	1.27	1.94	0.60	1.07	1.78	2.56
3.5	0.39	0.72	1.16	1.78	0.57	1.00	1.65	2.40
4.0	0.37	0.67	1.07	1.67	0.53	0.94	1.54	2.28
4.5	0.35	0.64	1.00	1.56	0.51	0.89	1.45	2.17
5.0	0.33	0.61	0.96	1.47	0.49	0.85	1.38	2.06
5.5	0.32	0.58	0.91	1.40	0.47	0.81	1.33	1.96
6.0	0.31	0.56	0.87	1.34	0.45	0.78	1.27	1.89

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FIELD DATA COLLECTION

by Max Lowdermilk, James Layton and Warren Smith*

INTRODUCTION

Data collection is one of the most important steps in the early phases of a project when the team is defining the problem and searching for solutions. An interdisciplinary team will study an interrelated system of irrigation, crops, soils, marketing and family relationships. Because these things influence each other, they are of equal importance to the engineer, agronomist, economist and sociologist.

Engineers and agronomists can develop different types of physcial technology. The social scientist's understanding of economic conditions and social relationships will enable them to determine the type of physical technology which will be most acceptable and beneficial to the farmer. A watercourse may be technically efficient with concrete lined canals and following an optimal route. But it may not be beneficial to the farmer if the high price of cement makes construction costs too great, or it may not be acceptable if the canal runs through property belonging to opposing kinship groups so that there will be no cooperation in repairing or cleaning it.

Accurate information collected by the interviewer will help the project team know which technology will be most useful to the farmers. Inaccurate or incomplete information may cause the wrong technology to be used which may harm rather than help the farmers and his family. Also, the interviewer will have direct contact with a large number of farmers. The goodwill that he creates can contribute greatly to the project when the team or government attempts to implement the new technology in the villages.

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Interviewing requires great skill. The interviewer must completely understand the meaning of the questions he will ask. He must know enough about the subjects to know if the answers are reasonable. He must also understand the farmer so that he can gain his cooperation. Developing these skills requires a great deal of training and the work is hard, but data collection can be a rewarding job. The interviewer will gain a better understanding of other people and will learn much about the problems of farmers. Most important, the interviewer may form lasting friendships with the people in the area where he is working.

DEVELOPMENT OF THE SURVEY QUESTIONNAIRE

The questionnaire is the most frequently used instrument for collecting socio-economic data. Understanding its design and purpose will help the project personnel make the best use of it. Most socio-economic surveys are designed to obtain information from a single interview. This reduces cost, both in terms of money and time, of obtaining data. Information that is not asked for or not recorded during the first interview is usually lost to the data analyst. This makes it essential that the questionnaire be designed as carefully as possible before interviewing begins. It is far less costly to spend additional time designing a good questionnaire than to return for a second interview to obtain important information that should have been obtained the first time.

DEFINITION

A questionnaire is a written form with a set of questions to be answered by a respondent and with instructions for the interviewer on how to ask the questions and record the answers. The questions will be organized in a way that the answers can be easily tabulated and statistically analyzed.

The questionnaire will usually contain some open-ended questions which will require the respondent to give his opinion and some closed-ended questions that contain predetermined answer categories into which the respondent's answer will be placed. Some questions will be directed to the interviewer asking for objective and subjective observations. There will also be requests for information about the interview such as identity of interviewer, location of the interview, data and time.

DESIGNING THE QUESTIONNAIRE

The person most responsible for the questionnaire is the social scientist. He has the greatest amount of training and experience in formulating questions so they can be understood by the farmers, and in designing the questionnaire format to facilitate its use by the interviewer and data processor. However, all team members should be involved in determining the topics to be covered in the questionnaire and should be encouraged to submit questions. Team members from a particular discipline can often provide technical background and insights related to other disciplines.

Data processing personnel should be consulted if the data is going to be mechanically tabulated and analyzed. They may make suggestions about format design which will reduce punching error or increase flexibility for cross tabulation of data.

The project sponsor should be given a draft of the questionnaire. This will insure that the project personnel and the sponsor are in agreement on the information that will be collected. The sponsor representative often has "pet questions" that he would like included so the questionnaire should be shown to him before it is finalized. The final draft of a questionnaire should be reviewed and approved by all team members.

WHO USES THE QUESTIONNAIRE

An interviewer will use the questionnaire to obtain the information. He must understant the questions (know the correct interpretation) and be able to follow the instructions.

A field supervisor will be responsible for seeing that the interviewer completes the required number of interviews and will edit the questionnaires for accuracy and completeness. He may also be required to do some of the preliminary tabulations.

Data processing personnel will transfer the data from the questionnaire to punch cards and then to computer tapes. The key punch operators must be able to follow the card punching instructions and transfer the information from the questionnaire.

The data analyst will use the statistical information to write a report which will reflect the conditions of the survey area.

THE QUESTIONNAIRE

Creed

A creed expressing the general attitudes the interviewer should have with regard to his job and the farmers may be added to the questionnaire.

The creed should reflect the cultural and professional emphasis for the specific region and project. Here is an example of a creed which may provide general quidelines.

1. I come as a guest to the village and into the house of the farmer. I will accept hospitality graciously, but never demand it. I will pay all debts and in no way take unfair advantage of my position.
2. I shall respect the farmer, his family and all villagers. Never will I be discourteous when I am with them. I will always respect his opinion, no matter what that opinion is.
3. At all times my personal conduct will reflect respect for religious, social and family traditions. Whenever invited and appropriate, I will participate in religious and social celebrations. I will follow village customs. I will wear appropriate clothing. I will treat women with proper courtesy and respect, and I will speak to the villagers as equals.
4. Because my work will be of service to the people of this area and my nation, I will fulfill my responsibilities to the best of my ability. This will be done with honesty and goodwill to reflect honor on myself and those with whom I work. I will always work in such a manner that when I leave, researchers who follow me will always be welcomed in the village because through my example the people will know that we have come to help.

Information about the Interviewer

The questionnaire should require the following information at the beginning of the interview: a) name of interviewer; b) name of the respondent(s); c) location of interview; d) data of interview; and e) time of interview.

Introduction

A short paragraph written in the local idiom should be provided at the top of the questionnaire to be read by the interviewer as an introduction to the interview. This should include: a) what the interview is about and how the information will be used; b) how the respondent was chosen; c) that his name will not be associated with his answers; d) who is sponsoring the survey. This provides only the basic framework for the introduction. The interviewer should be prepared to spend some time expanding on the introduction and answering questions that the respondent may have.

Questions

General Comment. Questions should be short and to the point. They should be written in the language of the country and as much as possible in the local dialect. It is useful to have a person from the local area read the questions and make changes that he thinks would make them more understandable. Questions should also be asked using local unit measurements and weights. Respondents may become uninterested or uncooperative if they have trouble understanding the questions. Also, they may become defensive about being asked questions they feel are unreasonable or for which they feel the answer is obvious. For example, if the interviewer is standing near the farmer's electric irrigation pump, he does not need to ask how he pumps his water. Many questions can be answered by observation.

Closed-ended Questions. Closed-ended questions either provide the respondent with a set of alternative answers to choose from or categories are provided for the interviewer into which he can fit the answer. For example, how many hectares of land do you own: 1) none; 2) one to two; 3) three to five; 4) six or more.

A major advantage of this type of questions is that the interviewer can easily and accurately record the answer. If the question is ambiguous the interviewer will immediately see that it does not fit a category and can clear up any misunderstanding. It also makes it easier to hand tabulate the data in the field for preliminary reports.

The biggest disadvantage of the closed-ended question is that it forces answers into predetermined categories, thereby losing some of the richness and variation that can provide insight into areas being explored. The categories themselves must be carefully designed. They are usually based on the designer's prior experience, knowledge of the subject areas and pretest responses. When the survey is being done in an area in which there is very little known about the socio-economic variables, it is easy to miss much important information by using inappropriate categories. Experience has shown that in some cases multiple choice questions or semantic differential scales are not easily understood. Multiple choice questions may be answer suggestive and distort replies.

Open-ended Questions. The open-ended question usually asks for the farmer's opinions. For example, do you feel it is fair for the government to charge the farmer directly for the amount of water he is using? Why? This encourages the farmer to discuss his opinion.

An important advantage of this type of question is that the respondent has the opportunity to provide an answer from his own perspective. The cultural perspectives of the project team may be entirely different from those of the farmers whom they are interviewing and the farmers may have a different rationality set from what was expected by the project team.

The open-ended question is more demanding for respondent, interviewer, and analyst. A "what is your opinion about . . . ." requires the respondent to attempt to answer which will satisfy the interviewer. The interviewer is expected to distinguish between relevant and irrelevant answers and probe on vague or ambiguous answers. If the data is being used for statistical purposes (rather that for case studies) the answers will have to be coded. Coding open-ended questions requires careful interpretation of replies and errors can reduce the reliability of the survey.

Sequence of Questions. The order in which questions are asked can add to the quality of the answers and increase respondent cooperation. Most surveys require several different types of information. These can be thought of as information blocks. Questions should be ordered so that one block of information is obtained before going on to another. Questions should go from general to specific. If events involve some chronological sequence the questions should follow the chronological order.

An exception to the above is the sequence of "sensitive" questions. These may differ within different cultures, but these will usually include most family and income questions. The less sensitive of these can be included at the end of the information blocks. The most sensitive should be asked at the end of the questionnaire so that if the respondent objects to answering a question somewhere in the middle of the interview, he may terminate the interview at that point.

Well trained and experienced interviewers may be able to disregard the question order on the interview form. By the interviewer quiding discussion toward the questionnaire topics the farmer may provide much information without being asked directly for it. The natural flow of conversation will put the farmer more at ease and help insure his cooperation.

Pre-Coded Questionnaire

Data processing codes should be placed on the questionnaire so that key punch operators can transfer the codes directly from the questionnaire to the punch card. Card and column number are printed next to each question on the questionnaire or the card and column instructions may be given in a key punch instruction manual.

The following is an example of a pre-coded question.

Card I   Column 18

Q 5   How many children are in your family?

____ 1) 1-2   ____ 2) 3-4   ____ 3) 5 or more   ____ 4) none

The interviewer would place a check mark in the blank that corresponded to the farmer's answer.

The example above is a closed-ended question and represents a "pre-coded" question. A variation of this is an open-ended question which has a card and column but the code number must be inserted by the interviewer at a later time. For example,

Card I   Column 19 ______

Q 6   What is your opinion of government plans for changing the cana; system?

In this case, answers from a large number of respondents would be used to create categories of responses. Each category would be assigned a code number and the appropriate code would be entered in the blank to the right of column 19.

Length of the Questionnaire

A long questionnaire is tiring for the interviewer and the respondent. This may cause the farmer to become restless or give incomplete answers. Also, the interviewer may tend to hurry through questions without giving adequate explanations and he may become less alert to answers which should be challenged. The questionnaire should be limited so that the interview lasts an hour or less. If the necessary information requires more than that, it may be necessary to make an appointment with the farmer for a future date.

Physical Characteristics of the Questionnaire

The 8 1/2 x 11 inch paper size is usually easier to handle that the larger size. Paper quality should be good. Questionnaires will be handled a great deal and lost or torn pages occur more frequently with low grade paper. If there are subsamples within the survey the questionnaires may be color coded.

SURVEY PRETEST

What is a Pretest

The survey pretest is very much like the first test flight of a new airplane. It is the research team's opportunity to try out in miniature scale the questionnaire, interviewing, sampling, tabulation, and logistics before doing the actual survey. The pretest should be carried out under as nearly the same field conditions as anticipated for the main study.

Purpose of the Pretest

The purpose of the pretest is to discover and correct small problems in the "finished product" before the full-scale survey is begun. The survey design isn't finished, but it should have progressed to a nearly complete stage. Discussion with informants, interview training, small scale trials for each separate element should already have been done. Results should show where modifications should be made. If there are serious faults and major changes are necessary, they should be made and then a pretest done a second time.

The pretest is an important link in the chain of survey development. Most socio-economic surveys are designed to be carried out in a short period of time and with a single contact for each respondent. Once the survey interviewing has begun, any major problems may be costly in terms of money and the quality and quantity of information.

Pretest Elements

The following are elements which are involved in a survey and should be examined in the pretest. The number of pretest interviews should be large enough so that each of the elements will have a fair test.

Questionnaire Pretest

1. Problems with the questions
   a. The question may be vague or unclear.
   b. The question may be too long which makes it difficult for the farmer to follow.
   c. The farmer may not understand some of the words because the dialect of his village is different.
2. Measuring devices may be necessary to obtain better estimates. It may be found that the farmer has difficulty in accurately estimating crop yields, the amount of feed given to animals, etc.

3. Memory aids may be necessary to help the farmer with certain questions. These may include any records that he has kept or information that has been obtained from the reconnaissance survey.
4. Change in the sequence of the questions may increase the farmer's willingness to give answers or improve the quality of his answers.
5. Sensitive questions may need to be reworded or repositioned in the questionnaire. In some cases they may be deleted.

Interviewing Pretest

1. The interviewer will become familiar with using the questionnaire.
2. The interviewer can communicate any problems back to the survey designer in debriefing sessions.
3. Field supervisors have an opportunity to evaluate the interviewer's training, honesty and enthusiasm.

Sampling Pretest

1. The pretest can provide important sampling information.
    a. Population size
    b. Geographic dispersion
    c. Settlement patterns
    d. Suitability of stratification classifications
2. Check adequacy and accuracy of maps and sampling lists.

Tabulation Pretest

1. Frequency tabulations may indicate data consistency problems or a need for a change in closed-ended question categories. This will be especially evident by examining the "all other" category in these questions.
2. By coding and tabulating open-ended questions, it may be possible to close some of these questions.
3. Further interviewer training may be indicated if the tabulator has difficulty in understanding the responses or if he cannot read the handwriting.
4. Pretest tabulations should indicate significant differences in responses among different sample subgroups which may affect stratification change.

Operations and Logistics Pretest

1. Pretest can provide a realistic estimate of the average number of questionnaires per day that can be completed.

2. The supervisor can determine the amount of supervision necessary to maintain quality control.
3. Realistic deadlines can be set from the above information.
4. The pretest is a good time to listen to interviewer complaints caused by the stress of living and traveling in strange surroundings and make whatever adjustments are necessary.

EWUP
How to do it
Field Procedure

FIELD DIARIES

by James Layton and Max Lowdermilk[*]

Field diaries will be defined as instruments by which personal observations and thoughts are recorded during the period of time in which a researcher is engaged in the research process. The purpose of a field diary is more than an exercise of putting down in writing random thoughts and happenings; it is supposed to be a systematic method of observation which supplements the formal measures of the research design. Again, it is a personal account of what is occuring in the project area. In order for the field diary to serve a useful purpose, it must first incorporate four major objectives and then it must meet those objectives through a systematic pattern of observation and a complete expression of feelings. The discussion that is to follow will detail the construction of a proper field diary, and in so doing will be organized according to the format set out in Figure 1.

OBJECTIVES FOR THE FIELD DIARY

The first objective of a field diary is to place the research process into the appropriate context. This diary can be used to describe the situation in which the research activity is placed and thus allow for the different phenomena occuring within that activity to have a greater meaning. For instance, before a researcher enters into a research program that person must be aware of the socio-physical situation that will encompass the research. Aspects of the situation that can help place the research program into its proper perspective include the demographic composition of the population to be studied, the social structural makeup of that population (i.e., the degree of complexity in the society, the degree and type of

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[*] This How-To-Do-It was taken from The Problem Identification Handbook (April 1, 1980). Developed by the CSU-Pakistan Water Management Project sponsored by U.S. Agency for International Development, Contract No. AID/TAC-1100.

GENERAL FORMAT OF CATEGORIES TO BE INCLUDED IN THE CONSTRUCTION OF FIELD DIARIES

OBJECTIVES

- PLACE PROCESS IN CONTEXT
- DESCRIBE PROCESS
- EVALUATE PROCESS
- SENSITIZE RESEARCHER

PROCEDURE FOR WRITING

CONTENT OF DIARY

OBSERVATIONS

IMPRESSIONS

SUBSTANTIVE MATERIAL

RESEARCH PROCESS

SUBSTANTIVE MATERIAL

CONSEQUENCES

RESEARCH PROCESS

FIELDS OF OBSERVATION
Phy.
Dem.
Org.

UNITS OF OBSERVATION
Level
Situation

BEHAVIOR

- INTERACTION AMONG PARTICIPANTS

METHODOLOGICAL ASPECT OF PROBLEM

Figure 1.

stratification, etc.) and the cultural-attitudinal nature of the population (its values, beliefs, etc.). In addition, the physical environment of the population to be studied can tell the researcher many things about that population. Writing down impressions of this socio-physical environment will sensitize the researcher to the parameters that will quide the research activity.

A second objective of the field diary is to describe the research process itself. Questions that need to be answered regarding this process may be subsumed under the following headings: who, what, why, where, when and how. Who refers to the sample being surveyed and the relationship between the researcher and the people being studied. What effect does the researcher have on the people and therefore the answers that they will give him. Is the researcher an outsider, a member of the group, a leader, a threat, or someone else? This relationship between the researcher and the people being studied is an extremely important item to be written down in the field diary, for this relationship will effect how questions will be answered.

The what question is concerned with the informating being gathered. Is this information going to create conflict, is it going to make people suspicious, or is it perceived by the studied population to be of help to them? Again, a description of what type of information is gathered will help the researcher to make proper inferences about the data gathered.

The questions of why, where, when, and how are procedural questions that can also affect the information gathered. What is of concern here is that when a researcher begins to interpret information received from a selected group of people being studied, the information will have much greater meaning when it is placed in the proper context concerning the collection of that information. Here is where the diary can be of great help for it can describe this procedure of collecting data and thus provide insights into what influences are present when the information is obtained.

Third, the field diaries should provide a forum for the evaluation of the research activity. Here the researcher can record successes and failures, idiosyncratic events, problems that are solvable and those that are not, plus other conditions that shape the form of the research activity. Based on this information the researcher can then evaluate how the project is proceeding. Finally, the fourth objective of the field diary is to provide a means by which the researcher can become more sensitized to the various conditions affecting the project. Through the recording of observations and beliefs a researcher can pick up subtle clues as to how the project is progressing. Not only can that researcher then initiate action to follow the course of the research activity of modify that activity, but also that person can feel much closer to the project and its workings.

PROCEDURE FOR WRITING A FIELD DIARY

In writing the field diary, there is no special format that must be followed but there are some general considerations that should be followed. Three general considerations of importance are the schedule to be followed, the administrative support provided for writing a field diary, and the medium used to record the field diary. Regarding the schedule consideration, field diaries should be written daily and in chronological order. The reason for this is with a daily schedule, the many events and situations occurring during the working period can be recorded with less chance of being forgotten or changed because of forgetfulness. It is possible to help motivate a researcher to keep a diary by using various administrative incentive and sanctioning devices. Also, the project can print forms containing a checklist of what should be considered when one is writing a diary. Information for the diaries can be collected by directly writing into notebooks or by using tapes which are then transcribed. Again, writing a field diary can ce accomplished in many ways, the critical concern is that it is written on a regular schedule according to some systematic outline.

CONTENT OF THE FIELD DIARY

The content of the diary should be organized under two general categories: observations and impressions. Regarding the types of personal observations that can be made, there are two dimensions which can be tapped. The first dimension is the substantive material to be observed. This includes first the field of observation, next the units of observation, and third the actual behavior of the individuals involved in the research process (Figure 1).

The field of observation includes a description of the physical setting, a description of the demographic setting, and a description of the organizational setting of an area. The physical setting will include such items as the climate, the geographic area, resources, etc. Under the demographic setting descriptions such as the concentration of people, the movement of people, and general characteristics of the people (age, ratio, sex ratio, fertility, etc.) will be the focus of discussion. Finally, the organizationsl setting will include such items as a description of the stratification network in the social system, the communication network, the degree of complexity in this system, etc. All in all, this description will place the research project into the overall perspective of the situation as seen by the observer.

Within that situation the units of analysis are to be observed. One must be aware of the level of abstraction that one is observing. Observations can be made on individuals, small groups, clans, families, tribes, villages, and so on. Observations can also be made on situations and the interaction involved in that situation. Within these units the third component of substantive material is to be observed; i.e., behavior. The unit's action with regard to various situations is subject to observation and detailed description.

The second dimension of observation has to do with the research process itself. Here two categories of observation are crucial: (1) the interaction of the participats and (2) the methodological aspect of the process. Observation of the interaction among relevant units includes the interaction between the research team and the people of concern to the researchers, the interaction among the team members, and the interaction between the research team and the various governmental agencies involved in the research project. These observations again are supplementary to formal evaluative procedures of field personnel. (See section in handbook on the evaluation procedures of personnel.) As to the methodological aspect of the research project, one can observe how the conceptualization of the problem is progressing and fitting into the situation, how the data collection procedures are being established and carried out, and finally how the analysis is taking form. In short, what is of concern here in this second dimension of observation is to record how the research process is being implemented.

The second general category that belongs in a field diary is the impressions that the recorder has regarding the observations. Impressions are very important in that they will provide the context from which the observations of the researcher can be evaluated. Thus impressions should be given on all aspects of the research process that are observed. These impressions are individaul opinions, concerns, or general comments on the various conditions of the research project. It can be through these impressions that new ideas may emergy and a better understanding of the dynamics of the research process may occur.

In conclusion, field diaries are instruments by which personal observations and thoughts are recorded. These diaries should be written daily and there should be some organized method of observation. The observations should be supplemented with personal impressions of what is occurring. Finally, it must be made clear that these diaries are personal, subjective treatments that are utilized to supplement the "formal" method of the research process. These persona documents can be utilized to make the research process more complete and thus more responsive to its stated goals and objectives.

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Field Procedure

FIELD INTERVIEW TECHNIQUES

by Max Lowdermilk, James Layton and Warren Smith*

OBJECTIVE

The objective of the interviewer is to obtain information which will reflect the farmer's actual socio-economic conditions and to elicit data about properties of the farmer's social web--kinship group, subcommunity affiliations, organizations, etc.

RESPONSIBILITY

The primary responsibility of the interviewer is: a) interview all of the respondents which are assigned to him; b) record all responses accurately, but be alert for any answers that may not be fully correct (in this case the interviewer may ask for further explanation of the answer given, for example, do mean . . . . or does this include all . . . .); c) obtain all data required by the questionnaire. The interviewer also has the responsibility of understanding how the data will be used so that he can communicate any questionnaire design problems to his supervisor early in the data collection process.

GUIDELINES

Good interviewing is a combination of carefully following instructions, but at the same time using personal judgment. The following section contains instructions which should be used as guidelines rather than unbreakable rules. Although the following instructions should be followed whenever possible, each interview situation will be different and the interviewer must be flexible in his interviewing technique.

1. Meet with key opinion leaders and authorities in the village before interviewing. Explain who is sponsoring the survey and how the information

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*This How-To-Do-It was taken from The Problem Identification Handbook (April 1, 1980). Developed by the CSU-Pakistan Water Management Project sponsored by U.S. Agency for International Development, Contract No. AID/TAC-1100.

will be used. In some cases the village leaders may wish to be interviewed. This will show the farmers that the leaders approve of the survey and will add status to those chosen to be interviewed.

2. Be sensitive to the traditions and customs of the village. The interviewer will often work among farmers whose lifestyle and customs differ from his own. There are some things the interviewer can do to minimize these differences and gain greater acceptance. Wear appropriate informal work clothes when interviewing farmers. When speaking to farmers treat them as equals, not as an officer might treat one of his subordinates. Also, tey to use the language dialect of the village in which you are working. Carefully follow all local customs with regard to religious observances and mourning periods. Although a village may be generally receptive to the interviewer, political events may occur which temporarily make the interviewer unwelcome. Announcements by the government or other countries may make farmers unwilling to give interviews for a few days.

3. Take time to explain the purpose of the interview. Farmers are often suspicious of strangers. They may be afraid you will be responsible for increasing their taxes, or will discover some illegal activities in which they are involved. Before beginning the questions, the interviewer should explain how the farmer was chosen and why the study is being done. Answer honestly any questions the farmer may have. Assure the farmer that data will be kept confidential. Reports will refer only to summaries of numbers. No one will be able to trace answers to a specific respondent.

4. Be thoroughly familiar with the questionnaire. Since many questions relate to each other, a good knowledge of the questionnaire will help the interviewer know if an answer is relevant and help him interpret questions for the respondent. In answering one question the farmer may continue his discussion and provide answers to many other questions without being asked. The interviewer should be able to note these answers in the appropriate places on the questionnaire. He will be able to do this only if he is completely familiar with the questionnaire.

5. Be sure to have adequate directions for locating the farmer-respondent. Much valuable time can be lost searching for a respondent. Village leaders are a good source for obtaining information about the location of house or farm of a respondent. He may also know if the respondent is likely to be at his fields. A guide who lives in the area may be hired. He will not only

know the farm of the respondent, but also where he can most likely be found. If he is well liked in the village, he may be useful in introducing the interviewer to the respondent.

6. Interview the family member best able to answer the questions. The head of the household is often an uncertain term when extended families are involved. The oldest male member of the family may be the head in terms of social status, but have little decision making power or knowledge of farm operations. Crop and irrigation data may be known only by a person who works in the field. Marketing, price or cost data may have to come from a different person. Older family members may be best qualified to answer questions about sociological relationships.

7. Ask to complete the questionnaire at a later time if the farmer wishes to stop the interview before it is complete. Farmers may not have time to complete the questionnaire during the first interview. If this is the case, make an appointment to complete it at another time, but as soon as possible. It is important that the questionnaire is completed even if this requires a second visit.

8. Put the farmer at ease and gain his confidence. Offers of cigarettes to adults and candy to children will help gain the farmer's cooperation. Walking with the farmer through his fields and discussing farm topics will show him that you have a sincere interest in his work. At the same time you will be able to make observations which will relate to information required by the questionnaire.

9. Whenever it is appropriate make actual counts or take actual measurements. Livestock may be counted and storage areas measured. Field areas may be estimated by counting the steps required to walk around the field. Amounts of livestock feed fed daily may be weighed.

10. Interview the farmer in private if possible. The presence of other persons, especially other farmers, may cause the respondent to give answers which he would like his neighbors to hear, rather than true answers. Interviewing the farmer in his fields is one of the best ways of insuring a private interview. However, if others are around do not make the farmer or the other persons uncomfortable by insisting that the two of you be left alone. Use your best judgment.

11. Think critically about the information you are receiving. The farmer may misinterpret a question, the answer may not be complete, or the answer

may not be consistent with other answers or with what you have observed on the farm. Use your best judgment in rephrasing the question or probing for a better answer. Do not confront the respondent with the suspicion that he is not answering honestly. Note this on the margin of the quesionnaire and finish the interview. It is better to lose one piece of information than to have the respondent become angry and stop the interview before it is finished.

12. At the end of the interview check to see that all questions have been answered. At this time you may discuss any inconsistencies you may have noted, but avoid antagonizing the respondent. Write any comments that you may have about the interview which may be useful to those who will tabulate and analyze the data.

13. Thank the respondent for his cooperation. It is important that the interview is concluded on a note of good will. Other farmers will ask the respondent about the interview. Their cooperation will depend a great deal on the attitude of the respondents previously interviewed. Also, you may need to return to obtain further information or clarify some answer that he has given you.

EWUP
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Field Procedure

SAMPLING

by James Layton and Max Lowdermilk*

Sampling is defined as some part of a larger body which is especially selected to represent that whole population with regard to some particular trait. The following brief discussion will describe the sampling procedure by first presenting the basic aspects of this procedure, and then by presenting an example of one type of sampling design. From this presentation, the reader should achieve a basic understanding of how the sampling procedure is organized.

ASPECTS OF SAMPLING PROCEDURE

From the definition presented, a sample involves the select choosing of a number of elements in the population which as a unit represents that population. A population is defined as any complete group whether of people, houses, farms, etc. (Figure 1). Individual units which make up that population are called elements (Figure 1). A sample consists of a number of elements combined together to form a mini-population (Figure 1).

The proper size of the sample, which allows for a proper degree of precision, depends partly on the purpose of the study and also on how much error the researcher is willing to tolerate. In other words, the sample will not be an exact picture of the population and therefore some error in matching that sample to the population will be present. The point of concern for the researcher is how much error is acceptable. A rule of thumb is that a population which has a greater difference among the elements composing that population, the larger the sample must be. If every element in that population is exactly the same, then a sample of one is sufficient;

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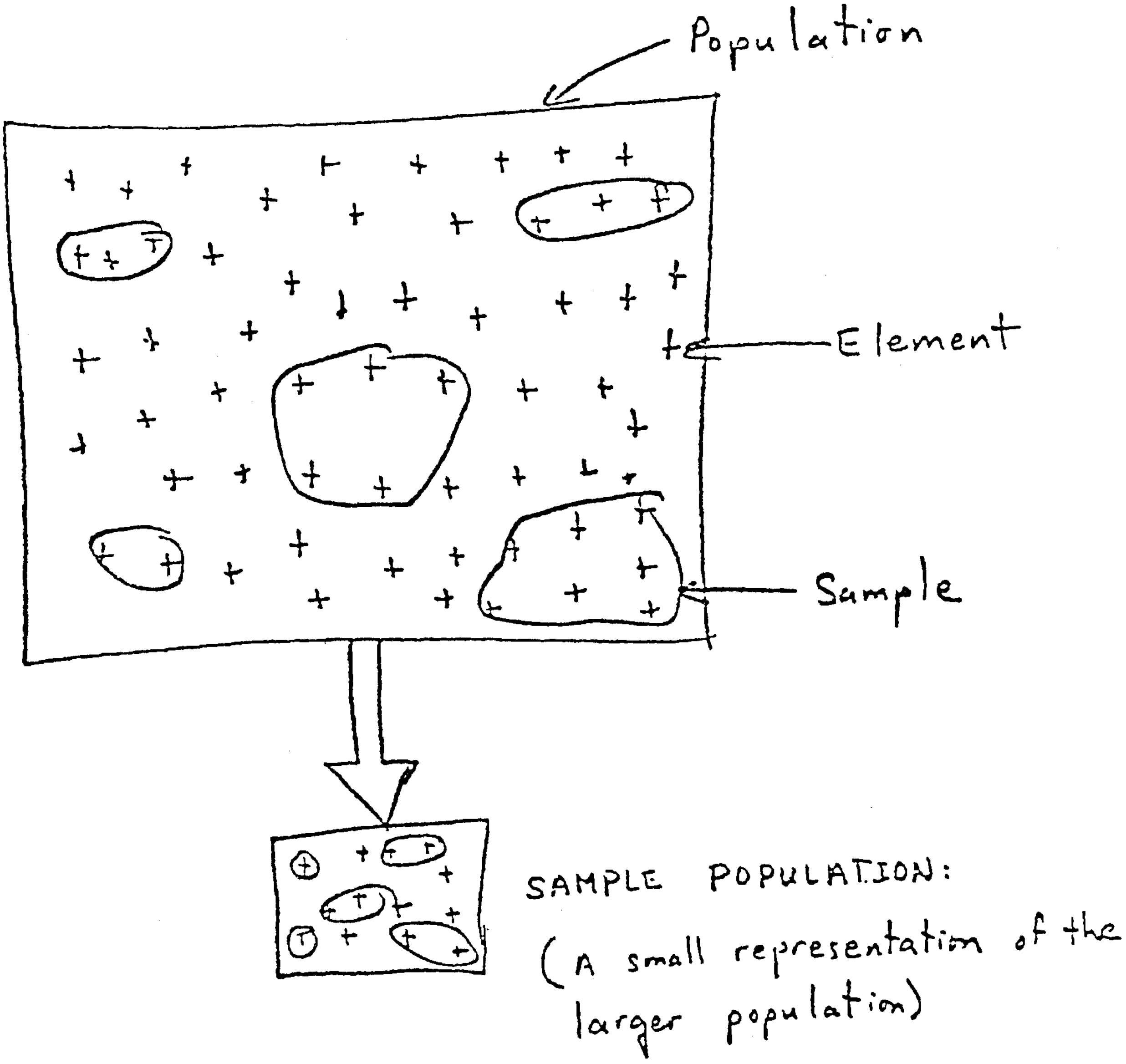
Population
Element
Sample
SAMPLE POPULATION:
(A small representation of the larger population)

Figure 1.

for highly complete populations with many differences, the sample must incorporate all of the differences that make up the population.

In establishing a specific sampling procedure certain questions must initially be asked and answered.

1. What are the resources that are made available for the study?
2. How much does the researcher already know about the population?
3. What is the size of the population?
4. What is the degree of accessibility of those elements chosen to be interviewed?
5. To what extent does the researcher want to generalize the results to the study from the sample to the population?

The answers to these questions will set the boundaries designating which sampling procedures will be appropriate and which procedures will be inappropriate.

Table 1 presents a brief description of six sample procedures that are often used in social science research. The main point of division among the various procedures involves the notion of probability. Probability sampling is a process of sample selection in which elements are chosen by chance methods and have known probabilities of selection. Those methods that do not involve chance selection are called nonprobability sampling. In the procedures presented in Table 1, all involve probabilistic sampling except the judgment type. The use of probability in selecting the sample is important in that it provides a method to increase the precision of selecting the sample y neutralizing various types of bias. Depending on the situation, the more effecive samples will include a combination of the various types of sampling procedures and they in turn will include both probabilistic and nonprobabilistic methods.

In choosing a sample, a procedure that follows can be utilized.

1. Examine the area to be sampled as to the size of the population and the geographic area in which that population is settled.
2. Determine how the area should be divided, again according to population and/or geographic area.
3. Select a sampling procedure(s): simple random, stratified random, cluster, etc., either singly or in combination.
4. Apply that procedure chosen to the situation.
5. Obtain the sample.

TABLE 1

SAMPLING CHART

Type of Sampling	Brief Description	Advantages	Disadvantages
A. Simple random	Assign to each population member a unique number, select sample items by use of random numbers	1. Requires minimum knowledge of population in advance 2. Free of possible classification errors 3. Easy to analyze data and compute errors	1. Does not make use of knowledge of population which researcher may have 2. Large errors for same sample size than in stratified sampling
B. Systematic	Use natural ordering or order population; select random starting point between 1 and the nearest integer to the sampling ratio (N/n); select items at interval of nearest integer to sampling ratio	1. If population is ordered with respect to pertinent property, gives stratification effect, and hence reduces variability compared to A 2. Simplicity of drawing sample; easy to check	1. If sampling interval is related to a periodic ordering of the population increased variability may be introduced 2. Estimates of error likely to be high where there is stratification effect
C. Multistage random	Use a form of random sampling in each of the sampling stages where there are at least two stages	1. Sampling lists, identification, and numbering required only for members of sampling units selected in sample 2. If sampling units are geographically defined, cuts down field costs (i.e., travel)	1. Errors likely to be larger than in A or B for same sample size 2. Errors increase as number sampling units selected decreases
1. With probability proportionate to size	Select sampling units with probability proportionate to their size	1. Reduces variability	1. Lack of knowledge of size of each sampling unit before selection increases variability

TABLE 1 (Continued)

Type of Sampling	Brief Description	Advantages	Disadvantages
D. Strafified 1. Proportionate	Select from every sampling unit at other than last stage a random sample proportionate to size of sampling unit	1. Assures representativeness with respect to property which forms basis of classififying units; therefore yields less variability than A or C 2. Decreases chance of failing to include members of population because of classification process 3. Characteristics of each stratum can be estimated, and hence comparisons can be made	1. Requires accurate information on proportion of population in each stratum, otherwise increases error 2. If stratified lists are not available, may be costly to prepare them; possibility of faulty classification and hence increase in variability
E. Cluster	Select sampling units by some for of random sampling; ultimate units are groups; select these at random and take a complete count of each	1. If clusters are geographically defined, yields lowest field costs 2. Requires listing only individuals in selected clusters 3. Characteristics of clusters as well as those of population can be estimated 4. Can be used for subsequent samples, since clusters, not individuals, are selected, and substitution of individuals may be permissible	1. Larger errors for comparable size than other probability samples 2. Requires ability to assign each member of population uniquely to a cluster, inability to do so may result in duplication or omission of individuals

TABLE 1 (Continued)

Type of Sampling	Brief Description	Advantages	Disadvantages
F. Strafified cluster	Select clusters at random from every sampling unit	1. Reduces variability of plain cluster sampling	1. Disadvantages of stratified sampling added to those of cluster sampling 2. Since cluster properties may change, advantage of stratification may be reduced and make sample unusable for later research
H. Judgment	Select a subgroup of the population which, on the basis of available information, can be judged to be representative of the total population, take a complete count or subsample of this group	1. Reduces cost of preparing sample and field work, since ultimate units can be selected so that they are close together	1. Variability and bias of estimates cannot be measured or controlled 2. Required strong assumptions or considerable knowledge of population and subgroup selected

6. Evaluate that sample in terms of reliability and validity.
7. Locate the individuals to be contacted. With regard to this point, have backup plans for choosing other individuals if the originally chosen people cannot be contacted.

EXAMPLE

The following example will demonstrate how a watercourse may be divided up for the purpose of obtaining a representative sample to be used to test a specific hypothesis. Our hypothetical hypothesis is as follows: the farmer who is further away in distance from the outlet, the less wasteful that farmer is with regard to the use of irrigation water. Figure 2 is a map of one village area where the sample will be drawn. It will be assumed that the researcher has taken into consideration the first set of questions regarding resource availability, researcher knowledge, population size, subject accessibility, and generalizability, and that from this preliminary analysis the following sample has been drawn according to the below stated procedure.

1. Examination of the area to be sampled: the area of concern involves three watercourse systems with multiple crops being grown along the total length of all three systems.
2. Division of the area: the initial divisions will evolve around each watercourse (I, II and III). Within each watercourse area, the sections of the watercourses will be subdivided along main kacha roads (IA, IIC, IIIB, etc.). This procedure is known as area sampling.
3. Selection of sampling procedures: as we move through the various subdivisions in the watercourse a cluster sampling procedure will now occur. Here we randomly select various sections (constituting 25 percent of the total watercourse) of the watercourse that are near the outlet, far from that outlet, and somewhere in the middle (see boxes). One prerequisite to the choosing of these sections is that we will concentrate only on wheat fields so as to standardize our crop and therefore have a base for the necessary measure of water efficiency.
4. After the sections have been chosen a simple random sample of wheat farmers will be taken. For the purposes here we will take a 25 percent sample in each section (X). The distance of the fields will be measured in feet from the mogha outlet.

5. Next, the actual sample will be obtained and be ready for use.
6. This procedure will then be evaluated as to whether or not it does in fact represent the village area as a whole and thus the results of the test of the hypothesis can be generalized from the sample to the population.
7. Finally, the team goes out and contacts every farmer who is to make up the sample.

This sample is just a general presentation of the sampling process. Each area will have its own idiosyncrasies that will complicate the procedure. However, if one follows the above basic steps to obtain a sample, taking into consideration local situations, then that researcher can start to make inferences to the population about a specific hypothesis.

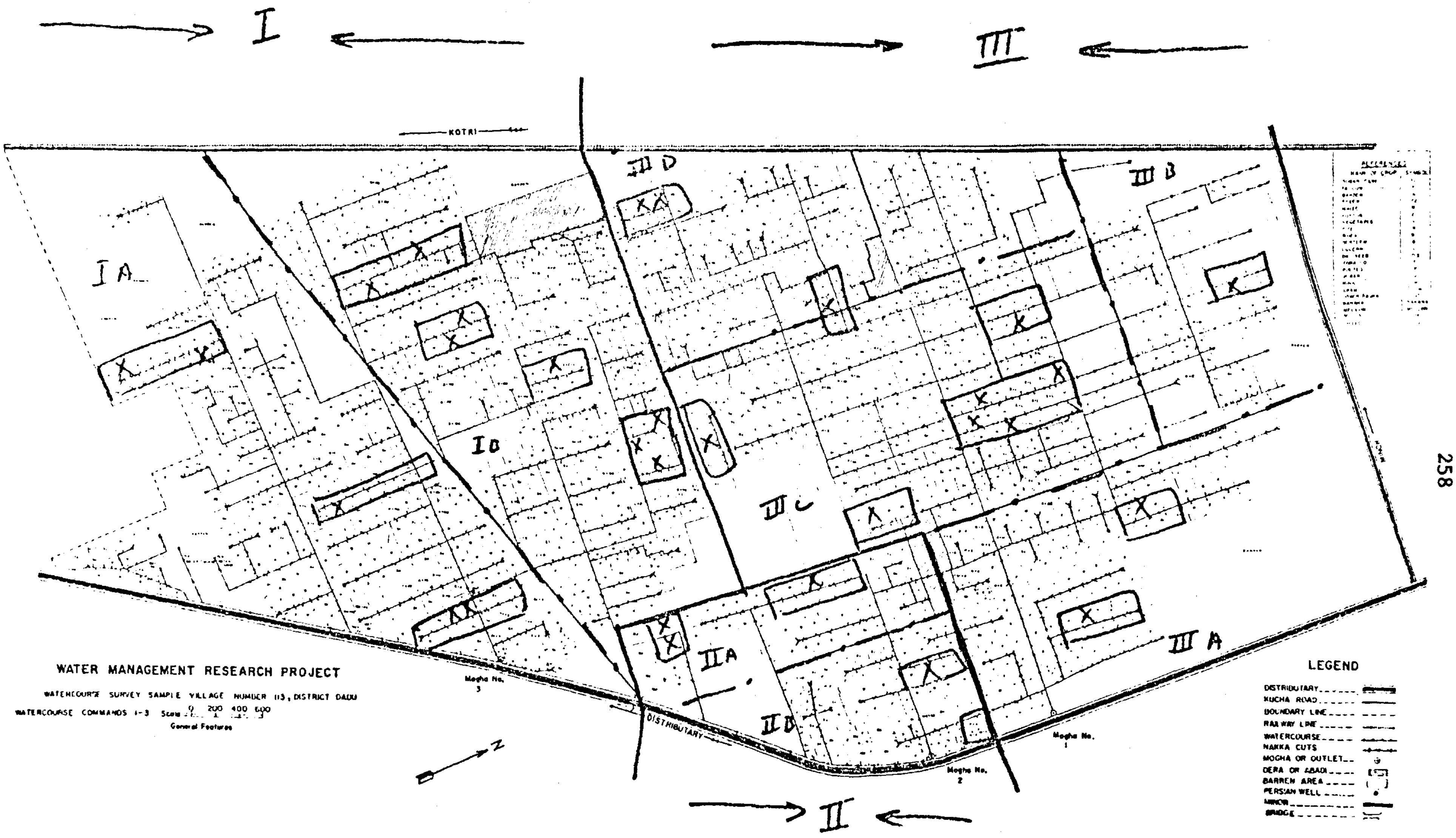
I
III
KOTRI
I A
I B
III D
III B
III C
III A
II A
II D
II
WATER MANAGEMENT RESEARCH PROJECT
WATERCOURSE SURVEY SAMPLE VILLAGE NUMBER 113, DISTRICT DADU
WATERCOURSE COMMANDS 1-3 Scale 0 200 400 600
General Features
Mogha No. 3
Mogha No. 2
Mogha No. 1
DISTRIBUTARY
N
LEGEND
DISTRIBUTARY
KUCHA ROAD
BOUNDARY LINE
RAILWAY LINE
WATERCOURSE
NAKKA CUTS
MOGHA OR OUTLET
DERA OR ABADI
BARREN AREA
PERSIAN WELL
MINOR
BRIDGE

Figure 2.

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VALIDITY AND RELIABILITY CHECKS: INTERVIEW DATA

by Max Lowdermilk and James Layton*

Then one is evaluating an interview schedule, the concern that should be placed above everything else is, does the information which is obtained via this schedule reflect what is truly occuring in the world? There are two main types of tests which are used to determine how well an interview schedule achieves what it is intended to achieve: validity tests and reliability tests. This presentation will discuss what is involved in reliability and validity measures.

Reliability is defined as the consistency, stability, or dependability of a measuring instrument. An example of this is when two independent investigators use the same interview instrument and come to the same results, the reliability of that instrument is said to be good. Validity, on the other hand, is a test to see if a measure does in fact measure what it is supposed to measure. For example, if in asking farmers to rank their farm problems in terms of their importance, farmers may respond by giving the highest ranking to water because they perceive that the researcher is involved with water management. There will be a low degree of validity because we would not be measuring the farmer's perceptions of his problems, but rather the farmer's perception of what the interviewer can do for him.

Reliability

There are two procedures which help determine the degree of reliability of an interview schedule: external consistency procedures and internal consistency procedures (see Figure 1). External consistency procedures compare the cumulative test results against themselves to verify the

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*This How-To-Do-It was taken from The Problem Identification Handbook (April 1, 1980). Developed by the CSU-Pakistan Water Management Project sponsored by U.S. Agency for International Development, Contract No. AID/TAC-1100.

PROCEDURES TO TEST RELIABILITY

External Consistency Procedures   Internal Consistency Procedures

Test-Retest   Parallel Form   Split-Half

DIFFERENT VALIDITY TESTS

Face Validity   Content Validity   Criterion Validity

Figure 1.

reliability of a measure. Two examples of this type of procedure are the test-retest measure and the parallel form of the same test.

A test-retest procedure involves the following situation. After the researcher has interviewed a farmer for the first time, that interviewer or another interviewer goes back to the same farmer after a determined time period and gives the farmer the same interview. The purpose for such a procedure is to see if there is measurable amount of agreement between the first and second tests. If there is then it can be inferred that there is a degree of reliability to the specific test.

The second procedure of external consistency is called the parallel form of the same test. An example of this technique would be where a farmer is first presented with one interview schedule measuring his knowledge of how the watercourse is managed, and then after a period of time is given another schedule containing different items which measures the same knowledge of how the watercourse is managed. Again if there is a measurable amount of agreement between the two tests, then a degree of reliability in the first survey can be inferred.

There are some problems in determining reliability from the above two procedures. The major problem that may occur is that the first test will affect the individual farmers by exposing that farmer to the points brought out by the questions. Therefore when the second test is administered, the farmer will already have been made aware of the questions and the person may change his answer because of this awareness. The interviewer should be aware of this reliability problem when interpreting how reliable the measurement tool is.

The second major procedure measuring reliability known as internal consistency procedures. This is an attempt to increase the reliability of a test by seeing if the respondents answer the various questions based on some pattern of agreement. In other words, if a number of questions are used to measure one variable, a respondent who answers low on one question should also answer low on the other questions in order to have a reliable questionnaire. A technique to measure this type of agreement if the split-half technique.

The split-half technique is designed to use a large number of equivalent questions and then after the data is collected, the questions will be divided into two halves and compared for their equivalence. An example of this technique would be as follows. The researcher wishes to measure the degree of innovativeness of farmers based on their income, education, and so on. In order to do this, a questionnaire was constructed which contained a list of a number in innovation which have been adopted in the region and this list was then presented to a respondent who checked the innovations he utilized. In testing the reliability of this instrument, the list of innovations was divided into two equivalent parts (that is both parts have an equal number of easy innovation and difficult innovations). A reliable instrument would be the instrument where farmers who scored high on one set of innovations would also score high on another set of variables which measured the same degree of innovativeness. Reliability is measured by Pearson's "r" or Spearman's rho.* Attachment A provides an example of a test-retest procedure.

Validity

The researcher's concern with validity, again, has to do with trying to find out if a measure is truly measuring what one is intending to measure. There are three main types of validity: (1) face validity, (2) content validity, and (3) criterion validity (Figure 1). The procedure that is least objective and perhaps most subject to error is <u>face validity</u>. One just looks at the concept to be measured and asks does it appear to get at the concept "on the face of it." For example, to measure a farmer's wealth by counting the amount of equipment he has on his farm would be a measure having face validity.

A second type of validity is called <u>content validity</u>. The question now becomes: is the substance or content of this measure representative of the content of the property being measured? For example, on an interview schedule measuring a farmer's degree of wealth; if that schedule only asks questions regarding the number of items in his house while neglecting the ownership of farm equipment, then the measure would not have high content

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*

$$r = \frac{\Sigma(X-\bar{X})\ (Y-\bar{Y})}{\sqrt{\Sigma(X-X)^2\ \ \Sigma(X-Y)^2}} \qquad \text{rho} = 1 - \left(\frac{6 \sum_{i=1}^{N} D_i 2}{N(N^2 - 1)}\right)$$

validity. A measure that has a high degree of content validity would be a measure that includes all aspects of a concept it is trying to measure.

Criterion validity is the third type of validity measure. Validity, in this sence, is measured by comparing the researcher's test with another test that is known to measure the concept under study. For example, if a researcher wanted to measure and compare the results of the test with a previously recognized measure that was also used. If the results are equivalent, then it can be said that a high degree of criterion validity is present.

Evaluations concerning validity and reliability are set up to find out if there are any biases occurring in the gathering of data. The following questions should be asked when constructing a measuring device, such as a questionnaire in order to determine its degree of validity and reliability.

(1) Does the form of the instrument introduce any bias?

- Is the questionnaire too long? This would account for poorly thought out answers toward the end due to the respondent becoming tired.

- Are the sensitive questions placed in an appropriate spot in the questionnaire? This would cause the respondent to not answer truthfully regarding the question.

- Do the questions actually extract the information needed to obtain the information wanted?

- Are there questions in the questionnaire which check other questions to see if the answers given are consistent?

(2) Does the cultural aspect of the measuring instrument lead to patterned biases?

- Does the language of the questions create an unpleasant atmosphere?

- Is the phraseology inappropriate?
- What is the bias emerging from an open-ended questionnaire vs. a closed-ended one?

(3) Are there mechanical factors that may emergy to create a patterned bias?

- What is the reading and writing aptitude of the respondent?
- What is the time schedule for the administration of each questionnaire? If the time is too short, then the interviewer may get in a hurry to complete his assignment and thus the quality of the answers will probably be effected.

(4) What environmental factors impede the validity and reliability of the measure?

- Is the personal interaction between the respondent and the interviewer appropriate? In other words, does the interviewer ask questions in a leading manner, does the socio-economic (class) difference between the two parties affect the questions, does the ethnic difference or similarity affect the interview, etc.
- Do the questions involve one's memory and if so, for how long?
- How are the physical facilities utilized in the interview? Is the atmosphere comfortable, hostile, friendly, etc.?

(5) Does the interpretation of the data lead to patterned biases occurring?

These questions must be taken into consideration when gathering data in order to ensure a proper degree of reliability and validity. In preparing the instruments these questions should be on the minds of the researchers, and every effort should be made to alleviate such conditions brought out by these questions that will interfere with proper reliability and validity criteria. The tests described above will demonstrate how effective these questions have been answered.

ATTACHMENT A

TEST RE-TEST RELIABILITY OF SELECTED MEASURES

Item	N	Pearson Product-Moment Correlation r	Percent of Sample Retested
Total Acres Owned	75	.996	19.3
Acres Cultivated This Watercourse	76	.978	19.6
Cropping Intensity (Kharif + Rabi)	74	.814	19.1
Nitrogen Fertilizer Applied to Wheat	73	.680	18.8
Wheat Yields (Maunds/Acre)	69	.840	17.8
Trading Full Irrigation Turns (Rabi + Kharif)	74	.926	19.1
Nitrogen Fertilizer Applied to Berseem	74	.686	19.1
Availability of Inorganic Fertilizer	74	.748*	19.1
Percent Increase in Wheat Yields	75	.926	19.3
Percent Increase in Wheat Acreage	72	.846	18.6
Availability of Credit for Fertilizer	70	.77*	17.1

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*Value represents, not an r coefficient, but a simple percentage of the re-test items identical in value to the original values. This procedure is necessitated by virtue of the type of nominal data gathered for these two items.

$$r = \frac{\Sigma(X - \bar{X})\;(Y - \bar{Y})}{\sqrt{\Sigma(X - X)^2 \quad \Sigma(X - Y)^2}}$$

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ANALYSIS OF INSTITUTIONAL SERVICES LINKAGES IN COMMUNITIES OR VILLAGES

by David Freeman with the assistance of Nenita Tapay

OBJECTIVES

The objectives of this analysis are:

1. to list and evaluate the available services in the farmers' locality or villages,
2. to identify the kind of problems encountered by farmers in dealing with available services,
3. to analyze and determine the type of linkages between institutional services from the viewpoints of institutional personnel and of farmer users, and
4. to come up with recommendations to resolve institutional service problems.

STATEMENT OF CONCEPTS AND PROCEDURES

Concept 1. Importance and Need of Institutional Services

Farmers need: 1) a market center providing markets for farm products and retail outlets for farm supplies and equipment; 2) adequate roads, both to connect the farms within each locality to its market center with outside world; 3) local verification trials of supposedly improved practices; 4) extension services; 5) access to farm production credit; 6) availability of irrigation services. All of these elements are highly complementary (see Figure 1).

Lowdermilk et al. (1978) in Pakistan indicated that farmers are burdened by the absence of effectively organized services in banking, agricultural extension, and irrigation. Evidence regarding the lack of services is marshaled from sample farmer responses to a series of questions having to do with their knowledge of, and contracts with, ten kinds of local officials who have responsibilities for working with farmers. Respondents earned the following points:

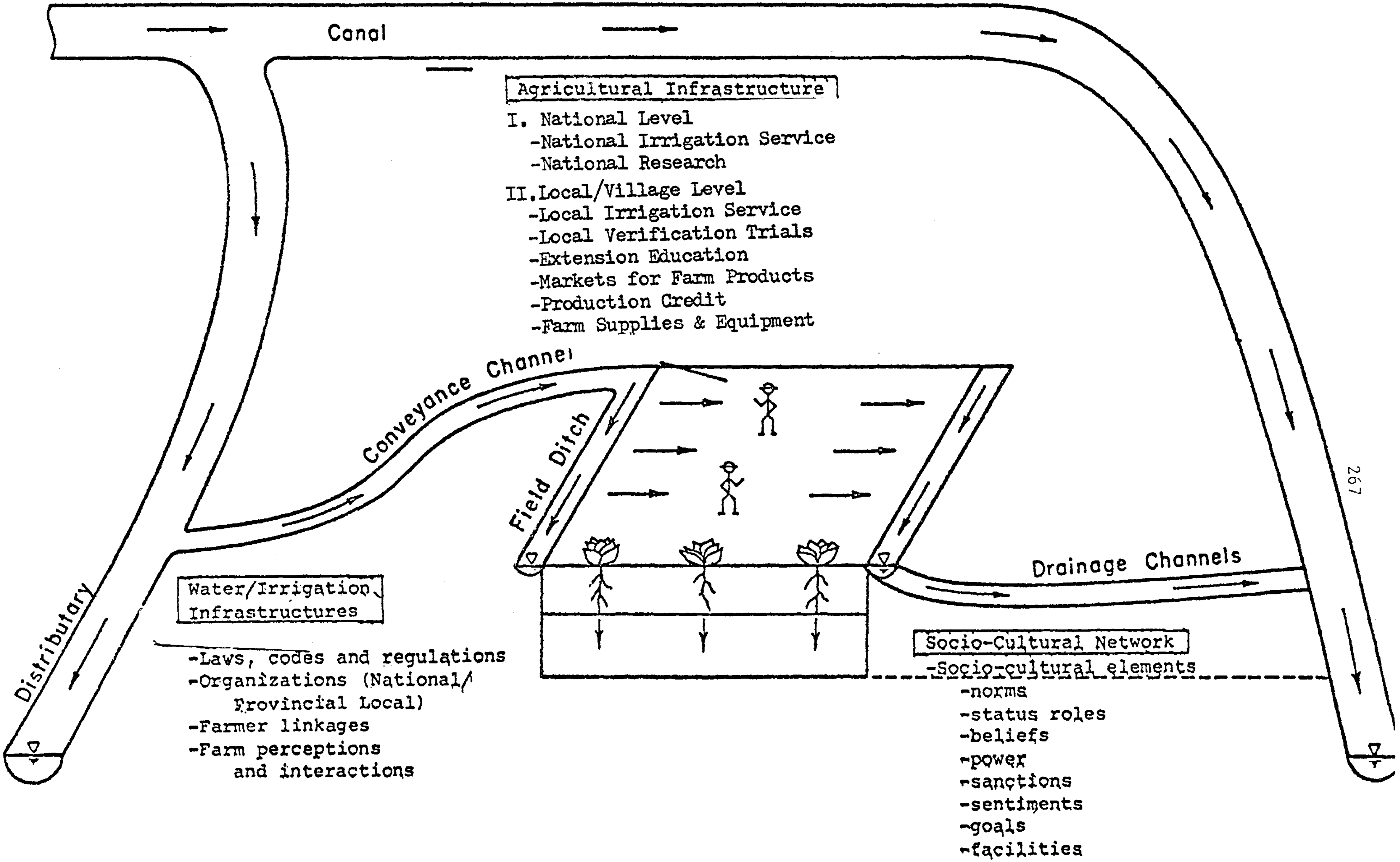

Figure 1. Idealized sketch of a farm irrigation system and institutional infrastructures.

a) One point for identifying the location of any given official's office or residence.

b) Two points for correct naming of any given official.

c) Points were granted to each respondent on a sliding scale for having had contracts with officials for the preceding three months. The more contracts, the more points.

The respondent will acquire a given total of points by identifying the location of at least one representative of each category, by correctly naming at least one representative, and by reporting frequent contracts within 90 days.

Figure 2 displays the distribution of sample farmer scores on the Institutional Service Index (Lowdermilk et al. (1978: Vol. 4, p. 188). The scores are skewed sharply. Overwhelmingly, sample farmers received low scores by virtue of the fact that they report little or no contracts with officials and they most typically cannot name them or identify their locations. Forty-one percent of the sample farmers score no points on the index, and 93 percent earn 50 or fewer points.

Farmer problems with lack of services is illustrated in Table 1, which displays scores on the index broken down by farm size class. Inspection of Table 1 shows that although 86 percent of the sample farmers score 15 or fewer points on the 110 point index, larger farmers do report a higher level of knowledge and contact in reference to services. The contingency coefficient (C) reveals a moderately strong relationship between increased farm size and reports of increased service. The "p" value reveals that the relationship would occur by chance less than one time in 10,000. Smaller farmers report poorer services than larger ones, but this fact should not mask the low level of services reported by farmers in all farm size categories.

The Pakistan farmers is constrained by the lack of services. This is evident when one examines that sub-set of services having to do with providing farmers with information about canal closures for cleaning, repair, rationing, and seasonal distribution (see Table 2). Sample farmers were asked as to whether they "never," "sometimes" or "often" receive information about canal closures. Water is a critical factor in crop production, and the Irrigation Department is explicity mandated to inform

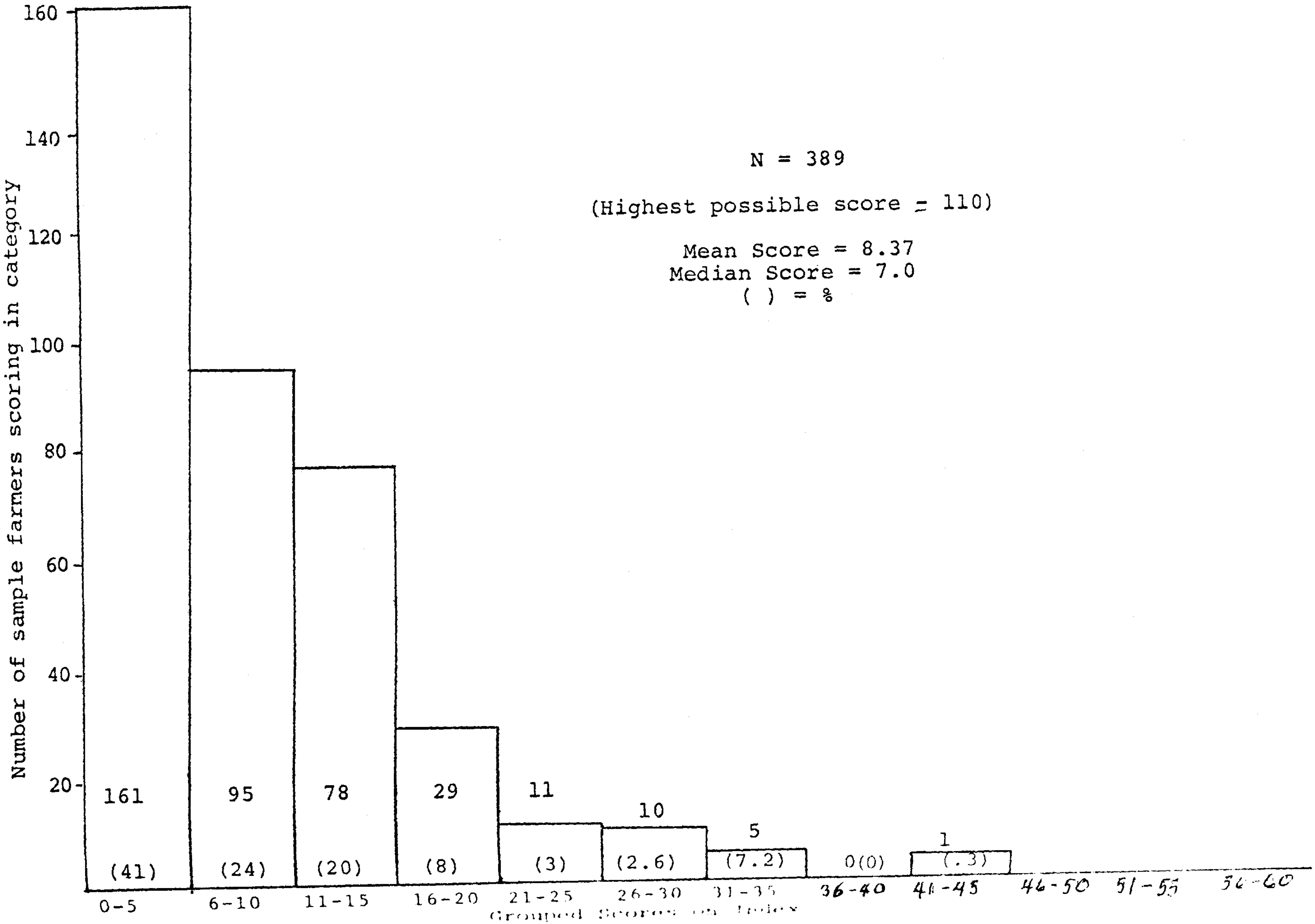

Figure 2. Distribution of farmers scores on Institutional Services Index.

Table 1. Institutional service index scores by farm size category.

Institutional service index score	Percent in farm size category (acres)						
	≤ 2.49	2.5-7.49	7.5-12.47	12.5-24.9	25-49.9	50+	Row %
0 - 5	12.9	12.3	9.0	6.9	.3	0	41.4
6 - 10	4.1	7.2	6.4	5.9	.8	0	24.4
11 - 15	1.8	3.9	7.2	5.9	1.3	0	20.1
16 - 20	1.0	.8	2.1	1.8	1.3	.5	7.5
21 - 25	0	.8	.8	.5	.3	.5	2.8
26 - 30	0	.5	0	1.0	.3	.5	2.3
31+	0	0	.3	.5	.3	.5	1.5
TOTAL	19.8	25.5	25.5	22.5	4.6	2.0	100%

N = 389
X^2 = 132.6
d.f = 30
P = .00001
C = .50

Table 2. Mean sample farmer scores on access to canal information index by farm class (range of possible scores = 0-16).

Farm Class Size (acres)	Mean Score	N
All sizes	3.33	388
≤ 2.49	2.29	77
2.5-7.49	2.81	99
7.5-12.49	3.62	99
12.5-24.29	3.98	88
25.0-49.99	4.12	17
50.0-74.99	7.25	8

farmers of impending scheduled canal closures; yet, farmers are poorly informed. A respondent who often receives advance information for the Irrigation Department by any means could potentially score 16 points on the index. Table 2 reveals that, overall, the average sample farmers scores only 3.3 points. No farmer in the sample scored half of the potential on the index, but average scores increased as farm size increased. Larger farmers did have greater access to information about impending canal closures than did smaller operators, but lack of information constrains sample farmers of all sizes.

Concept 2. The Organization as the Unit of Analysis

Although it is obvious that socio-political life consists of individual personalities, it is just as obvious that individual human beings to not behave randomly. Rather, all the different personalities are harnessed into organizational webs. Individual human beings are best analyzed and predicted from the standpoint of the organizations which they create and maintain to pursue collective action. Individuals live, die, come, go, get promoted and resign via the organizational webs and linkages of which they are a part. It is more important to measure properties of the social organizational web and its central activities, than it is to attempt to tap into all the different individual personalities. Small changes in certain aspects of the social web can make big differences to institutional services planning.

STATEMENT OF FIELD DATA COLLECTION/TECHNIQUE

1. Knowledge and evaluation of institutional services.

The objective is for the sample farmer to rate the availability and usefulness of local services. A list of available services must be constructed by following the format as illustrated below. Take note that personnel on the list of institutional services must be accessible to the sample farmer. Each sample farmer and his area of location will have a unique list of service personnel.

Personnel	Knows location	Knows name	Contacts past three months	Evaluation of Helpfulness +2: Highly 1: Some 0: No Help -1: Some Unhelpful
Ag. Ext. Officer				
Field Assistant				
Dev. Assistant				
Ag. Engineer				
Project Manager				
Bank/Credit People				
Cooperative Officer				
Farm & Equipment Supplier				
Fertilizer Agent				
Revenue Officer				
Irrigation Personnel				
a. local ditch rider				
b. turnout authority				
c. others (specify)				
____________________				
____________________				
____________________				
____________________				

2. List the kind of problems encountered by farmers in dealing with available institutional services in their village or locality.

Personnel	Problems
1. Ag. Officer	1.
	2.
	3.
2. Field Assistant	1.
	2.
	3.
3. Dev. Assistant	1.
	2.
	3.

3. Identify the key organizational network or institutional services linkages.

Identification of Key Organizational Networks or Linkages

At either state, district, or the village level, it is necessary to identify organizations or institutional services which are important to irrigation water management. Such organizations will vary from the relatively simple and small such as a local farmer irrigation association, to the large and complex such as a major fertilizer manufacturing firm. A list of such organizations can be constructed from the available services in the villages or locality. Generally, such a list will consist of local government organizations, and organizations providing credit, cooperative services, irrigation water, marketing of farm products, extension services, and others.

The list may be as limited or as extensive as you and your farmer informants wish to make it. However, as the list lengthens it probably will be wise to break it down by districts or villages to keep analysis as simple and straightforward as possible. Given an organization list, a matrix is constructed by:

1. Arranging the list of organizations vertically down the left-hand column and horizontally across the top as displayed in Figure 3.
2. Determining the linkages among the organizations by asking knowledgeable organizational informants to respond to a question. Generally, on issues of importance, representatives of my organization consult with ...
   a) Each organizational key informant supplies a rating in response to the questions which can be coded as follows:

      Always = 4
      Sometimes = 2
      Rarely = 1
      Never = 0
      Not Applicable (N/A) = 9
3. The grid then will display the mutual consulting patterns of the listed organizations. Those organizations which have high mutual relationships can be identified as an organizational network. There may be several such networks identified as well as a number of organizations which have few or no linkages.

Format of Sociometric Organizational Matrix

Organizational	Local Gov. Ext. Services		...	Credit Services	...	Commodity Production	...	Cooperatives	...	Irri. Water Assoc.
Local Government Extension Service										
.		2								
.	0									
.	1	1								
Credit Services										
.	2	4								
.	4	4								
.	4	2								
Commodity Production										
.	0	0								
.	1	2								
.	2	2								
Cooperatives										
.	0	1								
.	0	0								
.	4	4								
Irrigation Water Association										

Figure 3.

4. Several types of computations can be made on values generated in such a grid, but one of major interest is the centrality score. The centrality score expresses the organizational centrality or isolation. Basically, an organization which is rated "4" by many representatives of other will be much more central in the network than one which receives mostly zeros. Easy to compute, centrality values expressed as a percentage of the highest possible value are derived from the following formula:

$$\text{Centrality } (Cj) = \frac{A}{P}\ (100)$$

where
A = sum of actual scores received by a given organization j in a given row of the matrix,
P = sum of highest possible scores that could have been granted to an organization; N/A responses are excluded from the computation, and
j = a given organization.

The higher the centrality score, the more central the organization with respect to all other organizations on the matrix.

Tracking of Strategic Issues in the Organizational Network(s)

The basic structure of the organizational network is revealed on a matrix such as that displayed in Figure 1. The next question becomes: what are the major issues of concern in the network(s)? The sam key informants who supply the rating for the Figure 1 matrix can also be asked to identify the top three issues of concern to the organization at present. Such issues must be identified by an open-ended instrument so as not to force constructions of issues in inappropriate ways. Responses to the questions can be analyzed for content, coded, and entered on an organizational issues matrix such as that displayed in Figure 4. Figure 4, examined in light of Figure 3, will reveal which issues are of what importance according to each organization on the Figure 3 matrix. The issues can then be examined according to the centrality of the organizations with which they are associated. Examples of the kind of analysis which can be performed are provided in Figures 2, 3, and 4, and Tables 1 and 2.

Format of an Organizational Issues Matrix

Listing of Organizations (Same list as on Figure 1)	Issue Codes		
	1st Priority	2nd Priority	3rd Priority
Local Government Extension Services			
.			
.			
.			
Credit Services			
.			
.			
.			
Commodity Production			
.			
.			
.			
Cooperatives			
.			
.			
.			
Irrigation Water Association			

Figure 4.

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DE JURE-DE FACTO ANALYSIS OF IRRIGATION ORGANIZATIONS'S LAWS AND RULES

by Robby Laitos, Max Lowdermilk and David Freeman

OBJECTIVES

In this exercise, you will compare the specific laws and rules of an irrigation organization with the actual behavior of farmers in the field. Is there a difference between what the laws and rules state, and what is actually taking place in the field?

By conducting the analysis, certain objectives should be met:

1. To provide a good understanding of how the irrigation system operates at the farm level and the roles of local irrigation officials.
2. To identify how farmers behave when they have to work under specific irrigation codes.
3. To identify certain legal incentives and disincentives for the farmers.
4. To provide field data to policy makers and irrigation officials who are interested in improving the efficiency of farm water management.

CONCEPTS

In many parts of the world, laws and codes exist which regulate how an irrigation organization is supposed to operate. Some of these rules are very modern and efficient, while others need to be developed and updated to meet the needs of modern agriculture. While national and state laws are very important to the farmers, they vary in their impact on farmers in specific irrigation commands. This exercise will focus on those codes which affect local irrigation organizations and the specific behavior of irrigators.

In all countries, these local rules need to be relevant to today's demands. The regulations need to be flexible and provide incentives for farmers and organizations to utilize water efficiently and with equity. The rules should be able to be implemented easily and effectively. The codes should also take into consideration local customs and values, in addition to national goals. It is perhaps better to have no law than a law which is not and should not be obeyed and can easily lead to disrespect for any form of government.

The rules governing irrigation organizations and their members need to be examined objectively. Laws and rules are developed by people, and people should have the right to change these codes when they are outdated or no longer relevant to specific situations. This exercise will help you to examine critically irrigation organization's laws and codes. We want you to examine at the farm level how these laws operate as incentives or discentives to improved farm water management. As improvements and changes are made in the farm system we should always evaluate the existing codes and regulations.

To accomplish this evaluation, it is necessary that you study the difference between de jure and de facto situations. The work de jure refers to the legal or formal codes which are supposed to govern the irrigation organizations. The word de facto refers to how well these codes or laws are being implemented. In other words, de jure is what the law states, while de facto is what actually takes place. Often, the de jure and de facto situations will be very different, just as the official and actual operation of irrigation systems are often very different.

Some of the irrigation organization's laws may actually act as constraints to the farmers and the codes may be an inhibitor to change and progress. The farmers might be forced to break the law to obtain more flexibility in their irrigation operations. Such a lack of respect for the law and irrigation authorities could make some farmers angry and discouraged, and might even operate to increase the gap between large and small farmers. When conducting a de jure and de facto analysis of the irrigation organization's laws and rules you should ask yourself not only if there is a difference between the de jure regulations and the de facto situation, but are the laws themselves justifiable in terms of increased agricultural production, fairness and flexibility? If the laws are justified, then improved supervision and enforcement of the laws should be considered. But if the laws are not justified, then perhaps you should consider ways in which the laws could be changed.

When you meet with policy makers, government officials, and irrigation authorities in your country, a *de jure-de facto* analysis can provide them with valuable information. For instance, are some of the regulations acting as constraints or disincentives to the development of irrigation at the farm level? If the farmers do not like the laws and manipulate the system, is the government or irrigation association losing respect and money?

PROCEDURES

The *de jure-de facto* analysis is really very straightforward and simple to do. You need first to establish what the *de jure* codes are and then investigate at the farm level how well these are implemented.

1. Identify the codes which regulate the irrigation organization and the important variables for which field data are needed.
2. Develop and pretest a set of questions to be asked of the farmers who belong to the irrigation organization.
3. For each irrigation organization to be studied, choose 4 or 5 carefully selected farmers and 4 or 5 irrigation organization officials to be interviewed.
4. Compare and contrast the *de jure* laws with the *de facto* practices.

To gather data for this exercise, it is best simply to divide a piece of paper into a large left-hand colume and right-hand colum. The codes that govern the irrigation organization and its members would be listed under the left-hand *de jure* column, while the *de facto* situation resulting from field investigations would be listed in the right-hand column.

The following example should help to show you how the *de jure-de facto* analysis is done in the field. The data are taken from a study on a watercourse in Pakistan.

Selected watercourse rules and regulations: *de jure* versus *de facto* operation (based on a survey of one watercourse).

De jure (what the law states) Watercourse Regulations	*De facto* (what in fact takes place) Reports and Observations
I. Punishable by law to damage or manipulate outlet which controls flow from canal to watercourse. a. official regulated discharge 1.8 cusecs b. permissible cropping intensity 80% or about 213 acres for summer and winter	I. Outlet physically damaged and size enlarged. a. actual discharge is more than 3.0 cusecs b. actual cropping intensity observed 157% in 1974-75 or 373 acres for summer and winter c. 33 or 35 farmers report that outlet can be manipulated for a negotiable amount
II. Regulated and fixed turns cannot be changed unilaterally by farmers. a. trading of turns not permissible b. canal water not be be traded for tubewell and vice versa	II. Farmers at waterlift operate systematic local water exchange night and day. a. 60% of farmers report trading full turns and 86% report trading partial turns b. 10 farmers trade canal water for tubewell water on a regular basis
III. Illegal to use water of one outlet command area for fields on another command area.	III. About 22 acres of land where water from outlet investigated is used for the adjacent command area. a. physical evidence of connecting ditches and cement pipes to pass water across other watercourse b. 8 acres of investigated outlet command irrigated from adjacent watercourse
IV. Illegal to make unauthorized cuts in main watercourse or build any structure.	IV. Farmers have built a concrete cut in bank of adjacent watercourse (all of this documented by pictures).
V. Only a prescribed number of field outlets premissible per 25 acres, usually one	V. This watercourse has 3 outlets/cuts at farmers will--about 125/25 acres

De jure (what the law states) Watercourse Regulations	De facto (what in fact takes place) Reports and Observations
VI. Illegal to steal water.	VI. Farmers near the outlet which controls flow from canal to watercourse made cuts into the main watercourse and irrigated small rice fields at will. Observed and documented during measurements.
VII. Unauthorized remission of water rates cannot be given. Authorized remission cases must be approved by the divisional officer.	VII. 33 of 35 farmers report illegal payments to have the revenue official reduce their water assessment by bribes and extra tips.
a. farmers on systems constrained by presence of low capacity waterlift pay only 1/2 of revenue assessment	a. 7 farmers once on a waterlift but now on flow still pay the 1/2 rate
VIII. Watercourse repairs and maintenance to be checked by official who can have fines levied or water supply closed if main ditches are not kept in good repair.	VIII. Farmers work on watercourse only infrequently to remove silt accumulations. No supervision or fine ever levied for lack of watercourse maintenance.
IX. Illegal to bribe revenue or irrigation officials.	IX. 33 or 35 farmers report the customary bribes and 32 report paying it seasonally. Farmers report interactions with other officials when needed.
X. Canal Department must notify farmers of closures for repairs, cleaning, and rationing purposes.	X. 33 of 35 reported not receiving information in advance; 33 of 35 did not know rationing schedules started during watercourse study.

DATA ANALYSIS

When you have completed your investigation, take some time to study the differences between the _de jure_ regulations and the _de facto_ situation. If there are large differences between the two columns, then this might suggest that some of the irrigation organization's codes are outdated or not applicable to modern agriculture. Here it is best to use your own personal knowledge and judgement about these differences. As a committed interdisciplinary team member you should discuss these results with other members of your team, farmers, and irrigation officials, and then decide upon an appropriate course of action.

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IMPORTANCE OF SOCIAL CONFLICT ANALYSIS IN ON-FARM WATER MANAGEMENT

by David Freeman with the assistance of Theodoric Manley

INTRODUCTION

Irrigation systems are also involved in, and generate social conflict. Any set of rules for delivery and distribution of water will affect social groups unevenly. Some farmers will be advantaged at costs to others, some values promoted, other values will be undercut. Benefits for farmers at the "tail" of a watercourse may clearly disadvantage those toward the "head," that which assists "small" farmers may be opposed by larger ones.

Conflict management, control, and resolution is a significant function of irrigation organizations everywhere. For example, in Pakistan, at one time, local level formal irrigation organizations did not exist, which could have served to manage the inevitable conflicts. Thus, when local level informal kinship mechanisms failed to provide acceptable social conflict control and resolution, farmers either accepted an unhappy circumstance which may have undercut their productivity or they went well beyond the village to physically and socially remote agencies--the police, courts, or Irrigation Ministry. The costs of pursuing conflict in the courts or in the irrigation bureaucracy can be a substantial burden even for the larger farmers. Small operators may not have the resources for prolonged conflict in agencies beyond the village, especially when their opponents possess more wealth and power.

A METHOD FOR ESTIMATING SOCIAL CONFLICT CLEAVAGE PATTERNS

Objectives

The following materials will present basic concepts and procedures for a social conflict analysis.

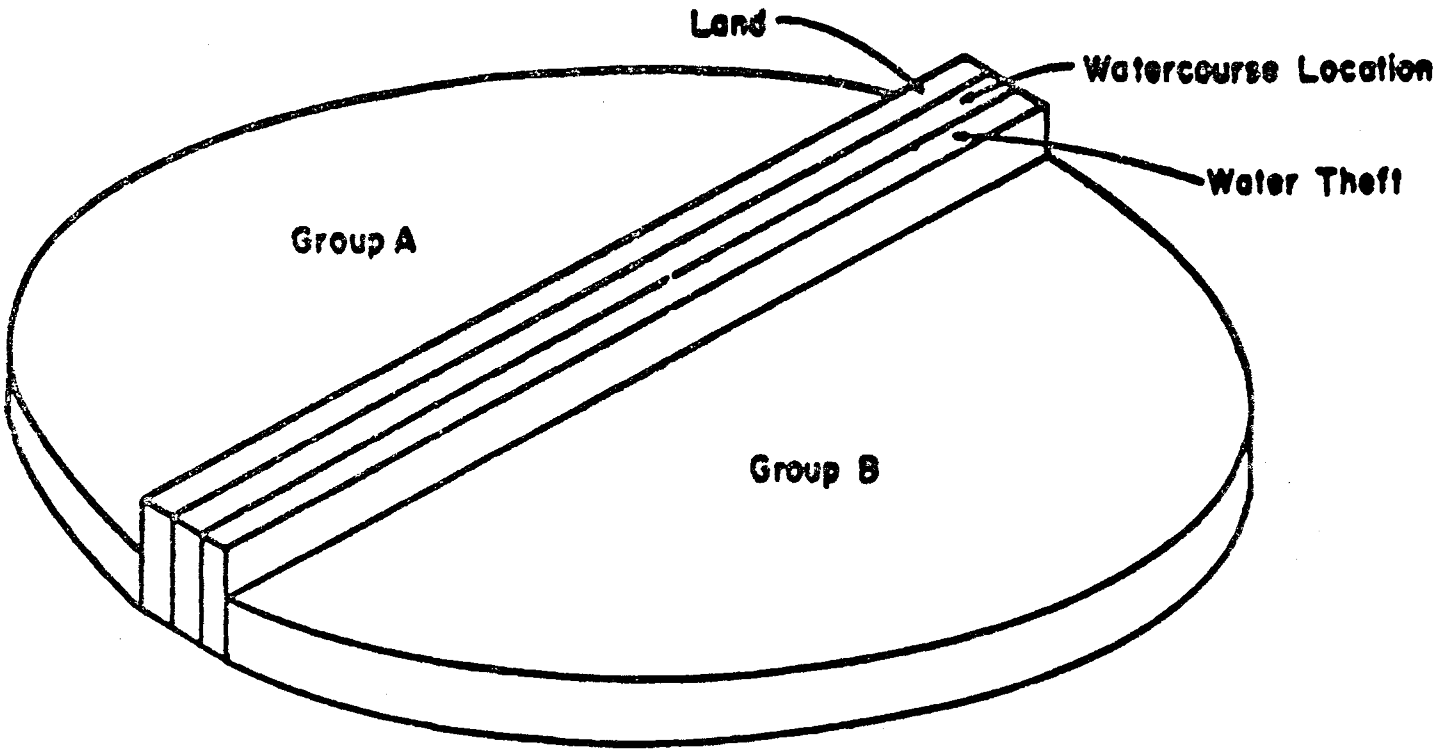
Statement of Concepts

Conflict Cleavages: are lines of division within or among social groups across which opponents fight.

Overlapping Cleavage Pattern: exists when groups are opposed on all significant cleavages. Opponents on one issue are opponents on all (see Figure 1). A winner on one issue will be a winner on all. Similarly, a loser on one issue is threatened with loss on all. Threat levels are high (Dahrendorf, 1959). Each opponent group develops togetherness based on the need for unity against the enemy. Each site must "cash in" whatever resources are available to stop the opponents from advancing their values (Freeman, et al., 1977).

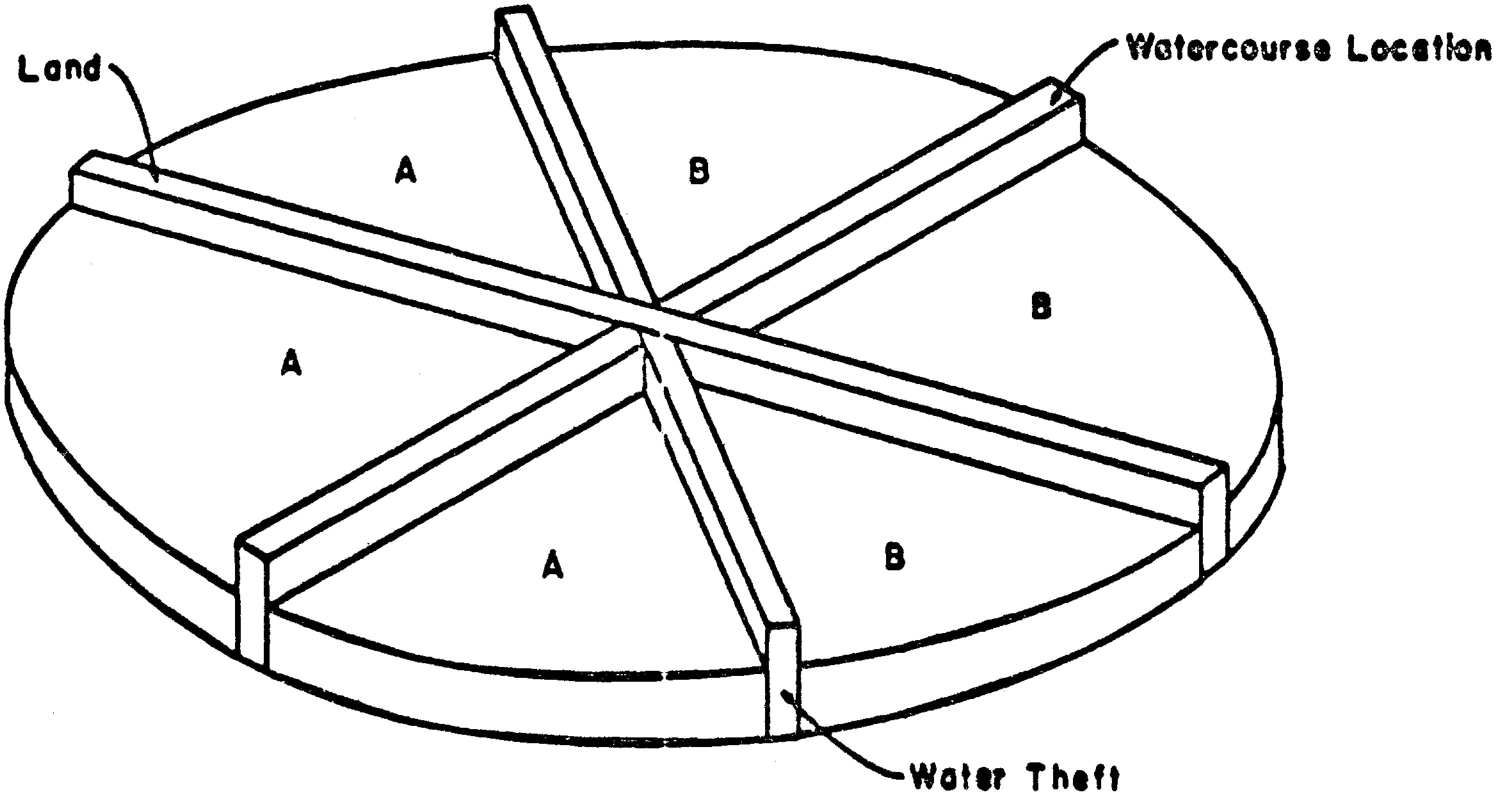
Cross-Cutting Cleavage Patterns: exist when a particular opponent group is in opposition to another group, but is allied in common cause with that same group in other significant conflicts (see Figure 2).

Social cohesion here is based on negotiation, trade-offs, social exchange, and bargaining. In summary, decision makers should evaluate alternative courses of action according to their estimated impact on the structure of social conflict.



Note: A's are Allied Against All B's on All Issues Over which there are Cleavages.

Figure 1. Overlapping Cleavages - High Polarization.



Note: Some A's are Allied with at Least Some B's on Each Issue Over which there are Cleavages.

Figure 2. Cross-Cutting Cleavages - Low Polarization.

A METHOD FOR ESTIMATING CONFLICT CLEAVAGE PATTERNS IN A PLANNING AREA

The preparations which should be made in advance of the social conflict exercise consist of the following:

(1) Define proposed management alternatives,i.e., water rights for all farms; water rights for large farmers only; no water rights.

(2) Determine the boundaries of the primary planning area.

(3) Define a list of the significant occupational, recreational, and cultural activities engaged in by groups in the primary planning area.

(4) Select key informants who will identify conflicts and parties of local groups on the issues.

Define an inventory of base cleavages.

(1) Identify base conflict cleavages central to the primary planning area. Cleavages are defined as lines of division across which groups oppose each other over differences in value preferences. The task is to identify the major patterns of conflict with whom over what issues? Base cleavages are determined by identifying the conflict issues central to the primary planning area. A list of cleavages frequently can be initially composed by examining conflicts discussed with key informants. Discussion with key informants knowledgeable about the planning area is the means to construct an initial list of conflict cleavages of importance.

(2) Make an inventory of the conflict cleavages. The issues must have implications for the planning area, not just particular individuals.

(3) Issues should be clear-cut and expressed in a "for" or "against" form. Example: for or against water rights to all farmers; for or against water rights to large farmers only.

(4) Prepare a hare ballot with the list of issues on it. Make a copy of the hare ballot for each participant. The hare ballot is employed to reduce a large number of issues to a manageable number for subsequent analysis of the social conflict data. This is accomplished by having the participants rank their issues in order of their importance on the day of the exercise (1 = most important ..., 10 = least important).

(5) Administer the hare ballot to each key informant. Have each informant rank the selected cleavages in order of importance. Collect the ballots.

(6) Compute the results of the hare ballot.

Those six issues with the lowest scores (i.e., the highest ranking) provide the base issues which are employed for the analysis of social conflict. Note that many issues could be listed on the hare ballot but only the top six issues need to be used for subsequent analysis. Experience has shown that six issues represent a good number, though as many as ten issues could be used in the analysis. This many issues, however, places a greater burden on the participants. (See next page for an example of the hare ballot).

INSTRUCTIONS TO INFORMANTS FOR MAKING SOCIAL CONFLICT ESTIMATES

ESTIMATING EXISTING BASE CLEAVAGES IN PLANNING AREA

You are asked to consider specific base cleavages (identified below, and listed on the left-hand side of your Response Sheet) and to estimate the position and degree, pro or con, that particular types of groups and organizations (listed across the top of your Response and Tab Sheets) will take toward each issue. In making each estimate, use the following scale:

-	0	+
Against	Neutral	For

LIST OF CLEAVAGES (Example)

1. For or against local faction charged with water theft
2. For or against local cooperative leadership
3. For or against ______________________________
4. For or against ______________________________
5. For or against ______________________________
6. For or against ______________________________

Note: This list is composed of those six cleavages highest ranked by all panel participants at the beginning of the conflict exercise.

EXAMPLE
HARE BALLOT
FOR RANKING BASE CLEAVAGES

Instructions: Please examine the issues listed below which have surfaced in public involvement meetings. Rank the issues in their order of importance using "1" to indicate the most important, "2" to indicate the second most important ... and 10 to indicate the least important.

CLEAVAGE	IMPORTANCE OF THE CLEAVAGE
#1 - For or against local cooperative leadership (example). . .	____________
#2 - For or against faction charged with water theft (example).	____________
#3 - For or against	____________
#4 - For or against	____________
#5 - For or against	____________
#6 - For or against	____________
#7 - For or against	____________
#8 - For or against	____________
#9 - For or against	____________
#10 - For or against	____________

RESPONSE SHEET (example)

Social Conflict Exercise
Establishing Base Cleavages

	LIST OF BASE CLEAVAGES					
Activities-Groups	Base Cleavage #1: Water Theft	Base Cleavage #2	Base Cleavage #3	Base Cleavage #4	Base Cleavage #5	Base Cleavage #6
Local Leaders of Faction 1						
Local Leaders of Faction 2						
Local Leaders of Faction 3						
Private Tubewell Group						
Public Tubewell Group						
Large/Small Farmer Coop						
Official Local Leadership Groups						
Water Management Personnel						
Extension Workers						
Police						
Revenue Officer						
Kinship Groups						
Cooperative Society Members						
Local School Leadership						

TABULATION SHEET

Social Conflict Exercise
Establishing Base
Cleavages

	BASE CLEAVAGE #1					BASE CLEAVAGE #2					BASE CLEAVAGE #3				
I.D.#															
Local Leaders of Faction 1															
Local Leaders of Faction 2															
Local Leaders of Faction 3															
Private Tubewell Groups															
Public Tubewell Groups															
Large/Small Farmer Coop.															
Official Local Leadership Groups															
Water Management Personnel															
Extension Workers															
Police															
Revenue Officer															
Kinship Groups															
Cooperative Society Members															
Local School Leadership															

ESTIMATIONS OF CONFLICT PATTERNS ASSOCIATED WITH PROPOSED MANAGEMENT ALTERNATIVES

You are asked to consider specific land management alternatives (listed below and at the top of your Response and Tab Sheets) and to estimate the position, that particular types of groups and organizations (listed on the left-hand side of your response and tab sheets) will take toward each management alternative. In making each estimate, use the following scale:

-1	0	+1
Against	Neutral	For

LIST OF MANAGEMENT ALTERNATIVES (Example)

ALTERNATIVE GREEN (A)

1. legally fixed water rotation based on acreage cultivable

ALTERNATIVE ORANGE (B)

2. legally fixed water rotation based on unit of time

ALTERNATIVE WHITE (C)

3. free market trade with no mixed allowed

Social Conflict Exercise

Part II: Management Alternatives

RESPONSE SHEET

Participant #________
Round #__________

Water Rights	Mgt. Alt. A			Mgt. Alt. B			Mgt. Alt. C			Mgt. Alt. D		
	a	n	f	a	n	f	a	n	f	a	n	f
Local Leadership of Faction 1	-1	0	+1	-1	0	+1	-1	0	+1	-1	0	+1
Local Leadership of Faction 2	-1	0	+1	-1	0	+1	-1	0	+1	-1	0	+1
Local Leadership of Faction 3	-1	0	+1	-1	0	+1	-1	0	+1	-1	0	+1
Private Tubewell Group	-1	0	+1	-1	0	+1	-1	0	+1	-1	0	+1
Public Tubewell Group	-1	0	+1	-1	0	+1	-1	0	+1	-1	0	+1
Large/Small Farmer Coop.	-1	0	+1	-1	0	+1	-1	0	+1	-1	0	+1
Official Local Leadership Groups	-1	0	+1	-1	0	+1	-1	0	+1	-1	0	+1
Water Management Personnel	-1	0	+1	-1	0	+1	-1	0	+1	-1	0	+1
Extension Workers	-1	0	+1	-1	0	+1	-1	0	+1	-1	0	+1
Police	-1	0	+1	-1	0	+1	-1	0	+1	-1	0	+1
Revenue Officer	-1	0	+1	-1	0	+1	-1	0	+1	-1	0	+1
Kinship Groups	-1	0	+1	-1	0	+1	-1	0	+1	-1	0	+1
Cooperative Society Members	-1	0	+1	-1	0	+1	-1	0	+1	-1	0	+1
Local School Leadership	-1	0	+1	-1	0	+1	-1	0	+1	-1	0	+1

a = against (-1); n = neutral (0); f = for (+1)

Social Conflict Exercise

Part II: Management Alternatives

TABULATION SHEET

	Mgt. Alt. A						Mgt. Alt. B						Mgt. Alt. C					Mgt. Alt. D					
Water Rights																							
Local Leadership of Faction 1																							
Local Leadership of Faction 2																							
Local Leadership of Faction 3																							
Private Tubewell Group																							
Public Tubewell Group																							
Large/Small Farmer Coop.																							
Official Local Leadership Groups																							
Water Management Personnel																							
Extension Workers																							
Police																							
Revenue Officer																							
Kinship Groups																							
Cooperative Society Members																							
Local School Leadership																							

ANALYSIS OF SOCIAL CONFLICT DATA

Establishing Base Conflict Patterns

1. A base activity group is selected. The activity group with the fewest neutral positions on the six base issues is selected as a base category. Local leadership of fraction one was chosen as the base for this example and is so designed at the top left on Tables 1 and 1.1.
2. Each of the other activity groups can then be seen as taking a position of alliance with, neutrality toward, or opposition to the base activity group's position. For example, faction two can be estimated to be either allied with, in opposition to, or neutral with regard to faction one's activities on a given cleavage.
3. The number of base cleavages upon which activity groups take positions is established. In this example, there were six cleavages upon which activity groups take positions. Once the list of base cleavages is established, then:
    a) The position of each activity group is recorded in the column headed "Observed Position" (see Table 1). The number that appears reports the number of times that particular activity group was estimated by the panel to be allied with, opposed to, or be neutral to, the position taken by the selected base activity group category. A six under "For Faction one and zero under Against Faction one" would indicate that the group was estimated to support the base position six out of six times.
    b) The observed pattern of support and opposition (Table 1: A column) is then compared to the expected pattern (Table 1: B column) that would ideally occur if there was a perfect pattern of cross-cutting conflicts. If conflicts were perfectly cross-cut, one would expect that each activity group would be half the time for the base activity group position and half the time against. Thus, given six cleavages on which the activity group is estimated to have taken a non-neutral position the expected pattern for perfectly cross-cut positions on the conflict fronts is 3/3. In those cases where groups are seen as neutral (0), the

expected pattern is based on only positive (+) or negative (-) positions. Consequently, since Faction two is estimated to be neutral on one cleavage, the expected pattern for Faction two is 2.5/2.5.

c) The question is now asked: How much deviation is there between the observed conflict patterns and the ideal cross-cutting pattern (Table 1: C column)? Scores are computed by determining the difference between the number of times a given group is for Faction one and the expected value and then determining the difference between the number of times each group was estimated to be against Faction one base activity group and the expected value. Because the sign attached to these numbers is not important, the signs are ignored. It is the number of units of deviation which is critical, not the direction of the deviation. Discarding signs, all deviation values are summed, which in the case of Table 1, equals 27 units of deviation from a pattern of pure cross-cutting conflict. This, then is the manner in which the base conflict pattern is established.

Relating the Conflict Pattern associated with each proposed Management Alternative to the Base Conflict Pattern.

1. The question is: given that the activity groups are estimated to assume the conflict patterns seen in Table 1 (Column A), will any given proposed management alternative be estimated to introduce more or less cross-cutting conflict into the existing pattern? More polarization will be reflected in increasing units of deviation from the pure cross-cutting distribution. Less polarization will be reflected in a reduction of the numbers of deviation units.
2. Each proposed management alternative is compared to the existing base conflict pattern presented in Table 1, A columns. The estimated positions are displayed under column headings D, E, F, and G in Table 1.1. Columns D, E, F, and G are devoted to presenting the conflict profile estimated by the researcher obtained under proposed alternative.

3. A (+1) appears if the position taken by the group would increase the deviation from the ideally expected split--3/3, 2/2, 1.5/1.5, ect. A (-1) appears if the established group position would decrease the deviation. A zero appears if the activity groups are estimated to take a neutral stance.
4. Incorporating the signs attached to each deviation value, the deviations are then algebraically summed across activity categories. A polarization score for each management alternative is thereby derived. The scores are recorded at the bottom of Table 1 and result in the following ranking of proposed management alternatives.

Management Alternative Ranking	Contribution to Increased Conflict Polarization
1. Green (A)	-4
2. Orange (B)	-3.5
3. White (C)	-1.5
4. Blue (D)	+2.5

INTERPRETING THE FINDINGS

Base Conflict Pattern

The sum of deviation scores across activity groups shown at the bottom of Table 1 indicate that the study area is unpolarized. This is to say that on several base cleavages, opponents on one are allied on others.

Effect of Conflict Pattern of Management Alternatives on Base Conflict Pattern

In the example, no proposed management alternative is unacceptable from a social conflict standpoint. The rankings reveal their relative desirability vis-a-vis each other, but even the the last ranked alternatives added only 2.5 units of polarization in a study area that is nonpolarized (see Table 1). Nevertheless, there is still a ranking of alternatives from most to least desirable. If Table 1 had revealed a number of highly polarized splits (5 or 6 times for the base group; zero times against) and if a given proposed alternative (Table 1.1) had further exacerbated the split by once again placing allies on base cleavages against old enemies, the contributions to increase polarization would be susbstantial and concern would be heightened to reflect or reassign that proposed alternative. Even if such alternatives are economically attractive and technically sound, they

TABLE 1

CONFLICT PATTERNS OVER SIX EXISTING BASE CLEAVAGES

(Example)

	COLUMN A			COLUMN B		COLUMN C
ACTIVITY GROUPS	OBSERVED POSITION			IDEALLY EXPECTED POSITION		DEVIATIONS FROM IDEAL EXPECTED POSITION
	FOR	AGAINST	NEUTRAL	FOR	AGAINST	
Local Leadership of Faction 1			0			
Local Leadership of Faction 2	2	3	1	2.5	2.5	-.5/+.5
Local Leadership of Faction 3	2	3	1	2.5	2.5	-.5/+.5
Private Tubewell Group	4	2	0	3	3	+1/-1
Public Tubewell Group	2	3	1	2.5	2.5	-.5/+.5
Large/Small Farmer Coop.	2	0	4	1	1	+1/-1
Official Local Leadership Groups	2	3	1	2.5	2.5	-.5/+.5
Water Management Personnel	2	4	0	3	3	-1/+1
Extension Workers	2	2	2	2	2	0/0
Police	1	0	5	.5	.5	+.5/-.5
Revenue Officer	4	2	0	3	3	+1/-1
Kinship Groups	3	3	0	3	3	0/0
Cooperative Society Members	4	2	0	3	3	+1/-1
Local School Leadership	5	1	0	3	3	+2/-2
						Σ27

TABLE [illegible]1

COMPARISON OF ESTIMATED POSITIONS ON MANAGEMENT ALTERNATIVES TO EXISTING CONFLICT PATTERN

(example)

	COLUMN D				COLUMN E				COLUMN F				COLUMN G			
ACTIVITY GROUP	MANAGEMENT ALTERNATIVE GREEN (A)				MANAGEMENT ALTERNATIVE ORANGE (B)				MANAGEMENT ALTERNATIVE WHITE (C)				MANAGEMENT ALTERNATIVE BLUE (D)			
	FOR	AGST	NEUTRAL	D	FOR	AGST	NEUTRAL	D	FOR	AGST	NEUTRAL	D	FOR	AGST	NEUTRAL	D
Local Leadership of Faction 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Local Leadership of Faction 2	X			-1	X			-1	X			-1	X			-1
Local Leadership of Faction 3	X			-1	X			-1	X			-1	X			-1
Private Tubewell Group		X		-1		X		-1	X			+1		X		+1
Public Tubewell Group		X		+1		X		+1			X	0			X	0
Large/Small Farmer Coop.		X		-1		X		-1			X	0			X	0
Official Local Leadership Groups	X			-1	X			-1			X	0	X			-1
Water Management Personnel	X			-1	X			-1			X	0	X			-1
Extension Workers		X		+.5			X	0			X	0			X	0
Police		X		-1			X	0			X	0			X	0
Revenue Officer		X		-1		X		-1	X			+1			X	-1
Kinship Groups		X		+.5		X		+.5	X			+.5		X		+.5
Cooperative Society Members		X		+1	X			+1	X			+1	X			+1
Local School Leadership		X		1	X			+1	X			+1	X			+1
				-4				-3.5				+2.5				-1.5

are of potential danger to social well-being and the choice context which a planning area can afford to diverse publics.

CONCLUSION

The change agent must be careful to 1) establish credibility with groups on all sides of the cleavage--something most difficult when cleavages are tightly polarized, and 2) insure that both costs and benefits of planned programs are shared with relative equality with groups on all sides of the cleavages. To introduce a change program which places the benefits largely on one side of an existing cleavage and to direct the disadvantages largely to the other side is to increase conflict polarization and flirt with social disruption, lack of cooperation and program paralysis no matter how technically feasible and how economically justifiable.

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EWUP
How to do it
Field Procedure

LINEAR PROGRAMMING TEACHING MANUAL
(Computer System HP 9825 A)

by M. I. Haider

INTRODUCTION

The programs in these collections enable the users to solve many types of linear programming problems. The technique used to optimize the objective function is a modified simplex method which incorporates variable bounds.

The linear programming package contains two different versions. The first version (Cartridge version) is referred to as L.P. 9825 A which contains the program and can hold the input data. The second version is referred to as 9885 M Flexible disk drive, and it also holds the program and input data. The 9885 M version allows larger problems to be solved and also contains some programs to set up a permanent data base for use in building LP problems

The programs in the Cartridge version are divided into two modes of operation: single or batch. The single mode allows the user to enter, modify, solve and print one problem at a time. The batch mode allows the user to specify up to 25 problems stored on the cartridge to be solved in a single run.

Both versions contain an unpacked and packed program. The unpacked data version stores one number per register and the packed version stores two numbers per register. The unpacked version should be used whenever possible to increase the accuracy of the results and the speed of calculations. The packed data version should be used when the problem is too large to be run with the unpacked version.

There are certain constraints placed on the user of these programs: (1) data are limited to six digits, (2) the user must set up all problems so that the constraints are separated by type: first less than or equal; second equalities; and finally the greater than or equal constraints.

If a problem is too large, error will occur when the matrix is dimensioned. The data in the L.P. Manual appendix informs the user about the general limit on problem sizes.

The 9885 M version also includes two additional features of matrix generation and problem building which use the data base previously entered and stores on the disk. These features can be used to build different problems using the data base and build problems for later optimization. For greater detail, see the L.P. Manual.

EXAMPLE

The example chosen as a study guide uses Egyptian farm data for the ABU RAIA region.

In this study guide the data are analyzed using both the Cartridge version and the Flexible disk drive version. In the first portion a simpler program which does not consider renting and hiring activities is used to illustrate the development of the Linear programming input matrix and interpreting the result. This is accomplished by using the unpacked cartridge version.

In the second portion an expanded model is used to illustrate the use of both cartridge and disk versions. The storage, retrieval, and data modification features of the program are illustrated using packed and unpacked progrmas of the 9885 M Flexible disk drive version.

Data Preparation

Input data for the nine crops considered in this example were obtained from farm crop budgets which were prepared by the project participants in the ABU RAIA region and from the data obtained from the Farm Records activity. A crop budget indicates the various variable costs, fixed costs, gross return, and net return associated with production of one feddan of a particular crop. The Farm Records can be used to identify the amounts of land, labor, capital, and other resources available to be allocated among the alternative uses.

In order to transform the crop budget data to a single linear programming input format, a number of assumptions and minor calculations are needed. In this example, wheat, flax, berseem and beans were selected as winter crops and cotton, rice, eggplant, tomato, and maize as summer crops. The rotation system was handled by considering two types of land in the input constraint, each with a total of five feddans. The winter and summer crops were assigned to winter and summer land respectively, by assigning (1) or (0) in the appropriate box as shown by the following input matrix.

For example, a one in Constraint 1 of the input matrix indicates that 5 feddans of winter land are available and a one in Constraint 2 makes the same 5 feddans available to summer crops. The third Constraint is for winter labor and Constraint 4 specifies the amount of summer labor available. Constraints 5 and 6 correspond to the availability of capital and water, respectively.

Total farm family labor force was also divided between winter and summer labor, Constraints 3 and 4 respectively. The assumption was made that each farm family has manpower equivalent to four men with allocation of about 80 percent of their time to the farming operation. This provides a labor constraint of 600 man-days of labor for each growing season. The data from the 12 farms, for which records are kept, indicate a family labor pool could provide the aforementioned amount of labor. However, if part of the family is engaged in off-farm employment, then the labor constraint should be revised downward or the hiring of labor should be considered.

Constraint 5 indicates the amount of all costs other than land, labor, water and management. These latter four cost items are treated as fixed costs. It is assumed that each farmer has access to 1,200 Egyptian pounds to purchase the required variable inputs. Constraint 6 indicates the number of irrigations required by each crop, and the constraint of 120 watering indicates the total of the 24 annual waterings allotment per feddan (5x24).

The value of the objective function for each crop indicates the return to fixed cost items which are maximized. If inputs such as labor and water can readily be purchased in the area, then they can be included in the variable cost. If they are available only in set amounts, a value is assigned to them. This inputted value or shadow price is useful in evaluation of the contribution of these factors to final output of the farming operation.

The upper and lower bounds specify the maximum and minimum amounts of each crop that must be produced. The maximum of five feddan for each crop means that the farmer has placed no upper constraint on any of the crop as the total available land is equal to five feddans. The lower bounds of 1 for wheat and cotton, and .5 for rice are used to illustrate the minimum feddans of each of these three crops that must be produced as may be

Matrix 1

Title: Egypt Farms

Variable Number	Objective Function	Lower Bounds	Upper Bounds	Variable Name	Winter land Constraint 1	Summer land Constraint 2	Winter labor Constraint 3	Summer labor Constraint 4	Capital Constraint 5	Water Constraint 6	Constraint 7	Constraint 8	Constraint 9	Constraint 10	Constraint 11	Constraint 12
1	72	1	5	Wheat	1	0	30	0	35.2	5						
2	113	0	5	Flax	1	0	39.5	0	32.3	6						
3	103	0	5	Berseem	1	0	18	0	43.2	11						
4	55	0	5	Beans	1	0	28	0	26.7	4						
5	135	1	5	Cotton	0	1	0	70.5	45.3	7						
6	84	.5	5	Rice	0	1	0	48	30.1	34						
7	263	0	5	Eggplant	0	1	0	234	265	36						
8	304	0	5	Tomato	0	1	0	248	296	22						
9	49	0	5	Maize	0	1	0	32	55.3	9						
Constraint Type (<=, =, >=)					<=	<=	<=	<=	<=	<=						
Constraint Values					5	5	600	600	1200	120						

COMPUTER PRINTOUT OF THE INPUT DATA

```
CONSTRAINT      1
 1.00 wheat
 1.00 flax
 1.00 berseem
 1.00 bean
< = 5.00

CONSTRAINT      2
 1.00 cotton
 1.00 rice
 1.00 eggplant
 1.00 tomato
 1.00 maize
< = 5.00

CONSTRAINT      3
 30.00 wheat
 39.50 flax
 18.00 berseem
 28.00 bean
< = 600.00

CONSTRAINT      4
 70.50 cotton
 48.00 rice
234.00 eggplant
248.00 tomato
 23.00 maize
< = 600.00

CONSTRAINT      5
 32.50 wheat
 32.30 flax
 43.20 berseen
 26.70 bean
 45.30 cotton
 30.10 rice
265.30 eggplant
296.50 tomato
 55.30 maize
< = 1200.00
```

```
CONSTRAINT      6
 5.00 wheat
 6.00 flax
11.00 berseem
 4.00 bean
 7.00 cotton
34.00 rice
36.00 eggplant
22.00 tomato
 9.00 maize
< = 120.00

OBJECTIVE
FUNCTION
MAXIMIZE
 72.00 wheat
113.00 flax
103.00 berseem
 55.00 bean
135.00 cotton
 84.00 rice
263.00 eggplant
304.00 tomato
 49.00 maize

VARIABLE LIMITS
wheat
 1.00, 5.00
flax
 0.00, 5.00
berseem
 0.00, 5.00
bean
 0.00, 5.00
cotton
 1.00, 5.00
rice
 0.50, 5.00
eggplant
 0.00, 5.00
tomato
 0.00, 5.00
maize
 0.00, 5.00
```

required by the Egyptian government. The value of bounds and constraints is hypothetically assigned and would be changed in the second portion (expanded model) of this Manual and would be further modified by the students to illustrate their impact on the profitability of the farming operation.

Using the Computer

The computer linear programming manual indicates how the computer can be activated and the input data entered into the computer. This step will be demonstrated directly by using the computer unit at the Engineering Research Center.

INTERPRETING THE RESULT

Solution

The solution indicates the number of feddans of different crops that the farmer should produce in order to maximize return to fixed inputs given the input constraints.

Slack and its associated number (SLK #) indicates the amount of a particular variable input that remained unused. Since slack such as for land (inputs #1 and #2) and summer labor (input #4) does not appear, this means that all of the available amounts of these inputs are being used. In this case the five feddans of land for the winter season were used in the production of flax and wheat. The five feddans of summer land was allocated to cotton, tomato, and rice production in 3, 1.5, and .5 feddans, respectively. The letter L to the right-hand side of wheat and rice indicates that these two crops are produced at their lower bounds and that if the lower bounds of one feddan for wheat and .5 feddan for rice were not set, then lesser or none of these crops may have been produced. The aforementioned crop production pattern resulted in a return of 1419.86 LE to the land, water and farmers' labor and management.

```
ANSWERS:

BASIS AFTER
ITERATION      3
VARIABLE  VALUE
flax        4.000
cotton      3.042
SLK 3     412.000
tomato      1.458          OBJECTIVE
SLK 5     451.243          FUNCTION
SLK 6      20.634          VALUE = -1419.86
wheat L     1.000          IN             3
rice L      0.500          INTERATIONS
```

When summer labor was increased from 600 man-days to 700 man-days, the production of tomatoes increased at the expense of cotton because it is more profitable, although more labor intensive. The tomato feddanage increased from 1.45 feddans to 2 feddans and cotton production decreased .55 feddans.

```
ANSWERS:

BASIS AFTER
INTERATION          3
VARIABLE  VALUE
flax        4.000
cotton      2.479
SLK 3     412.000
tomato      2.021          OBJECTIVE
SLK 5     310.004          FUNCTION
SLK 6      12.183          VALUE = -1635.07
wheat L     1.000          IN            3
rice L      0.500          ITERATIONS
```

This switching of .5 feddans of land from cotton to tomato production led to a net gain of 95 LE in the value of the objective function. If labor could be hired at half a pound per day, then there would be a net increase of 45 pounds in the farmer's return to his fixed inputs.

Because summer labor is still being completely used (SLK 4 does not appear), it means that more of summer labor could further increase net returns. A farmer should continue hiring more labor when available until the increase in net return per unit of labor hired is equal to the cost of the unit of labor hired. Labor hiring activity is illustrated in the second portion of this manual.

Dual Variables

The value associated with each constraint indicates that if one more unit of the constraint input was made available *ceteris paribus*, the value of the objective function would have been increased by that amount. Zero means a surplus of the variable input exists and, therefore, it has a zero opportunity cost--adding more of a resource would not increase the profits for the farm. In this case, the values 113 and 67.9 indicate the value of one more feddan of winter and summer land, respectively, to the farmer, given the other available inputs. If this farmer could rent one feddan of land for 30 pounds per cropping season, then the farmer would be able to increase his net return by 83 LE and 38 LE respectively. The value .952 indicates the contribution that one additional unit of summer labor can make to the value of the objective function. If labor could be hired at a daily rate less than this amount, it would pay to add labor.

```
DUAL VARIABLES:
COLUMN    VALUE
 10      113.000
 11       67.876
 12        0.000
 13        0.952
 14        0.000
 15        0.000
```

The objective function value which immediately follows dual variables in the solution indicates the return to the associated fixed costs. (See the section on Solution.)

SENSITIVITY ANALYSIS

RHS Ranging

This section indicates the lower and upper limits for each constraint where the basis variables (crops that entered the solution voluntarily) would remain in the solution. Lower and upper limits are signified by LL and UL, respectively. The B value indicates the amount of the variable input that remained for utilization for the voluntary portion of the basis variable (activities that entered the solution voluntarily). In this case it was the 4 feddans of flax as winter crop and 3.5 feddans for cotton and tomato (see solution #1). The difference between the original or assigned constraint and the B value indicates the amount of the factor inputs used by activities or portion of the activity of cotton, wheat, and rice that were forced or would have been forced into the program solution.

In the case of constraint for winter land, the LL=0 means that at any amount of land above zero, some amount of flax would have been produced. For summer crops LL= 2.04 means that if the availability of land was less than 2.04 feddans, then at least one of the two summer crops of cotton and tomato that were voluntarily produced would have no longer appeared in the solution as voluntary production. Likewise, the UL= 7.44 for winter land means that if the land availability was greater than 7.44, flax production on a voluntary basis would not have occurred as its allocation would have been taken over by other crops.

The same explanation holds regarding the role of the other constraints on the feasibility of production of crops termed as basis variables. The usefulness of this analysis is in providing information on the critical role

```
SENSITIVITY
ANALYSIS
* * * * * * * * * * *

RHS RANGING
* * * * * * * * * * *

CONSTRAINT          1
 LL =            0.00
 B  =            4.00
 UL =            7.44
CONSTRAINT          2
 LL =            2.04
 B  =            3.50
 UL =            7.17
CONSTRAINT          3
 LL =          158.00
 B  =          570.00
 UL =       UNBOUNDED
CONSTRAINT          4
 LL =          246.75
 B  =          505.50
 UL =          749.67
CONSTRAINT          5
 LL =          653.21
 B  =         1104.45
 UL =       UNBOUNDED
CONSTRAINT          6
 LL =           70.37
 B =            91.00
 UL =       UNBOUNDED
```

that various constraints play in production of various crops. In other words, it indicates the degree to which each crop may be sensitive to the level of availability of various factor inputs.

Basis Variable Coefficient Ranging

This section of the sensitivity analysis shows the lower and upper limits for objective function (return per feddan of a crop above variable costs) within which the identified crops (basis variables) would continue to remain in the solution, given the input constraints. C (J) represents the values of the objective function per feddan of the crops which were entered in the input phase.

In the case of cotton, if the value of objective function falls below 108.75 LE per feddan, the cotton production would fall to the minimum of one feddan. There would be no voluntary cotton production. And if the value of objective function per feddan of cotton exceeds 304 LE, then either flax or tomato or both may not be produced as they lose their share of resources to highly profitable cotton production.

```
BASIS VARIABLE
COEFFICIENT
RANGING
* * * * * * * * * * * *
VARIABLE:  flax
 LL        UNBOUNDED
 C(J)        -113.00
 UL          -103.00
VARIABLE: cotton
 LL        UNBOUNDED
 C(J)        -135.00
 UL          -108.75
VARIABLE: tomato
 LL        UNBOUNDED
 C(J)        -304.00
 UL          -273.96
```

Non-Basis Variables Coefficient Ranging

Non-basis signifies the variables (cropping activities) which were forced into the solution, variables that reached an upper bound, and those that did not enter the final solution. In this case, the lower limit would be UNBOUNDED--meaning that the LL is above the given objective function value C (J). The upper limit (UP) actually means the value of the objective function at or higher than that at which the particular cropping activity would enter the solution, *ceteris paribus*.

```
NON-BASIS
VARIABLE
COEFFICIENT
RANGING
* * * * * * * * * * *
VARIABLE:  wheat
 LL          UNBOUNDED
 C(J)           -72.00
 UL          UNBOUNDED
VARIABLE:  berseem
 LL          UNBOUNDED
 C(J)          -103.00
 UL          UNBOUNDED
VARIABLE: beans
 LL          UNBOUNDED
 C(J)           -55.00
 UL          UNBOUNDED
VARIABLE: rice
 LL          UNBOUNDED
 C(J)           -84.00
 UL          UNBOUNDED
VARIABLE: eggplant
 LL          UNBOUNDED
 C(J)          -263.00
 UL          UNBOUNDED
VARIABLE: maize
 LL          UNBOUNDED
 C(J)           -49.00
 UL          UNBOUNDED
```

Berseem did not enter the first solution as was observed. But when the value of the objective function for berseem was raised above 113 LE, berseem production completely substituted for flax production as a winter crop.

Since flax is harvested by the end of May and cotton, as summer rotation, needs to be planted by the first part of March, then berseem, which more easily rotates with cotton, would then become the practical choice. Given the smaller difference between C (J) value and UL for berseem compared with other winter crops, berseem, on economic grounds, would be the second best choice as a winter crop after flax. Further, berseem may be required to sustain livestock using in the farming operation. If such is the case, a minimum number of feddans of berseem as is consistent with the livestock feed requirements should be set as a lower bound (LL) in the problem.

```
OBJECTIVE FUNCTION
-72.00   wheat
-113.00 flax
-115.00 berseem
-55.00   beans
-135.00 cotton
-84.00   rice
-263.00 eggplant
-304.00 tomato
-49.00   maize
```

```
ANSWERS:
BASIS AFTER
ITERATION              3
VARIABLE       VALUE
berseem          4.000
cotton           3.042
SLK 3          498.000
tomato           1.458
SLK 5          407.643
SLK 6            0.634
wheat L          1.000
rice L           0.500

DUAL VARIABLES:
COLUMN         VALUE
 10            115.000
 11             67.876
 12              0.000
 13              0.952
 14              0.000
 15              0.000
OBJECTIVE
FUNCTION
VALUE = 1427.86
IN             3
ITERATIONS
```

ACTUAL PLANTING VERSUS COMPUTER OPTIMAL SOLUTION

	Actual	Computer Optimum		
	Average for 12 farms	Orignial data	700 MD[1/] labor	Berseem[2/] for flax
Winter Crops:				
Wheat	1.27	1.0	1.0	1.0
Flax	0.5	4.0	4.0	0.0
Berseem	3.4	0.0	0.0	4.0
Beans	0.1	0.0	0.0	0.0
Vegetables	0.25	---	---	---
TOTAL	5.52	5.0	5.0	5.0
Summer Crops:				
Cotton	2.12	3.0	2.5	3.0
Rice	2.6	0.5	0.5	0.5
Maize	0.6	0.0	0.0	0.0
Vegetables	0.34	1.5	2.0	1.5
TOTAL	5.66	5.0	5.0	5.0

[1/] Labor available for summer cropping season was raised from 600 man-day to 700 man-day.

[2/] Value of objective function for berseem was raised to 115 LE per feddan which allowed it to replace flax production (see section on non-basis variable).

EXPANDED MODEL

In this section the value of bounds and constraints was once again changed and the model expanded to include labor hiring and land renting activities. This was accomplished by adding six new activities and two new constraints to the original matrix. Variables 10 and 11 in the matrix indicate hiring of winter and summer labor which are constrained by an upper bound of 200 and 250 man-days respectively. Variables 12 and 13 indicate the renting in and renting out of land for the winter growing season, and variables 14 and 15 indicate the same land-renting activities for the summer growing season (see Matrix 2).

The land renting in activities are constrained to 4 feddans per season by adding Constraints 7 and 8 to the model. This method was considered instead of upper bound in order to overcome some program difficulties. The land renting out activities are limited to the 5 feddans of land available per season by use of upper bound.

The upper bounds for various cropping activities were raised to 9 feddans which includes the use of both owned and rented land in these cropping activities. Wage for hiring labor is assumed to be one pound per man-day, and the land renting activity is considered to cost 30 LE for a 6-month cropping season. The renting out of land is considered to bring a return of 29.5 LE instead of 30 LE in order to overcome cycling problems in computer analysis. It is further assumed that each feddan of land has a water allocation of 24 waterings per year or 12 waterings per cropping season.

The expanded model was analyzed using both a 9825 packed cartridge system and a 9885 M unpacked disk drive version. The 9885 M unpacked disk version program was obtained by the process of file creation and program transfer from cartridge to the blank disk. The disk version allows for greater storage space and facilitates data modification analysis.

The following two pages represent the printout of input data, result, and sensitivity analysis using the packed cartridge version. The exact data is stored on the disk and the summary result is presented on page 21 using the unpacked 9885 M disk program version.

The printout of input data and the sensitivity analysis as presented on pages 19-21 are similar to the material presented in section one except for the inclusion of new variables and constraints mentioned earlier. Focusing

Title: Egypt Farms

Matrix 2

Variable Number	Objective Function	Lower Bounds	Upper Bounds	Variable Name	Constraint 1	Constraint 2	Constraint 3	Constraint 4	Constraint 5	Constraint 6	Constraint 7	Constraint 8	Constraint 9	Constraint 10	Constraint 11	Constraint 12
1	72	1	9	Wheat	1	0	30	0	35.2	5	0	0				
2	113	0	3.5	Flax	1	0	39.5	0	32.3	6	0	0				
3	103	1	4	Berseem	1	0	18	0	43.2	11	0	0				
4	55	0	9	Beans	1	0	28	0	26.7	4	0	0				
5	135	1.5	9	Cotton	0	1	0	70.5	45.3	7	0	0				
6	84	1	9	Rice	0	1	0	48	30.1	34	0	0				
7	263	0	2	Eggplant	0	1	0	234	265	36	0	0				
8	304	.2	2	Tomato	0	1	0	248	296	22	0	0				
9	49	0	9	Maize	0	1	0	32	55.3	9	0	0				
10	-1.0	0	200	Hire WL	0	0	-1	0	1	0	0	0				
11	-1.0	0	250	Hire SL	0	0	0	-1	1	0	0	0				
12	-30	0	100	Rt wld	-1	0	0	0	30	-12	1	0				
13	29.5	0	5	Rt wldo	1	0	0	0	-29.5	12	0	0				
14	-30	0	100	Rt sld	0	-1	0	0	30	-12	0	1				
15	29.5	0	5	Rt sldo	0	1	0	0	-29.5	12	0	0				
Constraint Type (<=, =, >=)					< =	< =	< =	< =	< =	< =	< =	< =				
Constraint Values					5	5	300	300	950	120	4	4				

attention on the answer for the expanded model, it is found that some new renting and hiring activities that were allowed have taken place.

All the 4 feddans of land that were allowed to be rented for the winter cropping season have been used up, and the value of one additional unit of winter land (dual variable column 22) is estimated to be 55.7 LE. This means that, given other resources, an additional feddan of land that could be rented for LE 30 would increase return to the farmer. The second activity in the solution indicates that there were 143 man-days of labor hired for the summer cropping season.

There were only 1.1 feddans of summer land rented from the possible 4 feddans that were made available for renting. The reason for this inability to rent more summer land is lack of capital or funds needed to rent additional summer land. Slack #5 which represents capital availability does not appear on the solution which means that all LE 1200 of capital available to the farmer for the year has been used up by the purchases made for the farming operation. Slack #8 which represents the summer land available for renting that was not obtained by this farmer has a value of 2.9 which is the difference between the 4 feddans made available and the 1.1 feddans that were actually rented.

In terms of cropping activities for the winter season, there were 4.5 feddans of berseem, 3.5 feddans of flax, and 1 feddan of wheat produced. These crop productions add up to 9 total feddans of which 5 were owned by the farmer and 4 were rented. For the summer season the farmer cropped a total of 6.1 feddans (5 owned and 1.1 rented) of land. Rice and tomato as summer crops were required to be produced by 1.0 and .2 feddans respectively and the balance of 419 feddans was used for production of cotton.

PACKED CARTRIDGE

```
9825A LP
egypt

Constraint type
  order:

CONSTRAINT      1
 1.00 wheat
 1.00 flax
 1.00 berseem
 1.00 beans
-1.00 rtwld
 1.00 rtwldo
< = 5.00

CONSTRAINT      2
 1.00 cotton
 1.00 rice
 1.00 eggplant
 1.00 tomato
 1.00 maize
-1.00 rtsld
 1.00 rtsldo
< = 5.00

CONSTRAINT      3
 30.00 wheat
 39.50 flax
 18.00 berseem
 28.00 beans
 -1.00 hirewl
< = 300.00

CONSTRAINT      4
 70.50 cotton
 48.00 rice
 234.00 eggplant
 248.00 tomato
 32.00 maize
 -1.00 hiresl
< = 300.00

CONSTRAINT      5
 35.20 wheat
 32.30 flax
 43.20 berseem
 26.70 beans
 45.30 cotton
 30.10 rice
265.00 eggplant
296.00 tomato
 55.30 maize
  1.00 hirewl
  1.00 hirewl
 30.00 rtwld
-29.50 rtwldo
 30.00 rtsld
-29.50 rtsldo
< = 950.00

CONSTRAINT      6
 5.00 wheat
 6.00 flax
11.00 berseem
 4.00 beans
 7.00 cotton
34.00 rice
36.00 eggplant
22.00 tomato
 9.00 maize
-12.00 rtwld
 12.00 rtwldo
-12.00 rtsld
 12.00 rtsldo
< = 120.00

CONSTRAINT      7
 1.00 rtwld
< = 4.00

CONSTRAINT      8
 1.00 rtsld
< = 4.00
```

PACKED CARTRIDGE
(Continued)

```
OBJECTIVE
FUNCTION
MAXIMIZE
 72.00 wheat
113.00 flax
103.00 berseem
 55.00 beans
135.00 cotton
 84.00 rice
263.00 eggplant
304.00 tomato
 49.00 maize
 -1.00 hirewl
 -1.00 hiresl
-30.00 rtwld
 29.50 rtwldo
-30.00 rtsld
 29.50 rtsldo

VARIABLE LIMITS
wheat
 1.00, 9.00
flax
 0.00, 3.50
berseem
 1.00, 4.00
beans
 0.00, 9.00
cotton
 1.50, 9.00
rice
 1.00, 9.00
eggplant
 0.00, 2.00
tomato
 0.20, 2.00
maize
 0.00, 9.00
hirewl
 0.00, 200.00
hiresl
 0.00, 250.00
rtwld
 0.00, 100.00
rtwldo
 0.00, 5.00
rtsld
 0.00, 100.00
rtsldo
 0.00, 5.00
```

```
****************

YOUR VARIABLES 1
THROUGH       15
SLACK VARIABLES
              16
THROUGH       23


ANSWERS:

BASIS AFTER
ITERATION      7
VARIABLE  VALUE
rtwld      4.000
hiresl   143.064
SLK 3     50.750
cotton     4.900
rtsld      1.100
SLK 6     33.001
berseem    4.500
SLK 8      2.900
flax  U    3.500
wheat L    1.000
rice  L    1.000
tomato L   0.200

DUAL VARIABLES:
COLUMN    VALUE
 16       92.778
 17       37.099
 18        0.000
 19        1.237
 20        0.237
 21        0.000
 22       55.679
 23        0.000
OBJECTIVE
FUNCTION
VALUE = 1441.26
IN             7
ITERATIONS
```

PACKED CARTRIDGE
(Continued)

```
SENSITIVITY              BASIS VARIABLE                NON-BASIS
ANALYSIS                 COEFFICIENT                   VARIABLE
****************         RANGING                       COEFFICIENT
                         ****************              RANGING
RHS RANGING              VARIABLE: rtwld               ****************
****************          LL    UNBOUNDED              VARIABLE: wheat
CONSTRAINT      1         C(J)     -30.00               LL    UNBOUNDED
 LL =       -0.50         UL    UNBOUNDED               C(J)      72.00
 B  =        3.00        VARIABLE: hiresl               UL       101.11
 UL =        5.64         LL    UNBOUNDED              VARIABLE: flax
CONSTRAINT      2         C(J)      -1.00               LL    UNBOUNDED
 LL =        0.15         UL         0.57               C(J)     113.00
 B  =        3.80        VARIABLE: cotton               UL       125.58
 UL =        5.19         LL       108.59              VARIABLE: beans
CONSTRAINT      3         C(J)     135.00               LL    UNBOUNDED
 LL =      201.25         UL       245.90               C(J)      55.00
 B  =      252.00        VARIABLE: rtsld                UL        99.10
 UL =   UNBOUNDED         LL    UNBOUNDED              VARIABLE: rice
CONSTRAINT      4         C(J)     -30.00               LL    UNBOUNDED
 LL =       41.99         UL         0.00               C(J)      84.00
 B  =      202.40        VARIABLE: berseem              UL       103.58
 UL =      479.41         LL        73.89              VARIABLE: eggplt
CONSTRAINT      5         C(J)     103.00               LL    UNBOUNDED
 LL =      621.89         UL       115.58               C(J)     263.00
 B  =      782.30                                       UL       389.17
 UL =     1205.09                                      VARIABLE: tomato
CONSTRAINT      6                                       LL    UNBOUNDED
 LL =       32.60                                       C(J)     304.00
 B  =       65.00                                       UL       413.82
 UL =   UNBOUNDED                                      VARIABLE: maize
CONSTRAINT      7                                       LL    UNBOUNDED
 LL =        0.50                                       C(J)      49.00
 B  =        4.00                                       UL        89.76
 UL =        6.19                                      VARIABLE: hirewl
CONSTRAINT      8                                       LL    UNBOUNDED
 LL =        1.10                                       C(J)      -1.00
 B  =        4.00                                       UL         0.24
 UL =    UNBOUNDED                                     VARIABLE: rtwldo
                                                        LL    UNBOUNDED
                                                        C(J)      29.50
                                                        UL        85.80
                                                       VARIABLE: rtsldo
                                                        LL    UNBOUNDED
                                                        C(J)      29.50
                                                        UL        30.12
```

UNPACKED DISK

```
OBJECTIVE FUNCTION
 -72.00  wheat
-113.00 flax
-103.00 berseem
 -55.00  beans
-135.00 cotton
 -84.00  rice
-263.00 eggplant
-304.00 tomato
 -49.00  maize
   1.00  hirewl
   1.00  hiresl
  30.00 rtwld
 -29.50 rtwldo
  30.00 rtsld
 -29.50 rtsldo

MAXIMIZE
VARIABLE LIMITS
wheat
 1.00, 9.00
flax
 0.00, 3.50
berseem
 1.00, 4.00
beans
 0.00, 9.00
cotton
 0.00, 9.00
rice
 1.00, 9.00
eggplant
 0.00, 2.00
tomato
 0.20, 2.00
maize
 0.00, 9.00
hirewl
 0.00, 200.00
hiresl
 0.00, 250.00
rtwld
 0.00, 100.00
rtwldo
 0.00, 5.00
rtsld
 0.00, 100.00
rtsldo
 0.00, 5.00
```

```
YOUR VARIABLES       1
THROUGH             15
SLACK VARIABLES
                    16
THROUGH             23

ANSWERS:

BASIS AFTER
INTERATION           8
VARIABLE     VALUE
rtwld            4.000
hiresl         143.065
SLK 3           50.750
cotton           4.900
rtsld            1.100
SLK 6           33.001
berseem          4.500
SLK 8            2.900
flax   U         3.500
wheat  L         1.000
rice   L         1.000
tomato L         0.200

DUAL VARIABLES:
COLUMN          VALUE
 16             92.778
 17             37.099
 18              0.000
 19              1.237
 20              0.237
 21              0.000
 22             55.679
 23              0.000
OBJECTIVE
FUNCTION
VALUE =  1446.26
IN                   8
ITERATIONS
```

EWUP
How to do it
Field Procedure

DISCOUNTING

Albert Madsen

Concept Explained

When farmers are evaluating the potential payoff for such investments as land leveling, a water drainage system, or lining canals and ditches, they are hopeful that the investments will eventually pay for themselves. Concern about the future suggests that the time value of money must be considered--both the cost and income aspects of an investment must be weighed over time.

If money must be borrowed to finance a project and repayment is made at different periods through time, the question to be asked is: what is the present value of these future payments? A different concern is the potential amount of income that will be generated by the investment. The question asked in this case is: what is the present value of the future income that will be earned during the useful life of the investment item?

An associated problem for farmers is to evaluate the net results of two alternative investment possibilities, i.e., ditch lining vs. installing a drainage system. Project alternatives may have different earning amounts each period and different amounts of time the investment will be useful in producing farm income. There may also be different loan repayment arrangements which complicate efforts to make comparisons. Discounting is an economic tool which facilitates making comparisons of investment alternatives when future income or costs are a factor.

The basic concept to consider in viewing income is that a pound received today is worth more to the Egyptian farmer than a pound that will be received one year or more years from now. The income received today can be invested for future profit or loaned and earn interest. Thus, income received in the future must be discounted by some factor to estimate the comparability between having an Egyptian pound now vs. a similar amount in the future. If the farmer must pay 20 percent interest to borrow funds to purchase seed, fertilizer, etc., it will cost 20 cents per pound each year to borrow money. In view of this cost, having one pound available one year from now is worth only .83 LE compared to having that pound today. The discount formula for this future value is:

$$PV = \frac{1.0 \text{ LE}}{1.0 + r} \quad \text{where}$$

PV = present value of the future income
r = the discount rate (the same as the interest rate of 20 percent in this case).

$$\text{Thus, } \frac{1.0 \text{ LE}}{1.0 + .20} = .83 \text{ LE}$$

Present Value of a Fixed Income for Indefinite Future Time

If a farmer expects to earn the same amount each year for the foreseeable future from an investment, the present value of each 1 LE annual income is 1/r. If the discount rate (r) is 20 percent, each pound per year has a present value (pv) of 5 LE ($\frac{1}{.20} = 5$). If a farmer invested in a drainage system that increased the value of crop production 100 LE each year indefinitely into the future, the present value of this income stream is $\frac{100 \text{ LE}}{.20} = 500$ LE. Farmers would want to compare this present value to the cost of the drainage system. Other things being equal, if present value of the investment exceeds the present value of the income stream, the investment should not be made.

Present Value of a Different Income Amount Each Period

Frequently, the expected earnings from investments in land, machinery, equipment, or capital improvements vary from period to period. The discounting formula for this situation becomes:

$$PV = \frac{LE_1}{(1+r)^1} + \frac{LE_2}{(1+r)^2} + \frac{LE_3}{(1+r)^3} + \ldots \frac{LE_n}{(1+r)^n}$$

where LE_i [i = 1 to n] represents amounts earned during period 1 through n.

For example, assume that an Egyptian farmer invests a water pump which he expects to increase crop production valued at the equivalent of:

50 EL the 1st year
200 EL the 2nd year
100 EL the 3rd year
75 EL the 4th year

At the end of the fourth year, the pump will be sold for 150 EL. The farmer wants to know how much he can consider paying for the pump. This can be estimated by discounting the annual returns as follows, assuming a discount rate of 20 percent:

$$PV = \frac{50 \text{ LE}}{(1 + .20)^1} + \frac{200 \text{ LE}}{(1 + .20)^2} + \frac{100 \text{ LE}}{(1+.20)^3} + \frac{75 \text{ LE}}{(1+.20)^4} + \frac{150 \text{ LE salvage}}{(1+.20)^4}$$

The present values of the income each year are summed to obtain the total present value of the pump.

$$PV = 41.67 + 138.89 + 51.80 + 36.23 + 72.46 = 347.05$$

In this example, the farmer would not want to pay more than 347 LE for the pump.

The Present Value of Alternative Investments

Assume that farmers in one sakia decided to pool their money to improve the irrigation system. They can raise up to 10,000 LE for this investment. The group must make a choice between purchasing a large pump or lining the main feeder ditches. It will cost 9500 LE for a pump and the yearly increase in net value of the sakia's crop production is:

4000 LE the 1st year
3000 LE the 2nd year
2000 LE the 3rd year
1500 LE the 4th year
1000 LE the 5th year
900 LE the 6th year

After the sixth year the used pump will be sold for 2500 LE. The present value of this investment, assuming a discount rate of 20 percent, would be:

$$PV = \frac{4000 \text{ LE}}{(1+.20)^1} + \frac{4000 \text{ LE}}{(1.2)^2} + \frac{3000 \text{ LE}}{(1.2)^3} + \frac{1500 \text{ LE}}{(1.2)^4} + \frac{1000 \text{ LE}}{(1.2)^5} + \frac{900 \text{ LE}}{(1.2)^6}$$

$$+ \frac{2500 \text{ LE salvage}}{(1.2)^6} = 12545 \text{ LE}$$

The second investment considered is to line the main feeder ditches at a cost of 9700 LE. This ditch improvement is expected to increase net crop returns 2000 LE per year for the next 11 years.

The present value of this alternative would be the sum of each year's discount value or year 1 through 11:

$$PV = \frac{2000 \text{ LE}}{(1+.20)^1} + \frac{2000 \text{ LE}}{(1.2)^2} + \ldots + \frac{2000 \text{ LE}}{(1.2)^{11}} = 8653.59$$

To eliminate laborious computations of this nature, tables have been constructed in include conversion factors by which the expected costs or returns can be multiplied obtain the present value. The use of these tables is explained in the final section of this "how-to-do-it."

In comparing the present value of the two investment alternatives, it can be seen that the pump is the better investment alternative resulting in the highest returns above investment cost (3045 LE for the pump vs. a loss of 1046 LE for ditch lining).

Discounting Future Costs

A concept parallel to that of discounting future income to estimate the present value of an income stream is that of discounting future costs to estimate a present value of the future costs. Using the rationale previously explained, it can be seen that paying a bill one year from now is actually cheaper than making the payment now. The delayed payment would allow the investor to deposit his money in a bank and earn interest or invest in a profit-making enterprise for one year before making the payment. Thus, the net payment would be less in the future than making the payment now.

The procedure for estimating the present value of a series of future payments (costs) is the same as the procedure for estimating the present value of future incomes. To obtain a true picture of net benefits from investments that have payments and incomes over time, both the costs and returns should be discounted. The discounted costs must be subtracted from the discounted benefits to arrive at the net benefit figure. For example, if the discounted cost of an investment was 1200 LE and the discounted income was 1500 LE, the net benefit from the investment would be 300 LE or 1500 LE minus 1200 LE.

Using Discount Tables

Using discount tables saves time and simplifies calculating present values of future returns or costs. Table 1 can be used when the same amount of money is received each time period (an annuity), as was assumed in our example for lining feeder ditches, or when payments are the same each period. To utilize Table 1, identify the applicable discount rate at the top of the page and follow down the appropriate column to the number of

Table 1. Present Value of a Uniform Income Each Period.

n	8%	9%	10%	11%	12%	13%	14%	15%	16%
1	.926	.917	.909	.901	.893	.885	.887	.870	.862
2	1.783	1.759	1.736	1.713	1.690	1.668	1.647	1.626	1.605
3	2.577	2.531	2.487	2.444	2.402	2.361	2.322	2.283	2.246
4	3.312	3.240	3.170	3.102	3.037	2.974	2.914	2.855	2.798
5	3.993	3.890	3.791	3.696	3.605	3.517	3.433	3.353	3.274
6	4.623	4.486	4.355	4.231	4.111	3.998	3.889	3.784	3.685
7	5.206	5.033	4.868	4.712	4.564	4.423	4.288	4.160	4.039
8	5.747	5.535	5.335	5.146	4.968	4.799	4.639	4.487	4.344
9	6.247	5.995	5.759	5.537	5.328	5.132	4.946	4.772	4.607
10	6.710	6.418	6.145	5.889	5.650	5.426	5.216	5.019	4.833
11	7.139	6.805	6.495	6.207	5.938	5.687	5.453	5.234	5.029
12	7.536	7.161	6.814	6.492	6.194	5.918	5.600	5.421	5.197
13	7.904	7.487	7.103	6.750	6.424	6.122	5.842	5.583	5.342
14	8.244	7.786	7.367	6.982	6.628	6.302	6.002	5.724	5.468
15	8.559	8.060	7.606	7.191	6.811	6.462	6.142	5.847	5.575
16	8.851	8.313	7.824	7.379	6.974	6.604	6.265	5.954	5.668
17	9.122	8.544	8.022	7.549	7.120	6.729	6.373	6.047	5.749
18	9.372	8.756	8.201	7.702	7.250	6.840	6.467	6.128	5.818
19	9.604	8.950	8.365	7.839	7.366	6.938	6.550	6.198	5.877
20	9.818	8.129	8.514	7.963	7.469	7.025	6.623	6.259	5.929
24	10.529	9.707	8.985	8.348	7.784	7.283	6.835	6.434	6.073
25	10.675	9.823	9.077	8.422	7.843	7.330	6.873	6.464	6.097
30	11.258	10.274	9.427	8.694	8.005	7.496	7.003	6.566	6.177
36	11.717	10.612	9.677	8.879	8.192	7.598	7.079	6.623	6.220
40	11.925	10.757	9.779	8.951	8.244	7.634	7.105	6.642	6.233
48	12.189	10.934	9.897	9.030	8.297	7.671	7.130	6.659	6.245
50	12.233	10.962	9.915	9.042	8.304	7.675	7.133	6.661	6.246
60	12.377	11.048	9.967	9.074	8.324	7.687	7.140	6.665	6.249

Table 1. (Continued)

n	17%	18%	19%	20%	21%	22%	23%	24%	25%
1	.855	.848	.840	.833	.826	.820	.813	.806	.800
2	1.585	1.566	1.547	1.528	1.509	1.492	1.474	1.457	1.440
3	2.210	1.174	1.140	2.106	2.074	2.042	2.011	1.981	1.952
4	2.743	2.690	2.639	2.589	2.540	2.494	2.448	2.404	2.362
5	3.199	3.127	3.058	2.991	2.926	2.864	2.803	2.745	2.689
6	3.589	3.498	3.410	3.326	3.245	3.167	3.092	3.020	2.951
7	3.922	3.812	3.706	3.605	3.508	3.416	3.327	3.242	3.161
8	4.207	4.078	3.954	3.837	3.726	3.619	3.518	3.421	3.329
9	4.451	4.303	4.163	4.031	3.905	3.786	3.673	3.566	3.463
10	4.659	4.494	4.339	4.192	4.054	3.923	3.799	3.682	3.571
11	4.836	4.656	4.487	4.327	4.177	4.035	3.901	3.776	3.656
12	4.988	4.793	4.611	4.439	4.278	4.127	3.985	3.851	3.725
13	5.118	4.910	4.715	4.533	4.362	4.203	4.053	3.912	3.780
14	5.229	5.008	4.802	4.611	4.432	4.265	4.108	3.962	3.824
15	5.324	5.092	4.876	4.675	4.489	4.315	4.153	4.001	3.859
16	5.405	5.162	4.938	4.730	4.536	4.357	4.189	4.033	3.887
17	5.475	5.222	4.990	4.775	4.576	4.391	4.219	4.059	3.910
18	5.534	5.273	5.033	4.812	4.608	4.419	4.243	4.080	3.928
19	5.584	5.316	5.070	4.843	4.635	4.442	4.263	4.097	3.942
20	5.628	5.353	5.101	4.870	4.657	4.460	4.279	4.110	3.954
24	5.746	5.451	5.182	4.937	4.713	4.507	4.318	4.143	3.981
25	5.766	5.467	5.195	4.948	4.721	4.514	4.323	4.147	3.985
30	5.829	5.517	5.235	4.979	4.746	4.534	4.339	4.160	3.995
36	5.862	5.541	5.253	4.993	4.757	4.542	4.345	4.165	3.999
40	5.871	5.548	5.258	4.997	4.760	4.544	4.347	4.166	3.999
48	5.879	5.554	5.262	4.999	4.761	4.545	4.348	4.167	4.000
50	5.880	5.554	5.262	4.999	4.762	4.545	4.348	4.167	4.000
60	5.882	5.555	5.263	5.000	4.762	4.545	4.348	4.167	4.000

years or periods considered. For example, assume a discount rate of 15 percent and a 5-year period of earnings. The conversion factor is 3.352. This factor was derived by summing

$$\frac{1}{(1+.15)^1} + \frac{1}{(1+.15)^2} + \frac{1}{(1+.15)^3} + \frac{1}{(1+.15)^4} + \frac{1}{(1+.15)^5}$$

$$= .870 + .756 + .658 + .572 + .497 = 3.353.$$

If 100 LE is received each year, the present value of the investment is 100 LE x 3.353 = 335.30 LE.

If a different amount of income is received each year, then the discount rate conversion factor for each individual year must be taken from Table 2 and multiplied by the income received that year. The multiplied totals are then summed. For example, assume a discount rate of 12 percent and returns of 50 LE the first year, 100 LE the second year, and 150 LE the third year. The 12 percent rate column is identified at the top of the table and the conversion factors for each year noted. The computations are as follows:

50 LE x .89 or $(1/1+.12)$ = 44.50 LE
100 LE x .80 or $(1/1+.12)^2$ = 80.00 LE
150 LE x .71 or $(1/1+.12)^3$ = 106.50 LE
Present value of three years income 231.00 LE

It was previously demonstrated that if there is a salvage value associated with the investment, the relevant income should be considered in the year the item is sold and the relevant conversion factor selected from Table 2.

Table 2. Present Value of 1.00 LE In a Specific Period.

n	8%	9%	10%	11%	12%	13%	14%	15%	16%
1	.926	.917	.909	.901	.893	.885	.877	.870	.862
2	.857	.842	.826	.812	.797	.783	.769	.756	.743
3	.794	.772	.751	.731	.712	.693	.675	.658	.641
4	.735	.708	.683	.659	.636	.613	.592	.572	.552
5	.681	.650	.621	.593	.567	.543	.519	.497	.476
6	.630	.596	.564	.535	.507	.480	.456	.432	.410
7	.583	.547	.513	.482	.452	.425	.400	.376	.354
8	.540	.502	.467	.434	.404	.376	.351	.327	.305
9	.500	.460	.424	.391	.361	.333	.308	.284	.263
10	.463	.422	.386	.352	.322	.295	.270	.247	.227
11	.429	.388	.350	.317	.287	.265	.237	.215	.195
12	.397	.356	.319	.286	.257	.231	.208	.187	.168
13	.368	.326	.290	.258	.229	.204	.182	.163	.145
14	.340	.299	.263	.232	.205	.181	.160	.141	.125
15	.315	.275	.239	.209	.183	.160	.140	.123	.108
16	.292	.252	.218	.188	.163	.141	.123	.107	.093
17	.270	.231	.198	.170	.146	.125	.108	.093	.080
18	.250	.212	.180	.153	.130	.111	.095	.081	.069
19	.232	.194	.164	.138	.116	.098	.083	.070	.060
20	.215	.178	.149	.124	.104	.087	.073	.061	.051
24	.158	.126	.102	.082	.066	.053	.043	.035	.028
25	.146	.116	.092	.074	.059	.047	.038	.030	.024
30	.099	.075	.057	.044	.033	.026	.020	.015	.012
36	.063	.045	.032	.023	.017	.012	.009	.007	.005
40	.046	.032	.022	.015	.011	.008	.005	.004	.003
48	.025	.016	.010	.007	.004	.003	.002	.001	.001
50	.021	.013	.009	.005	.004	.002	.001	.001	.001
60	.010	.006	.003	.002	.001	.001	.000	.000	.000

Table 2. (Continued)

n	17%	18%	19%	20%	21%	22%	23%	24%	25%
1	.855	.847	.840	.833	.826	.820	.813	.806	.800
2	.731	.718	.706	.694	.683	.672	.661	.650	.640
3	.624	.609	.593	.579	.564	.551	.537	.524	.512
4	.534	.516	.499	.482	.467	.451	.437	.423	.410
5	.456	.437	.419	.402	.386	.370	.355	.341	.328
6	.390	.370	.352	.335	.319	.303	.289	.275	.262
7	.333	.314	.296	.279	.263	.249	.235	.222	.210
8	.285	.266	.249	.233	.218	.204	.191	.179	.168
9	.243	.225	.209	.194	.180	.167	.155	.144	.134
10	.208	.191	.176	.162	.149	.137	.126	.116	.107
11	.178	.162	.148	.135	.123	.112	.103	.094	.086
12	.152	.137	.124	.112	.102	.092	.083	.076	.069
13	.130	.116	.104	.093	.084	.075	.086	.061	.055
14	.111	.099	.088	.078	.069	.062	.055	.049	.044
15	.095	.084	.074	.065	.057	.051	.045	.040	.035
16	.081	.071	.062	.054	.047	.042	.036	.032	.028
17	.069	.060	.052	.045	.039	.034	.030	.026	.023
18	.159	.051	.044	.038	.032	.028	.024	.021	.018
19	.051	.043	.037	.031	.027	.023	.020	.017	.014
20	.043	.037	.031	.026	.022	.019	.016	.014	.012
24	.023	.019	.015	.013	.010	.008	.007	.006	.005
25	.020	.016	.013	.011	.009	.007	.006	.005	.004
30	.009	.007	.005	.004	.003	.003	.002	.002	.001
36	.004	.003	.002	.001	.001	.001	.001	.000	.000
40	.002	.001	.001	.001	.000	.000	.000	.000	.000
48	.001	.000	.000	.000	.000	.000	.000	.000	.000
50	.000	.000	.000	.000	.000	.000	.000	.000	.000
60	.000	.000	.000	.000	.000	.000	.000	.000	.000

EWUP
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PARTIAL BUDGETS

by Albert Madsen

Farmers are often faced with choices between two alternatives. Such choices may involve such questions as: Should I purchase a new diesel water pump or continue with the animal powered irrigation wheel? Should I line irrigation ditches or maintain ditches in the traditional manner? Should I produce corn rather than rice? These are the types of questions which can be evaluated using partial budgeting procedures.[1]

Partial budgeting is an organized method for appraising the effect a proposed change may have on the net returns of the farm. The four main steps in constructing a partial budget are:

1. Statement of the change being contemplated.
2. List key information required to estimate the impact of the potential change and list the assumption being made.
3. Make the economic analysis to estimate the net effect of the changes on income.
4. List all considerations or factors on which it is difficult to place a monetary value.

The typical partial budget consists of seven key parts (see the attached Partial Budget Form for the basic format):

1. Part I is a listing of additional costs that will be incurred if a new enterprise or factor is introduced. For example, identify and add up all the costs that will increase if the decision is made to introduce a new diesel powered irrigation pump. This will include fixed costs such as an allowance for depreciation, interest on

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[1] Most farm management textbooks deal with the mechanics of partial budgeting in some detail. Two U.S. Extension Publications referenced in preparation of this how-to-do-it are: "Partial Budgeting in Farm Management," Ohio State University Extension Facts, No. 142, and "Budgeting a Change," University of Nebraska Neb Guide, G77-333.

borrowed funds, taxes, shelter, etc. It will also include variable costs such as fuel, oil, grease, repairs, and labor. The hypothetical example presented in Exhibit 1 shows these added costs to be 2000 LE during the expected useful life of the pump.

2. Part II identifies the reduced receipts--returns that will no longer be received after the change is made. In our example, returns may not be reduced because the farmer would still be able to maintain the previous level of production and combination of products with the new means of lifting water. Thus, total reduced returns are zero in Exhibit 1. If a certain crop or product could no longer be produced after the diesel pump is installed, the sacrificed income would be the value of the product not produced.
3. Part III of the partial budget is a summation of the estimation of total additional costs from Part I and the reduced returns from Part II. In Exhibit 1 this value is 2000 LE.
4. Part IV is a listing of all additional returns that are expected if the new enterprise or factor is introduced. In our example, it would be the total value of the additional crops or livestock that could be produced from the availability of more irrigation water and more timely application due to the diesel pump. In the Exhibit 1 example, it is assumed that increased yields or higher value crops will increase returns by 1650 LE during the useful life of the pump.
5. Part V consists of estimates of all costs that will be eliminated if the old enterprise or factor is replaced. In our example, when the animal powered water wheel is replaced there would be a reduction in the number of draft animals to feed, a reduction in irrigation wheel repairs, and perhaps a reduction in irrigation labor requirements. In Exhibit 1 these cost savings amount to 10,000 LE.
6. Part VI contains the total of the gains--additional returns (Part VI) plus the reduced costs (Part V). In Exhibit 1 these gains are shown to be 2670 LE over the useful life of the pump.
7. Part VII shows the net change in income from the potential introduction of the new enterprise or production input. This is calculated by subtracting Part III (the negative impacts) from

Exhibit No. 1. Hypothetical Example

PARTIAL BUDGET FORM

Step 1. Proposed Change: Replace animal powered water wheen with diesel powered water pump.

Step 2. Key Information and Assumptions:
1. More irrigation water will be made available.
2. Fuel costs will increase at about the same rate as the past 5 years.
3. Crop prices will increase the same as the past 5 years.

Step 3. Economic Analysis

ITEMS THAT REDUCE NET INCOME

Part I. Added Costs:

Variable costs: fuel, grease repairs, oil, etc.	LE 1500
Fixed costs: interest on loan, depreciation, taxes, etc.	5000
Total Added Costs	LE 2000

Part II. Reduced Returns:

All crops and livestock produced when the water wheel was used can still be produced using the diesel pump	LE
Total Reduced Returns	LE 0.00

Part III. Total Added Costs and Reduced Returns LE 20,000

ITEMS THAT ADD TO NET INCOME

Part IV. Added Returns:

Maize	LE 4,000
Berseem	1,500
Rice	3,000
Tomatoes	8,000
Total Added Returns	LE 16,500

Part V. Reduced Costs:

Draft animal feed costs	LE 5,000
Irrigation wheel repairs	1,000
Labor	4,200
Total Reduced Costs	LE 10,200

Part VI. Total Added Returns and Reduced Costs LE 26,700

PART VII. NET CHANGE IN FARM INCOME (PART VI MINUS PART III): LE 6,700

Step 4. Non-monetary considerations.

Diesel pump repair parts may be difficult to obtain.

ar[illegible]s are more familiar with animals than with machinery.

Part VI (total gains). If Part VII shows that income can be significantly increased through the proposed change, action can be taken to make changes considered. If Part VII indicates that income will be reduced or that there will be little positive impact, the farmer can see the risk in making the change before action is taken. It is much better to identify potential benefits or costs before money or labor is committed to an unprofitable project. In the Exhibit 1 example, there was fairly substantial [6700 LE] benefit from introducing the irrigation pump. However, before a final decision is made, the producer should make a "sensitivity analysis" of the proposed change. This would involve testing various levels of crop yields, prices, or costs to see the effect on the net changes in farm income. Also, the more monetary considerations should be carefully examined before the final decision is made.

A note of caution: partial budgeting is only as accurate as the input data. A positive net change implies that it may be wise to proceed with the alternate plan. A negative amount implies that it would not be profitable to proceed with the change. Erroneous data can lead to serious mistakes.

Exhibit No. 2 Budget Form for Producing Additional Copies

PARTIAL BUDGET FORM

Step 1. Proposed Change: ____________________

Step 2. Key Information and Assumptions:
1. ____________________
2. ____________________
3. ____________________

Step 3. Economic Analysis

ITEMS THAT REDUCE NET INCOME

Part I. Added Costs:

____________________ LE ________
____________________ ________
____________________ ________
____________________ ________
____________________ ________

Total Added Costs LE ________

Part II. Reduced Returns:

____________________ LE ________
____________________ ________
____________________ ________
____________________ ________
____________________ ________

Total Reduced Returns LE ________

Part III. Total Added Costs and Reduced Returns LE ________

ITEMS THAT ADD TO NET INCOME

Part IV. Added Returns:

____________________ LE ________
____________________ ________
____________________ ________
____________________ ________
____________________ ________

Total Added Returns LE ________

Part V. Reduced Costs:

____________________ LE ________
____________________ ________
____________________ ________
____________________ ________
____________________ ________

Total Reduced Costs LE ________

Part VI. Total Added Returns and Reduced Costs LE ________

PART VII. NET CHANGE IN FARM INCOME (PART VI MINUS PART III): LE ____________

Step 4. Non-monetary considerations.

EWUP
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FARM ENTERPRISE BUDGETING

by Albert G. Madsen

A farm enterprise budget is a systematic collection of relevant costs and returns associated with a specific crop, livestock, or other farm enterprise. Enterprise budgets do not remain the same from year to year, and so it requires a continuous effort to keep input costs and product prices current so that production costs and potential revenue can be accurately estimated. Without current information serious errors may be made in evaluating the economic consequences of alternatives available to the producer.

In some countries, public agencies assume responsibility for preparing enterprise budgets for major crop and livestock enterprises. Where this service is not available, producers or local organizations must prepare these budgets to the best of their ability.

Individual cost items are different for each enterprise budget. This can be seen in Tables 1 through 4 which are budgets prepared by the Egypt Water Use Project teams for cotton, rice, maize and berseem. For example, the cotton budget identifies seed costs and planting seeds by hand. The rice enterprise budget, on the other hand, identifies costs for nursery plants pulling and transplanting. Cost items are different because there are different production input items and production operations that are unique to each crop. However, there are certain costs categories common to all enterprise budgets. These are termed as variable costs and fixed costs.

Variable costs or operating costs are those costs which change with the level of production during a given time period. As the production of rice is increased the farmer will have to purchase more seed, use more labor, apply more water and fertilizer, etc. Thus, these type costs vary with the rate at which they are used up in the production of crops or livestock. Variable costs are escapable in that they stop when production stops. To minimize economic losses, producers must receive high enough returns to at least cover all variable costs and make some contribution to fixed costs in

Table 1. CROP ENTERPRISE COST STUDY *
COTTON AT ABU RAIA AREA (1)

Prepared by: GENE , YUSEF & GAMAL AYAD
Identifier Code: TP-1,Trk-1,F-1
Date Prepared: August 20,1978

EGYPT WATER USE & MANAGEMENT PROJECT

Item	Unit	Number of Units	Price or Value per unit L.E.	Total income or Costs L.E.
Income				
Unginned cotton	Kentar (2)	5.0	35.000	175.00
Stalks.	Camel load	5.0	3.000	15.00
Total Income				190.00
Variable Costs				
Organic fertilizer.	Cubic meter.	20.0	0.600	12.00
Plow with tractor,(3 times).	Feddan	3.0	2.000	6.00
Smooth with cows and drang.	Feddan	1.0	2.000	2.00
Furrow "" "" """ plow.	Feddan	1.0	2.000	2.00
Clean ditch.	Man hour	10.0	0.200	2.00
Smooth with cows and drang.	Feddan	1.0	1.000	1.00
Seeds.	Kaila (3)	7.0	0.300	2.10
Plant seeds by hand.	Woman hour	24.0	0.080	1.92
Chemical fertilizers:		0.0	0.000	0.00
Super phosphate (0-15.5-0).	Kg.	100.0	0.022	2.20
Ammonium Nitrate (33.3-0-0).	Kg.	200.0	0.050	10.00
Spread chem. fert.by hand.	Man hour	10.0	0.200	2.00
Irrigation:		0.0	0.000	0.00
first irrigation.	Man hour	6.0	0.200	1.20
Second irrigation.	""" ""	4.0	0.200	0.80
Third irrigation.	""" ""	4.0	0.200	0.80
Fourth irrigation.	""" ""	4.0	0.200	0.80
Fifth irrigation	""" ""	4.0	0.200	0.80
Sixth irrigation.	""" ""	4.0	0.200	0.80
Seventh irrigation.	""" ""	4.0	0.200	0.80
Eighth irrigation.	""" ""	4.0	0.200	0.80
Nineth irrigation.	""" ""	4.0	0.200	0.80
Pumping water with d.pump.	Pump hour	38.0	0.700	26.60
Thin by hand.	Boy hour	18.0	0.050	0.90
Hoeing (two times).	Man hour	14.0	0.200	2.80
Weeding (three times).	Boy hour	36.0	0.070	2.52
Pick insect eggs as needed.	Feddan	1.0	9.000	9.00
Chemical control of insects.	"""	1.0	8.000	8.00
The first cotton pick. (4)	Woman hour	120.0	0.080	9.60
The second cotton pick. (5)	""" ""	120.0	0.080	9.60
Transport unginned cotton.	Feddan	1.0	1.000	1.00
Cut stalks.	Man hour	30.0	0.200	6.00
Transport stalks.	Camel load	5.0	0.500	2.50
Labor to load stalks.	Man hour	5.0	0.200	1.00
Total Variable Costs				130.34
Return Above Variable Costs				59.66
Fixed Costs				
Land rent. (6)	Month	9.0	5.000	45.00
Management charge.	"""	9.0	1.000	9.00
Total Fixed Costs				54.00
Grand Total Costs				184.34
Return Above All Costs				5.66

FOOTNOTES:

* this study for an area of one feddan.
(1) Cotton planted during the period Feb. 20 to March 10, the previous crop is berseem or ,very rarely, a fallow.Most farmers grow berseem as a winter crop.The previous summer crop is usualy rice or Maize.
(2) 1 kentar of unginned cotton = 157.5 Kg.
(3) 1 kaila of cotton seeds = 10 Kg.
(4) The first pick of cotton = 3.5 kentar.
(5) the second pick of cotton = 1.5 kentar.
(6) Cotton requires only 8 months growing season,but there is much preparation required to shape the land and irrigation ditches.This requires almost one additional month making a total of nine months.

	LABOR DISTRIBUTION			WATER DISTRIBUTION, CU METERS			
	Man Hours	Woman Hours	Boy/Girl Hours	First Irrig.	Second Irrig.	Third Irrig.	Fourth Irrig.
October	50	120	0	538	0	0	0
November	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0
January	0	—0—	0	0	0	0	0
February	40	0	0	868	0	0	0
March	14	24	18	645	0	0	0
April	10	0	12	538	0	0	0
May	13	0	12	538	0	0	0
June	6	0	12	538	0	0	0
July	13	0	0	538	0	0	0
August	6	0	0	538	0	0	0
September	6	120	20	538	0	0	0
Total	158	264	74	Total Water Applied=	5271 cu meters		

FOOTNOTES:

--One working day = 6 hours.
--Water distribution estimation based on ELTOBGY'S book.

Table 2. **CROP ENTERPRISE COST STUDY ***
WHEAT AT ABU-RAIA AERA (1)

Prepared by: 4STUDNTS&FAROUK ABDELAL — EGYPT WATER USE & MANAGEMENT PROJECT
Identifier Code: Tp-1,Trk-1,f-7
Date Prepared: AUGUST 20, 1979

Item	Unit	Number of Units	Price or Value per unit L.E.	Total income or Costs L.E.
Income				
Wheat grains	Ardab	8.0	8.000	64.00
Wheat straw	Camel load	6.0	6.000	36.00
Total Income				100.00
Variable Costs				
Org. Fert. transportation	Donkey load	150.0	0.050	7.50
Labor to spread org. fert.	Man hour	6.0	0.200	1.20
Plowing	Tractor hour	2.0	1.250	2.50
Land smoothing	Tractor hour	1.0	1.250	1.25
Seeds	kaila	6.0	1.000	6.00
Labor to spread seeds	Man hour	3.0	0.200	0.60
Weeding	Boy hour	12.0	0.100	1.20
CHEMICAL FERTILIZER		0.0	0.000	0.00
Ammonium nitrate (31.5-0-0)	Kg.	150.0	0.050	7.50
Labor to spread chem.fert.	Man hour	4.0	0.200	0.80
IRRIGATION (2)		0.0	0.000	0.00
Sakia rent	Sakia hour	15.0	0.080	1.20
Cow or Bufflo rent	C.or B. hour	15.0	0.300	4.50
Girl or Boy to observe sakia	B.or G. hour	15.0	0.100	1.50
Labor to spread water	Man hour	15.0	0.200	3.00
HARVESTING		0.0	0.000	0.00
Labor for harvesting	Man hour	36.0	0.200	7.20
Thrashing	Machine hour	6.0	1.150	6.90
Winnowing	Machine hour	3.0	1.150	3.45
TRANSPORTATION		0.0	0.000	0.00
Labor for loading	Man hour	3.0	0.200	0.60
Transport grains by camel	Camel load	3.0	1.000	3.00
Total Variable Costs				59.90
Return Above Variable Costs				40.10
Fixed Costs				
Land rent	Month	6.0	5.000	30.00
Management charge	Month	6.0	1.000	6.00
Total Fixed Costs				36.00
Grand Total Costs				95.90
Return Above All Costs				4.10

FOOTNOTES:

* This study for an area of one feddan.
(1) These data was collected from 4 study cases at ABU-RAIA site byIBRAHIM ELSHENNAWY, MOHAMED ELGAZZAR, ABDELHALIM ELSHERBINY and MOHAMED SALAMA Students from FACULTY OF AGRICULTURE AT KAFR ELSHEIKH-ECONOMICS DEPARTMENT
(2) Wheat needs about 5 irrigations , 1F. needs about 1600 cu. meters ,

	LABOR DISTRIBUTION			WATER DISTRIBUTION, CU METERS			
	Man Hours	Woman Hours	Boy/Girl Hours	First Irrig.	Second Irrig.	Third Irrig.	Fourth Irrig.
October	0	0	0	0	0	0	0
November	12	0	3	180	0	0	0
December	3	0	3	400	0	0	0
January	0	0	12	0	0	0	0
February	7	0	3	345	0	0	0
March	3	0	3	348	0	0	0
April	3	0	3	327	0	0	0
May	39	0	0	0	0	0	0
June	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0
Total	67	0	27	Total Water Applied=	1600 cu meters		

FOOTNOTES:

Water requirements based on our project research stations' data .
- Working day = 6 hours .

Table 3. CROP ENTERPRISE COST STUDY *
MAIZE AT ABU-RAIA AREA (1)

Prepared by: GENE ,YUSEF & GAMAL AYAD EGYPT WATER USE & MANAGEMENT PROJECT
Identifier Code: TP-1,Trk-1,F-5
Date Prepared: September 15,1978

Item	Unit	Number of Units	Price or Value per unit L.E.	Total income or Costs L.E.
Income				
Maize grain	Ardeb (2)	13.0	8.000	104.00
Green tassles for animal feed.	Estimated	0.0 1.0	0.000 5.000	0.00 5.00
Straw	Camel load	6.0	1.000	6.00
Total Income				115.00
Variable Costs				
Organic fertilizer includes		0.0	0.000	0.00
transportation.	donkey load	300.0	0.060	18.00
Labor to spread manure.	Man hour	12.0	0.200	2.40
Land preparation:		0.0	0.000	0.00
rent of two cows.	Cow hour	24.0	0.180	4.32
Labor to balance plow.	Man hour	12.0	0.200	2.40
Rent of a plow.	Plow day	2.0	0.250	0.50
Seeds.	Kaila (3)	1.5	1.250	1.88
Labor for making ditches.	Man hour	6.0	0.200	1.20
Labor for cleaning ditches.	" ""	6.0	0.200	1.20
Labor for thinning.	" ""	6.0	0.200	1.20
Ammonium nitrate (31-0-0)	Kilogram	300.0	0.050	15.00
Labor to spread fertilizer ,		0.0	0.000	0.00
two times.	Girl hour	24.0	0.070	1.68
Weeding.	Man hour	18.0	0.200	3.60
Irrigation: (4)		0.0	0.000	0.00
Rent of cows.	Cow hour	28.0	0.180	5.04
Rent of wheel.	Wheel hour	28.0	0.080	2.24
Labor to spread water.	Man hour	28.0	0.200	5.60
Boy to drive animal,for wheel	Boy hour	28.0	0.050	1.40
Harvesting:		0.0	0.000	0.00
Cut stalks.	Man hour	18.0	0.200	3.60
Pull cobs,tie straw in bundle	" ""	18.0	0.200	3.60
Carry straw to village by		0.0	0.000	0.00
hired camel.	Camel hour	6.0	0.350	2.10
Carry cobs to village by don-		0.0	0.000	0.00
key.	donkey hour	10.0	0.100	1.00
Labor to load donkey.	Man hour	10.0	0.200	2.00
Boy to drive donkey.	Boy hour	10.0	0.050	0.50
Thresh corn by hand.	Woman hour	48.0	0.070	3.36
Total Variable Costs				83.82
Return Above Variable Costs				31.19
Fixed Costs				
Rent of land.	Month	4.0	5.000	20.00
Management charge.	Month	4.0	1.000	4.00
Total Fixed Costs				24.00
Grand Total Costs				107.82
Return Above All Costs				7.19

FOOTNOTES:

* This study for an area of one feddan.
(1) Planting date is May 1 to May 31.Harvesting time is Sep. 1 to Sep. 30. Previous crop is wheat,flax,berseem or broad beans.Previous summer crop is cotton or rice.
(2) One ardeb of maize grain = 140 kilogram.
(3) One kaila = 1/12 ardeb = 11.67 kilogram.
(4) Irrigation before planting 4 hours
""""" after one month 3 hours
""""" after 1 month + 11 days 3 hours
""""" each 12 days (6x3 hours) 18 hours
TOTAL irrigation hours 28 hours

	LABOR DISTRIBUTION			WATER DISTRIBUTION, CU METERS			
	Man Hours	Woman Hours	Boy/Girl Hours	First Irrig.	Second Irrig.	Third Irrig.	Fourth Irrig.
October	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0
January	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0
May	34	0	4	350	0	0	0
June	20	0	20	275	275	0	0
July	17	0	17	275	275	275	0
August	17	0	9	275	275	275	0
September	46	48	10	0	0	0	0
Total	134	48	62	Total Water Applied=		2550 cu meters	

FOOTNOTES:

Table 4. CROP ENTERPRISE COST STUDY *

BERSEEM AT ABU RAIA ARIA (1)

Prepared by: GENE , YUSEF , GAMAL AYAD
Identifier Code: E-1,Tek-1,F-3
Date prepared: September 15,1978

EGYPT WATER USE & MANAGEMENT PROJECT

Item	Unit	Number of Units	Price or Value per unit L.E.	Total income or Costs L.E.
Income				
3 cuts sold standing	Kerat cut(2)	72.0	1.500	108.00
X24 kerats.		0.0	0.000	0.00
1 cut for seed.	Kaila (3)	8.0	4.000	32.00
Straw.	Load	4.0	1.250	5.00
Total Income				145.00
Variable Costs				
Seeds.	Kaila	1.5	8.000	12.00
Labor to spread seeds.	Man hour	2.0	0.150	0.30
Chemical fertilizers:		0.0	0.000	0.00
Super phosphate (0-15.5-0).	Kg	100.0	0.022	2.20
Ammonium nitrate (31-0-0).	" "	50.0	0.050	2.50
Labor to spread chem. fert.	Man hour	2.0	0.150	0.30
Cleaning drain (LE 0.01/M).	""" ""	12.0	0.250	3.00
Harvesting 4th cut (4).	""" ""	18.0	0.200	3.60
Transporting by camel.	Camel load	6.0	0.500	3.00
Labor to load camel.	Man hour	3.0	0.200	0.60
Threshing by tractor.	Tractor hour	2.0	1.750	3.50
Labor for threshing.	Man hour	6.0	0.250	1.50
Winnowing.	""" ""	12.0	0.250	3.00
Irrigation: (5)		0.0	0.000	0.00
Cow or buffalo rent.	C.or B. hour	49.0	0.330	16.17
Sakia rent.	Sakia hour	49.0	0.080	3.92
Labor to spread water.	Man hour	49.0	0.200	9.80
Total Variable Costs				65.39
Return Above Variable Costs				79.61
Fixed Costs				
Land rent.	Month	7.0	5.000	35.00
Management charge.	" "	7.0	1.000	7.00
Total Fixed Costs				42.00
Grand Total Costs				107.39
Return Above All Costs				37.61

FOOTNOTES:

* This study for an area of one feddan.
(1) Planting date is October 20 to November 15. The immediate preceeding crop may be rice, maize. Cotton is not an alternative following crop since it must be planted by march 10.
(2) On the average 1 kerat cut of green berseem weighs 320 Kg.
(3) The price of seeds at planting time is higher than price at harvest time.
(4) The final harvest is before May 20.
(5) Irrigation at planting time 4 hours
Second irrigation after 1 month 5 hours
Third irrigation after 25 days 5 hours
Fourth irrigation after winter closure 7 hours
Then 1 irrigation each 11 days (7X4 hrs.) 28 hours
TOTAL time for irrigation 49 hours

	LABOR DISTRIBUTION			WATER DISTRIBUTION, CU METERS			
	Man Hours	Woman Hours	Boy/Girl Hours	First Irrig.	Second Irrig.	Third Irrig.	Fourth Irrig.
October	0	0	0	0	0	0	0
November	6	0	0	181	0	0	0
December	6	0	0	227	0	0	0
January	6	0	0	317	0	0	0
February	9	0	0	181	181	181	0
March	18	0	0	181	181	181	0
April	12	0	0	181	0	0	0
May	9	0	0	0	0	0	0
June	38	0	0	0	0	0	0
July	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0
Total	104	0	0	Total Water Applied=	1992 cu meters		

NOTES:

Water distribution estimation based on ELGHAGY'S book.
Working day= 6 hours.

the short run. If variable costs are not covered, other things being equal, it is better not to produce the particular product.

The second cost category is fixed costs. These costs are also referred to as ownership or overhead costs since there often is difficulty in allocating some costs to specific products or enterprises. Fixed costs are those costs that are not related to the level of production--they continue whether or not production occurs. Costs frequently falling into this category are depreciation, interest, taxes, etc. The attached crop enterprise budgets have classified land rent and a management overhead charge as fixed costs.

The four-crop enterprise cost studies attached also include information to help decision makers in enterprise selections or planning for labor and water use. This information identifies labor and water requirements by month for each crop. After the enterprises that will be involved each month are identified, the total monthly requirements for labor and water can be estimated from the relevant tables. The next step is to estimate the amounts of labor and water available to the farm each month. By relating the input requirements and the input availability, it is possible to identify when there is surplus labor or water that can be used for other purposes or where there may be shortages of labor and water. If shortages occurred in a particular month the farmer would have to make arrangements for hiring additional labor and buying or renting more water rights. If financial or other constraints prevented farmers from obtaining the necessary inputs, then different enterprise combinations would have to be considered. Although labor and water flow budgets are much simpler than cash flow budgets (which have been prepared as a how-to-do-it for this manual), they are important to the overall success of the farm.

Enterprise budgets in Tables 1 through 4 can be used by individual producers as basing points for on-farm problem identification. When farm costs, production, or returns seem to be out of line with those of the enterprise budgets, in depth analysis of management and production practices can be made to identify where problems may exist. This would involve consultation with engineers to evaluate water application and drainage practices and consultation with agronomists to consider the adequacy of cultivation, seeding rates, fertilization, etc. Sociologists may assist in determining why certain practices are followed that may reduce production or family income.

EWUP
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PREPARING A CASH FLOW BUDGET

by Albert Madsen

The preparation of a cash flow budget, whether formal or informal, is critical to decision making on farms. A budget which shows the sources, amounts, and timing of cash income and expenses is especially relevant to decisions concerning investments for irrigation systems. Partial budgets may show the economic benefits from improvements in water application or drainage but the ability to pay off debts that may be incurred to make the improvements is not shown in a partial budget.

A cash flow budget may consist of two tasks. The first task is to identify the actual cash flow that occurred during the past year. This would involve the documentation of monthly income and expenditures for each of the past 12 months. This information may be prepared from farm records or the best estimate of the farmer. The second and more difficult task is to project next year's cash flow. This estimate may be guided by historical results and crop and livestock plans for the future. For major investments, such as land leveling, installing lined ditches and irrigation water pumps, or land purchases, it will be necessary to pay off loans over time periods of more than one year. This will require projecting expenditures and incomes for longer time periods to better estimate the ability to repay investments.

The following worksheets provide a step-by-step procedure to construct the cash flow budget. The entries are mostly self-explanatory, but every area of the world and every farm has its own particular cash flow characteristics. The forms may have to be adjusted to meet the conditions of individual producers.

In order to illustrate the use of the worksheets for monthly cash planning, a hypothetical example of an Egyptian farm is presented. The 8 feddan case farm is assumed to produce tomatoes and wheat.

CASH FARM RECEIPTS

Worksheet 1A, Estimation of Cash Farm Receipts: Crop and Other Income, indicates that wheat was sold in May and that income is received from tomatoes during October, November and December. It is assumed that the farmer can perform work for others during February, March, April and August using his equipment and animals to earn the amounts indicated in the "Other Farm Income" column.

For Worksheet 1B, Estimation of Cash Farm Receipts: Livestock Products and Livestock Sales, it is assumed that the farm has two cows which are used as draft animals and also for milk production. Only one cow is shown to produce milk during June through November which provides time for each cow to be dry for a period and produce a calf. It is assumed that one calf is sold each year in September and the other may die or is butchered for the family. The totals in the last column of Worksheet 1B are included in the final column of Worksheet 1A.

Since only two crops are produced it is not necessary to utilize Supplemental Worksheet 1, Estimation of Receipts from Crop Sales, to complete Worksheet 1A. However, Supplemental Worksheet 1 is included to show the type of information it provides.

CASH FARM EXPENSES

Worksheets 2A through 2E and Worksheet 3 are used to estimate cash farm expenses. All expenses should be recorded when they are expected to be incurred. The expense categories are commonly used in farm records. Interest expenses are not included in this series of worksheets because it is difficult to separate the principal payment and interest in future debt payments. Debt payments including interest expenses are entered in Supplemental Worksheet 3 and Worksheet 6. The method for projecting future costs is to estimate the inflation or deflation for each category and then make further adjustment by individual circumstances for a particular farm. For example, labor wage rates may increase and also the amount of labor used may increase. Thus, the expected cost of this item would be larger than the simple adjustment for wage rates.

Labor, Feed and Livestock Purchase Cash Farm Expenses are estimated on Worksheet 2A. It is assumed that the cows are fed only farm produced feed and that no livestock are purchased for feeding and later resale. Thus the feed and livestock purchase columns are blank. The labor expenses are distributed among the months in which labor must be hired as shown in the first columns. Worksheet 2B, Estimation of Cash Farm Expenses: Machinery contains entries for custom work hired to plow and harvest. The machinery repairs may apply to cultivators or water wheel.

Worksheet 2C, Estimation of Cash Farm Expenses: Crops, identifies cost estimates for fertilizer, seeds, sprays and land rent. It is assumed that this farm does not rent. The estimated change in fertilizer costs reflect the rapid rate of price increases of this input. Sprays and insecticides are also expected to increase significantly.

Estimation of Cash Farm Expenses: Real Estate Expenses identified in Worksheet 2D are not substantial since this farm does not have buildings which are in need of repairs. However, there are some expenses associated with maintaining fences and ditches. Property taxes are not large.

Worksheet 3E, Estimation of Cash Farm Expenses: Utility, Marketing, Misc., identifies farm expenses for utilities which do not apply to this farm. The marketing costs for this farm include costs for transporting the fertilizer to the farm and the cost of hauling the wheat to market. No charges are made for transporting tomatoes since these are carried to the local market by family members at no cash expense to the farm enterprise.

Worksheet 3, Summary of Cash Farm Expenses, pulls together all of the farm expenses identified to this point. The worksheets from which the monthly data are taken are identified with the parentheses at the top of each column. The row and column data can be summed to check for mistakes.

Worksheet 4, Capital Purchases Planned, provides for detailed itemization of expected capital purchases. The hypothetical farm with which we are dealing does not anticipate expenditures of this nature during the comming year.

The preparation of Worksheet 5, Cash Inflow and Outflow for Next Year: Including Nonfarm; Excluding Credit, is a critical step to arriving at the potential cash flow for a farm. The "cash farm receipts" in column 1 are taken from the last column of Worksheet 1A. The "net nonfarm cash income" in this case is assumed to come from sale of family members handicraft during the tourist season. The sources of information for other columns are identified within the parentheses. Care must be exercised in calculating column 8, "cash inflow minus cash outflow." Negative results should be enclosed by parentheses. Family expenses must be estimated for each month and entered in column 6. Families frequently find if difficult to estimate expenses and so Supplement Worksheet 2, *Family Living Expenses*, is provided to act as a guide in preparing this estimate of monthly family expenditures.

Worksheet 6, *Projected Cash Flow Budget*, is the end product toward which we have been working in preparation of the previous information. It provides a guide for the use of short-term credit and to guide decision making in assuming long-term debt. The manager must constantly evaluate the ability of the farm and family to service debt.

Cash inflow less outflow excluding credit transactions [Column 1]--The numbers in this column are the difference between cash inflow and cash outflow on Worksheet 5.

Scheduled Debt Payments [Column 2]--listed on this column is the principal and interest that the business is required to pay each month. Supplemental Worksheet 3 can be used to arrive at the projected debt payments for next year.

Capital Purchase Loans [Column 3]--For many capital purchases the farm manager knows in advance that he will borrow all or part of the money from a bank, a government agency, machinery dealer, or other source. When this is the case, the amount of the loan should be included in this column. When he starts making payments on the loan (probably the following month), the amount of the payment (principal and interest) should be included in Column 2, scheduled debt payment (Supplemental Worksheet 3 can also be used).

Uncommitted Cash Flow [Column 4]--This is the money that is projected to be left over or that must be obtained after the cash inflow-outflow, debt payments and new capital loans are considered. If figures in this column are positive, the money is available: 1) to pay back short-term borrowings or make additional payments on longer term debt or 2) to add to the family's ready cash fund. [Family living expenses have already been accounted for.] If these data are negative, the deficit must be covered either: 1) from reductions in the family's ready cash fund or 2) by short-term borrowing from a bank, individual, etc. or by charging feed, fertilizer, or other bills.

New Short-term Debt [Column 5]--This column is used to record new short-term debt which is projected to be required to cover a negative uncommitted cash flow.

Additional Debt Payments [Column 6]--These are payments of interest and principal on short-term debt and additional principal payments on longer term debt (it is assumed that interest paid on longer-term debt is covered in the scheduled debt payments).

Cash Flow This Month [Column 7]--This is the projected change in the family ready cash fund for the month.

Cash Flow Balance [Column 8]--It will be noted that this farm ended the past year [or started this year] with 1000 LE in the family ready cash fund. This column is the running balance of cash on hand. It should be kept in mind that transactions take place daily not monthly and that a significant balance may be required to meet day-to-day fluctuations. The October balance of 12 LE would probably be too low and additional borrowing required.

In parentheses at the top of each column is identified the sequence of adding and subtracting as follows:

Cash Inflow less Outflow Excluding Credit
\- Scheduled Debt Payments
\+ Capital Purchase Loans
= Uncommitted Cash Flow
\+ New Short-term Debt
\- Additional Debt Payments
= Cash Flow: This Month
\+ Balance from Last Month
= Cash Flow: Balance

An indication of good short-term credit management is that at least one of the columns, "New Short-term Debt" or "Additional Debt Payments," is zero for each month. Short-term credit should be managed to maintain a somewhat constant cash flow balance without paying back money and then turning around and reborrowing it immediately. One rule of thumb would be to repay short-term debt whenever the money will not be reborrowed for at least two months; otherwise the money could be left in the family ready cash account to cover the cash flow deficit in the following month.[1/]

[1/] The following publication has been used as a guide in preparing this material: Milligan, Smith & LaDue, February 1976, Monthly Cash Flow Planning, Department of Agricultural Economics, Cornell University, AE Ext. 76-2.

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THE PRODUCTION FUNCTION AND FARM PROFIT MAXIMIZATION

by Albert Madsen

Factor Inputs and Product Outputs

The physcial relationships between the application of different levels of the factors of production (inputs) and associated product output levels are concepts generally understood by most producers. Producers in arid regions, for example, may not have detailed measures of production response to variable inputs but they understand that if water is not applied crops will be lost. They also recognize that as additional increments of water are correctly applied, total crop yield will increase until a point is reached when total production will actually decrease as overwatering occurs. Similar input-output relationships can be evaluated for inputs such as fertilizer, labor, pesticides, seed, etc. (It should be emphasized that the response to selected inputs is related to the present level of production and the kind of farming practices presently in use.)

A hypothetical production function or total product (TP) curve with associated average product (AP) and marginal product (MP) curves and three stages of production are shown in Figure 1.

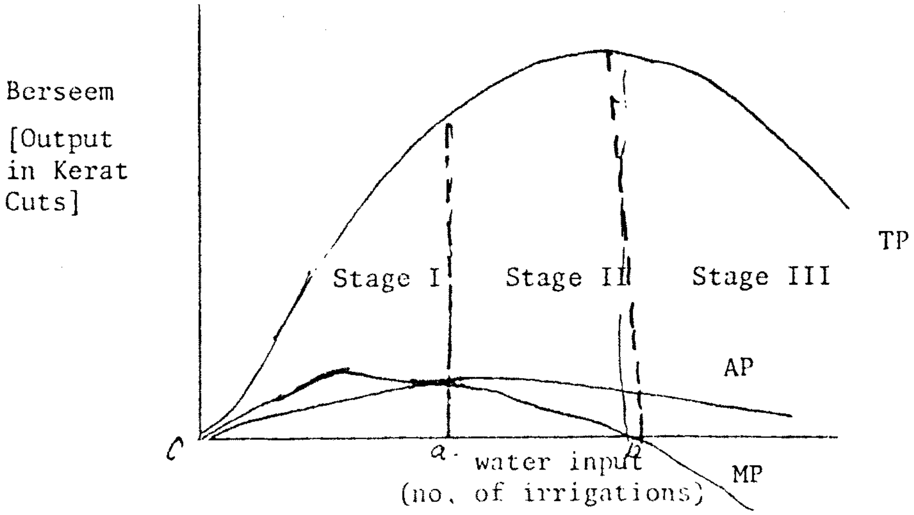

Figure 1. Hypothetical production function for a single input (water) and a single output (berseem).

The total product (TP) curve represents the total amount of berseem produced with different amounts of water applied. The average product (AP) curve is the total production at each water application level averaged over all irrigations (TP ÷ the number of irrigations) or product output per irrigation. The marginal product (MP) curve represents the additional quantity of berseem that is produced by adding each additional irrigation (change in total product ÷ the change in number of irrigations). For example, assume that with five irrigations the farmer is producing 42 kerat cuts of berseem and by adding the sixth irrigation 47 kerat cuts will be produced (Table 1, columns 1 and 2). The added berseem production is 5 kerat cuts (47-42) and the added irrigation is 1(6-5).MP = 5/1 or 5.

Three stages of the production are evident:

(1) In stage 1, the marginal product (the increase in total berseem production from the last additional application of water) is higher than the average berseem production (total product divided by total inputs). All other things equal, it is not rational to produce at the stage 1 level since the output from the last unit of input is higher than the average production of all inputs. The average product of all inputs will be increased as long as the marginal product is higher than the average product. In Table 1 it will be noted that the marginal product exceeds the average product of berseem up to the fourth irrigation.

(2) Stage II begins where AP = MP (at point "a") in Figure 1 and at about the fourth irrigation in Table 1. At this point in the berseem production function for the input water, the average production of berseem is at its highest level. This stage is considered the rational zone of production and it extends to the point where total production of berseem output is a maximum which is where the marginal product is zero (the last increment of water added does not produce additional berseem). This point is reached at irrigation number nine as indicated in column 2, Table 1 or at point "b" Figure 1.

(3) Stage III is an irrational level of water application because the total production of berseem is actually decreased and the production response to the last irrigation of water applied is actually negative. (Note the results of the tenth irrigation presented in column 2, Table 1.)

The agronomists and engineers must provide the coefficients for production response at different levels of input application. Farmers do

Table 1. Basic Input-Output Data and Related Costs and Returns for the Production of Berseem with an Alternative Number of Irrigations.[1]

Physical Input-Output Data				Economic Data											
				Total Costs			Average Costs			Marginal Costs		Returns			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Units of Water Applied (input)	Kerat Cuts of Berseem (total product)	Marginal Product of Fertilizer per Unit	Average Product of Fertilizer per Unit Col.2 ÷ Col.1	Fertilizer Cost (Variable Cost) Col.1 x 4 LE	All Other Costs (Fixed Costs)[2]	Total Cost Col.5 + Col.6	Average Variable Cost Col.5 ÷ Col.2	Average Fixed Cost Col.6 ÷ Col.2	Average Total Cost Col.8 + Col.9	Cost per Unit of Additional Input (MFC) Col.5 ÷ Col.1[3]	Cost per Unit of Additional Output (MC) Col. 11 ÷ Col.3	Total Return (TR) Col.2 x 2 LE	Net Returns (Profit) Col.13 - Col.17	Marginal Return per Unit of Input (MVP) Col. 3 x 2 LE	Marginal Return per Unit of Output (MR) Col.15 ÷ Col.13
Irrigations		Kerat Cuts		Egyptian Pounds											
0	0	0	0	0	20	20	0	-	-	[4]	-	-	-20	-	-
1	5	5	5.00	4	20	24	.80	4.00	4.80	4	.80	10	-14	10	2
2	16	11	8.00	8	20	28	.50	1.25	1.75	4	.36	32	-4	22	2
3	26	10	8.70	12	20	32	.46	.77	1.23	4	.40	52	20	20	2
4	35	9	8.75	16	20	36	.46	.57	1.03	4	.44	70	34	18	2
5	42	7	8.40	20	20	40	.48	.48	.96	4	.57	84	44	14	2
6	47	5	7.80	24	20	44	.51	.43	.94	4	.80	94	50	10	2
7	51	4	7.30	28	20	48	.55	.39	.94	4	1.00	102	54	8	2
8	54	3	6.75	32	20	52	.59	.37	.96	4	1.33	108	56	6	2
9	56	2	6.20	38	20	56	.68	.36	1.04	4	2.00	112	56	4	2
10	55	1	5.50	40	20	60	.73	.36	1.09	4	4.00	110	40	2	2

[1] The data do not represent actual output, costs and returns for berseem production. Egyptian terminology has been used to facilitate the learning process.

[2] Fixed costs per feddan are assumed to be 20 LE.

[3] Difference between successive total products divided by differences between successive total input units.

[4] Each unit of variable input costs 4 LE.

not have the expertise or the income to experiment with different crops and variable inputs. They have general information from historical events but not the detail that may be desirable.

In absence of specific production function data, farmers or researchers can recognize whether or not a particular farm is producing within a range of acceptable results. This evaluation may be based upon community-wide averages with regard to yields, input use, net returns, capital availability, etc. Such data provide a first approximation of the potential range for improvement of the farm operation.

Farmers must decide within their own family goals the amount of water (or other inputs) to apply. If survival is the only objective and inputs are "free," then the maximization of basic food production per feddan may be a rational decision.

COST AND RETURN CONSIDERATIONS

The physical input-output relationships identify the stage of production in which production should be conducted but this stage can extend over a wide range of input levels. To identify the more exact level of input application or level of output production (assuming that the objective is profit maximization) it is necessary to establish the cost of the factors of production and the prices of value of products produced. Table 1 again serves as an example to demonstrate the relationships between the production function and profit maximization from the point of view of adding inputs in incremental amounts or increasing production by incremental amounts.

Conversion of Farm Products to Monetary Values

From the hypothetical production function we obtain the total amount of an established crop of berseem that can be produced from increasing irrigations of water (columns 1 and 2, Table 1). (It should again be noted that the production response to water will vary according to the current level of application of other inputs.) For each irrigation the average product and marginal product or amounts of berseem produced have been calculated and identified in columns 3 and 4 of Table 1. If each of the quantities in columns 2, 3, and 4 are multiplied by the price per kerat cut of berseem (assumed to be 2 pounds Egyptian) the total returns or total value products are obtained and presented in column 13. The marginal value product (MVP) or marginal returns are shown in column 15.

Identifying Costs

Variable costs are those costs that change as production is increased or decreased. The variable cost will equal the cost per feddan to apply the different number of irrigations. In this example it is assumed that it costs 4 pound Egyptian per irrigation to apply the water to berseem. (The variable costs are shown in column 5, Table 1.) For this example it has been assumed that only the amount of water is varied and all other inputs are fixed or do not vary with the level of production of berseem. Such fixed costs could be taxes, family labor, long-term debt payments, etc. These fixed costs are assumed to equal 20 LE per feddan and are shown in column 6, Table 1. The total costs are the sum of the variable and fixed costs (column 7).

Other critical cost data needed to identify the level of inputs which will maximize profits is marginal factor cost (MFC). This is the cost of each added input. If the cost of the last unit of input is the same as the cost of the first unit of input the MFC remains constant as demonstrated in column 11, Table 1.

Deciding upon the Most Profitable Level of Input (Water) Application

Through trial and error one can find the most profitable level of input application. This would be the level where Total Return (TR) less Total Cost (TC) = Profit is greatest. This calculation can become very laborious and time-consuming. A more direct way to identify the level of input application which will maximize profits is to apply inputs to the point where the marginal value product (MVP) shown in column 15 is equal to the marginal factor cost (MFC) shown in column 11. In our example this would occur at nine irrigations. This concept can be proven by computing the net revenue (profit) for each irrigation. It will be found that the greatest profit will occur at the ninth irrigation. If additional irrigations are applied then profits will not be maximized.

Deciding upon the Most Profitable Level of Output (Berseem)

Frequently it is desirable to determine the most profitable level of crop or livestock production. Again the marginal principle provides the most direct solution to this problem. In this case, however, the two elements required are: marginal cost (MC) (the cost of producing an additional berseem) and marginal revenue (MR) or the price at which the additional unit of berseem can be sold. To maximize profits the producer will increase production to the point where MC = MR. In other words, the cost of producing the last unit of berseem should equal the price at which this last unit of production can be sold. In the hypothetical example presented in Table 1, every unit (karet cut) of berseem sold by the farmer can be sold at 2 pounds Egyptian (column 16, Table 1). The marginal costs are calculated by dividing the cost of the last unit of input (each irrigation costs 4 pounds Egyptian per feddan) by the marginal product (karet cuts of berseem produced by the additional irrigation). The result is shown in column 12, Table 1. In the example presented, the profits are maximized at an output of 56 kerat cuts of berseem per feddan. It will be noted that this production level is the level of production achieved when the most profitable amount of water was applied (MFC = MVP). Thus, it matters not whether the analysis is done from the point of view of input application or from the point of view of product output, the solution will be the same. The main factors affecting the level of production at which profits will be maximized within stage II of the production function are: (1) the production function itself, (2) the cost of the factors of production (inputs) and (3) the price of the output (product price).

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SOIL-WATER ENGINEERING LABORATORY MANUAL

by Ignacio G. Garcia-Casillas[*]
(Edited by William E. Hart)

This laboratory manual was developed to be used in a first course in soil-water engineering. It is designed to give students knowledge of how to obtain data from soils, using different physical soil measurements.

For all soil-water engineering students it is necessary to have knowledge in this field, because sooner or later he or she will face practical problems in which physical soil data is required. This manual attempts not only to provide students with the methods by which soil physical parameters are obtained, but also to explain the principles of each method and the examination of data obtained with them, by using different principles of estimation.

In conclusion, this laboratory manual is aimed at encouraging students in their future research by providing them with comprehensive methods for making analyses of soil more enjoyable and interesting, leading to appropriate results.

The author expresses his deepest gratitude to Dr. William E. Hart for his guidance, advice and helpful criticism throughout the preparation of this manual.

EDITOR'S NOTE

Several changes have been made in this copy of the text to make it compatible with the course notes for AE330, Soil-Water Engineering, by Arthur T. Corey and William E. Hart.

EXERCISE 1

BULK SPECIFIC WEIGHT OR GRAVITY

Object: To determine the bulk specific weight or gravity of a soil using the excavation method.

INTRODUCTION

Bulk Specific weight (or gravity) is the ratio of the weight (or mass) of a dry bulk volume of soil to the weight (or mass) of an equal volume of water.

$$\gamma_b = \frac{W_s}{W_w} , \tag{1-1}$$

where γ_b is the bulk specific weight ($F\ F^{-1}$), W_s is the dry weight of the soil and W_w is the weight of an equal volume of water (F). Bulk specific weight is needed for converting water content on a dry weight basis to water content on a volume basis.

The bulk specific gravity of a soil is given in units of mass per mass, and thus has the same numerical value as the bulk specific weight. The same symbol, γ_b , is used for both terms.

There are several methods for evaluating bulk specific weight but they can generally be divided into <u>direct</u> and <u>indirect</u> methods.

The direct methods consist essentially of taking a sample whose soil (dry) weight and volume can be determined. In the excavation method an irregularly shaped hole is dug and the volume of the hole is determined. In the core method a cylindrical known volume of soil is removed. In the clod method the soil is removed as a block and its volume is determined by displacement. In each of these methods, the mass or weight of the removed soil is determined after drying.

In the indirect method, transmitted or scattered gamma radiation is measured and the combined liquid-solid component of the soil mass is determined.

THE EXCAVATION METHOD

Bulk specific weight is determined using this method by excavating a quantity of soil. Its weight is determined after drying. To determine the volume of this excavated soil, the hole volume is measured, using either a rubber balloon filled with water, or by filling it with sand (sand funnel technique). Only the rubber balloon technique will be discussed here.

The rubber balloon technique

The volume is determined by forcing a water-filled balloon into the excavation. The volume of the excavated soil sample is then equal to the volume of the water in the balloon.

Special apparatus (Figure 1-1)

The device described here is distributed by Soiltest, Inc., 2205 Lee Street, Evanston, Illinois, 60202, U.S.A. It is called a Volumeasure and the assembly is Part No. CN-980. The component part numbers are given below.

1.	Aluminum base.	(Part No. CN-980-B)
2.	Water reservoir (graduated cylinder of heavy-walled glass).	(Part No. CN-980-I)
3.	Air pump. To provide either pressure or vacuum.	(Part No. CN-980-P)
4.	Control valve.	(Part No. CN-980-3)
5.	Pressure tube.	(Part No. CN-980-k)
6.	Rubber balloon.	(Part No. CN-980-0)
7.	Cylindrical support of aluminum with carrying handle, attached to aluminum base with screws.	(Part No. CN-980-C)
8.	Field plate of aluminum.	(Part No. CN-980-D)

Items 1 through 7 make up the measurement assembly.

Procedure

1. Level the soil surface and remove loose soil at the test site.
2. Place the field plate on the test site.
3. Place the measurement assembly on the field plate.
4. With the control valve closed set the air pump for pressure operation, open the control valve, pump the water-filled balloon into the test site and record the volume of water in the cylinder. This is the initial reading. Do not overpump.
5. Close the control valve, reverse the air pump to vacuum operation, open the control valve and return the water to the cylinder.
6. Remove the measurement assembly without disturbing the field plate.

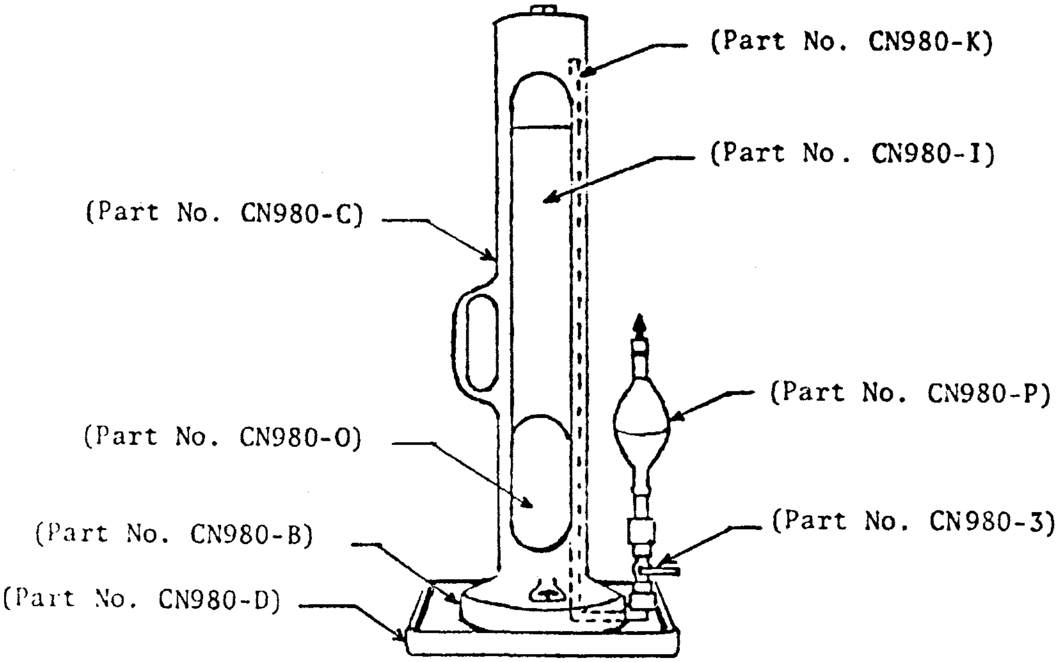

Figure 1-1. Rubber balloon assembly on the field plate.

7. Excavate a soil sample through the center hole of the field plate, leaving a hole with a diameter of approximately 10 cm and a depth of approximately 12 cm. A tablespoon is a suitable tool for excavating the hole. All excavated soil should be recovered.
8. Place the measurement assembly on the field plate.
9. With the control valve closed set the air pump for pressure operation, open the control valve, pump the water-filled balloon down into the excavated hole and read the volume of the water in the cylinder. This is the final reading. Do not overpump.
10. Reverse the air pump to vacuum position and return the water to the cylinder.
11. Calculate the volume of the excavated hole by subtracting the initial reading (step 4) from the final reading (step 9).
12. Determine the oven dry weight of the soil excavated from the hole by drying it to constant weight at a temperature of approximately 105°C. The soil sample should be left in the oven for at least 24 hours.
13. Calculate the bulk specific gravity by converting the volume of the hole to the weight of an equal volume of water (1 g of water = 1 cm^3) and then use Equation 1-1 to determine q_b. Sample data and results are given in Table 1-1.

Analysis of results

In the analysis of measurements of bulk specific gravity using the rubber balloon technique, we will use two different estimations--the point estimate, which is a single number and the interval estimate, which are two two numbers that determine an interval.

The best estimator for the true central value is the average (Appendix A, Equation A-1). The average of the six determinations of bulk specific gravity of Table 1-1 is $\gamma_b = 1.63$. The standard deviation (Appendix A, Equation A-3) is $S = 0.091$. The confidence interval given by the student's t-test (Appendix A, Equation A-5), with confidence limits of 95 percent is:

$$1.53 \leq \gamma_b \leq 1.72$$

Thus we can say that the bulk specific gravity lies within the range of 1.53 to 1.72 g g^{-1} with a probability of 0.95.

Comments

Another term often used to describe soil is the bulk density,

$$\rho_b = \frac{M_s}{V_b} \qquad (1\text{-}2)$$

where ρ_b is the bulk density ($M\ L^{-3}$), M_s is the dry mass of the sample (M) and V_b is the bulk volume of the sample (L^3). Because the weight of the dry soil, W_s is equal to $g\ M_s$ (where g is the acceleration of gravity) and the weight of an equal volume of water W_w is equal to $V_b\ \gamma_w$ (where γ_w is the specific weight of water),

$$\rho_b = \frac{W_s/g}{W_w/\gamma_w} \qquad (1\text{-}3)$$

Thus,

$$\rho_b = \gamma_b\ \frac{\gamma_w}{g} \qquad (1\text{-}4)$$

In the metric system, $\gamma_b \cong 980$ dyne cm^{-3} and $g \cong 980$ dyne g^{1}. Therefore, ρ_b is approximately equal, numerically, to γ_b .

Table 1-1. Suggested field sheet for use with the rubber balloon technique.

Name: Lee Wheeler Date 7/12/77

Soil sample location: Benson Farm Soil type: Clay-loam

DATA AND CALCULATIONS

Sample number (1)	Container number (2)	Container weight in g (3)	Cylinder initial reading in cm^3 (4)	Cylinder final reading in cm^3 (5)	Volume of water in cm^3 (5)-(4) (6)	Gross wet weight of soil sample in g (7)	Gross dry weight of soil sample in g (8)	Net weight of dry soil sample in g (8)-(3) (9)	Bulk specific weight of soil sample in g^{-1} (9)÷(6) (10)
1	18	85.0	180	380	200	458.2	440.2	355.2	1.776
2	19	28.0	200	305	105	208.0	203.0	175.0	1.662
3	17	85.0	495	717	222	461.0	442.0	357.0	1.608
4	05	28.5	495	620	125	242.3	237.5	209.0	1.672
5	22	27.3	882	1025	143	268.2	252.5	225.2	1.575
6	12	84.4	882	1160	278	520.0	505.1	420.7	1.513

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EXERCISE 2

POROSITY

Object: To determine the porosity of a soil using the density method.

INTRODUCTION

The pore system of a soil is the voids between the solid grains of the soil. The geometry of the pores is difficult to describe because the soil particles, and thus the pores, differ greatly in size and shape. Characterizations of the pore system are important in investigations of the storage and movement of soil water.

POROSITY

The porosity of a soil is the ratio of the volume of pores to the bulk volume of soil (i.e., soil grains plus pores). Porosity can be determined by several methods, all of which aim to measure the pore volume of a known bulk volume of soil.

Direct method

The most direct method of determining the porosity is to measure the bulk volume of a sample of soil and then to compact it so as to destroy all its voids and again measure the volume. Thus, the porosity is computed as follows:

$$\phi = \frac{V_b - V_s}{V_b} = 1 - \frac{V_s}{V_b} , \tag{2-1}$$

where ϕ is the porosity ($L^3\ L^{-3}$), V_b is the bulk volume of a sample before compacting (L^3) and V_s is the bulk volume of a sample of soil after compacting (L^3) and is equal to the volume of the solid grains.

Density method

Calculating porosity from density measurements simply involves converting data from densities to volumes. Since bulk density is defined as the ratio of the dry mass of soil (oven-dry) to the bulk volume of the soil, from Equation 1-2 the bulk volume of the soil, V_b (L^3), is

$$V_b = \frac{M_s}{\rho_b} , \tag{2-2}$$

where ρ_b is the bulk density ($M\ L^{-3}$) and M_s is the mass of the soil (M).

Similarly, from the definition of particle density, ρ_b , one obtains the relationship given by,

$$V_b = \frac{M_s}{\rho_b} \quad , \tag{2-3}$$

where V_b is the total volume (L^3) occupied by solid particles having the total dry weight W_s . Now V_s/V_b is the fraction of the volume occupied by the solid particles. From the above definitions, the porosity ϕ is equivalent to the fraction of the bulk volume not occupied by solids, that is,

$$\phi = 1 - \frac{\rho_b}{\rho_p} = 1 - \frac{\gamma_b}{\gamma_s} \quad , \tag{2-4}$$

where γ_a is the specific weight of the solid grains.

Porosity is often expressed as a percentage, P_ϕ . In this case the porosity values obtained by Equations 2-1 and 2-4 are multiplied by 100.

Procedure

1. Determine the bulk density by the procedure described in Exercise 1 (See comments).

2. In cases where great accuracy is not required, use the assumed value of 2.65 g/cm^3 for particle density of mineral soil. If great accuracy is desired, particle density may be determined using a method described by Black *et al.*, (1965).

3. Insert density values into Equation 2-4.

Example of porosity determination using the density method

Using the excavation method and the rubber balloon technique (Exercise 1), a set of bulk density values were found for a specific soil. Assuming the values of 2.65 g/cm^3 for particle density, and inserting these values into Equation 2-4, the results of Table 2-1 were obtained.

Analysis of porosity determinations given in Table 2-1

The average of the six determinations of porosity of Table 2-1 is $\phi = 0.374$ (Appendix A, Equation A-1). The standard deviation is $S = 0.022$ (Appendix A, Equation A-3). The confidence interval given by the student's t-test (Appendix A, Equation A-5), with a probability of 0.95, is

$$0.351 \leq \phi \leq 0.397 \quad .$$

Thus, we can say that the true value of porosity lies within the range of 0.351 to 0.397 with a probability of 0.95.

Table 2-1. Values obtained for porosity determination using the density method.

W_s in g (1)	V_b in cm^3 (2)	ρ_b in $g\ cm^{-3}$ (1)-(2) (3)	ρ_p in $g\ cm^{-3}$ (4)	ϕ in $g\ cm^{-3}\ (g\ cm^{-3})^{-1}$ 1 - (3)÷(4) (5)
355.2	200	1.77	2.65	0.332
174.5	105	1.66	2.65	0.374
357.0	222	1.61	2.65	0.392
209.0	125	1.67	2.65	0.370
233.0	143	1.63	2.65	0.384
450.3	278	1.62	2.65	0.389

Other methods

Methods other than those outlined above have been proposed for porosity measurements. One such method is that of the absorption of liquids on the surfaces of soil particles. Surface area can then be determined, and, if the pore geometry is known, the porosity size can also be determined. Another way to obtain the pore volume is to measure the resistance of the medium to flow through the pores. The various methods of porosity determination have been compared and evaluated against each other on several occasions (Roger, 1969). However, no general statements can be made as to which is the "best" method.

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EXERCISE 3

WATER CONTENT OF SOILS

Object: To determine the water content of soils using direct and indirect methods.

INTRODUCTION

Measures of soil water content are needed in many types of soil studies. In the field, knowledge of the water available for plant growth requires the measurement of soil water content. In the laboratory, many physical and chemical properties of soil require knowledge of the soil water content.

The water content of the soil on a dry weight (or mass) basis is the ratio of the weight (or mass) of the water in the soil to the weight (or mass) of the dry soil. Thus,

$$W = \frac{W_w - W_d}{W_d} = \frac{W_w}{W_d} - 1 \quad , \qquad (3\text{-}1)$$

where W is the soil water content on a dry weight or mass basis ($F\ F^{-1}$ or $M\ M^{-1}$), and W_w and W_d are, respectively, the wet weight or mass and the dry weight or mass of the soil. The water content is frequently expressed as a percent of the dry weight of soil,

$$P_w = 100\ W \qquad (3\text{-}2)$$

where P_w is the dry weight water percentage.

There are some applications of soil water data, particularly in connection with rainfall and irrigation, in which it is more useful to express the water content as the ratio of the volume of water in the soil to the bulk volume of the soil. Thus,

$$\theta = \frac{V_w}{V_s} \quad , \qquad (3\text{-}3)$$

where θ is the soil water content on a volume basis ($L^3\ L^{-3}$), V_w is the volume of the water in the soil (L^3) and V_s is the bulk volume of the soil (L^3).

The soil water content (dry weight basis), W , and the soil water content (volume basis), r , are related by:

$$\theta = W\ \gamma_b \quad , \qquad (3\text{-}4)$$

where γ_b is the bulk specific weight of the soil (Exercise 1). The soil water content (volume basis), θ, is sometimes expressed as a percentage of the bulk volume of soil that is water,

$$P_\theta = 100\ r \quad , \tag{3-5}$$

where P_θ is the soil water content on a volume percentage basis.

PRINCIPLES

Determination of the soil water content of soils may be accomplished by direct and indirect methods. Direct methods are those where the water in the soil is removed from the soil by evaporation, distillation or chemical reaction. Determination of the amount removed may be by one or more of the following methods:

1. Measurement of the weight loss of the soil sample by evaporation.
2. Collection of water by distillation. The soil sample is mixed with mineral oil (of a higher boiling point than water) and heated. The water is driven off by heating and collected by distillation to give the original water content in the soil sample (Henderson, 1953).
3. Extraction of water with substances which will replace it in the sample and measurement of some physical or chemical property of the extracting material which is quantitatively affected by water content (Bouyoucos, 1931).

Two indirect methods are those of neutron scattering and neutron gamma ray absorption. In the neutron scattering method a radioactive source is placed in the soil and the emitted neutrons are modified (slowed down) by any water held in the soil. In the gamma ray absorption method, the degree to which a beam of monoenergetic gamma rays is attenuated (reduced in intensity) in passing through a soil column is measured. If the density of the soil is constant, then changes in the attenuation represent changes in water content.

GRAVIMETRIC METHOD FOR DETERMINING SOIL WATER CONTENT

Water content determinations by gravimetric methods (dry weight basis) involve weighing the moist sample, removing the water from it and weighing the now dry sample to determine the amount of water removed. Soil water content is then obtained by using Equation 3-1. Water may be removed from the sample in any number of ways, but the simplest and most-used one is the oven-drying method. It is also the standard against which all other methods are checked.

Special apparatus

1. Auger or sampling tube or other suitable device to take a soil sample.
2. Soil containers with tight-fitting lids.
3. A drying oven with means for controlling the temperature between 100°C and 110°C.
4. A desiccator with active desiccant.
5. Balance for weighing the samples.

Procedure

1. Take soil samples at the desired depth.
2. Place sample of approximately 100 grams of soil in containers with tight-fitting lids.
3. Weigh the samples immediately or store them in such a way that evaporation is negligible.
4. Place the samples in a drying oven with the lids off, and dry them to constant weight at approximately 105°C for 24 hours.
5. Remove the samples from the oven, replacing the covers, and place them in a desiccator containing active desiccant.
6. Weigh samples when cool.
7. Subtract the container weight from the total weights obtained in steps 3 and 6.
8. Compute the soil water content using Equation 3-1.

Analysis of results obtained using the gravimetric method for determining soil water content

In the analysis of the obtained soil water content of Table 3-1, we will calculate the average (Appendix A, Equation A-1), the standard deviation (Appendix A, Equation A-3), and the confidence interval (Appendix A, Equation A-5).

The average value for the soil water content of Table 3-1 is

$$\bar{W} = 0.084 \quad .$$

The standard deviation is

$$S = 0.013 \quad .$$

The confidence interval in which the central value falls within a given probability is computed using the student t-test. With a confidence level of 95 percent and six observations,

$$0.0702 \leq W \leq 0.0977 \quad .$$

Table 3-1. Suggested field sheet for use in determining the soil water content by the gravimetric method.

Name: Leroy Salazar Date: 6/23/77

Location: Greeley Research Farm Kind of soil: Clay loam

DATA AND CALCULATIONS

Sample number (1)	Depth of sample (2)	Container number (3)	Container weight g (4)	Wet weight of sample plus can g (5)	Dry weight of sample plus can g (6)	Net weight of wet sample, W_s (5)-(4) (7)	Net weight of dry sample, W_d (6)-(4) (8)	Soil water content, Eq. 3-1, g/g [(7)÷(8)]-1 (9)
1	45	13	38.9	136.3	129.4	97.4	90.5	0.076
2	45	12	37.0	137.5	131.1	100.5	94.1	0.068
3	45	27	38.9	135.2	126.7	96.3	87.7	0.098
4	45	8	37.3	132.3	124.3	95.0	87.0	0.092
5	45	9	37.3	134.5	126.3	97.2	89.0	0.084
6	45	11	37.6	131.6	124.2	94.0	86.6	0.085

Thus we can say that the true value of soil water content lies within the range of 0.072 to 0.0977 with a probability of 0.95.

Comments

Certain general requirements must be met in the development of a procedure for obtaining accurate and reproducible water content measurements. Foremost of these is the requirement that the sample be dried at a specific temperature to constant weight with nothing being lost but water.

Reproducibility in water content measurements can be achieved in two ways: (1) treating every sample of a set to be compared exactly the same way in terms of such things as sample size, drying temperature and drying time. (2) following the procedures listed previously as closely as possible.

NEUTRON SCATTERING METHOD

The atomic age has provided a modern practical method of measuring soil water content through the use of high energy neutrons and measuring the degree to which they are slowed down in the soil. When high energy neutrons are emitted from a source of radiation material, they collide with atomic nuclei that are nearby. If the nuclei with which they collide are of a heavier mass they will bounce off retaining practically all their original velocity. If, however, the particle with which the neutron collides is of approximately the same mass as the neutron, it will be slowed down. Such neutrons are said to be thermalized and they can be detected as described below.

In soils, there are few elements that are effective in thermalizing neutrons. The atomic nucleus most effective in slowing neutrons is that of hydrogen, which has approximately the same mass as a neutron. Lithium, beryllium, boron and carbon may also thermalize neutrons but they are less effective as their atomic weights are greater. In soil, these latter elements usually occur in small to insignificant amounts, but hydrogen occurs in large amounts as a component of water.

A probe, containing a source of high energy neutrons and a counter for detecting the thermal neutron flux, is lowered into an aluminum or steel tube that has been placed in the soil. Because hydrogen is chiefly responsible for thermalizing the neutrons, the rate at which thermal neutrons are detected is proportional to the number of hydrogen nuclei present in the vicinity of the source and detector, provided that the rate of emission of fast neutrons and the geometry of the area through which the neutrons are scattered are constant.

Special apparatus (Figure 3-1)

1. Source of fast neutrons, such as 2 to 5 mc of radium or 100 mc of American-beryllium. These sources have half-lives of 1,600 and 460 years, respectively.

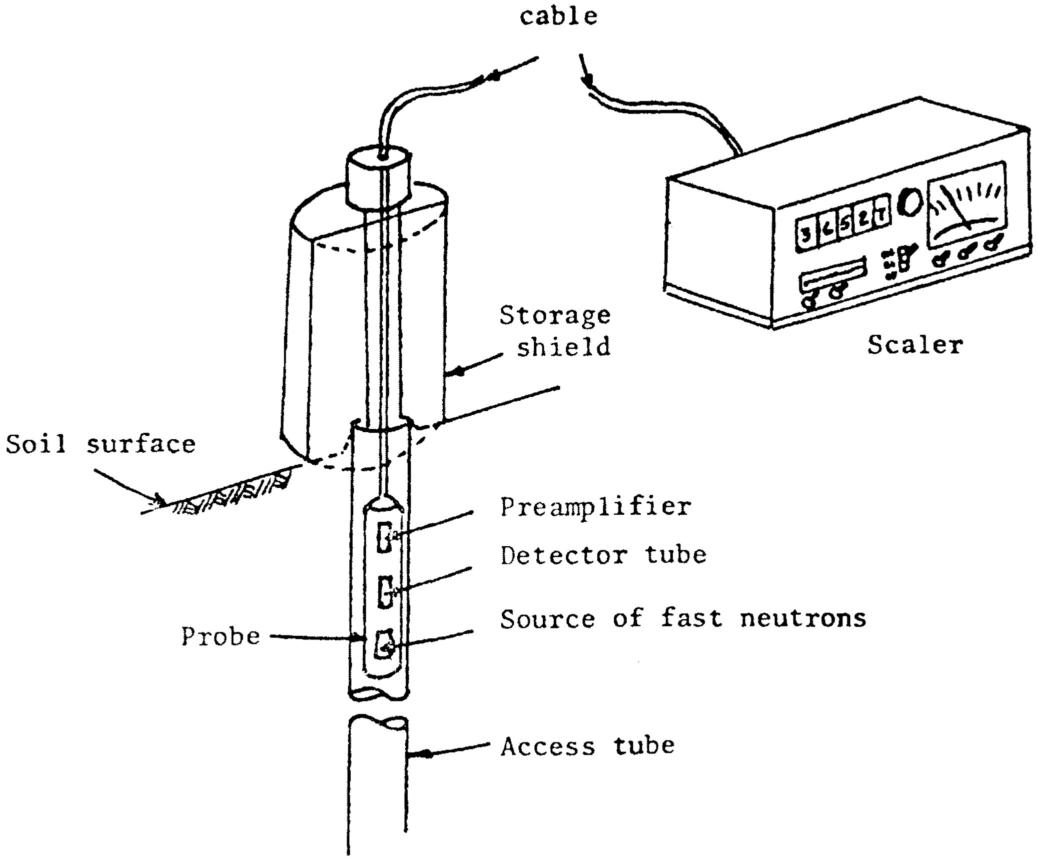

Figure 3-1. Equipment for determining soil water content by the neutron scattering method.

2. Shield for storage of the neutron source between readings and when the unit is not in use. Shielding commonly used consists of lead and paraffin or polyethylene.

3. Detector tube for thermal neutrons. The one most commonly used is a glass container filled with inert and boron-trifluoride gases. It is mounted in a cylindrical arrangement along with a transistorized preamplifier. When a thermal neutron passes through the gases contained in the detector tube it causes momentary ionization, resulting in a brief pulse of current flow, or a "count". The rate of occurrence of such counts is registered and then converted empirically to the water content of the soil.

4. Counting device. The counting device may be a "scaler" where each thermal neutron reacting with the gases contained in the detector tube is counted and is accumulated, or it may be registered on a "rate meter" where the rate of reaction is indicated.

5. Access tubing and soil auger. Aluminum or steel tubing is most commonly used. There are two sizes of access tubing--1.7 mm (20-gauge) wall steel tubing with an outside diameter of 4.12 cm (1.62 in), and 1.3 mm (0.05 in.) wall aluminum irrigation tubing with an outside diameter of 5.08 cm (2 in.) in diameter. A soil auger slightly smaller than the tubing should be used for drilling the access hole.

Procedure

The installation of access tubes in a field (steps 1 and 2) is done before determining the soil water content using the neutron scattering method. Successive steps (3 to 8) are done several times to obtain the soil water content (volume percentage basis).

The scaler or rate meter should be on standby power for 30 minutes prior to usage and between each reading.

1. Drill the access hole vertically straight, with a diameter slightly smaller than the access tube in order to avoid air pockets around it.

2. Close the access tube with a rubber stopper or with a metal or plastic plug at the bottom, and then insert the access tube into the access hole. Leave several centimeters of the tubing above the soil surface and close it with a rubber stopper or with a metal or plastic cover to prevent entrance of trash and water when measurements are not being made.

3. Place the neutron source, detector and shield at the entrance to the access tube.

4. Connect the neutron source cable to the scaler or rate meter.

5. Turn the scaler or rate meter from standby to on and take a count with the probe in the storage shield reading of one minute duraction.

6. Lower the probe into the access tube and take a scaler or rate meter count of one minute duration at successive depth intervals, starting at least 30 cm from the soil surface. Fifteen-cm intervals are ordinarily used. These are called the depth counts.

7. After completing the readings at different depths return the probe to the storage shield and take a scaler or rate meter reading of one minute

duration. The average of this count and the count taken in step 5 is called the standard count, N_{std}.

8. Divide depth counts by the standard count N_{std}, to obtain count ratios and then using the calibration curve for the instrument and soil, find the soil water content on a volume percentage basis.

The calibration curve

A calibration curve is sometimes supplied with the instrument, but since differences in soils are known to exist, a separate calibration should be made for each soil.

The calibration curve can be determined by taking a series of readings in at least three test holes, at at least four depths. Gravimetric soil water content and bulk specific gravity samples are also taken at the same depth (Exercise 1 and section on Gravimetric Method For Determining Soil Water Content). Convert dry weight basis water content to volume percentage basis by using Equations 3-4 and 3-5 and plot data points of water content

Table 3-2. Suggested field sheet for use with given data to obtain a calibration curve.

Name: Leroy Salazar Date: 6/20/77

Location: Greeley Experimental Farm

Standard Count N_{std} (1)	Depth in cm (2)	Depth Count N (3)	Count Ratio N/N_{std} (3)÷(1) (4)	Gravimetric Water Content in (g/g)x100 (5)	Bulk Specific Gravity g/g (6)	Volume Percentage Basis (5)x(6) (7)
37 873	15 to 30	27 155	0.72	18.0	1.45	26.1
37 873	30 to 60	33 023	0.87	18.2	1.70	30.9
37 873	60 to 90	19 807	0.52	11.9	1.47	17.5
37 873	90 to 120	20 124	0.53	9.5	1.90	18.0
38 059	15 to 30	27 674	0.73	16.8	1.43	24.0
38 059	30 to 60	28 733	0.75	13.8	1.70	23.5
38 059	60 to 90	20 037	0.53	13.0	1.47	19.1
38 059	90 to 120	21 119	0.55	10.7	1.90	20.3
38 059	15 to 30	25 033	0.66	15.7	1.43	22.5
38 059	30 to 60	23 460	0.62	12.8	1.70	21.8
38 059	60 to 90	19 756	0.52	10.4	1.47	15.3
38 059	90 to 120	21 495	0.56	10.4	1.90	19.8

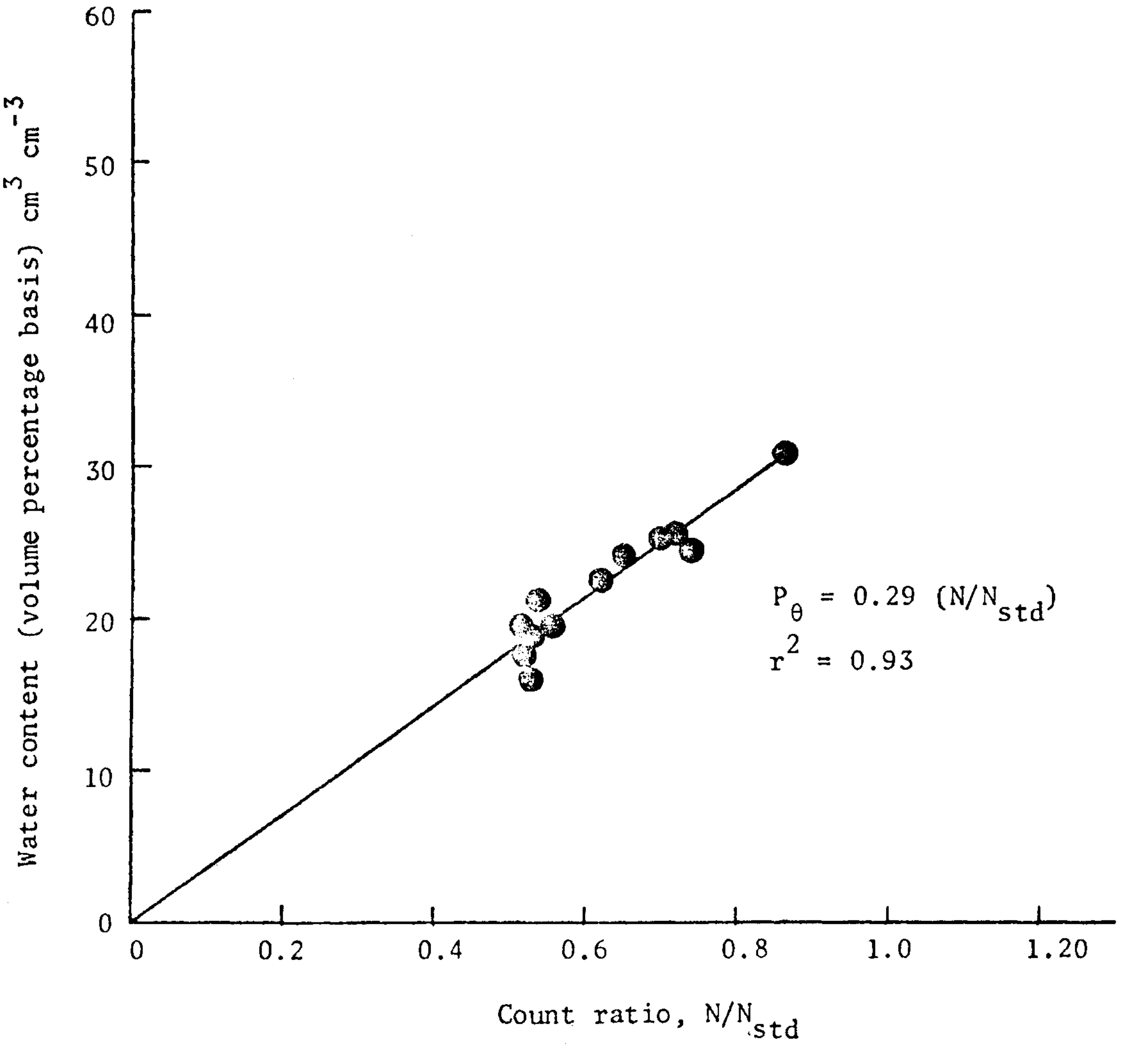

Figure 3-2. Neutron probe calibration curve obtained from data given in Table 3-2.

vs. the count ratios obtained at the same depths (Figure 3-2). A straight line is then drawn through the data points using the method of least squares (Appendix A, Method of Least Squares). Sample data are given in Table 3-2.

For a linear count ratio-water content curve or linear portions of such curves, the volumetric water content is given by the formula

$$P_\theta = (1/S)(N/N_{std}) \quad , \qquad (3\text{-}6)$$

where S is the slope, N is the soil water depth count and N_{std} is the standard count.

Safety in using neutron scattering equipment

With reasonable attention to safety rules the health hazard involved in using the equipment is small. Important precautions are the following:

1. Keep the probe in its shield at all times except when it is lowered into the access tube (in the soil) for measurements.
2. Reduce exposure to the small radiation escaping the shield by keeping at least two meters away except when changing the position of the probe and by keeping the open end of the probe and shield pointed away from personnel.
3. Transport the probe in the back of a truck or in a car trunk.
4. When the probe is not in use, lock it in a storage cabinet. Label the cabinet plainly to indicate the presence of radioactive meterials.

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EXERCISE 4

TOTAL WATER AVAILABILITY

Object: To determine the field capacity and permanent wilting point for calculating total available water.

INTRODUCTION

The total available water in the soil is the amount of water that can be used or removed from the soil in the support of plant life.

The total available water is the difference between the soil water content upper limit, which is called FIELD CAPACITY, and a soil water content lower limit, the PERMANENT WILTING POINT. The field capacity has long been considered the soil water content of a fallow soil a few days after thorough wetting by rainfall or irrigation, when the profile is not influenced by a water table and when the rate of drainage due to gravity has decreased to a relatively low value. The permanent wilting point is the soil water content at which the plant can no longer obtain water through its root system as fast as it is being lost by transpiration and consequently desiccates to the death point. These soil water contents are given as a fraction on a dry weight basis. Thus,

$$TAW = (FC - PWP)\ \gamma_b\ Y \quad , \qquad (4\text{-}1)$$

where TAW is the volume of total available water per area of soil surface ($L^3\ L^{-2}$), γ_b is the bulk specific gravity of the dry soil ($F\ F^{-1}$ or $M\ M^{-1}$, Exercise 1), Y is the depth of the root zone (L) and FC and PWP are the field capacity and permanent wilting point respectively ($W\ W^{-1}$ or $M\ M^{-1}$).

FIELD CAPACITY

The field capacity does not have a precise value because downward water movement following surface wetting decreases at a rate dependent upon texture, profile variability and the amount of water added. Thus, the time following wetting that the field capacity should be measured for meaningful interpretation is different for different soils and conditions.

Regardless of the lack of precision with which the field capacity can be defined or determined, it is an important concept, especially in irrigated agriculture. An estimate of the field capacity is needed to determine the amount of irrigation water required to recharge the profile throughout the root zone depth.

Field sampling method for determining field capacity

This method is based on sampling a field and measuring its soil water content over a period of time.

Procedure

1. Select a field site containing the soil to be measured.
2. Place a raised border (A simple earthen dike is sufficient) around an area of at least 3 meters square and add sufficient water by flooding to nearly saturate the soil to the depth desired (i.e., the root zone of the crop to be grown).
3. Cover the area with a vapor barrier to prevent evaporation.
4. Take soil samples throughout the root zone each day after wetting.
5. Determine the soil water content of the samples (dry weight basis) and plot soil water content vs time (Figure 4-1). The amount of water in the soil will decrease rapidly for about one day after wetting. Water continues to move out at a decreasing rate for many more days. The soil is said to be at field capacity when the rate of outflow becomes low.

The curve on Figure 4-1, gives the field capacity at a particular soil depth. Different curves may be obtained at different depths due to soil variation and water movement within the soil profile.

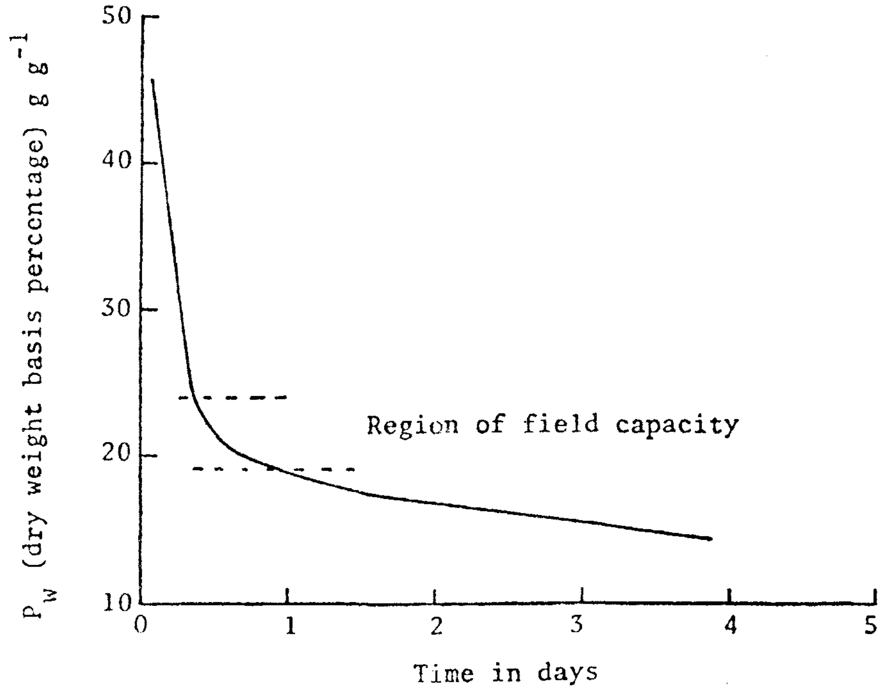

Figure 4-1. Field capacity determination curve.

1/3-bar percentage method

It has been found in most soils that the soil water content (dry weight basis) retained in a sample of soil which has previously been screened and wetted in a standardized manner and then brought to equilibrium on a porous ceramic plate at a pressure of 33.33 kPa (1/3 bar or 4.83 psi), represents approximately the field capacity of the soil.

Special apparatus.

1. A pressure plate extractor with regulated air pressure of 0 to 500 kPa (Figure 4-2). The pressure plate extractor consists of a pressure chamber over a porous ceramic plate.
2. A porous ceramic plate (Figure 4-3). Porous ceramic plates are available with various permeabilities for use with the 1/3 bar percentage method. A commonly used one has a water flow rate of approximately 2 ml hr^{-1} cm^{-2} when under a pressure of 100 kPa. The allowed bubbling pressure (i.e., the pressure required to force air through the plate after it has been thoroughly wetted with water) is between 138 and 207 kPa.
3. Sample retaining rings. The most commonly used are rubber rings of 5 cm in diameter and 1 cm high, but rings of various sizes cut from other materials that do not deteriorate under water (i.e., brass), may also be used.

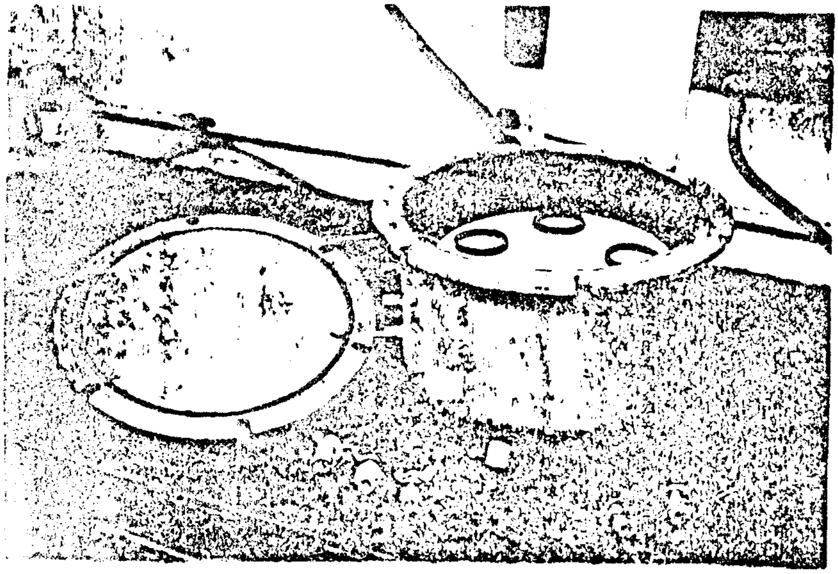

Figure 4-2. Pressure plate extractor with regulated air pressure of up to 500 kPa.

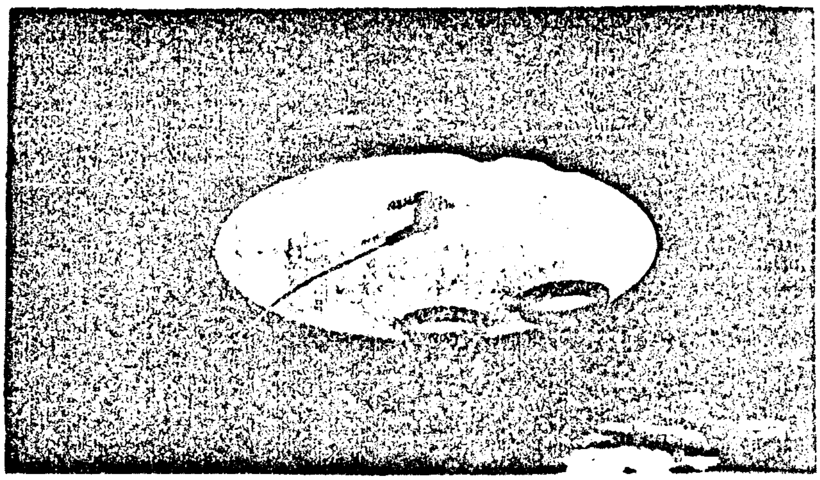

Figure 4-3. Retaining rings on the porous ceramic plate.

Procedure

1. Pass the soil through a 2-mm round-hole sieve, using a rubber pestle if necessary.
2. Level the soil in the retaining rings and allow the samples to stand for at least six hours with an excess of water on the ceramic plate.
3. At the completion of the wetting process remove the excess water from the ceramic plate with a pipet or syringe.
4. Close the pressure plate extractor and apply a pressure of 33.33 kPa across the samples on the ceramic plate until water stops emerging from the extractor outlet. This occurs when equilibrium between the soil samples and the applied pressure is reached. Twelve hours is usually sufficient time when the ceramic plate described in special apparatus is used.
5. Reduce the pressure, open the extractor, and quickly transfer the samples to moisture-proof containers with lids, for determining the soil water content using the dry weight basis procedure (Exercise 3). The soil water content obtained will be the field capacity.

Comments

The range of field capacities that has been found in most agricultural soils is from 0.15 to 0.25 (dry weight basis).

PERMANENT WILTING POINT

The permanent wilting point is usually defined as the water content (dry weight basis) of a soil when plants growing in it are first reduced to a wilted condition from which they cannot recover in an approximately saturated atmosphere.

Permanent wilting point determination using an indicator plant

In this method indicator plants are grown in pots and alternately subjected to a dark, humid chamber, and sunlight. The procedure is outlined in detail below.

Procedure

1. Place a measured amount (about 600 grams) of air-dried soil in a number 2 friction top can.
2. Make a soil water determination (dry weight basis) on a separate sample so that the dry weight of soil is known and at each

irrigation the water content of the soil in the container can be brought up to the desired soil water content. Add nitrogen and other nutrients as needed to produce good plant growth.

3. Wet the soil in the container thoroughly without water-logging, and reweigh the container. The water content corresponding to field capacity is a convenient starting point.
4. Plant several seeds of dwarf sunflower (Helianthus annus) and after germination, cut off all but the best seedling. Make a sufficiently large hole in the lid to allow the stem to pass through the lid, and replace the lid on the container.
5. Grow the plant in a green house or under a cloth shade until the third pair of leaves is fully developed. Repeatedly check the soil water content to ensure that there is an adequate supply of water during the plant development period, but do not waterlog the plant. Adjust the aerial environment of the plant to a condition where normal plant development occurs but where the environmental demand for water is low.
6. After the third pair of leaves has developed, irrigate the soil in the container with enough water to bring the water content to the starting point (Step 3). Fill the space between the hole in the lid and the stem with cotton to reduce soil evaporation to a low level, and allow the plant to wilt.
7. After drooping of the lower leaves occurs place the plant in a dark chamber with a saturated atmosphere. If the plant revives remove it and allow it to transpire until the lower leaves droop. Again place it into the saturated atmosphere. Repeat this procedure until the plant does not revive. If the plant no longer revives when placed in the saturated atmosphere, the permanent wilting point has been reached.
8. Cut off the plat at soil level and weigh the plant. Determine the soil water content (Exercise 3), making an adjustment for the weight of the plant roots.

Calculations

An adjustment of the soil water content determination at the permanent wilting point must be made to account for the weight of the plant roots in the soil. The adjustment is made by using the following formula.

$$PWP = \frac{A - B - (0.4Z)}{B - T - (0.1Z)} , \qquad (4\text{-}2)$$

where PWP is the permanent wilting point expressed as a soil water content on the dry weight basis ($M\ M^{-1}$), A is the gross weight of the container plus soil, water, and roots when PWP has been reached, B is the gross weight of the container plus soil and roots after drying, Z is the weight of green sunflower tops and T is the weight of the container. The quantity 0.4Z is the approximate weight of water in the roots and 0.1Z is the approximate weight of dry matter in the roots.

15-bar percentage method

It has been found that the 15-bar soil water content (dry weight basis) retained in a sample of soil is closely correlated with the permanent wilting point. This provides a convenient method for estimating the permanent wilting point.

Special apparatus.

1. A pressure plate extractor with regulated air pressure designed to work at 1 500 kPa (15 bar or 217.5 psi). (Figure 4-4).
2. A porous ceramic plate with a rate of flow greater than 0.015 m hr^{-1} cm^{-1} when a pressure of 1 500 kPa (217.5 psi) is applied. The minimum allowable bubbling pressure is greater than 1 520 kPa.
3. Sample retaining rings. Same as those described in section on special apparatus.

Procedure

1. Pass the soil through a 2 mm round sieve, using a rubber pestle if necessary.
2. Level the soil in the retaining rings and allow the samples to stand for at least six hours with an excess of water on the ceramic plate.
3. At the completion of the wetting process remove the excess water from the ceramic plate with a pipet or syringe.

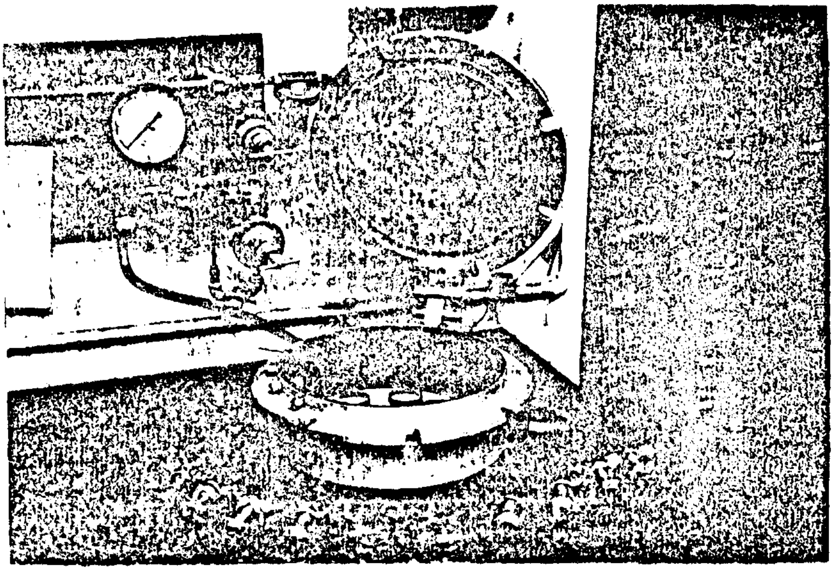

Figure 4-4. Pressure plate extractor with regulated air pressure and designed to work at 1 500 kPa (15 bar or 217.5 psi).

4. Close the Pressure Plate and apply a pressure of 1 500 kPa (217.5 psi) until equilibrium is reached for the soil samples contained in the rings of the ceramic plate. Thirty-six hours is usually sufficient time.
5. When equilibrium is obtained, open the cell and quickly transfer the samples to moisture-proof containers with lids, for determining the soil water content using the dry weight basis procedure (Exercise 3). The soil water content obtained will be the permanent wilting point.

Comments

In most soils the PWP is in the range from 0 to 0.2 on a dry weight basis.

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EXERCISE 5

SOLUBLE SALTS BY ELECTRICAL CONDUCTIVITY

Object: To determine the soluble salts concentration in a soil using the electrical conductivity method.

INTRODUCTION

The electrical conductivity, EC, of the soil solution is commonly used for indicating the total soluble salts concentration. Electrical conductivity can be quickly and accurately determined and has long been used for determining the soluble salts concentration in soils.

PRINCIPLES

Electrical conductance is expressed in mhos and is the reciprocal of electrical resistance which is given in ohms. Electrical conductance is used in describing the salts concentration of soil solution because it varies with salt content.

The standard unit for electrical conductivity, EC (mhos/cm), is a large unit and most solutions have an electrical conductivity which is very much less than one unit. It is customary to choose a smaller subunit, the micro mho/cm (μmho/cm), that gives a more convenient location of the decimal point when recording or expressing data. This practical electrical conductivity unit (μmho/cm) is equal to 10^{-6} mho/cm.

SPECIAL APPARATUS

1. Alternating current wheatstone bridge, for electrical conductivity measurements with balancing resistance adjustable to 1 ohm (Figure 5-1).
2. Conductivity cell. This consists of a pair of 1 cm square platinum electrodes separated by 1 cm. These electrodes are conveniently arranged for immersion in a standard manner in a solution whose conductivity is to be measured. This cell usually has a capacity of 2 ml.
3. Extractor or vacuum system.
4. Medium grade filter paper and porcelain funnel (Figure 5-2).
5. Erleymeyer flasks with stoppers.

REAGENT

A 0.01 N solution of potassium chloride is used as a standard solution and is made by dissolving 0.7455 grams of potassium chloride (KCl) in one liter of distilled water. The electrical conductivity of this solution is 0.0014118 mho/cm at 25°C.

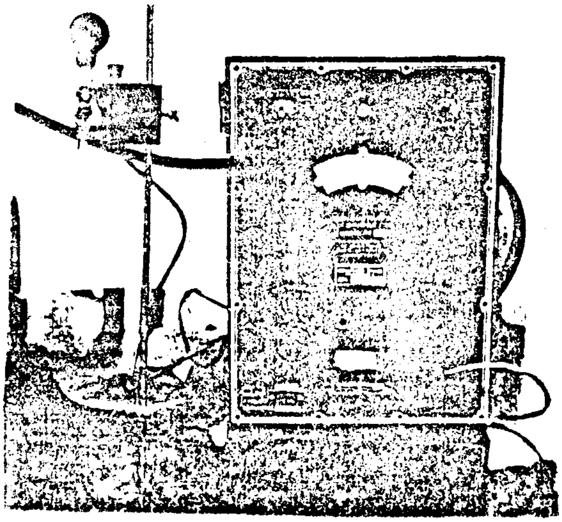

Figure 5-1. Conductivity cell (left), and wheatstone bridge.

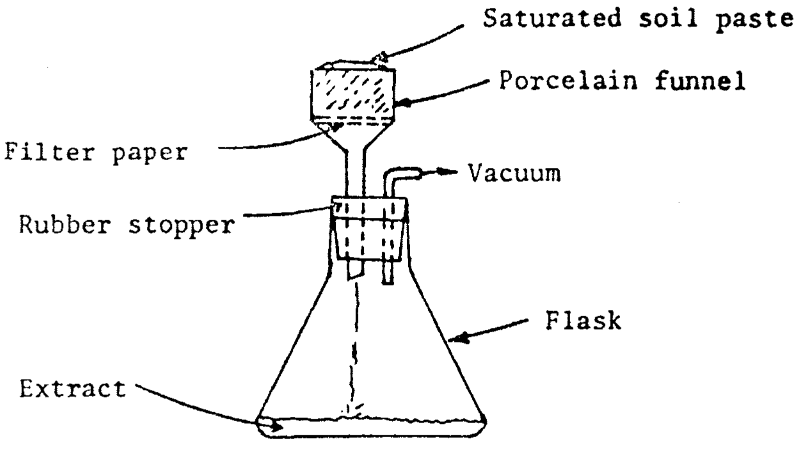

Figure 5-2. Porcelain funnel and flask connected to a vacuum system.

PROCEDURE

1. Prepare the saturated soil paste by adding distilled water to a sample of soil while stirring with a spatula. At saturation the soil paste glistens as it reflects light, flows slightly when the container is tipped, and slides freely and cleanly off the spatula for all soils but those with a high clay content. The mixing process is easier if the soil sample is first passed through a 2-mm sieve and air dried.
2. Place a medium grade filter paper on the porcelain funnel and then place the saturated soil paste on the paper. Connect the porcelain funnel to a vacuum extractor and apply vacuum. Vacuum extraction should be terminated when air begins to pass through the filter.
3. Collect and store the soil solution extract from the saturated soil paste in clean stoppered bottles.
4. Fill and empty the cell twice with 0.01 N potassium chloride solution at 25°C. The first two fillings are discarded and serve to avoid disturbances from solutions previously used in the cell. Refill the cell with the same solution at 25°C. Most cells carry a mark indicating the level to which they should be filled or immersed.
5. Follow the manufactures' instructions in balancing the bridge. Read the cell resistance and calculate the cell constant, k , as follows.

   $$k = (R_{KCl})(0.0014118) \ , \qquad (5\text{-}1)$$

   where R_{KCl} is the resistance reading (ohms) of a 0.01 N potassium chloride solution at 25°C having known electrical conductivity of 0.0014118 mhos/cm.
6. Rinse the cell twice with the soil solution extract to be measured. The adequacy of rinsing is indicated by the absence of resistance changes with successive rinsings. If only a small amount of the soil solution extract is available, the cell may be rinsed with acetone and ventilated until it is dry.
7. Refill the cell with the soil solution extract and record the resistance of the cell, R_s , and the soil solution extract temperature, t.

CALCULATIONS

The electrical conductivity, EC_t , of the soil solution extract at the temperature of measurement, t , is calculated as follows,

$$EC_t = \frac{k}{R_s} \quad . \tag{5-2}$$

For soil solution extracts, a temperature conversion factor, f_t , obtained from Table 5-1 should be used for converting calculated electrical conductivity values to their equivalent values at 25°C. Thus,

$$EC = (EC_t)(f_t) \quad . \tag{5-3}$$

EXAMPLE OF ELECTRICAL CONDUCTIVITY DETERMINATION

The data given in Table 5-2 represents an example of soluble salts concentration determination using the electrical conductivity method.

Table 5-1. Temperature conversion factors, f_t , for converting conductivity data on soil solution extracts to the standard temperature of 25°C. (Richards, 1954).

°C	f_t	°C	f_t	°C	f_t
3.0	1.709	22.0	1.064	29.0	0.925
4.0	1.660	22.2	1.060	29.2	0.921
5.0	1.613	22.4	1.055	29.4	0.918
6.0	1.569	22.6	1.051	29.6	0.914
7.0	1.528	22.8	1.047	29.8	0.911
8.0	1.488	23.0	1.043	30.0	0.907
9.0	1.448	23.2	1.038	30.2	0.904
10.0	1.411	23.4	1.034	30.4	0.901
11.0	1.375	23.6	1.029	30.6	0.897
12.0	1.341	23.8	1.025	30.8	0.894
13.0	1.309	24.0	1.020	31.0	0.890
14.0	1.277	24.2	1.016	31.2	0.887
15.0	1.247	24.4	1.012	31.4	0.884
16.0	1.218	24.6	1.008	31.6	0.880
17.0	1.189	24.8	1.004	31.8	0.877
18.0	1.163	25.0	1.000	32.0	0.873
18.2	1.157	25.2	0.996	32.2	0.870
18.4	1.152	25.4	0.992	32.4	0.867
18.6	1.147	25.6	0.988	32.6	0.864
18.8	1.142	25.8	0.983	32.8	0.861
19.0	1.136	26.0	0.979	33.0	0.858
19.2	1.131	26.2	0.975	34.0	0.843
19.4	1.127	26.4	0.971	35.0	0.829
19.6	1.122	26.6	0.967	36.0	0.815
19.8	1.117	26.8	0.964	37.0	0.801
20.0	1.112	27.0	0.960	38.0	0.788
20.2	1.107	27.2	0.956	39.0	0.775
20.4	1.102	27.4	0.953	40.0	0.763
20.6	1.097	27.6	0.950	41.0	0.750
20.8	1.092	27.8	0.947	42.0	0.739
21.0	1.087	28.0	0.943	43.0	0.727
21.2	1.082	28.2	0.940	44.0	0.716
21.4	1.078	28.4	0.936	45.0	0.705
21.6	1.073	28.6	0.932	46.0	0.694
21.8	1.068	28.8	0.929	47.0	0.683

Table 5-2. Suggested laboratory sheet for use with the electrical conductivity method for determining soluble salts.

Name______________________________ Date_________________________

Location__________________________ Kind of soil_________________________

DATA AND CALCULATIONS

Sample number (1)	Soil solution extract temperature in °C (2)	Conversion factor to 25°C f_t (Table 9-1) (3)	Soil solution extract resistance reading in ohm (4)	Cell constant in cm^{-1} (5)	Electrical conductivity in mho/cm ((5)÷(4))x(3) (6)	Electrical conductivity in micro mho/cm (6) x 10^6 (7)
1	21	1.087	215	0.46	0.002326	2326
2	21	1.087	240	0.46	0.002083	2083
3	21	1.087	205	0.46	0.002439	2439
4	21	1.087	195	0.46	0.002564	2564
5	21	1.087	225	0.46	0.002222	2222
6	21	1.087	230	0.46	0.002174	2174

The resistance of the cell with a standard solution at 25°C was measured and found to be

$$R_{KCl} = 330 \text{ ohms} ,$$

and the cell constant was,

$$k = (330 \text{ ohms})(0.0014118 \text{ mhos/cm}) = 0.46 \text{ cm}^{-1}. \qquad (5\text{-}1)$$

The average <u>of</u> the six electrical conductivity determinations given in Table 5-2 is $EC = 2\ 117$ mmhos/cm (Appendix A, Equation A-1). The standard deviation is $S = 155$ mmhos/cm (Appendix A, Equatio A-3). Using the student's t-test (Appendix A, Equation A-5) and a probability confidence interval of 95 percent (Appendix A, Table A-2).

$$1\ 954 \ \mu\text{mhos/cm} \leq EC \leq 2\ 280 \ \mu\text{mhos/cm}$$

Thus, we can say that the true value of electrical conductivity lies within the above range with a probability of 95 percent.

COMMENTS

In areas where irrigation waters of low salinity are used, the concentration of soil solution extracts frequently range in electrical conductivity below 4 000 μmhos/cm. In these situations little or no evidence of salt injury has been found and almost any crop adapted to the climatic conditions may be grown. In areas where the soil solution extracts range in conductivity to 8 000 μmhos/cm many of more sensitive crop plants do not thrive, but such crops as cotton, alfalfa, sugar beets and cereals, including grain sorghums, may grow well and produce excellent crops.

Table 5-3. Crop condition related to the electrical conductivity of soil solution extract from the saturated soil paste.

Scale of conductivity, mmhos/cm

0	4 000	8 000	15 000
All crops thrive no evidence of salt injury.	Sensitive crops do no thrive. Tolerant crops may do well.	Crop growth restricted, yield usually poor.	Only a few species survive.

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EXERCISE 6

CAPILLARY PRESSURE MEASUREMENTS WITH TENSIOMETER

Object: To measure capillary pressure using tensiometers.

INTRODUCTION

Capillary pressure is the difference in pressure between air and water at a point where they are in contact (interfaces). This definition is expressed by:

$$P_c = P_{air} - P_w , \tag{6-1}$$

where P_c is the capillary pressure ($F\ L^{-2}$), and P_{air} and P_w are the pressure of the air and water, respectively, at the interface. If the air phase is interconnected P_{air} is atmospheric pressure and hence, by convention, equal to zero. In this case,

$$P_c = - P_w \quad . \tag{6-2}$$

Water adheres to solids more strongly than does air, which causes the air-water interfaces to become curved, resulting in interfacial tension forces that oppose the force due to pressure differences. Surface tension s is an interfacial force per unit length that acts along the perimeter of the interface in directions tangent to the curved surface. The relationship between tension forces and force due to pressure difference is known as capillarity. The fundamental equation is

$$P_c = \sigma(\frac{1}{r_1} + \frac{1}{r_2}) \quad \text{or} \quad P_{air} - P_w = \sigma(\frac{1}{r_1} + \frac{1}{r_2}) \quad , \tag{6-3}$$

where r_1 and r_2 are radii of curvature in any two mutually perpendicular planes at the point where P_c is to be evaluated.

When a curved interface forms a portion of a sphere (Figure 6-1) of radius r_1 the capillary pressure equation may be obtained by equating the force due to interfacial tension, $2\pi r\sigma$, and the force due to pressure difference between air and water, $\pi r^2 P_c$.

$$\pi r^2 P_c = 2\pi rs \quad . \tag{6-3}$$

Solving for P_c,

$$P_c = \frac{2\sigma}{r} \quad . \tag{6-4}$$

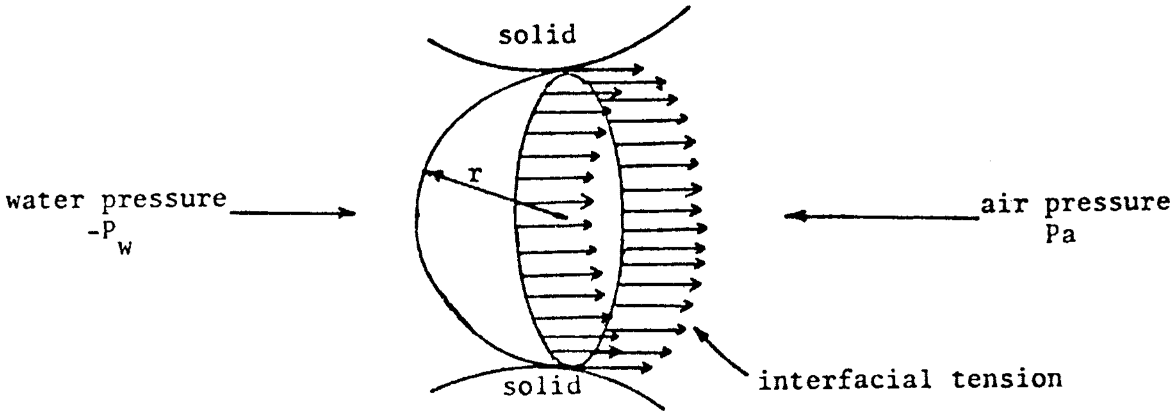

Figure 6-1. Idealized portion of sphere in air-water interface (McWhorter and Sunada, 1977).

The amount of water in a particular soil can be related to the capillary pressure P_c because the radii of the air-water interfaces must decrease as capillary pressure increases. The fact that air-water interfaces must become more sharply curved with increasing P_c means that water must occupy increasingly smaller pores and void subspaces as P_c is increased.

A simple and very commonly used method of evaluating the capillary pressure is through the use of the tensiometer. A tensiometer is a device consisting of a porous cup connected through a rigid system to a pressure gauge capable of registering pressure values between zero and that of the atmosphere.

PRINCIPLES

The various types of tensiometers (Figure 6-2) operate similarily in that a water-saturated porous cup is maintained in contact with the soil-water and is connected by a sealed water column to a pressure (negative) measuring gauge. Tensiometers differ only in geometry, kind of gauge and materials used in construction.

A porous cup is positioned in the soil where information on capillary pressure is desired. The cup, the connecting tube, and the sensing element of a vacuum indicator are all filled with water. Film water in the soil near the cup is in contact with bulk water inside the cup through pores in the cup wall. Flow, in or out through the cup wall, tends to bring the cup water into hydraulic equilibrium with the soil water. As soil water is depleted by root action, or replenished by rainfall or irrigation, corresponding changes in readings on the tensiometer gauge occur.

A reading of zero capillary pressure on the tensiometer indicates a condition of "free water" in the soil. That is, if a hole were made at a depth of the cup, then water would flow into the hole. At the other extreme, as a soil is dried by root action, the reading on the tensiometer increases, corresponding to the amount of water withdrawn, until the limit on the vacuum gauge is reached. The theoretical upper limit is 100 kPa of vacuum (1 bar).

Capillary pressure is indicated explicitly by a tensiometer in the range from zero to 85 kPa. The tensiometer is said to be limited in usefulness since it measures only up to 85 kPa of capillary pressure (due

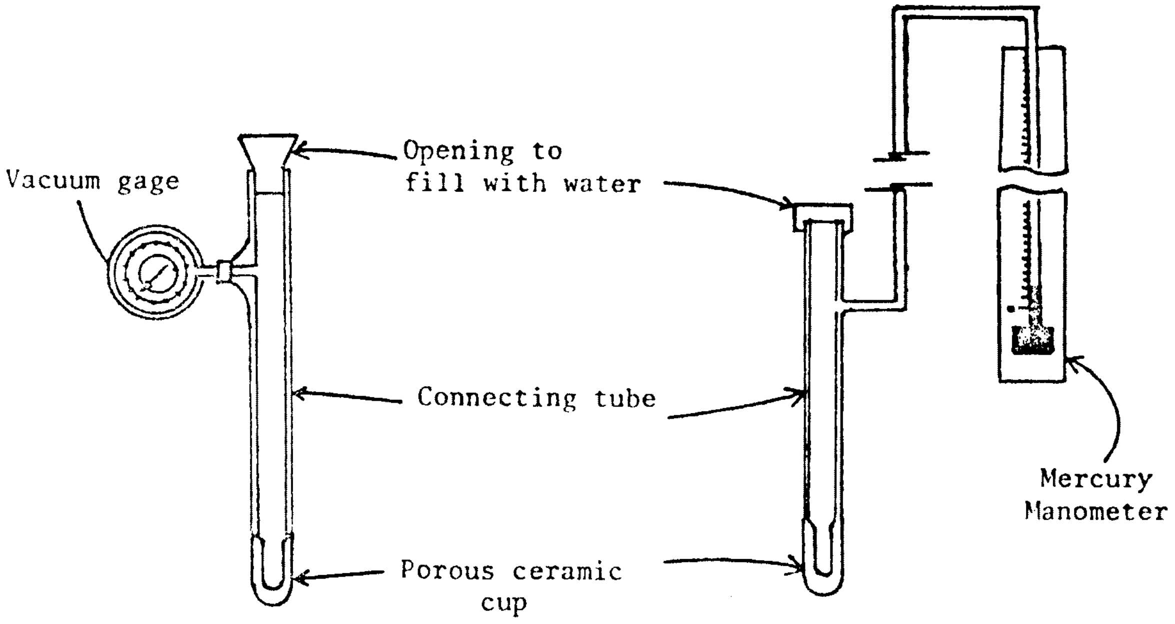

Figure 6-2. Tensiometers illustrating types of pressure gauges, the dial-type diaphram gage (bourdon gage) on the left and the mercury type gauge on the right.

to Mechanical limitations) where the ideal instrument should read as high as 1 500 kPa (15 bars) which is related to the permanent wilting point.

The limitation of the useful range of tensiometers appears less severe when stated in terms of the available soil water content range of the soil (Figure 6-3).

The data of Figure 6-3 were obtained with commonly used pressure plate and membrane equipment (Exercise 4). Such curves usually show capillary pressure related to water content on a dry weight basis or volume basis. However, "available water depletion" is a scale commonly used to express soil water relations in connection with irrigation management. For Figure 6-3, soil water content values were converted to the available water depletion scale by using two conventions: (a) that instruments in the field usually read 5 to 10 kPa of capillary pressure after irrigation, and (b) that 1 500 kPa is an accepted value of capillary pressure when plants permanently wilt, i.e., zero and 100% available water depletion, respectively. As shown in Figure 6-3, these conventions bring all the curves for various soils in close agreement only at the two extremes.

The curves in Figure 6-3 show that, for all but clay soils, tensiometers are capable of indicating soil moisture conditions in the range from 0 to 57 percent (or more) of available water depletion.

Tensiometers with vacuum gauges may have the dial scale in various units. The metric unit for measuring capillary pressure is the kPa. However, tensiometers are commonly calibrated in centibars (1 centibar = 1 kPa). Some commercial types express the pressure readings in "percent available soil water". When this is done an attempt is made to relate capillary pressure to soil water content. This "attempt" may result in erroneous soil water content indications, since at the same capillary pressure reading, two different textured soils will differ substantially in soil water content. When the mercury manometer is used the capillary pressure may be calculated directly from the length of the mercury column when the zero reading for the instrument is known.

Temperature has an influence on tensiometer use. If heat is conducted into or out of the soil through the instrument, so that the soil around the cup is warmer or colder than the surrounding soil at that depth, soil water will move out of or into the soil near the cup surface due to this. This

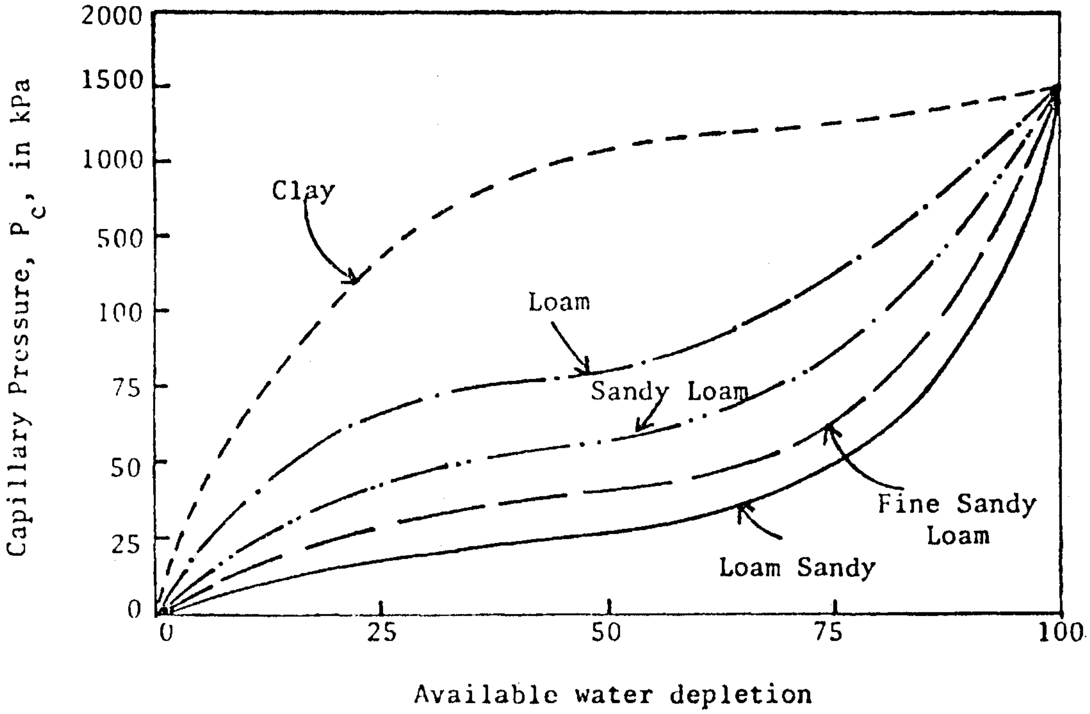

Figure 6-3. Soil water retention curves for soils of different textures (Richards and Marsh, 1961).

would cause the tensiometer to indicate a capillary pressure that was not characteristic of the normal soil conditions. Modern tensiometers are usually constructed of plastic tubing so that heat conductivity is low and the thermal effect is minimized. Nevertheless under certain conditions it may be desirable to shade the instrument from direct sunlight during the hottest part of the day. Another limitation of the tensiometer as far as temperature is concerned, is that the instrument cannot be subjected to freezing conditions. The reasons are obvious.

TENSIOMETER DESIGN

To perform satisfactorily a tensiometer must fulfill certain requirements. The materials used for construction should be durable under a wide range of conditions. All joints and materials except the cup must be impermeable to both air and water. The ceramic wall of the cup, when thoroughly wetted, must withstand an air pressure in excess of 100 kPa without bubbles showing when the cup is immersed in water. The cup conductance to water should be in excess of 1 ml per minute when 100 kPa of hydraulic pressure is applied across the cup wall. The sensing gauge should require only a small volume of liquid displacement corresponding to a large change in pressure. One milliliter per 100 kPa (1 bar) change in reading has been found satisfactory for most uses.

INSTALLATION

1. Prepare a hole to the desired depth using a soil auger or probe of the same outside diameter as the cup so that, when the cup is inserted in the hole, there will be intimate contact between the cup and the soil surrounding it. Care should be taken so that the hole remains round and uniform.
2. Drop a small quantity of loose friable soil into the hole, and unless the soil is one that puddles easily pour a small amount of water into the hole.
3. Fill the tensiometer with deaerated, distilled water before installation. The use of distilled water in the tensiometer prevents plugging of the pores in the ceramic wall due to minerals in natural water.
4. Push the tensiometer firmly into the bottom of the hole with a twisting downward motion applied to the connecting tube. <u>Do not push on gauge</u>.

5. Compress soil around the body at the soil surface and pile it slightly so that water will not collect around the instrument.
6. Protect tensiometers to prevent field damage by bracketing the instrument with bright colored stakes or covering it with a box, tile or steel pipe.

READING THE TENSIOMETER

1. Early morning reading is desirable as a condition near equilibrium exists (water movement in plants and soil at this time has virtually ceased).
2. Read the tensiometer at about the same time each day.
3. Take readings frequently enough so that the change from one reading to the next is not greater than 10 to 15 kPa on the gauge. If irrigation is oftener than once a week, take daily readings. If irrigation is monthly, twice-a-week readings are adequate.
4. Generally, a reliable reading may be made 24 hours after installation.

TENSIOMETER READING RECORD

Capillary pressure data may be recorded in graphical form (Figure 6-4).

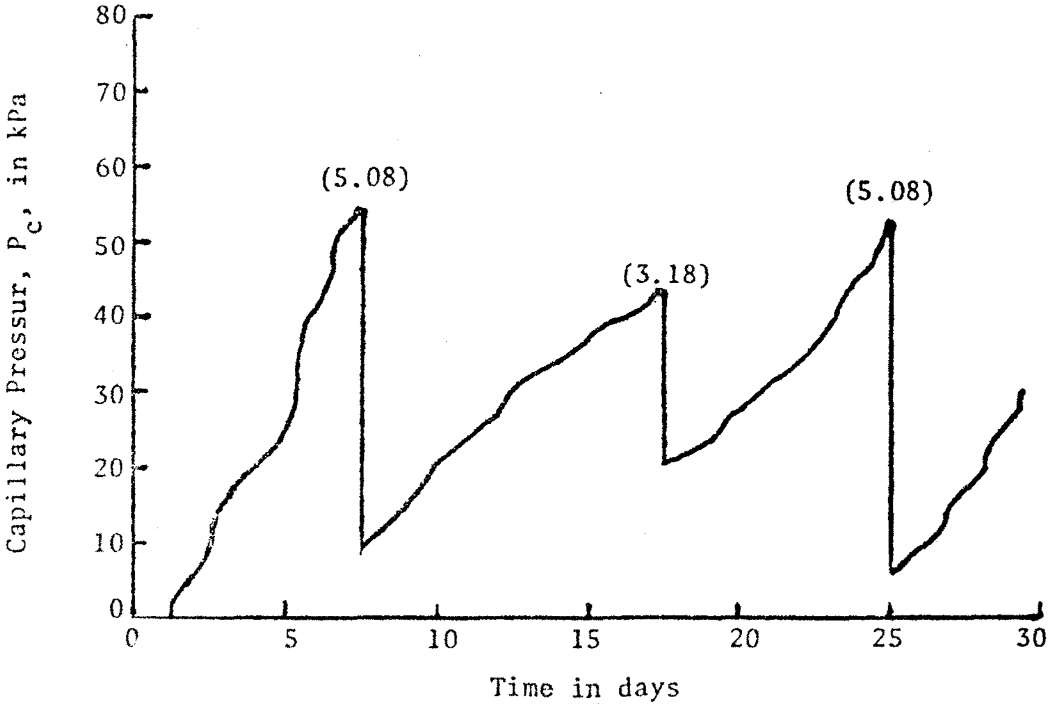

Figure 6-4. Tensiometer reading record. The numbers at the peaks of the curve are irrigations in cm.

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EXERCISE 7

This material, in revised form appears in Section ____, pp. ____ to ____ of the manual.

EXERCISE 8

INFILTRATION

Object: To measure the infiltration on an agricultural soil using a cylinder (ring) infiltrometer and a blocked furrow infiltrometer.

INTRODUCTION

The term infiltration refers specifically to the entry of water into soil through an air-soil surface. The time rate at which water is absorbed by the soil is known as the infiltration rate and has the dimensions of volume per unit area per unit time ($L^3L^{-2}T^{-1}$). These units reduce to depth per unit time (LT^{-1}). The cumulative infiltration, which has a dimension which reduces to length (L), represents the depth of water infiltrated into the soil.

In all irrigation methods, except subsurface irrigation, water is applied to the surface of land where it subsequently enters the soil and is stored for later use by the plants. Thus, the infiltration rate of water into the soil under field conditions, sometimes called intake rate, and the cumulative infiltration are of fundamental importance. Unless water can enter the soil and be stored in the soil profile, crops cannot be grown.

PRINCIPLES

Several methods have been developed for determining the infiltration characteristics of a soil. A few of the most commonly used ones are mentioned here, but in this exercise we will only consider the cylinder (ring) infiltrometer and the blocked furrow infiltrometer.

Methods which are frequently used to determine infiltration characteristics of soils under field conditions for both basin and border irrigation are:

1. Cylinder (ring) infiltrometer.
2. Basin infiltrometer.

There are two common methods used for furrow irrigation,

3. Blocked furrow infiltrometer.
4. Inflow-outflow measurements on a segment of the furrow.

Finally, there is a method applicable to both border and furrow irrigation,

5. Volume balance techniques based upon the rate of advance of the water front and estimated or measured values of the volume of water in surface storage.

Infiltration measurements must be made under field conditions which closely parallel those expected at the time of irrigation. Thus, the antecedent moisture condition at the time of irrigation must be considered. In addition, the type of irrigation to be used must be considered. In border or basin irrigation, the surface through which infiltration occurs is a nearly horizontal plane, the soil surface is entirely flooded, and flow into the soil is primarily one-dimensional. In furrow irrigation, the infiltrating surface approximates a trapezoidal or parabolic prismatic section and the infiltration that occurs is two-dimensional rather than one-dimensional. In sprinkler irrigation, the infiltrating surface is often approximated as a horizontal surface. The measurement of infiltration rates for sprinkler irrigation systems is more complicated than for surface irrigation systems. It is affected by several factors, such as the energy and size of the falling drops, the frequency at which these drops fall and other conditions dependent upon the operating conditions of the sprinkler system.

CYLINDER (RING) INFILTROMETER

The cylinder infiltrometer is a metal cylinder (Fig. 8-1) which is driven into the soil. It measures primarily the vertical rate of water movement into the soil surface (one-dimensional) from the pond it encloses. The infiltration data using the cylinder infiltrometer is obtained by measuring the water level inside of the cylinder at periodic intervals. After water penetrates the soil to the depth of the bottom of the cylinder, it will begin to spread radially as well as vertically and the infiltration rate will change accordingly. Buffer ponds surrounding the cylinder are used to minimize this effect. Buffer ponds can be constructed by forming an earthen dike around the cylinder or by driving a larger diameter cylinder into the soil concentric with the cylinder infiltrometer. Water is maintained in the area between the two cylinders at about the same depth as that in the inner cylinder. The water level within the inner cylinder and the buffer area should be at the depth to be expected during the irrigation.

The apparatus (and corresponding installation procedures) described in the following sections are very inexpensive. More sophisticated equipment involves separate reservoirs with float valves for controlling the water level in the infiltrometer.

Special apparatus

1. A cylinder infiltrometer, 20 to 30 cm in diameter and 30 to 40 cm in length, made of smooth steel, strong enough to be driven into the ground, but still thin enough to enter the soil with minimum disturbance. Cold rolled steel about 0.20 cm thick (14 gage) will usually work, but it may need reinforcement around the upper edge. The larger the diameter of the cylinder and the deeper the cylinder penetrates the soil, the less will be the edge effects and the greater will be the accuracy of the measurements.
2. A buffer cylinder having a diameter at least 30 cm greater than the infiltrometer and a length of about 20 cm. Construction should be similar to that of the infiltrometer. Alternately, the buffer "ring" can also be a diked area surrounding the cylinder infiltrometer.
3. A water level gage for measuring the changes of water level in the cylinder infiltrometer. A simple gage is shown in Figure 8-1, although other arrangements are possible.

Other equipment used with the cylinder (ring) infiltrometer

1. Equipment for installing cylinders in the ground without disturbing the soil in the interior of the cylinder. This equipment can be a metal plate or a heavy timber, and a sledge hammer for pounding the infiltrometer into the soil.
2. A plastic sheet or other waterproof membrane.
3. A stop watch.

Installation procedure

1. Select a representative location for each cylinder and examine carefully for signs of unusual surface disturbances, such as stones that might damage cylinders, cracks which might give nonrepresentative readings, etc. Avoid areas that may have been affected by unusual animal or machinery traffic.
2. Drive the infiltrometer cylinder to a depth of at least 15 cm. The cylinder should be installed as vertically as possible. This can be assured by checking the alignment frequently during the installation procedure. A carpenter's level can be used for the check, but usually adequate checking can be done by eye. Do not

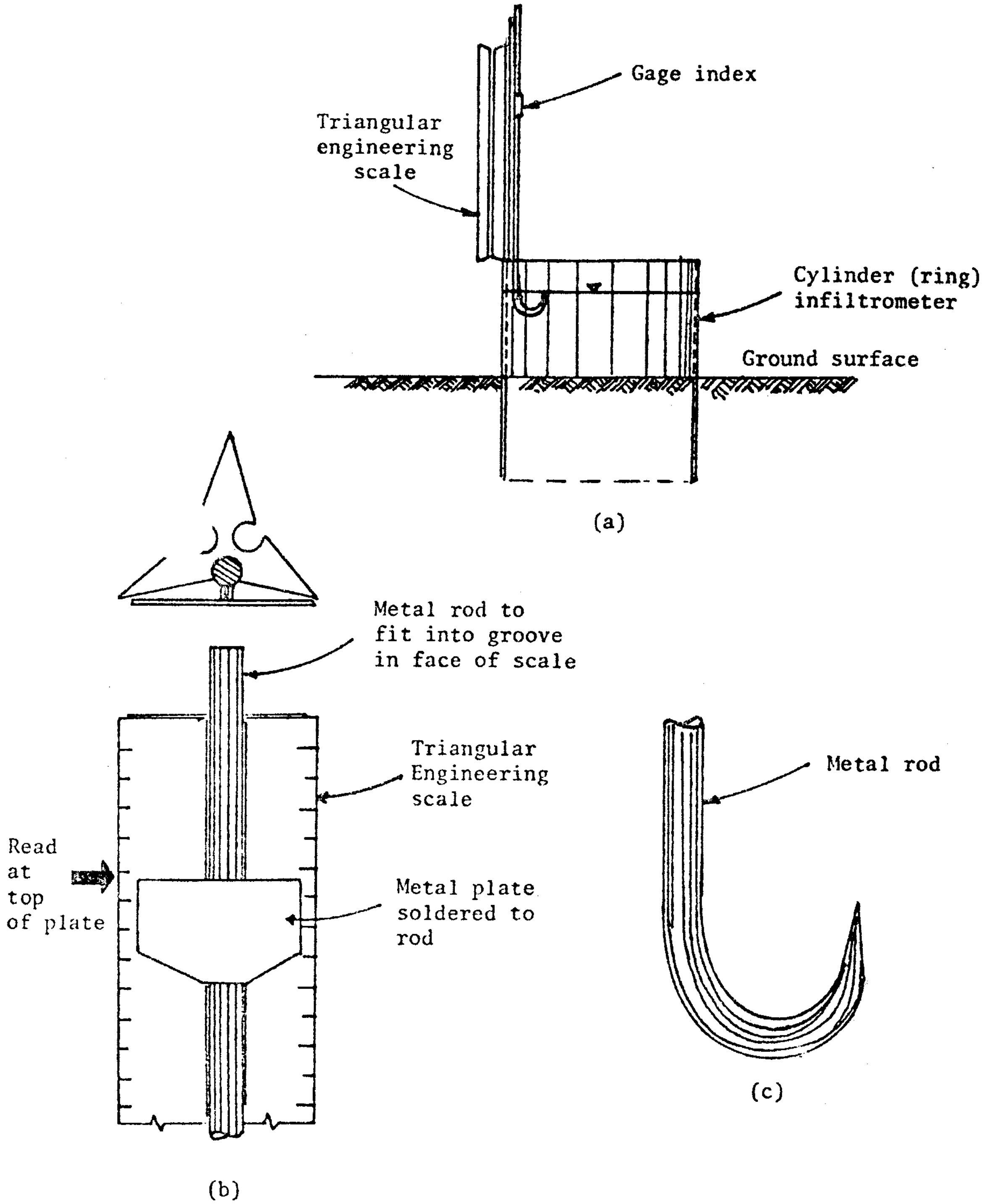

Figure 8-1. Water level gage--construction and installation details.
(a) Water level gage in use on cylinder infiltrometer.
(b) Assembled water level gage.
(c) Detail of hook (full scale).

the cylinder into the soil irregularly so that first one side then the other goes down. This procedure produces poor contact between the cylinder wall and the soil, and may disturb the soil core within the cylinder. If the cylinder gets materially out of plumb while driving, remove it and reset it in a comparable area nearby.

3. Set buffer cylinder around infiltrometer and drive it into the soil. This outside cylinder, however, need not be driven as deep as the cylinder infiltrometer. Generally, 5 to 10 cm into the soil will be adequate.
4. Install the water level gage.

Measurement

1. Fill the buffer pond with water to a depth of at least 5 cm and maintain approximately the same depth throughout the period of observation.
2. Place a plastic sheet, or other waterproof membrane, on the soil within the cylinder infiltrometer so that it forms a "bowl" to hold the water. The plastic should be in contact with the soil at the bottom of the infiltrometer and extend up the walls of the infiltrometer at least 10 to 15 cm.
3. Fill the cylinder infiltrometer with water to a depth of about 10 cm and record this depth. In extremely porous (high intake) soils, a greater depth may be needed.
4. Place the hook gage (tip of the hook gage is set at water level) and measure the distance to the water level from some datum. This is the initial depth reading, corresponding to the initial time reading.
5. Quickly, but gently, remove the plastic membrane. Record the time at which this is done. This is the initial time reading.
6. Make additional hook gage readings at periodic intervals and record the hook gage and time readings. Intervals between observations usually should be short (2 to 5 min) at the start of the test. After 5 measurements the intervals may be increased (10 to 30 min). After about 2 hours, measurements made at 45- to 60-minute intervals will usually be sufficient.
7. When the water level has dropped 4 to 5 cm in the cylinder infiltrometer, add a sufficient volume of water to return the

water surface to its approximate initial level. The known volume of water, divided by the cross-sectional area of the cylinder, gives the depth of water added within the cylinder. This depth must be added to the last previous reading to give an adjusted water level reading from which the next water level gage reading will be subtracted to obtain the depth of water which has entered the soil in the next time interval. See the example of refilling a cylinder infiltrometer in Table 8-1.

8. Where abnormally high or low infiltration values are indicated by the test results, the infiltrometer should be dug out and the soil examined for possible causes. If while running the test an obvious cause for high rate of infiltration can be seen, such as water rising outside the cylinder, the test should be terminated immediately and the cylinder moved to a nearby location and reinstalled.

Analysis of infiltration data obtained using the cylinder (ring) infiltrometer.

During the infiltration test, data is recorded on a field sheet (Table 8-1). Columns 1 and 4 refer to time and depth readings, respectively. Column 2 gives the elapsed time since the beginning of the test and is derived from column 1 (clock time). Column 3 represents the change in time, Δt , and is the difference between two successive elapsed times of column 2. Column 5 lists the changes in depth reading, Δz , and is the difference betwee two successive depth readings of column 4. Column 6 is the ratio of change in depth (column 5) to change in time (column 3) and is the infiltration rate. Column 7 is the cumulative infiltration, z , which is calculated by adding the changes in depth reading (column 5) in a cumulative manner.

Usually the infiltration rate and cumulative depth, columns 6 and 7 respectively, in Table 8-1, are plotted against time and a smooth curve is drawn through them (Figure 8-2).

Table 8-1. Suggested field sheet for use with data obtained using the cylinder (ring) infiltrometer.

Location Benson's farm Observer Peter Haw Date 7/16/77

crop Corn Type of soil Clay-loam

Clock time readings in hr and min (1)	Elapsed time in minutes (1)-(1)' (2)	Change in elasped time (ΔT) in minutes (3)	Depth in mm (4)	Change in depth (Γz) in mm (4)-(4)' (5)	Infiltration rate dz/dt in mm/hr 60x(5)÷(3) (6)	Cumulative infiltration in mm (7)'+(5) (7)
8:00	0		132.0			0.0
		2		1.1	33.0	
8:02	2		130.9			1.1
		4		1.8	27.0	
8:06	6		129.1			2.9
		4		1.1	16.5	
8:10	10		128.0			4.0
		5		1.5	18.0	
8:15	15		126.5			5.5
		10		2.0	12.0	
8:25	25		124.5			7.5
		5		1.0	12.0	
8:30	30		123.5			8.5
		30		5.5	11.0	
9:00	60		118.0			14.0
		30		3.0	6.0	
9:30	90		115.0			17.0
		30		4.0	8.0	
10:00	120		111.0			21.0
		60		7.0	7.0	
11:00	180		104.0			28.0
	240	60	100.0	4.0	4.0	
12:00	refill		132.0			32.0
		60		4.5	4.5	
13:00	300		127.5			36.5
		35		2.5	4.3	
13:35	335		125.0			39.0

NOTE: (x)' means the value in column x at the previous time.

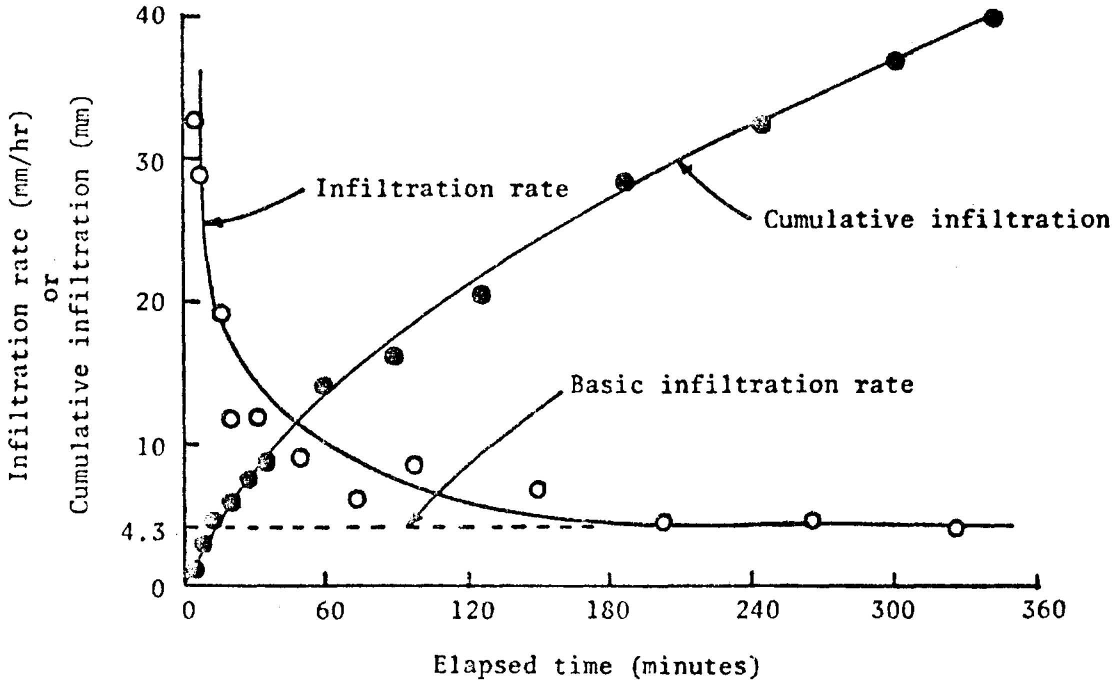

Figure 8-2. Infiltration curves.

The rate at which a soil absorbs water usually decreases rather rapidly with time. After several hours, however, it usually becomes nearly constant. This is called the basic infiltration rate.

When cumulative infiltration data is plotted against time on log-log paper, a straight line often represents the trend of the data points (Figure 8-3). An approximate line can be obtained by using either the least squares regression analysis (Appendix A) or the method of visual averages. Thus, the straight line drawn on log-log paper, using the cumulative infiltration, z , may be represented by the Kostiakov-Lewis relation,

$$z = K\,T^{a}, \qquad (8\text{-}1)$$

where z is the depth of water infiltrated into the soil (mm), T is the elapsed time in minutes, K is the cumulative infiltration at unit time, and a is the slope of the line, which is positive, usually less than 0.8, and always less than 1. The resultant equation for depth of water infiltrated into the soil is:

$$z = 0.82\ T^{0.68}\ \text{mm}.$$

A better representation of the depth infiltrated over long periods of time is sometimes obtained by using the modified Kostiakov relation,

$$z = KT^{a} + CT\ , \qquad (8\text{-}2)$$

where C is a constant equal to the basic infiltration rate (Figure 8-2).

The modified Kostiakov relation (Equation 8-2) may be obtained using either log-log paper or the linear regression analysis for a power fit curve.

The procedure using log-log paper is the same as that used to obtain the Kostiakov-Lewis relation Equation 8-1, but in this case, z - CT is plotted against elapsed time, obtaining the following relation,

$$z - CT = KT^{a}\ . \qquad (8\text{-}3)$$

Determination of a best fit curve is by trial and error, because the value of C is not known. Thus, various C's must be used. A good first guess is the apparent basic infiltration rate as determined from a plot of the data on rectangular grid paper (Figure 8-2).

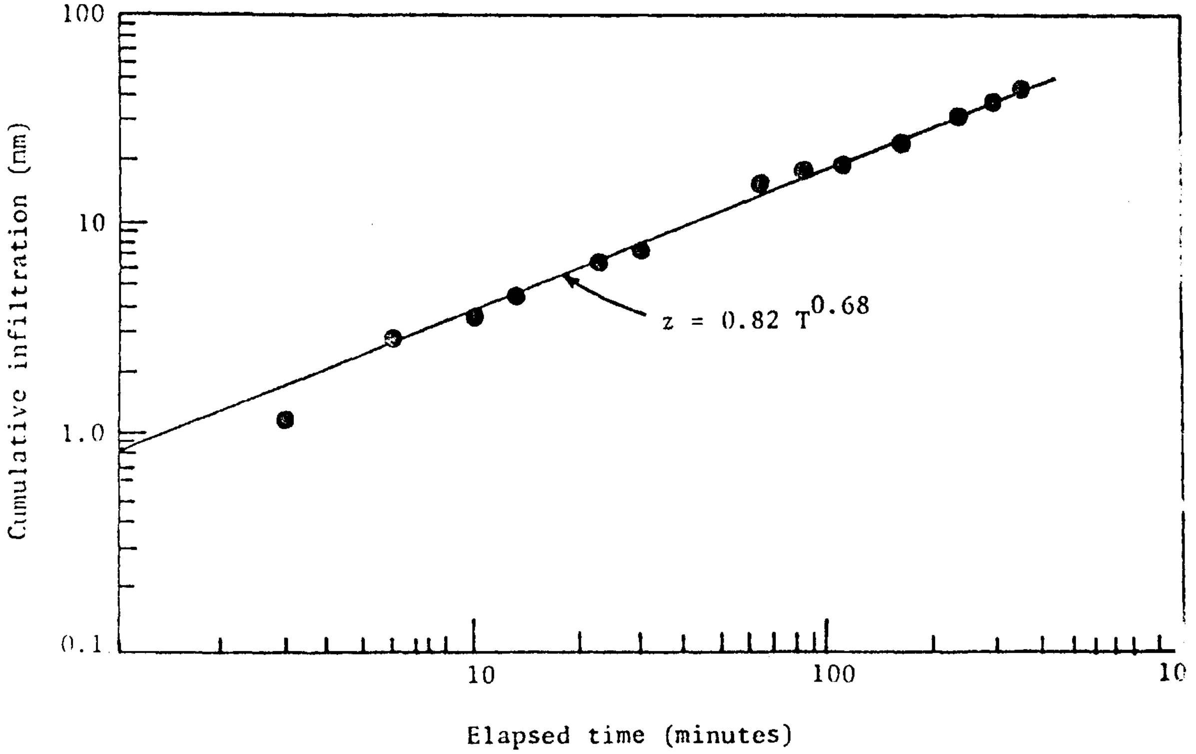

Figure 8-3. Cumulative infiltration plotted on log-log paper.

The equation for depth infiltrated over long periods of time for our example (Table 8-1) is:

$$z = 0.96T^{0.52} + (4.3/60)T \text{ mm} . \tag{8-4}$$

A ractical use for Equation 8-1 is to determine the time required to fill the soil with a given depth, z, of water. This can be done by rearranging Equation 8-1.

$$T = \frac{z}{K}^{1/a} \tag{8-5}$$

The infiltration rate equation may be found by differentiating Equation 8-1.

$$\frac{dz}{dT} = aK\ T^{a-1} , \tag{8-6}$$

where dz/dT is the infiltration rate (mm/min). The above equation is also represented as

$$I = kT^{n} \tag{8-7}$$

where I is the infiltration rate, dz/dT, k is equal to aK, and n is $a-1$ (which is always negative). Thus, the Kostiakov-Lewis infiltration rate equation for our example is

$$I = 0.56T^{-0.32} \text{ mm/min.} \tag{8-8}$$

When the observation of infiltration rate extends over long periods of time a better representation may be obtained by using the modified Kostiakov relation for infiltration rate,

$$I = kT^{n} + C . \tag{8-9}$$

Since n is always negative, the infiltration rate I will approach a constant value C as time increases. Thus, the infiltration rate equation for our example over long periods of time, will be calculated by differentiating the equation for depth infiltrated over long periods of time (Equation 8-4).

$$\frac{dz}{dT} = 0.50T^{-0.48} + (4.3/60) \quad \text{or} \quad I = 0.5T^{-0.48} + (4.3/60) \text{ mm/min.} \tag{8-10}$$

BLOCKED FURROW INFILTROMETER

One of the most commonly used methods for measuring the infiltration rate in furrow irrigation is the blocked furrow infiltrometer (Fig. 8-4). The blocked furrow infiltrometer measures the infiltration of water into the soil profile over a short segment of furrow (1 meter) in which water is ponded. The infiltration measured in this way is two-dimensional because it includes both horizontal and vertical movement of water into the soil. After the water penetrates the soil surface it will begin to spread laterally as well as vertically. In order to reduce excess lateral movement of water and simulate the actual irrigation, furrows adjacent to the one tested are filled with water. These are known as buffer furrows.

Special apparatus (Figure 8-4)

1. Six metal sheets, 90 cm wide, 30 cm high and 0.20 cm thick, with reinforcement at the upper end. One of the metal sheets must have an inlet.
2. Twenty-liter supply reservoir with attached piezometer.
3. Connecting plastic hose.
4. Regulating flow valve.
5. Hook gage to indicate the constant water level required in the furrow.

Other equipment used with the blocked furrow infiltrometer

1. Equipment for installing the metal sheets in the ground with a minimum disturbance of the soil surface. This equipment can be a metal plate or heavy timber and a sledge hammer for pounding the metal sheet into the soil.
2. Pair of pliers for regulating the flow valve.
3. Plastic sheet or other impermeable material.
4. Stop watch.

Installation procedure

1. Drive two metal sheets (one with an inlet) 1 meter apart vertically into the soil to a depth of approximately 15 cm, as indicated in Figure 8-4, with a minimum disturbance of the soil surface.
2. Set the supply container on a higher ground surface than the expected water surface elevation near the metal sheet with the inlet. The supply container should be installed as vertically as

possible. A carpenter's level can be used to check vertical orientation.

3. Connect the supply container to the inlet of the metal sheet using the plastic hose.
4. Set buffer furrows parallel to the infiltrometer by driving metal sheets 1 meter apart vertically into the soil to a depth of approximately 15 cm.

Measurement

1. Cover the furrow bottom with a plastic sheet or other impermeable material.
2. Fill the furrow bottom with water to a level at which water would normally flow in the furrow during irrigation.
3. Set the tip of the hook gage to correspond to the water level of step 2.
4. With the regulating valve closed, fill the supply reservoir with water to an appropriate level, and record the water level reading in the piezometer. This is the depth in the supply reservoir corresponding to the elapsed time of 0 minute (Table 8-2, column 2).
5. Fill the buffer furrows with water to a level at which water will normally flow in the furrow during irrigation and maintain approximately the same depth throughout the period of observation.
6. Quickly, but gently, remove the impermeable memembrane. (This time corresponds to the elapsed time of 0 minutes.)
7. Maintain the level of water at the initial depth (the tip of the hook gage in Figure 8-4) by regulating the inflow from the supply reservoir.
8. Periodically record the piezometer reading and the corresponding time. Time intervals between observations should usually be short (2 to 5 min) at the start of the test. After about one hour, measurements made at 45- to 60-minute intervals will be sufficient.

Analysis of infiltration data obtained using the blocked furrow infiltrometer

The method of analysis of the infiltration data obtained using the blocked furrow infiltrometer is similar to that used for the analysis of

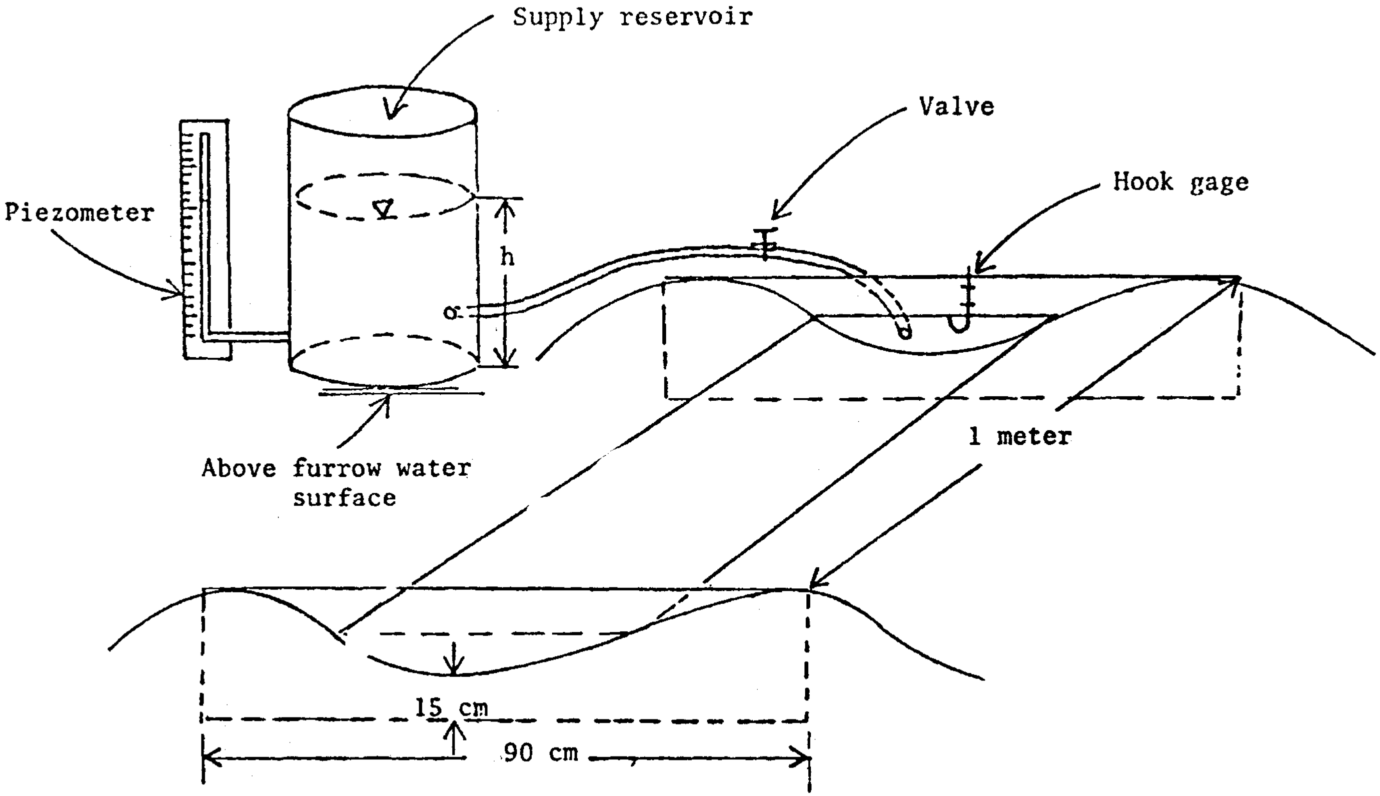

Figure 8-4. Blocked furrow infiltrometer (Salazar, 1977).

infiltration data obtained using the cylinder infiltrometer. In this analysis, the cumulative volume infiltrated (Column 5, Table 8-2) is plotted against elapsed time (Column 1, Table 8-2) and a smooth curve is drawn through them (Figure 8-5).

Table 8-2. Suggested field sheet for use with data obtained during blocked furrow test.

Location Hort. Exp. Station Observer Thomas Ley Date 7/15/77

Crop Pinto beans Type of soil Clay-loam

Cross-sectional area of cylindrical supply reservoir 609 cm^2

Spacing distance between furrow 102 cm

Elasped time in minutes (1)	Depth in supply reservoir in cm (2)	Depth change in cm (2)-(2)' (3)	Cumulative depth in supply reservoir in cm (4)'+(3)' (4)	Cumulative volume infiltrated in cm^3 (4) x 609 (5)	Elapsed time in minutes cm (1)	Depth in supply reservoir in (2)-(2)' (2)	Depth change in cm (3)	Cumulative depth in supply reservoir in cm (4)'+(3)' (4)	Cumulative volume infiltrated in cm^3 (4) x 609 (5)
0	11.3		0	0	30	13.3			
		14.1					1.0		
3	25.4		14.1	8 590	35	14.3		24.4	14 860
	refill	--					0.9		
5	10.1		--	--	40	15.2		25.3	15 400
		1.4					3.5		
7	11.5		15.5	9 440	60	18.7		28.8	17 540
		1.6				refill	--		
10	13.1		17.1	10 414	65	12.0		--	--
		2.4					7.4		
15	15.5		19.5	11 876	120	19.4		36.2	22 050
		1.6					7.3		
20	17.1		21.1	12 850	180	26.7		43.5	26 490
		1.4				refill	--		
25	18.5		22.5	13 702	182	21.3		--	--
	refill	--					3.0		
27	12.4		--	--	210	24.3		46.5	28 320
		0.9					2.7		
			23.4	14 250	235	27.0			

NOTE: Cross-sectional are of supply reservoir is 609 cm^2.
(x)' means the value in column x at the previous time.

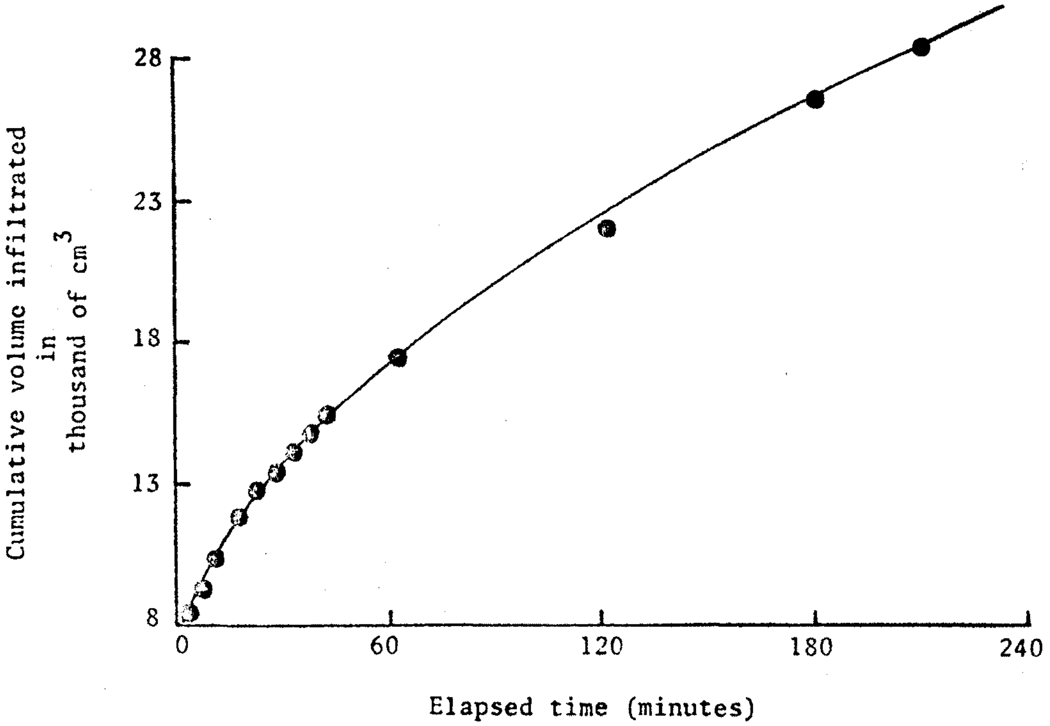

Figure 8-5. Cumulative volume infiltrated.

The representative cumulative volume infiltrated data may be represented by the exponential equation,

$$V = R\ T^{a}\ , \tag{8-11}$$

where V is the volume infiltrated (cm^3) in a meter of furrow, R and a are constant values determined by using either log-log paper or the linear regression analysis for a power fit curve (Appendix A).

Using the coefficients from our example (Table 8-2) the cumulative volume infiltrated equation is

$$V = 5\ 462.7\ T^{0.29}\ cm^{3}\ , \tag{8-12}$$

where 5 462.7 and 0.29 are the constant values of R and a respectively in Equation 8-11.

The cumulative volume infiltrated equation may be converted to cumulative depth infiltrated by dividing the cumulative volume infiltrated by its representative area.

$$A = LS\ , \tag{8-13}$$

where A is the representative area (cm^2), L is the furrow length (100 cm) and S is the spacing distance between furrows (102 cm). Thus, the equation for cumulative depth infiltrated is,

$$z = 0.53\ T^{0.29}\ cm\ , \tag{8-14}$$

which is Equation 8-1, used during the evaluation of data from the cylinder infiltrometer.

If the infiltration rate is needed, it may be obtained by differentiating the above equation,

$$\frac{dz}{dT} = 0.15\ T^{-0.71} \quad \text{or} \quad I = 0.15\ T^{-0.71}\ cm/min. \tag{8-15}$$

COMMENTS

Some of the advantages and disadvantages in using the cylinder (ring) infiltrometer are:

Advantages:

1. Little water is required for a test.
2. The cylinders are easy to transport and install.

Disadvantages:

1. Soil disturbance during installation may affect infiltration.
2. Entrapped air below the ponded surface and between cylinder walls may significantly reduce infiltration rates.
3. Variability in soil characteristics requires a large number of trials in order to establish mean infiltration characteristics.

Some of the advantages and disadvantages in using the blocked furrow infiltrometer are:

Advantages:

1. Only a limited supply of water is needed.
2. The water level in the furrow can be set to represent the actual average depth during an irrigation and the variability in infiltration rate due to changes in depth of water in the channel may be assessed.

Disadvantages:

1. The infiltrometer does not account for variability in soil characteristics along the furrow unless a large number of trials are made.
2. The infiltrometer does not account for the effect of changes in furrow cross-section during irrigation.

In addition, there is a disadvantage common to both methods, that of using ponded rather than running water. Neither of these methods assesses the effect of flow velocity and subsequent orientation of soil particles on the infiltration of water into the soil.

In furrow studies by Davis and Fry (1963), the infiltration rates determined with cylinder infiltrometers were in all cases one-half to one-fourth those determined by one of the other methods. Results on the same study showed that infiltrometers may overestimate furrow infiltration rate in medium-to-coarse-textured soils and underestimate furrow infiltration rates in medium-to-fine-textured soils.

The infiltration rate of water through soil vertically downwards is numerically equal to the hydraulic conductivity when the soil is saturated to a sufficient depth, because the gradient for flow is gravity (unit gradient). However, if the soil is relatively dry at a shallow depth, the infiltration rate may greatly exceed the hydraulic conductivity.

The infiltration rate depends on the same factors of the soil physical conditions as does the hydraulic conductivity. Among the physical properties of concern, the porosity of a soil is a major factor affecting infiltration rate because hydraulic conductivity is greatly dependent on soil particle spacing, especially when soil approaches saturation. The porosity of a soil is primarily dependent on soil texture and soil structure. However the soil structure is by no means stable in irrigated soils either with time or with space.

Other factors related to the infiltration rate of water under irrigated conditions are:

1. Surface soil conditions. Soil tillage can have a profound influence on the infiltration rate of the soil due to the physical disturbance of the soil surface and underlying soil by the tillage implements, as well as compaction caused by the tractor and implement wheels. In furrow irrigation, the compaction caused by the tractor wheels may cause the furrow bottom to exhibit much lower infiltration characteristics than the uncompacted sides. The type or amount of clay present may cause soils to crack upon drying thus providing for a high initial infiltration rate. These soils may swell quickly upon wetting to greatly reduce the infiltration rate.
2. Internal conditions of the soil mass. Soil texture, sorting of particles, hard pans, bacterial action, earth worms, chemical changes, and root development affect the movement of water through the soil mass.
3. Soil water content The infiltration characteristics of irrigated soils are greatly influenced by the water content of the soils. Infiltration rates generally decrease as the soil water content increases.
4. Hydrostatic head in the infiltrometer. High infiltration rate soils are sensitive to changes in hydrostatic head.
5. Temperature of the soil and water. Usually cool soil or water will lower infiltration rates.
6. Duration of application. The infiltration rate usually decreases rather rapidly with time (Figure 8-2).

7. The quality (salt content) of the water and soil. The salt content and type of salt in the water affect infiltration by altering soil structure.

The validity of infiltration studies, and their use, are not only dependent upon the above, but also upon the supporting data. Some important items are past cropping history, tillage, soil type, and soil structure. Therefore, the use of infiltration data should be tempered with sound judgment.

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APPENDIX A

STATISTICAL ANALYSIS OF MEASUREMENTS

INTRODUCTION

The purpose of any soil sampling is to obtain information about a particular soil. The sample usually is only a small portion of the entire soil mass in which we are interested. This large mass of soil is called the "population" or "universe". Information from the sample is of interest only in the sense that it yields information about the population.

There are certain characteristics in each population which describe it. The true value of each such characteristic in the population is called a parameter. The purpose of sampling is to estimate these parameters.

NUMERICAL METHODS OF ANALYSIS OF MEASUREMENTS

A measurement is a quantization of an attribute of the material under investigation. The quantization implies a sequence of operations or steps that yields the resultant measurement. Thus, the concept of measurement may include not only the steps used to obtain the measurement but also the use of that measurement by the investigator to draw conclusions.

Measures of central tendency

Several measures have been developed to represent central tendency, but only two--the arithmetic average and the median--will be explained here in detail. When the data are not skewed, these two measures will be about equal numerically. and either is a good indicator of central tendency. However, when data are skewed, the median may be a better measure than the arithmetic mean.

1. The mean or arithmetic average.

   The mean or arithmetic average is defined as the sum of all measurements divided by the number of measurements.

$$\bar{X} = \sum_{i=1}^{n} x_i/n \quad , \qquad \text{(A-1)}$$

where $\bar{X}$ is the symbol for the sample mean, x_i is the i^{th} measurement and n is the total number of measurements. Another measure of the central tendency is the median.

2. The median.

The median is used as a measure of central tendency when the distribution of measurements is skewed (i.e., a few observations are quite large or small in comparison to the others).

a) If n is odd the median is calculated by ordering the measurements from minimum to maximum, and then selecting the (n+1)/2 measurement. As an example, suppose we have the following measurements.

before ordering: 5, 6, 5, 4, 8, 9, 3
after ordering: 3, 4, 5, 5, 6, 8, 9
the median is equal to 5.

b) If n is even the median is calculated by ordering the measurements from minimum to maximum, and then averaging the n/2 and n/2+1 measurements. As an example, suppose we have the following measurements.

before ordering: 7, 6, 8, 5, 3, 10
after ordering: 3, 5, 6, 7, 8, 10
the median is equal to (6+7)/2 = 6.5

Measures of variability, spread or dispersion

3. The variance, S^2.

The variance is the average of the squares of the deviations of measurements about their mean. Thus, the definition formula for variance is

$$S^2 = \frac{\sum_{i=1}^{n} (x_i - \bar{X})^2}{n - 1} \qquad \text{(A-2)}$$

Note that the average is found by dividing by n-1, not n.

4. The standard deviation, S.

The standard deviation is the positive square root of the variance and is related to how far, on the average, a typical observation lies from the sample mean.

$$S = \sqrt{S^2} \qquad \text{(A-3)}$$

Population parameters

Typical population parameters are the mean, the variance and the standard deviation. These parameters are represented as follows,

1. The population mean, μ
2. The population variance, σ^2
3. The population standard deviation, σ

STATISTICAL INFERENCE

The objective of statistics is to make inference (prediction or decision) about the population parameters based upon information collected in the sample. We may estimate or predict the value of the parameter using an estimator. The estimator is a rule, generally expressed as a formula, that tells us how to calculate the estimate based upon information in the sample.

Types of estimators

Estimation procedures may be divided into two types, the point estimate and the interval estimate. The point estimate uses the information in the sample to arrive at a single number or point. The interval estimate uses the information in the sample to calculate two points which are to enclose the true value of the parameter estimated.

Point estimators

The best estimate of the population mean m is the sample mean, $\bar{X}$ (Equation A-1). The best estimate of the population variance s^2 is the sample variance, S^2. (Equation A-2). The best estimate of the population standard deviation s is the sample standard deviation, S (Equation A-3).

Interval estimation for the population mean

The interval estimation or confidence interval for a population mean may be easily obtained from the point estimates described in the above section

Large sample confidence interval for the population mean

If n is large (30 or more) and the distribution of $\bar{X}$ is approximately normal, the population standard deviation s is assumed to be known (Mendenhall, 1975). Thus, the interval estimation for the population mean is given by

$$\bar{X} \pm Z \frac{\sigma}{n} , \qquad \text{(A-4)}$$

where Z is the confidence coefficient which depends upon the desired probability confidence (Table A-1).

Table A-1. Common confidence intervals for the population mean.

Probability confidence	Confidence coefficient Z	Lower confidence interval	Upper confidence interval
0.90	1.645	$\bar{X} - 1.645\ s/n$	$\bar{X} + 1.645\ s/n$
0.95	1.960	$\bar{X} - 1.960\ s/n$	$\bar{X} + 1.960\ s/n$
0.99	2.580	$\bar{X} - 2.580\ s/n$	$\bar{X} + 2.580\ s/n$

We can find any desired confidence interval for the population mean m when the population standard deviation s is assumed to be known, by finding the appropriate Z values from a normal table which is usually given an any statistics textbook.

Small sample confidence interval for the population mean

If n is small (n less than 30) the confidence interval for the population mean μ is calculated using the student's t-test.

$$\bar{X} \pm t_{\alpha}\ S/n\ , \qquad \text{(A-5)}$$

where t_{α} is the test statistic and α is the degree of confidence desired.

Table A-2. Common test statistic values.

n	$t_{.90}$	$t_{.95}$	$t_{.99}$
2	6.314	12.706	63.657
3	2.920	4.303	9.925
4	2.353	3.182	5.841
5	2.132	2.776	4.604
6	2.015	2.571	4.032
7	1.943	2.447	3.707
8	1.895	2.365	3.499
9	1.860	2.306	3.355
10	1.833	2.262	3.250

METHOD OF LEAST SQUARES

One of the most common methods to fit functional relationships to experimental data is the method of least squares. In this type of fitting, the sum of the squares of the deviations of observed values from some functional form is minimized.

The experimental observations consist of a set of N data points (X_i, Y_i) in which Y_i is an observed value corresponding to an independent variable X_i.

Application of least squares to a straight line.

If the set of N data points (X_i, Y_i) is desired to fit a straight line, the functional form is,

$$Y = a + mX \tag{A-6}$$

where Y is the dependent variable, X is the independent variable and a and m are constant defined by:

$$a = \frac{\sum_{i=1}^{N} Y_i \sum_{i=1}^{N} X^2 - \sum_{i=1}^{N} X_i Y_i \sum_{i=1}^{N} X_i}{N \sum_{i=1}^{N} X_i^2 - \sum_{i=1}^{N} X_i^{\,2}} \tag{A-7}$$

and

$$m = \frac{\sum_{i=1}^{N} X_i Y_i - \sum_{i=1}^{N} X_i \sum_{i=1}^{N} Y_i}{\sum_{i=1}^{N} X_i^2 - \sum_{i=1}^{N} X_i^{\,2}} \tag{A-8}$$

The coefficient of determination, r^2, indicates how closely the equation fits the experimental data.

$$r^2 = \frac{\left[\sum_{i=1}^{N} X_i Y_i - \frac{\sum_{i=1}^{N} X_i \sum_{i=1}^{N} Y_i}{N}\right]^2}{\left[\sum_{i=1}^{N} X_i^2 - \left(\frac{\sum_{i=1}^{N} X_i}{N}\right)^2\right]\left[\sum_{i=1}^{N} Y_i^2 - \frac{\sum_{i=1}^{N} Y_i}{N}\right]^2} \tag{A-9}$$

The value of r^2 will lie between 0 and 1. The closer r^2 is to 1, the better the fit.

In the event that $a = 0$, the line has the equation

$$Y = mX \,,$$

and

$$m = \sum_{i=1}^{N} X_i Y_i \Big/ \sum_{i=1}^{N} X_i^2 \qquad \text{(A-10)}$$

LINEAR REGRESSION FOR POWER CURVE FIT

If the set of N data points (X_i, Y_i) were X_i 0 , Y_i 0 is desired to fit a power curve, the functional form is

$$Y = a_o X^b \qquad \text{(A-11)}$$

where Y is the dependent variable, X is the independent variable and a_o where a_o 0 and b are constants. By writing the above equation as

$$\ln Y = b \ln X + \ln a_o , \qquad \text{(A-12)}$$

the problem can be solved as a linear regression problem.

$$b = \frac{\displaystyle\sum_{i=1}^{N} (\ln X_i)(\ln Y_i) - \frac{(\sum_{i=1}^{N} \ln X_i)(\sum_{i=1}^{N} \ln Y_i)}{N}}{\displaystyle\sum_{i=1}^{N} (\ln X_i)^2 - \frac{(\sum_{i=1}^{N} \ln X_i)^2}{N}} \qquad \text{(A-13)}$$

$$a_o = \exp\left[\frac{\sum_{i=1}^{N} \ln Y_i}{N} - b\,\frac{\sum_{i=1}^{N} \ln X_i}{N}\right] \qquad \text{(A-14)}$$

The coefficient of determination r_o^2 is:

$$r_o^2 = \frac{\left[\displaystyle\sum_{i=1}^{N} (\ln X_i)(\ln Y_i) - \frac{(\sum_{i=1}^{N} \ln X_i)(\sum_{i=1}^{N} \ln Y_i)}{N}\right]^2}{\left[\displaystyle\sum_{i=1}^{N} (\ln X_i)^2 - \frac{(\sum_{i=1}^{N} \ln X_i)^2}{N}\right]\left[\displaystyle\sum_{i=1}^{N} (\ln Y_i)^2 - \frac{(\sum_{i=1}^{N} \ln Y_i)^2}{N}\right]} \qquad \text{(A-15)}$$

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APPENDIX B

LABORATORY EQUIPMENT AND MATERIALS REQUIRED FOR THE LABORATORY OF SOIL-WATER ENGINEERING

EXERCISE	DESCRIPTION	QUANTITY REQ.
1. Bulk specific gravity and 2. Porosity	Rubber ballon assembly	3
	Field plate for rubber balloon assembly	3
	Tablespoon (30 cm long)	3
	Soil sample cans (tight fitting lids - medium size)	10 gross or more
	Balance to weight ± 0.1 grams	2
	Large oven to dry samples at 105°C	1
	Heavy steel brush to clean cans	2
3. Water content	Soil sampler	
	(a) Soil auger	3
	(b) Oakfield prove	3
	Cans (tight lids)	See above
	Balance to weight ± 0.1 grams	See above
	Large oven to dry samples at 105°C	See above
	Desiccator of at least 30 cm in diameter with active desiccant	See above
	Neutron probe (equipment)	2
	Aluminum access tubing 5.08 cm (2 in) in diameter for the neutron probe (installed--1.5 meter lengths)	5
	N° 9 rubber stopper	10
4. Total water availability	Cans (tight fitting lids)	See above
	Balance to weight ± 0.1 grams	See above
	Oven to dry samples at 105°C	See above
	Desiccator	See above
	Soil sampler	See above
	Plastic sheeting (3 m X 3 m minmum)	1 large roll
	Number 2 friction top can	10 gross or more
	Nitrogen and other nutrients as needed to produce good plant growth	

EXERCISE	DESCRITPION	QUANTITY REQ.
4. continued	Dwarf sunflower (*Helianthus annus*)	
	Seeds	150 grams
	Humid chamber	1 large unit
	Analytic balances (to measure to 0.0001 gram)	1
	Pressure plate extractor with regulated air pressure of up to 100 kPa	1
	Porous ceramic plate with rate of flow of approximately 1 200 $ml/hr/cm^2$ when is under pressure between 24.14 and 31.72 kPa	5
	100 ml glass pipette	1
	Sample retaining rings	50
	Source of air pressure (compressed air)	1
	Source of Vacuum (Vacuum pump)	1
	Pressure plate extractor (designed to work at 15 000 kPa 15 bar or 217.5 psi)	2
	Porous ceramic plate with a bubbling pressure greater than 15 000 kPa)	2
	Rubber pestle	5
	2 mm round hole sieve	2
5. Soluble salts by electrical conductivity	Conductivity cell	3
	Wheatstone bridge or other conductivity meter	3
	Extractor or vacuum system	See above
	Suction manifold with 12 valved outlets	1
	Porcelain funnel	2 dozen
	Medium grade filter paper	2 boxes
	50 ml glass bottles with stoppers	50
	Thermometer °C	5
6. Capillary pressure with tensiometer	Tensiometer with vacuum gauge 60.96 cm (24 in) long	10
	Distilled water source	1
	Thin walled metal tube of same outside diameter as the tensiometer	3
	Heavy Hammer (1#)	2
	No. 2 Shovel	2
	2 gal. bucket	2

EXERCISE	DESCRIPTION	QUANTITY REQ.
7. Hydraulic conductivity by the auger hole	5.08 cm (2 in) Centrifugal pump system for quick removal of water from the auger hole	1
	Auger hole of at least 10 cm of diameter and cased (2 meter depth)	1
	Water elevation indicator (See Figure 7-2)	1
	Stop watch	1
	Tape measure	1
8. Infiltration rate	Cylinder infiltrometer (20 to 30 cm in diameter and 30 to 40 cm long)	6
	Buffer cylinder (with diameter at least 30 cm greater than the infiltrometer)	6
	Means for installing cylinder	6
	Means for measuring the change of water level in the infiltrometer	6
	Plastic sheeting	See above
	Six metal sheets (14 gage) 90 cm wide and 15 cm high (one taped for 1.27 cm (1/2 in) tygon tubing)	5
	20-liter bucket	5
	Plastic hose (1.27 cm (1/2 in) tygon tubing)	10 meter
	Stop watch	5

APPENDIX

FARM IDENTIFICATION 8 Feddan Farm

WORKSHEET 1A. ESTIMATION OF CASH FARM RECEIPTS: CROP AND OTHER INCOME

		CROP SALES						OTHER FARM INCOME 2/		CASH FARM OPERATING RECEIPTS 3/
		THIS YEAR			NEXT YEAR 1/					
MONTH	CROP	QUANTITY	PRICE	VALUE	QUANTITY	PRICE	VALUE	THIS YEAR	NEXT YEAR	
Jan.										100 LE
Feb.								150 LE	300 LE	400
Mar.								100 LE	120 LE	220
Apr.								100 LE	120 LE	220
May	wheat	64 ardabs	8.0 LE	512 LE	70 ardabs	8.5 LE	595 LE			695
Jun.										50
Jul.										50
Aug.								80 LE	100 LE	150
Spt.										275
Oct.	tomato	26000 units	.035 LE	910	2800 units	.04 LE	1120 LE			1170
Nov.	tomato	52000 "	.035 LE	1820	5000 "	.04 LE	2000 LE			2050
Dec.	tomato	2600 "	.035 LE	910	26000 "	.04 LE	1040 LE			1140
TOTAL				4152			4160 LE	430 LE	640 LE	6520 LE

1/ From Supplemental Worksheet No. 1--Estimation of Receipts from crop Sales.

2/ Include income from work performed for others, rental of land, water, draft animals, or machinery to others and sales of used machinery or equipment. Do not include income from livestock or livestock products.

3/ Value of next year crop sales plus other farm income next year plus total expected receipts for livestock products and livestock (from Worksheet No. 1B).

FARM IDENTIFICATION 8 Feddan Farm

WORKSHEET 1B. ESTIMATION OF CASH FARM RECEIPTS: LIVESTOCK PRODUCTS AND LIVESTOCK SALES

	LIVESTOCK PRODUCTS SALES: MILK & EGGS							RECEIPTS LIVESTOCK SALES		
MONTH (PRODUCED)	NUMBER OF cows	PRODUCTION PER cow	TOTAL PRODUCTION	PRICE PER liter	RECEIPTS THIS YEAR	MONTH (RECEIVED)	EXPECTED RECEIPTS NEXT YEAR	THIS YEAR	NEXT YEAR	TOTAL RECEIPTS FROM LIVESTOCK PRODUCTS & LIVESTOCK NEXT YEAR
Dec.	2	60 liters	120 liters	.80 LE	100 LE	Jan.	96 LE			100 LE
Jan.	2	60 "	120 "	.80	100	Feb.	96			100
Feb.	2	60 "	120 "	.80	100	Mar.	96			100
Mar.	2	60 "	120 "	.80	100	Apr.	96			100
Apr.	2	60 "	120 "	.80	100	May	96			100
May	2	60 "	120 "	.80	100	Jun.	96			100
Jun.	1	60 "	60 "	.80	50	Jul.	48 LE			50
Jul.	1	60 "	60 "	.80	50	Aug.	48			50
Aug.	1	60 "	60 "	.80	50	Spt.	48			50
Spt.	1	60 "	60 "	.80	50	Oct.	48	200LE	225LE	275
Oct.	1	60 "	60 "	.80	50	Nov.	48			50
Nov.	1	60 "	60 "	.80	50	Dec.	48			50
TOTAL			1080 Liters		900 LE		864 LE	200LE	225LE	1125 LE

FARM IDENTIFICATION 8 Feddan Farm

SUPPLEMENTAL WORKSHEET 1. ESTIMATION OF RECEIPTS FROM CROP SALES

PRODUCTION				SALES			
CROP	FEDANS	YIELD	TOTAL PRODUCTION	MONTH	QUANTITY	EXPECTED PRICE	VALUE

Not necessary for this farm.

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WORKSHEET 2A. ESTIMATION OF CASH FARM EXPENSES: LABOR AND FEED AND LIVESTOCK PURCHASE

	LABOR PERCENT CHANGE 10		FEED PURCHASE PERCENT CHANGE 0		LIVESTOCK PURCHASE* PERCENT CHANGE 0	
MONTH	THIS YEAR EL	NEXT YEAR EL	THIS YEAR EL	NEXT YEAR EL	THIS YEAR EL	NEXT YEAR EL
Jan.	91	100		(Not applicable to this farm.)		
Feb.	20	22				
Mar.	12	13				
Apr.	12	13				
May	78	86				
Jun.	130	143				
Jul.	149	164				
Aug.	161	177				
Sep.	204	224				
Oct.	154	169				
Nov.	302	332				
Dec.	168	185				
TOTAL	1481	1628				

*Livestock purchased for feeding - growing and later resale should be included here. Livestock purchased for draft or herd expansion should be included as capital items in worksheet 4.

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WORKSHEET 2B. ESTIMATION OF CASH FARM EXPENSES: MACHINERY

	CUSTOM WORK HIRED PERCENT CHANGE 15		REPAIRS PERCENT CHANGE 20		FUEL PERCENT CHANGE 0		TOTAL MACHINERY EXPENSE
MONTH	THIS YEAR LE	NEXT YEAR LE	THIS YEAR LE	NEXT YEAR LE	THIS YEAR LE	NEXT YEAR LE	NEXT YEAR LE
Jan.					Not applicable to this farm.		
Feb.							
Mar.			20	24			24
Apr.							
May	83	95					95
Jun.	48	55					55
Jul.							
Aug.			15	18			18
Sep.							
Oct.							
Nov.	30	35					35
Dec.							
TOTAL	161	185	35.00	42			227

FARM IDENTIFICATION 8 Feddan Farm

WORKSHEET 2C. ESTIMATION OF CASH FARM EXPENSES: CROPS

MONTH	LIME AND FERTILIZER PERCENT CHANGE 75		SEEDS AND SPRAYS PERCENT CHANGE 50		CROP EXPENSE	LAND RENT PERCENT CHANGE	
	THIS YEAR LE	NEXT YEAR LE	THIS YEAR LE	NEXT YEAR LE	NEXT YEAR LE	THIS YEAR LE	NEXT YEAR LE
Jan.						Not applicable to this farm.	
Feb.							
Mar.							
Apr.							
May			260	390	390		
Jun.	128	224			224		
Jul.							
Aug.							
Sep.							
Oct.			192	288	288		
Nov.	60	105			105		
Dec.							
TOTAL	188	329	452	678	1007		

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WORKSHEET 2D. ESTIMATION OF CASH FARM EXPENSES: REAL ESTATE EXPENSES

	LAND AND BUILDING EXPENSE (REPAIRS, ETC.) PERCENT CHANGE 15		PROPERTY TAXES PERCENT CHANGE 5	
MONTH	THIS YEAR LE	NEXT YEAR LE	THIS YEAR LE	NEXT YEAR LE
Jan.				
Feb.	25	29	50	53
Mar.				
Apr.				
May				
Jun.	50	58		
Jul.				
Aug.				
Sep.				
Oct.	35	40		
Nov.				
Dec.				
TOTAL	110	127	50	53

FARM IDENTIFICATION 8 Feddan Farm

WORKSHEET 2E. ESTIMATION OF CASH FARM EXPENSES: UTILITIES, MARKETING, MISC.

	UTILITIES PERCENT CHANGE ____		MARKETING (TRANSPORTANTION, ETC.) PERCENT CHANGE 20		MISCELLANEOUS PERCENT CHANGE .20	
MONTH	THIS YEAR LE	NEXT YEAR LE	THIS YEAR LE	NEXT YEAR LE	THIS YEAR LE	NEXT YEAR LE
Jan.	Not applicable to this farm.					
Feb.						
Mar.						
Apr.						
May			24	29		
Jun.						
Jul.						
Aug.						
Sep.					25	30
Oct.						
Nov.						
Dec.						
TOTAL			84	101	25	30

FARM IDENTIFICATION 8 Feddan Farm

WORKSHEET 3. SUMMARY OF CASH FARM EXPENSES

MONTH	LABOR (2A)	FEED (2A)	LIVESTOCK (2A)	MACHINE (2B)	CROP (2C)	RENT (2C)	LAND BUILDING (2D)	TAXES (2D)	UTILITIES (2E)	MARKETING (2E)	MISC. (2E)	TOTAL
Jan.	100	None	None			None			None			100
Feb.	22						29	53				104
Mar.	13			24								37
Apr.	13											13
May	86			95	390					29		600
Jun.	143			55	224		58			72		552
Jul.	164											164
Aug.	177			18								195
Sep.	224										30	254
Oct.	169				288		40					497
Nov.	332			35	105							472
Dec.	185											185
TOTAL	1628			227	1007		127	53		101	30	3173

FARM IDENTIFICATION 8 Feddan Farm

WORKSHEET 4. CAPITAL PURCHASES PLANNED

MONTH	LAND & BUILDING		MACHINERY		DRAFT AND PRODUCING LIVESTOCK*		TOTAL CAPITAL PURCHASES
	ITEM	COST**	ITEM	COST***	ITEM	COST	
Jan.							
Feb.	This farm does not plan any capital purchases for the next year.						
Mar.							
Apr.							
May							
Jun.							
Jul.							
Aug.							
Sep.							
Oct.							
Nov.							
Dec.							
TOTAL							

*Capital purchases of livestock include all livestock purchases for planned expansion. Replacement purchases are livestock expenses and should be entered in Worksheet 2A.

**Cost is monthly payment on loans.

***Cost is cost after trade-in is deducted.

FARM IDENTIFICATION 8 Feddan Farm

WORKSHEET 5. CASH INFLOW AND OUTFLOW FOR NEXT YEAR: INCLUDING NONFARM; EXCLUDING CREDIT

MONTH	1 CASH FARM RECEIPTS (FROM WORK-SHEET 1A)	2 NET NON-FARM CASH INCOME*	3 TOTAL CASH INFLOW (EX. BORROWING)	4 CASH FARM EXPENSES (FROM WORK-SHEET 3)	5 CAPITAL PURCHASES (FROM WORK-SHEET 4)	6 FAMILY LIVING EXPENSE**	7 TOTAL OUTFLOW (EX. PRIN-CIPAL PAY-MENTS)	8 CASH INFLOW (Col.3) MINUS CASH OUTFLOW (Col. 7)
Jan.	100		100	101	None Planned	175	276	(176)
Feb.	400		400	104		175	279	121
Mar.	220		220	37		175	212	8
Apr.	220		220	13		330	343	(123)
May	695		695	600		175	775	(80)
Jun.	50	200	250	552		175	727	(477)
Jul.	50	200	250	164		175	339	(87)
Aug.	150	75	225	195		175	370	(145)
Sep.	275		275	254		175	429	(154)
Oct.	1170		1170	497		175	672	498
Nov.	2050		2050	473		175	648	1402
Dec.	1140		1140	184		175	359	781
TOTAL	6520	475	6995	3174		2255	5429	1566

*All non-farm receipts minus non-farm business expenses. Family living expenses are included in column 6.

**Supplemental worksheet 2 is provided to assist in calculating family living expenses.

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SUPPLEMENTAL WORKSHEET 2. FAMILY LIVING EXPENSES

MONTH	FOOD	CLOTHING	DWELLING& HOUSEHOLD EXPENSE	PROPERTY & INCOME TAXES	UTILITY & TRANSPORT. EXPENSE	PAYMENT INTO SAVINGS & NON-FARM INVESTMENTS	OTHER FAMILY EXPENSES	CREDIT PAYMENTS	TOTAL FAMILY LIVING EXPENSE
Jan.	75	30	40		10		5	15	175
Feb.	75	30	40		10		5	15	175
Mar.	75	30	40		10		5	15	175
Apr.	75	30	40	155	10		5	15	330
May	75	30	40		10		5	15	175
Jun.	75	30	40		10		5	15	175
Jul.	75	30	40		10		5	15	175
Aug.	75	30	40		10		5	15	175
Sep.	75	30	40		10		5	15	175
Oct.	75	30	40		10		5	15	175
Nov.	75	30	40		10		5	15	175
Dec.	75	30	40		10		5	15	175
TOTAL	900	360	480	155	120		60	180	2255

FARM IDENTIFICATION 8 Feddan Farm

WORKSHEET 6. PROJECTED CASH FLOW BUDGET

	1	2	3	4	5	6	7	8
							CASH FLOW	
MONTH	CASH INFLOW LESS OUTFLOW EXCLUDING FARM CREDIT TRANSACTIONS (from Wrkst. 5)	SCHEDULED DEBT PAYMENTS: PRINCIPAL AND INTEREST* (-)	CAPITAL PURCHASE LOANS (+)	UNCOMMITTED CASH FLOW (± sum)	NEW SHORT TERM DEBT (+)	ADDITIONAL DEBT PAYMENTS (-)	THIS MONTH (± sum)	BALANCE 1000
Jan.	(176)	30		(206)			(206)	794
Feb.	121	20		101			101	895
Mar.	8	20		(12)			(12)	883
Apr.	(123)	30		(153)			(153)	730
May	(80)	20		(100)			(100)	630
Jun.	(477)	20		(497)			(497)	233
Jul.	(89)	30		(119)			(119)	144
Aug.	(145)	20		(165)	675		510	654
Sep.	(154)	20		(174)			(174)	480
Oct.	498	30		(468)			(468)	12
Nov.	1402	20		1382		700	682	694
Dec.	781	20		761			761	1443
TOTAL		280			675	700		

*Supplemental worksheet 3 is provided to assist in projecting monthly debt payments.

FARM IDENTIFICATION 8 Feddan Farm

SUPPLEMENTAL WORKSHEET 3. SCHEDULED DEBT PAYMENTS

	DEBT PAYMENTS - PRINCIPAL AND INTEREST*							
MONTH	Land Purchase	Cash						TOTAL SCHEDULED DEBT PAYMENTS
Jan.	20	10						30
Feb.	20							20
Mar.	20							20
Apr.	20	10						30
May	20							20
Jun.	20							20
Jul.	20	10						30
Aug.	20							20
Sep.	20							20
Oct.	20	10						30
Nov.	20							20
Dec.	20							20
TOTAL	240	40						280

*Include all scheduled payments: Real estate loans, liens on livestock and equipment, payments to machinery dealers, etc. Be certain to include payments on loans that will be added during the year.