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FIELD EVALUATION OF METHODS FOR MEASURING BASIN IRRIGATION PERFORMANCE

By Satyansu S. Kundu
and Gaylord V. Skogerboe

Water Management Research Project
Colorado State University
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FIELD EVALUATION OF METHODS FOR MEASURING

BASIN IRRIGATION PERFORMANCE

by

Satyansu S. Kundu and Gaylord V. Skogerboe

ABSTRACT

A detailed description of field procedures employed to obtain necessary data for evaluating basin irrigation performances of several irrigation events is outlined. Two analytical techniques are described and used for calculating infiltrated water depths through station-areas delineated by a grid system within the basin. Both techniques require an infiltrometer test and infiltration opportunity time of each station-area during an irrigation event.

A modified volume balance technique is described and is used to develop an infiltration equation which should represent the actual infiltration characteristics of the entire basin during an irrigation event. The infiltrated water depth of each station-area is also calculated by using the infiltration equation developed by this method. All three methods are used for measuring basin irrigation performance and their applicability for measuring performance parameters is compared.

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NOMENCLATURE

SYMBOL	DEFINITION
a_{ij}	area represented by ijth station.
A	constant of infiltration function of the Kostiakov type.
A_j	area of the strip j covered by water.
$A_p(t)$	area covered by water at time t.
A_T	total area of the basin.
$A(t_a)$	area covered by water at any time of advance t_a.
B	exponent of infiltration function of the Kostiakov type.
h	head of water in the discharge measuring device.
h_c	deficient amount of water in relation to average depth of applied water.
i	row number of the grid station.
j	column or strip number of the grid station.
k	total number of stations within length x_j.
K	shape factor of the subsurface water profile.
L	total length of the basin.
m	total number of row in the basin.
n	total number of column or strip in the basin.
p	number of constant discharge time periods.
P_1, P_2	weighing factors for the actual and estimated water volumes respectively.
q'	row number of the stations with infiltrated depth less than $\bar{y}$.
Q	a constant inflow discharge during an irrigation.
Q_k	a constant inflow discharge for a period of time t_k.
r	exponent of the advance function.

NOMENCLATURE cont'd

SYMBOL	DEFINITION
r'	column numbers of the stations with infiltrated depths less than $\bar{y}$.
R	ratio for adjusting estimated depth of infiltrated water at a station when measured volume of water is not reliable.
t	time since start of irrigation event.
ta_{ij}	time of advance at the ijth station.
t_{co}	total basin delivery time.
top_{ij}	time of opportunity at the ijth station.
tr_{ij}	time of recession at the ijth station.
T	actual volume of applied water during an irrigation.
T_{est}	estimated total volume of water infiltrated into the soil.
UCC	Christiansen's uniformity coefficient.
U_d	distribution efficiency.
$V_p(t)$	total volume of water stored on the surface at time t.
W	total basin width.
ΔW_j	width of strip j.
x_j	the advance distance on any strip j.
x_{j_1}	first portion of length x_j (Fig. 5.1 (b)).
x_{j_2}	second portion of length x_j (Fig. 5.1 (b)).
Δx	distance between two consecutive stations in any strip.
$\bar{y}$	actual average depth of applied water.
Yad_{ij}	adjusted depth of estimated infiltrated water at the ijth station.
y_{ij}	actual depth of water applied at the ijth station.

NOMENCLATURE cont'd

SYMBOL	DEFINITION
y_{io}	depth of water at the basin upper end
y_{j_1}	average depth of water for the length x_{j_1}
y_{j_2}	average depth of water for the length x_{j_2}
$y_{co_{ij}}$	depth of water standing at the ijth station at irrigation cutoff time
$y_{t_{ij}}$	depth of infiltrated water at the ijth station estimated using opportunity time up to irrigation cutoff time
$y_{typ_{ij}}$	estimated depth of water infiltrated at the ijth station as calculated from typical infiltrated curve
$\bar{y}_{typ}$	average depth of infiltrated water calculated using $y_{typ_{ij}}$ values
$\bar{y}(t)$	average depth of infiltrated water at time t
$y_{field_{ij}}$	depth of infiltrated water at ijth station estimated by modified volume balance method
$\bar{y}_{field}$	average depth of infiltrated water over the entire basin estimated by modified volume balance method

Section 1

INTRODUCTION

Considerable research has been reported regarding the determination of water application efficiencies for surface irrigation systems. Most of this research has been directed towards border and furrow irrigation methods. Even though basin irrigation methods came into practice thousands of years ago, and is used today to irrigate more land in the world than any other irrigation method, very little research work has been conducted to evaluate the hydraulic performance of basin irrigation practices, or more importantly, to develop criteria for improving present basin irrigation practices.

Related Research

In spite of low water application efficiencies commonly encountered with surface irrigation methods, it has been reported (Kruse and Heermann, 1977) that the application of new techniques in level basin irrigation can produce application efficiencies near 90 percent. The two important components of the systems are precise land leveling using lasers and good management practices.

Sharma (1978) conducted research work on level basins used for wheat production and concluded that the time of the spread (advance) of water in level basins is dependent on inflow stream size, area of the basin, and the infiltration rate of the soil. He also developed a dimensional analysis technique to describe the hydraulic relationships for determination of the time of spread of the irrigation water across a basin.

Clemens and Strelkoff (1979) presented dimensionless advance curves for level basins using power-law-infiltration-function exponents ranging from 0 to 1 in increments of 0.1. They used inflow cutoff time as the characteristic time in defining the nondimensional parameters. These curves are useful in predicting irrigation advance, recession, maximum surface water depths, and the final soil moisture distribution.

Kincaid (1979) analyzed and compared various techniques for determining the constants in a time-based logarithmic infiltration function based on field plots employing either basin irrigation or basin-furrow irrigation (level furrows constructed within a flat basin). These field plots were located in the Grand Valley of western Colorado, which is the same irrigated area used in the studies reported herein.

A recent publication (Peri, Skogerboe and Norum, 1979) has given a comprehensive definition and description of basin irrigation and outlined a procedure for the evaluation and improvement of basin irrigation systems, showing the interactions between physical characteristics of the basin, hydraulic properties of the soil, and various management parameters. A simple model has been presented for the determination of the infiltrated water distribution under basin irrigation which can be applied to both level and sloped basins. This report also outlines a procedure for field evaluation of the infiltration equation for basin irrigation.

Objectives

The primary objective of this field study was to verify some of the evaluation methods for basin irrigation described by Peri et al. (1979). The two secondary objectives emphasized in this report are: (1) estimation of water distribution uniformities based upon field data of infiltrated water depths; and (2) determination of the infiltration function by a volume balance technique.

Section 2

EXPERIMENTAL DESIGN

The field study was conducted in the Grand Valley of western Colorado on basins containing a Billings silty clay loam soil which is a prominent agricultural soil in this valley. The experimental site was located on the State Home Farm about three miles east of the city of Grand Junction. This site was selected because it has similar soil characteristics commonly encountered in the Punjab and Sind provinces of Pakistan. The site had been cropped with barley the previous year before level basins were constructed in the spring of 1979. The bulk density and porosity of the soil are 1.50 gm/cm^3 and 45.0 percent, respectively.

Prior to leveling, the site had a north to south (N-S) slope of 0.5 percent and an east to west (E-W) slope of 0.31 percent. Figure 2.1 shows the elevations prior to and after laser leveling in a grid system of 15.24 m x 15.24 m. An area of 45.7 m x 61.0 m was, at first, leveled by a conventional method and then a laser controlled scraper was used for precision leveling. The final grid readings indicated that the leveling was accomplished with an accuracy of $\pm$ 0.02 m (Figure 2.2). The maximum cut was 0.168 m at the N-E corner grid point and the maximum fill was 0.234 m at the S-W corner grid point. This leveled area was divided into two plots of 36.6 m x 36.6 m and 18.3 m x 36.6 m

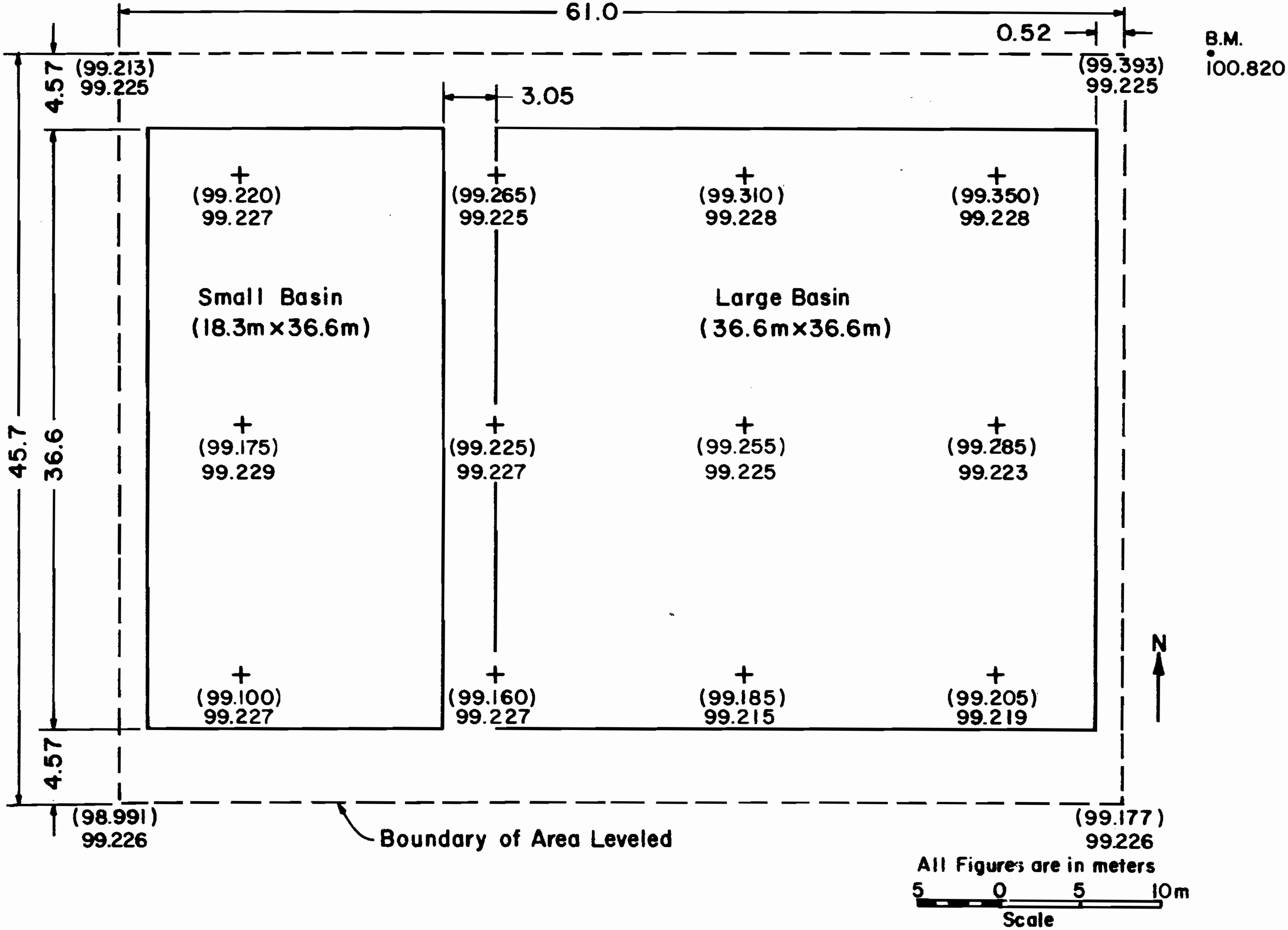


Figure 2.1. Grid station elevations before (parenthesized numbers) and after leveling.

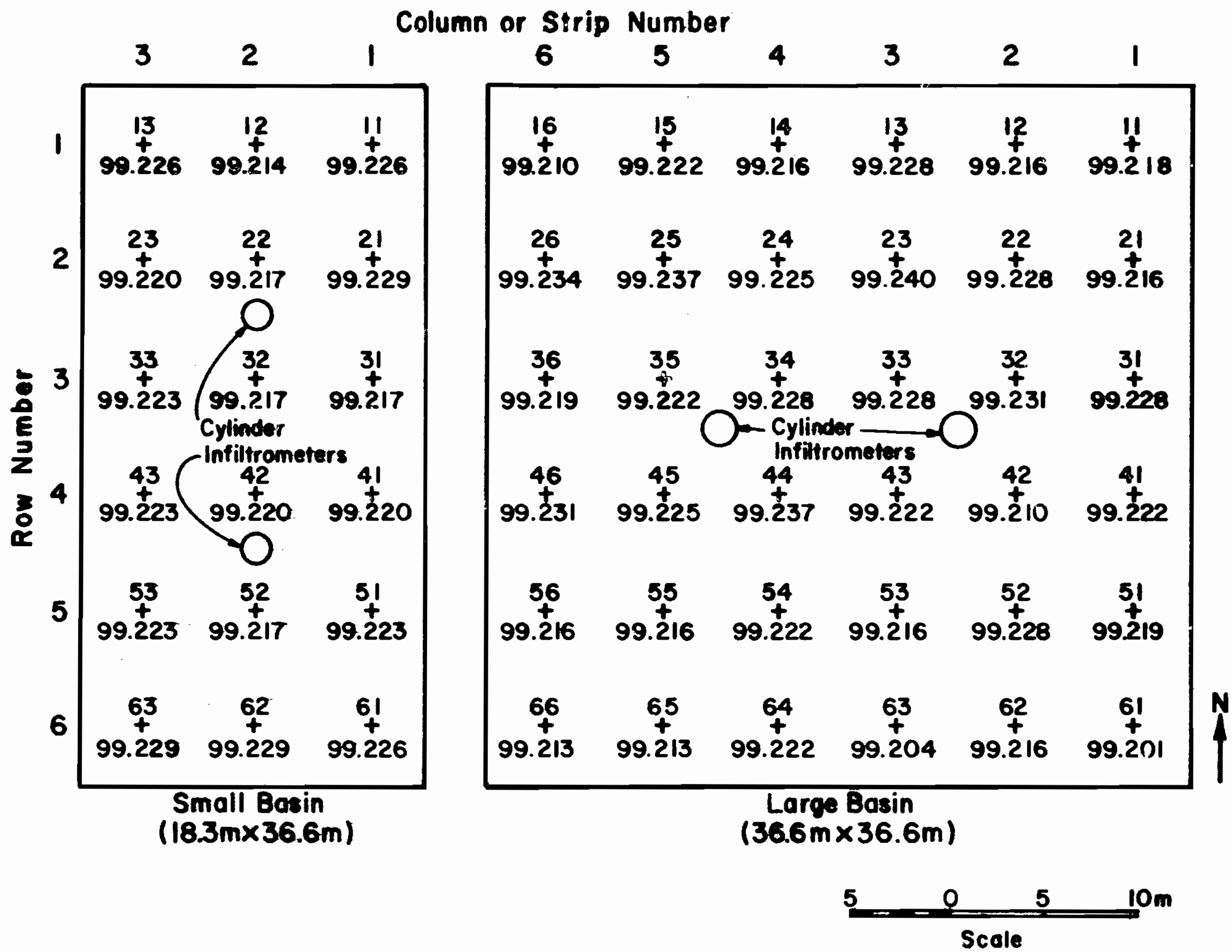


Figure 2.2. The locations of grid stations for monitoring irrigation showing station elevations in meters before first irrigation (i.e., after leveling) and station numbers.

sizes which are, hereafter referred to as the small and the large basin, respectively (Figure 2.2). Dikes or bunds for the basin plots were constructed using a tractor mounted scraper.

The plots were cultivated for planting using roto-tiller equipment, running it first in the N-S direction and then in the E-W direction. Immediately after that, the fertilizers (140 kg of actual N/ha, 112 kg of 50 percent P/ha and 112 kg of 44 percent K/ha) were applied to each basin before corn was planted and were incorporated into the soil by chiseling to approximately 20 cm depth followed by roller harrowing. Sweet corn (Kandy Korn), a variety requiring 85 days to mature was planted in both basins at approximately 76 cm row spacing, 5 cm deep, and at a rate of 69,000 seeds/ha. Again seven weeks after planting anhydrous ammonia was applied with irrigation water at a rate of 50 kg of actual N/ha to both plots.

The Billings silty clay loam soil is known to develop a thick soil crust under irrigation, especially when water is allowed to run over the surface and then dry, or upon drying after a rainfall event. (This same phenomenon occurs on the majority of soils in Pakistan.) Therefore, it was deemed necessary to apply irrigation water during the first two weeks after planting by sprinkler irrigation in order to keep the soil surface continually moist until seed germination and plant emergence occurred. A total of 76 mm of water was applied by sprinkler irrigation to each basin during this period. During the rest of the growing season, the water was applied to the basins using gated pipes.

The crop was harvested 96 days after planting. The yield in terms of number of ears, grain yield and total dry matter yield per hectare were measured (Appendix F).

Section 3

FIELD MEASUREMENTS AND DATA COLLECTION

Five irrigations were applied to each plot. The methods and facilities that were developed to measure and collect data, and the observations that were recorded during the course of this investigation, are reported in this chapter.

Location of Grid Stations

Before the first direct water application, stakes were located within the plots on a grid system of 6.1 m x 6.1 m except that a 6.0 m x 6.0 m grid system was used for the small basin during the first irrigation (Figure 2.2). The area represented by each station before each irrigation was determined (see Tables A-1 to A-6). Each stake (station) was carefully banded with eight different colored tapes (16 mm wide) beginning from the top of the stake so that the surface depth of water at each station could be measured to a maximum depth of 128 mm (8 x 16 mm). The elevation of the soil surface at each station was determined using a surveyor's level; then the stakes were driven to the edge of the lowest color band before every irrigation (Figure 3.1).

The area represented by the stations close to the dikes (also called bunds) surrounding each basin were not uniform, since the dikes were not at uniform distance from the outer stations. Therefore, the area represented by

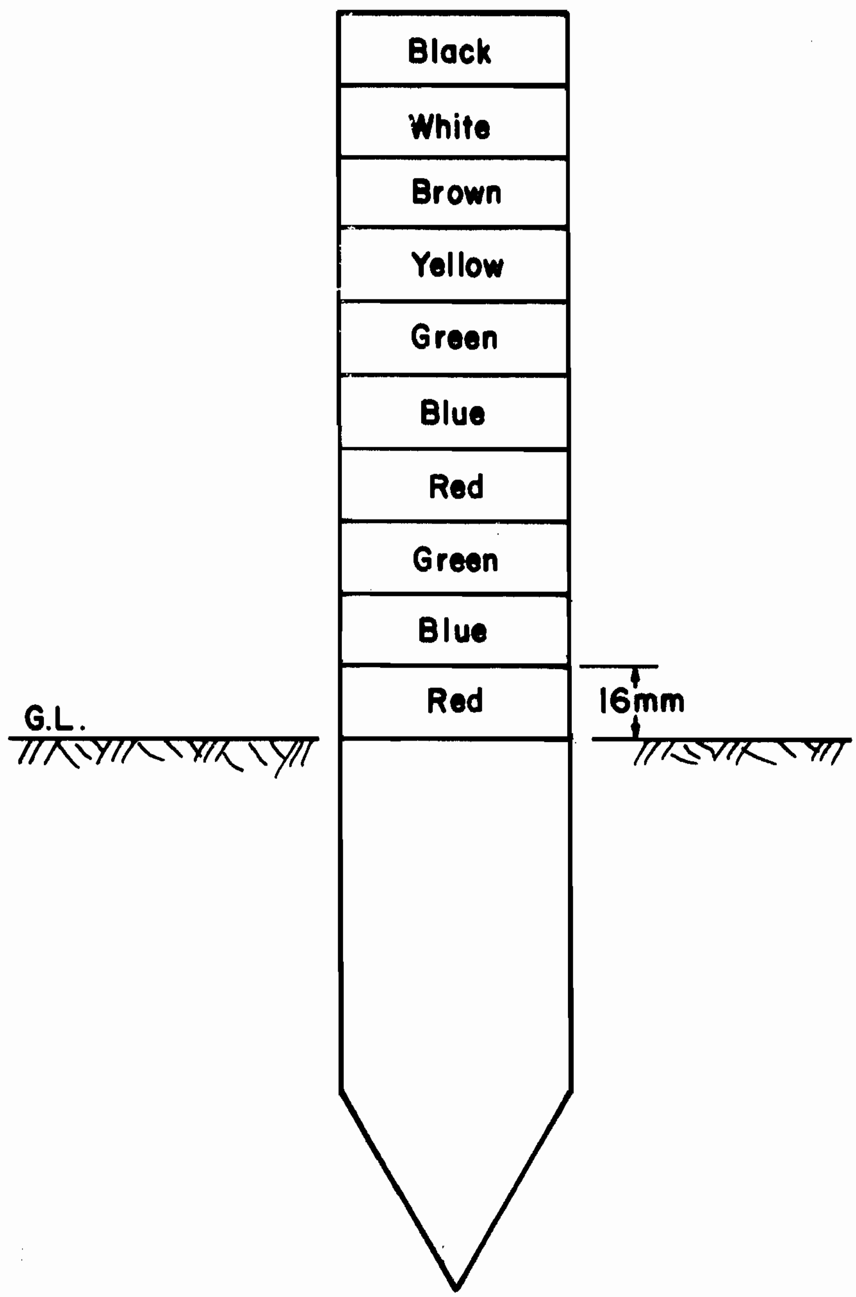


Figure 3.1. Diagram of a typical stake used to measure water depth at each grid station.

each station was measured and calculated before the first, second, and third irrigations. Since the difference between the measurements before the second and third irrigations (symbolized by S2 and S3 for the small basin or L2 and L3 for the large basin) were negligible, measurements were not taken after the third irrigations. The area represented by each station during the third irrigation was considered to remain practically unchanged through the rest of the growing season. The differences in area represented by the same station during the first few irrigations was caused by soil settlement in the dikes surrounding each basin (see Tables A-1 to A-6).

Grid Station Elevations

Elevations of the soil surface at each grid station was taken before every irrigation which provided the topography of the basin. Since water seeks its own level, these elevations provided a check on the final water depth readings at each station at the end of the ponding phase. Grid station elevations are also important for precisely drawing the water surface profiles during the advance and for calculating the volume of surface water storage in the basin.

Soil Moisture Content

Soil moisture samples were taken from the top 15 cm, then from every 30 cm through the root zone depth. Samples were collected at five locations in the large basin and three locations in the small basin. The average soil moisture content (SMC) of the root zone was determined one day before and 3 to 4 days after each irrigation by the gravimetric method. Besides this method, neutron probe data were collected every week for determining soil moisture content in the top five foot depth of soil at four locations in the large basin and two locations in the small basin. The locations of the soil sampling stations are shown in Figure 3.2.

Soil moisture samples were collected every week starting from the third week after planting until two weeks before harvesting. The average soil moisture contents in the basins before each irrigation are presented in Table 4.1.

Water Delivery and Flow Measurement System

A three horsepower (hp) low-head, high-discharge electrical pump was used to deliver water from a sump to an overhead reservoir. The sump was two feet in diameter and three feet deep, and was continuously supplied with water from an irrigation ditch. The overhead reservoir tank was six feet in diameter and two feet deep and had overflow pipes that conveyed excess water to the sump. The outflow pipe from this reservoir led to a weir box. A control valve was located between the reservoir and weir box. A schematic diagram of the water measuring and delivery system is presented in Fig. 3.3.

The weir box had a 45 degree weir notch with the bottom of the notch located 0.85 ft above the base of

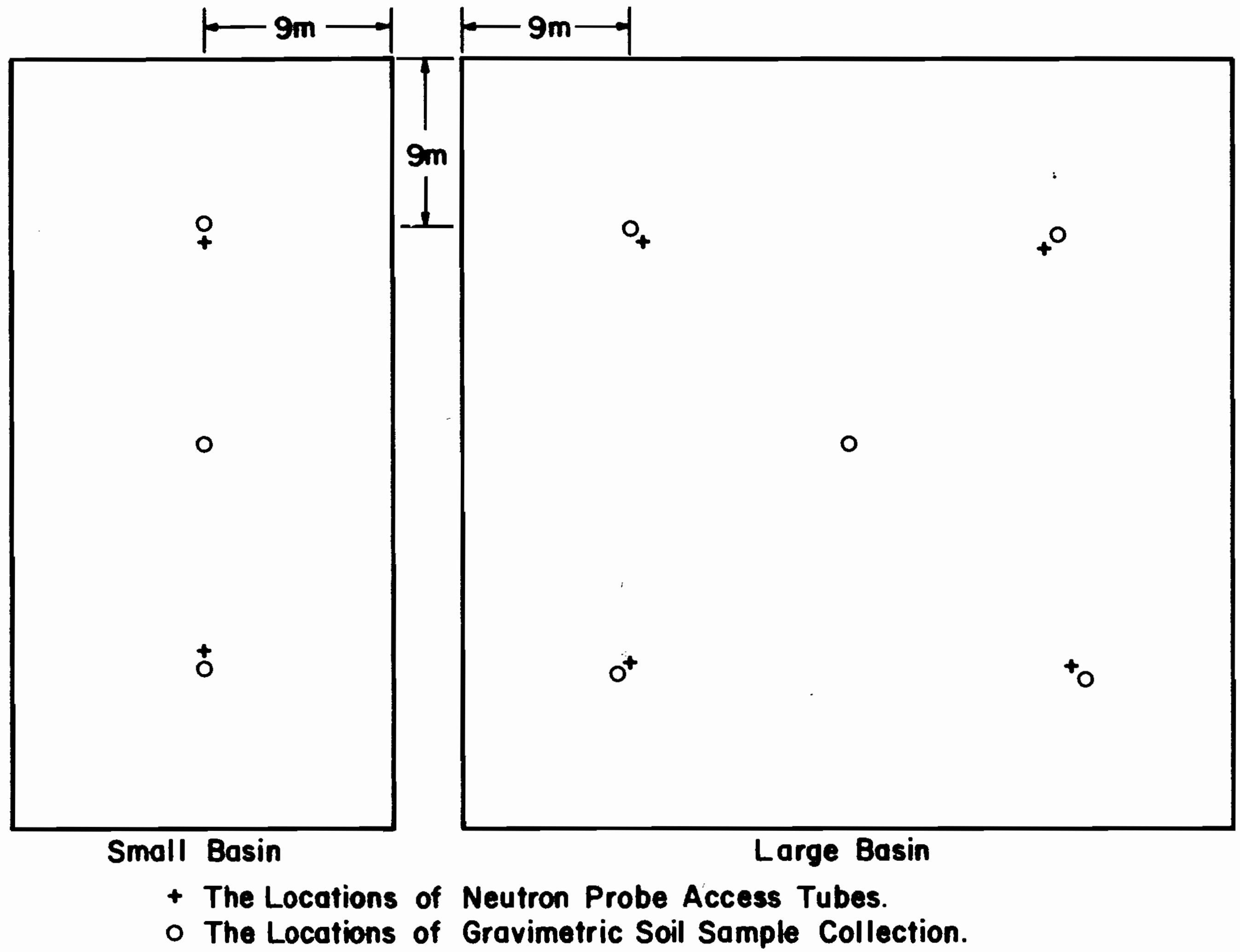


Figure 3.2. The soil sampling locations on the two plots.

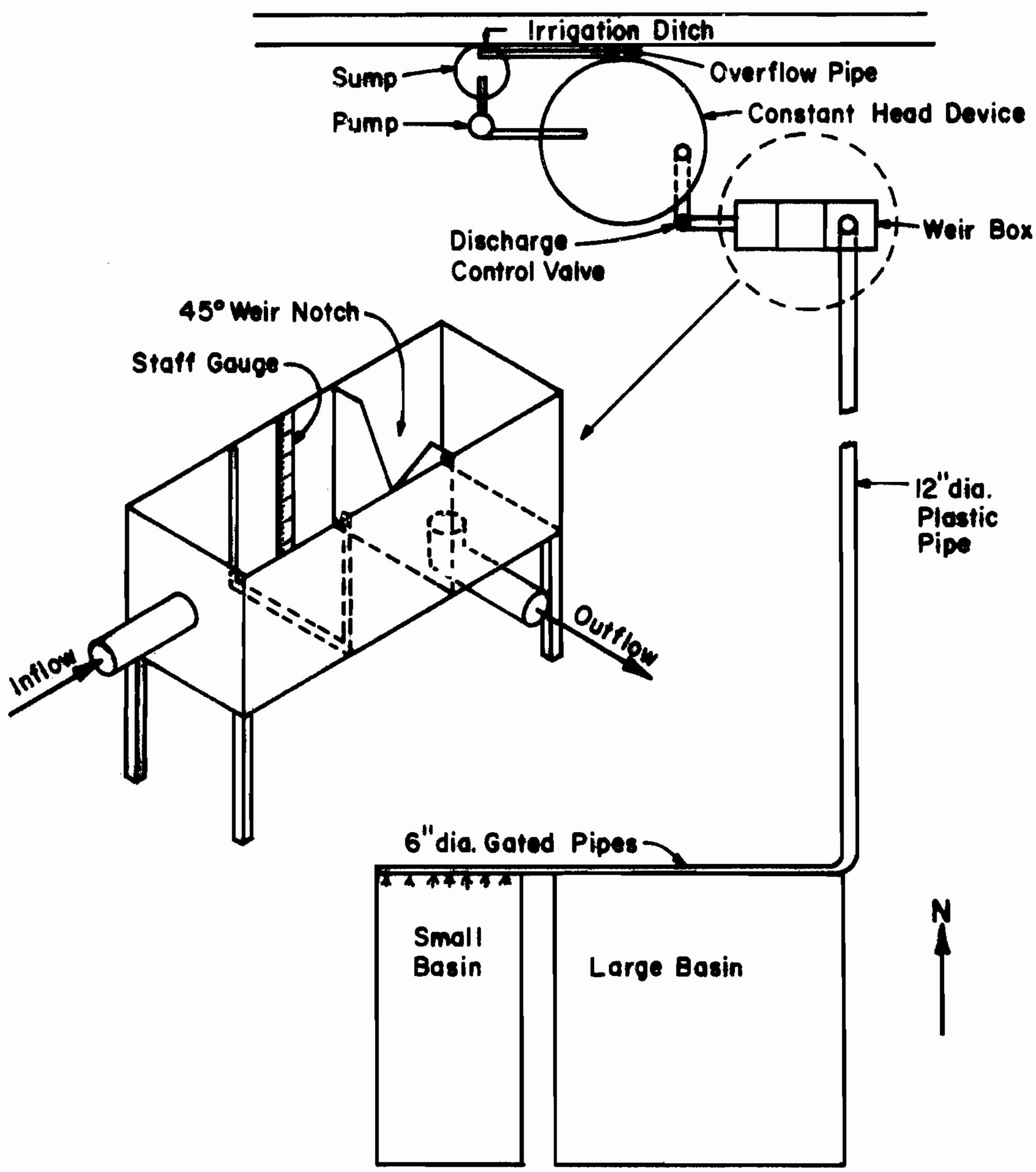


Figure 3.3. Schematic diagram of water measuring and delivery system.

the rectangular box. The weir was calibrated by conveying water through the weir at different discharge rates for a known time period and collecting the outflow in a reservoir of known dimensions. The head of water in the weir for each run (measured by a staff gauge) and the volume collected during the known time period was used to develop the calibration curve for the weir. The calibration curve is presented in Fig. 3.4. The free-flow discharge capacity of the weir was 19.0 liters per second (ℓ/s).

A 12-inch diameter plastic pipe connected the weir box outlet to the gated pipes on the basin dikes (Fig. 3.3) The head of water through the weir was read frequently in order to adjust the control valve preceeding the weir box so that the inflow rate to the basin would remain essentially constant during each irrigation.

Application of Irrigation Water

Both basins were flood irrigated one week before planting. During the two weeks after planting, irrigation water was applied by a sprinkler system instead of flooding to ensure good plant emergence. Four more flood irrigations were applied to each basin at 2-leaf, 6-leaf, 10-leaf and between the silking and blister stages. The discharge rates and depths of application for each basin are listed in Table 3.1 for the pre-irrigation (S1 and L1)

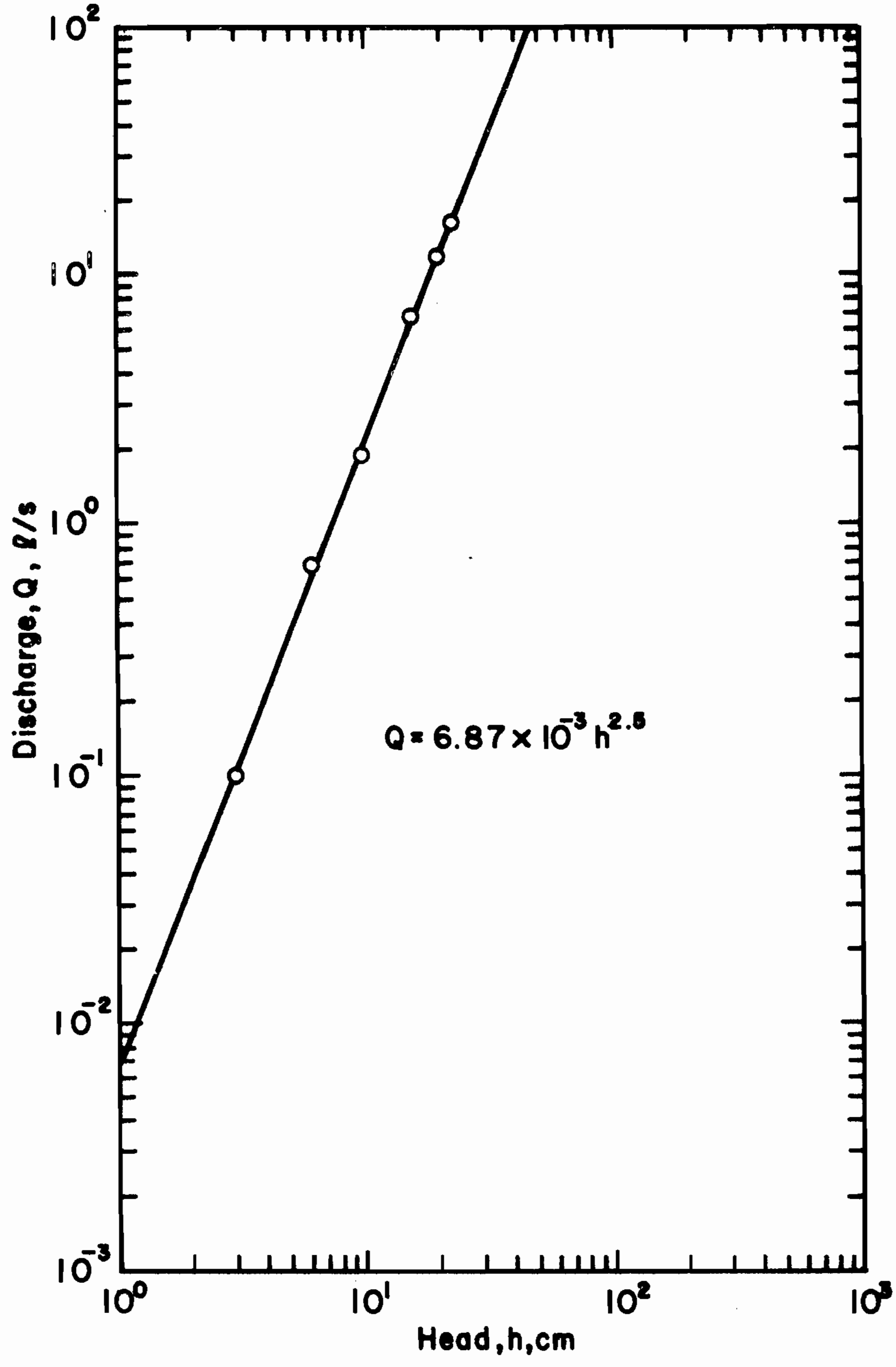


Figure 3.4 Relationship between head and discharge of 45-degree weir.

and the irrigations at the four stages of growth (S2, S3, S4, S5, and L2, L3, L4, L5).

Additional Observations

The monitoring of each irrigation including the following observations in addition to those already mentioned: (1) inflow start time; (2) inflow discharge rate during irrigation; (3) advance time to each station; (4) advance contours at several times during the advance phase; (5) depths of water at each station at the time each advance contour was drawn; (6) ponding start time; (7) inflow shut-off time; (8) depths of water at each station at inflow shut-off time, which corresponds to the beginning of the depletion phase; (9) time corresponding to end of depletion phase and beginning of recession phase; (10) water contours during the recession phase; and (11) time when the recession phase is completed (no water remaining in the soil surface).

Photographs (Figure 3.5) were simultaneously taken when advance contours were being plotted for visual presentation and verification of accuracy of the plotted advance contours. The photographs were taken during each irrigation until the crop foliage made it impossible to see the advancing water front.

Infiltration rates were measured during each irrigation with cylinder infiltrometers 30 cm in diameter driven 15 cm into the soil. Two such infiltrometers were

t_a = 10.0 minutes

t_a = 33.0 minutes

t_a = 63.0 minutes

t_a = 93.0 minutes

Figure 3.5. The photographs showing the contours of water front at several times of advance, t_a, during irrigation S1.

Table 3.1 Discharges and average depths of application of each irrigation to basin plots.

Basin size	Irrigation No.	Date	Discharge (ℓ/s)	Total Inflow time (min)	Total Inflow (m^3)	Avg. depth of application (mm)
18.3m x 36.6m approx.	S1	6/11/79	6.90	200.0	82.80	128.8
"	S2	7/11/79	8.18	130.0	63.80	99.1
"	S3	7/26/79	5.77	180.0	62.32	96.7
"	S4	8/08/79	8.20	125.0	61.50	95.5
"	S5	8/30/79	6.94	130.0	63.80	84.0
36.6m x 36.6m approx.	L1	6/12/79	13.84	180.0	149.47	112.0
"	L2	7/11/79	16.33	120.0	117.58	87.5
"	L3	7/25/79	12.62	156.0	118.12	87.9
"	L4	8/07/79	16.40	95.0	93.48	69.6
"	L5	8/30/79	13.88	113.0	94.11	70.1

installed in each basin and the tests were started when the irrigation water front almost encompassed them. The locations of the cylinder infiltrometers in the basins are shown in Figure 2.2.

Section 4

EVALUATION OF IRRIGATION PERFORMANCE

In this study, the infiltrated water depths during each irrigation were estimated by two methods:

1. Adjusted Infiltration Equation; and
2. Split-Time Infiltration.

These methods are described below in detail.

Adjusted Infiltration Equation

A flow chart is presented in Figure 4.1. It illustrates the steps to be followed in calculating the irrigation performance parameters by the Adjusted Infiltration Equation method. The details of these steps are described below.

The opportunity time, t_{op}, was calculated for each station (Tables D-1 to D-10) by:

$$t_{op_{ij}} = t_{r_{ij}} - t_{a_{ij}} \tag{4-1}$$

where i and j denotes the row and column numbers, respectively, $t_{r_{ij}}$ is the time of recession at the ijth station (Tables D-1 to D-10) interpolated from recession contours, and $t_{a_{ij}}$ is the time of advance at the ijth station (Figures C-1 to C-10).

The typical infiltration curves were developed from the two infiltration tests carried out in each basin during irrigation (Figures B-1 to B-10). The typical infiltration curve for each basin is the mean infiltration curve of the two data sets. The mean infiltration curve was developed

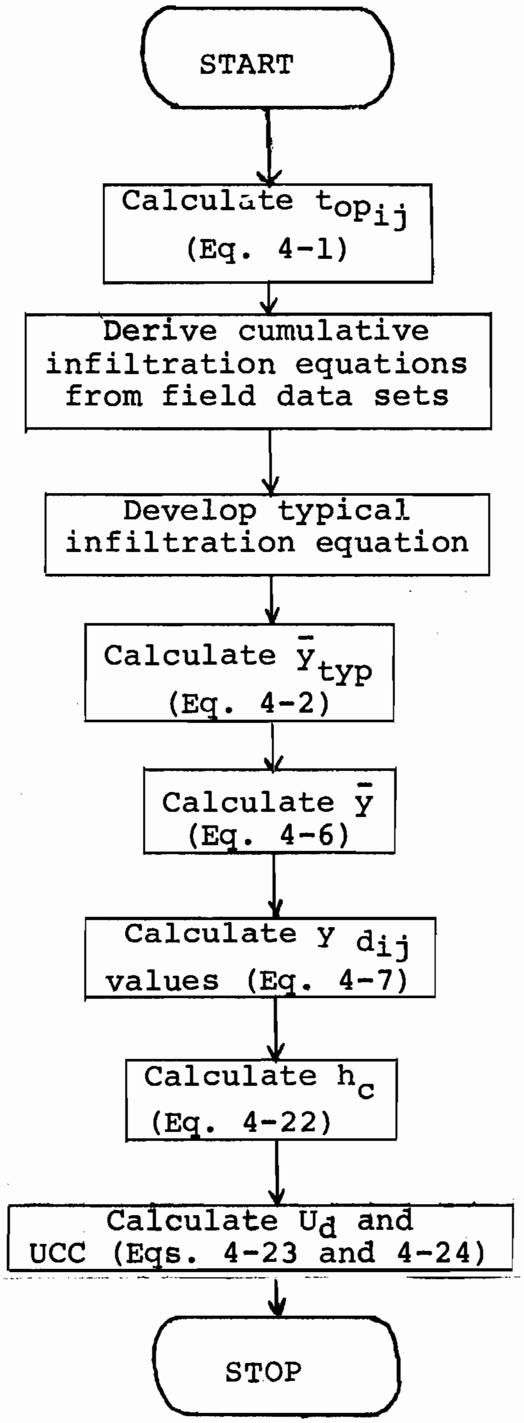


Figure 4.1. Flow chart for calculating irrigation performance parameters by the Adjusted Infiltration Equation method.

after deriving cumulative infiltration equations for each data set by the method of least squares. The coefficient of determination (r^2) values for cumulative infiltration equations were determined and are presented in Figures B-1 to B-10. From the two measurements of cumulative infiltration in each basin during each irrigation, two cumulative infiltrated depths (one value from each infiltrometer measurement) would correspond with each selected value of opportunity time. Then, the mean of these two depths could be plotted against each corresponding value of opportunity time to create a plot representing the typical (mean) infiltration curve. This procedure was done for both the small basin and the large basin, so that each basin had its own unique mean infiltration curve.

Using the calculated t_{op}, based upon advance and recession measurements, the depth of water infiltration at each station was estimated from the typical infiltration curves (one curve for the small basin and another curve for the large basin). The average infiltrated depth, $\bar{y}_{typ}$, was calculated (Tables D-1 to D-10) by:

$$\bar{y}_{typ} = \frac{1}{A_T} \sum_{i=1}^{m} \sum_{j=1}^{n} (y_{typ_{ij}} \cdot a_{ij}) \qquad (4\text{-}2)$$

where m,n = total number of rows and columns, respectively; $y_{typ_{ij}}$ = estimated depth of water infiltrated at the ijth station as calculated from the infiltration curve; a_{ij} = area represented by the ijth station; and A_T = total area.

The estimated total volume of water infiltrated into the soil, T_{est}, can be calculated from the depth infiltrated at each station.

$$T_{est} = \sum_{i=1}^{m} \sum_{j=1}^{n} (y_{typ_{ij}} \cdot a_{ij}) = A_T \cdot \bar{y}_{typ} \qquad (4\text{-}3)$$

The actual volume of water applied during irrigation is given by:

$$T = \sum_{k=1}^{p} Q_k \, t_k \qquad (4\text{-}4)$$

where Q_k = a constant inflow discharge for a period of time, t_k, and p = number of such time periods. When the inflow discharge is constant at Q throughout the basin delivery time, t_{co}, then

$$T = Q \cdot t_{co} \qquad (4\text{-}5)$$

The actual average depth of water applied during the irrigation is:

$$\bar{y} = \frac{T}{A_T} \qquad (4\text{-}6)$$

Usually, $T_{est} \neq T$; that is $\bar{y} \neq \bar{y}_{typ}$; consequently, the cumulative depth infiltrated at each station should be adjusted.

The adjustment of the water depths at each station to the actual applied depth corresponding to the measured inflow to the basin is dependent on the accuracy of the infiltration equation and the discharge measurements. The measurement of the actual applied volume, as obtained by discharge and time measurements, was significantly more accurate and reliable than the infiltration measurements. Therefore, the actual volume applied was regarded as the correct volume of water and the depth of water, y_{ij}, at each of the stations was adjusted accordingly. At the same time, the typical infiltration curves were also adjusted. Using the actual delivery volume of water, T, as the real amount of water applied during irrigation, the water depth at each of the stations was adjusted (Tables D-1 to D-10) to:

$$y_{ad_{ij}} = y_{ij} = y_{typ_{ij}} \frac{T}{T_{est}} = y_{typ_{ij}} \frac{\bar{y}}{\bar{y}_{typ}} \qquad (4\text{-}7)$$

The typical infiltration curve was adjusted by drawing a parallel line on logarithmic paper passing through the point $\bar{y}$ having the same mean opportunity time ($\bar{t}_{op}$) from the typical infiltration curve that corresponds with $\bar{y}_{typ}$. In other words, using logarithmic paper, the adjusted infiltration curve was obtained by plotting $\bar{y}_{typ}$ on the typical infiltration curve, then marking a point on the same vertical line (corresponding to the same opportunity time) with cumulative depth, $\bar{y}$, and drawing a line parallel to the typical one through this new point (Figures B-1 to B-10). Using this technique, the adjusted infiltration curve provided the same adjusted depths as given by Eq. 4-7. The values of the constant A and exponent B in the infiltration equation are presented in Table 4.1 for each irrigation event.

In cases where the actual volume of water is somewhat doubtful and cannot be relied upon as the real measure of the volume of water applied to the field, adjustment of the $y_{typ_{ij}}$ should be done according to a weighted combination of T and T_{est}. Each water depth $y_{typ_{ij}}$ is adjusted by multiplying it by the ratio:

Table 4.1. Values of constant A and exponent B in the cumulative infiltration equation* ($I=At^B$).

Irrigation	Initial SMC (percent of dry wt.)	A, B Values			
		Test 1	Test 2	Typical	Adjusted
S1	17.97	4.94, 0.432	6.82, 0.395	5.86, 0.412	8.74, 0.412
S2	17.62	8.66, 0.210	5.73, 0.254	7.16, 0.230	25.63, 0.230
S3	17.03	5.53, 0.216	2.68, 0.386	3.88, 0.300	12.79, 0.300
S4	17.58	5.85, 0.291	1.94, 0.456	3.79, 0.352	6.51, 0.352
S5	15.36	16.96, 0.178	20.30, 0.119	18.50, 0.149	35.81, 0.149
L1	18.07	1.87, 0.704	2.64, 0.653	2.25, 0.676	2.46, 0.676
L2	18.02	0.58, 0.612	1.95, 0.457	1.21, 0.513	2.59, 0.513
L3	16.37	3.00, 0.300	3.15, 0.289	3.08, 0.295	10.01, 0.295
L4	16.45	6.03, 0.183	1.75, 0.409	3.58, 0.280	7.66, 0.280
L5	14.68	6.14, 0.192	3.26, 0.246	4.67, 0.214	14.44, 0.214

*cumulative infiltration in mm and time in min.

$$R = \frac{P_1 T + P_2 T_{est}}{(P_1 + P_2) T_{est}} \qquad (4\text{-}8)$$

where P_1, P_2 are weighting factors for the actual and estimated volumes, respectively (Peri, Skogerboe and Norum, 1979). For example, if $P_1 = P_2$, that is the reliability of the water volume measurement is assumed to be the same as the infiltration measurements, the ratio of R in Eq. 4-8 will be:

$$R = \frac{T + T_{est}}{2T_{est}} \qquad (4\text{-}9)$$

The adjusted water depths for each station are then given by:

$$y_{ad_{ij}} = Ry_{typ_{ij}} \qquad (4\text{-}10)$$

For the case in which the volume of water T is considered the real amount of water applied during irrigation, substituting $P_2 = 0$ gives:

$$R = \frac{T}{T_{est}} \qquad (4\text{-}11)$$

The adjusted water depths, $y_{ad_{ij}}$, were then regarded as the real water depths, y_{ij}, that infiltrated at each station. These depths were considered to be the depths infiltrated over the area represented by the corresponding stations.

The water depths calculated by the Adjusted Infiltration Equation method are presented in Tables D-1 to D-10.

Split-Time Infiltration Method

A flow chart is presented in Figure 4.2 that illustrates the steps to be followed in calculating the irrigation performance parameters by the Split-Time Infiltration method. The details of these steps are described below.

The Split-Time Infiltration method of estimating water distribution over the entire basin was based on (1) water infiltration depth in each area calculated by using opportunity time ($t_{op_{ij}}$) for each station as:

$$t_{op_{ij}} = t_{co} - t_{a_{ij}} \quad (4\text{-}12)$$

where $t_{a_{ij}}$ is the time of advance at the ijth station (Tables D-1 to D-10) and t_{co} is the irrigation cutoff time and (2) the depths of water standing at each station at the irrigation shutoff time, $y_{co_{ij}}$. Therefore, the average infiltration depth over each station area is given by:

$$y_{ij} = At^{B}_{op_{ij}} + y_{co_{ij}} = y_{t_{ij}} + y_{co_{ij}} \quad (4\text{-}13)$$

where A and B are constants in the cumulative infiltration equation, and $y_{t_{ij}} = At^{B}_{op_{ij}}$. (4-14)

The assumption made in (2) is plausible assuming little or no lateral movement of water occurred from one station area to another after the cutoff time; which implies that all the water standing in any one station area infiltrated vertically through the soil. The water depths at the stations were read a minute or two after the

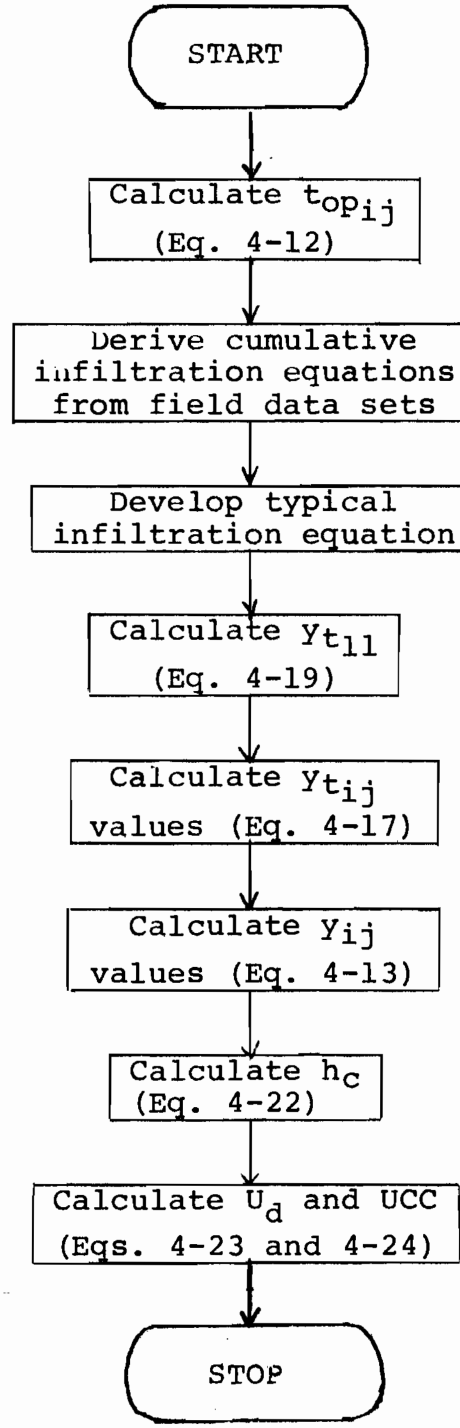


Figure 4.2. Flow chart for calculating irrigation performance parameters by the Split-Time Infiltration method.

cutoff time when the movement of water across the basin had practically ceased.

The total quantity of water is given by:

$$T = \bar{y} \cdot A_T = \sum_{i=j}^{m} \sum_{j=1}^{n} a_{ij} \cdot y_{ij} \qquad (4\text{-}15)$$

From Eqs. 4-13 and 4-15,

$$\bar{y} \cdot A_T = \sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij} y_{t_{ij}} + \sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij} y_{co_{ij}} \qquad (4\text{-}16)$$

Again, from Eq. 4-14,

$$y_{t_{ij}} = y_{t_{11}} \; (t_{op_{ij}}/t_{op_{11}})^B \qquad (4\text{-}17)$$

Where $y_{t_{11}}$ is the depth of infiltrated water at the station 11, which is estimated using the opportunity time at that station ($t_{op_{11}}$) as defined in Eq. 4-12.

Substituting Eq. 4-17 in Eq. 4-16,

$$T = y_{t_{11}} \sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij} \; (t_{op_{ij}}/t_{op_{11}})^B + \sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij} y_{co_{ij}} \qquad (4\text{-}18)$$

Then,

$$y_{t_{11}} = \frac{T - \sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij} y_{co_{ij}}}{\sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij} (t_{op_{ij}}/t_{op_{11}})^B} \qquad (4\text{-}19)$$

The values of $y_{t_{ij}}$ for i=1, 2, . . . m and j=1, 2, . . . n were calculated using Eq. 4-17, and substituted in Eq. 4-13 to obtain the values of y_{ij}.

The water depths calculated by this method are presented in Tables D-11 to D-19. These values for irrigation number S4 have not been reported since $y_{co_{ij}}$ values at the irrigation cutoff time could not be read for unforeseen reasons.

Irrigation Performance Parameters

The total quantity of water applied during an irrigation event was:

$$T = \sum_{i=1}^{m} \sum_{j=1}^{n} y_{ij} \cdot a_{ij} \qquad (4\text{-}20)$$

The average depth of water applied during an irrigation event was:

$$\bar{y} = \frac{T}{A_T} \qquad (4\text{-}21)$$

The deficient amount of water in relation to $\bar{y}$, expressed as a depth is given by:

$$h_c = \frac{1}{A_T} \sum_{i=1}^{q'} \sum_{j=1}^{r'} (\bar{y} - y_{ij}) a_{ij} \quad \text{for } y_{ij} < \bar{y} \qquad (4\text{-}22)$$

where q', r' are the row and column numbers of the station with infiltrated depths less than $\bar{y}$.

The Distribution Uniformity was calculated by:

$$U_d = \frac{\bar{y} - h_c}{\bar{y}} \qquad (4\text{-}23)$$

Also, Christiansen's (1942) Uniformity Coefficient was calculated for each irrigation event using

$$UCC = 1.0 - ((\sum_{i=1}^{m} \sum_{j=1}^{n} (\{y_{ij} - \bar{y}\}) a_{ij})/T) \qquad (4\text{-}24)$$

The flow charts for the two methods of adjusting the infiltration curve presented in Figures 4.1 and 4.2 illustrate the steps in calculating h_c, U_d and UCC. The values of h_c, U_d and UCC calculated by these two methods are presented in Tables 4.2 and 4.3, respectively.

Table 4.2. Distribution Uniformity and Christiansen's Uniformity Coefficient for each irrigation using the Adjusted Infiltration Equation method.

Irrigation	S1	S2	S3	S4	S5	L1	L2	L3	L4	L5
T (m^3)	82.82	63.80	62.32	61.50	53.13	149.47	117.58	118.12	93.48	94.11
A_T (m^2)	643.02	644.12	644.17	644.17	644.17	1334.95	1343.67	1343.26	1343.26	1343.26
$\bar{y}$ (mm)	128.77	99.1	96.74	95.47	84.03	111.97	87.50	87.94	69.59	70.06
h_c (mm)	1.76	1.03	1.57	1.29	0.88	4.64	5.69	1.16	0.74	1.47
U_d (percent)	98.64	98.96	98.38	98.64	98.95	95.86	93.49	98.68	98.93	97.90
UCC (percent)	98.83	97.94	96.80	97.24	97.93	92.02	87.02	97.39	97.88	97.49

Table 4.3. Distribution Uniformity and Christiansen's Uniformity Coefficient for each irrigation using the Split-Time Infiltration method.

Irrigation	S1	S2	S3	S4	S5	L1	L2	L3	L4	L5
h_c (mm)	2.94	3.76	3.04	--	3.05	5.81	4.04	3.51	3.16	3.18
U_d (percent)	97.72	96.21	96.86	--	96.37	94.81	95.38	96.01	95.46	95.46
UCC (percent)	95.42	92.33	93.51	--	93.62	89.58	90.77	91.94	90.97	91.36

Section 5

INFILTRATION EQUATION BY MODIFIED VOLUME BALANCE

In the preceding section, the depth of water infiltrated at each area represented by a station was estimated by two methods. The accuracy of these estimations is basically dependent on the accuracy of the infiltration equation developed by the cylinder infiltrometer tests. In many cases, the infiltration equation thus established may not represent the actual infiltration characteristics of the entire basin due to the variability in soil characteristics over the basin and the irrigation conditions which, in actuality, may differ to a great extent from the infiltrometer test conditions. A procedure that is similar to that of Christiansen et al. (1966) was modified by Peri et al. (1979) to establish a field infiltration equation based on a volume balance technique. In this section this procedure is described and is used to develop infiltration equations for two irrigations, S1 and L1, which were the pre-irrigation for the small basin and large basin, respectively. Also, the irrigation performance parameters were determined based upon the infiltration equation derived by the Modified Volume Balance Technique.

Modified Volume Balance Technique for Basin Irrigation

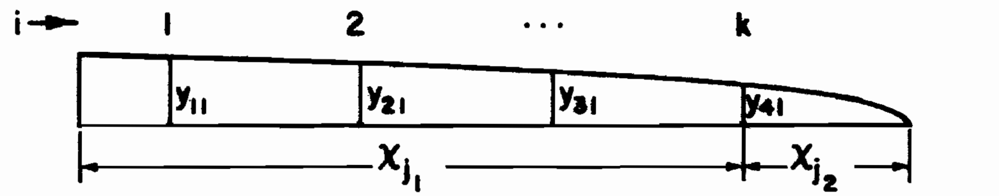
The average depth of infiltrated water, $\bar{y}(t)$, at time t can be computed from the total volume of water stored on the surface, $V_p(t)$; the area covered by water, $A_p(t)$; and the actual inflow volume, Qt.

$$\bar{y}(t) = (Qt - V_p(t))/A_p(t) \quad (5\text{-}1)$$

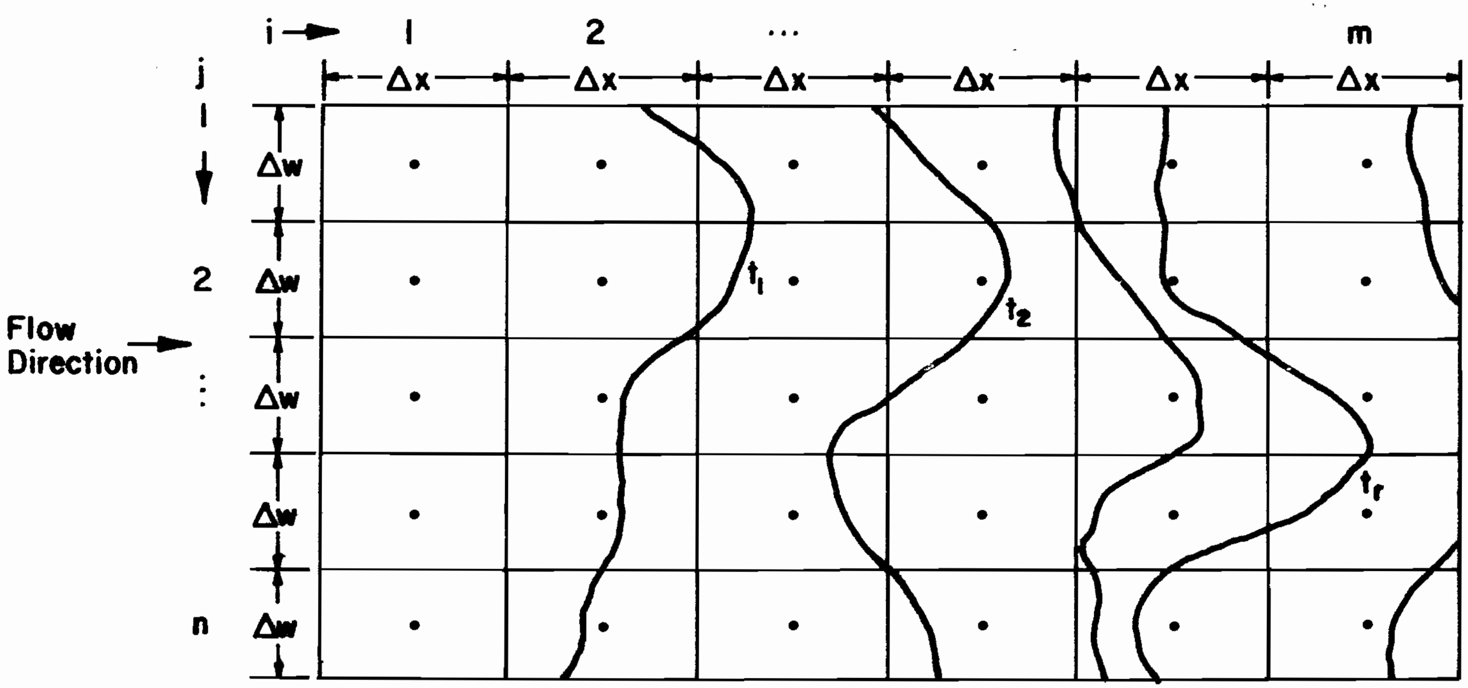
If $\bar{y}(t)$ can be determined, at several times, then the relationship between t and $\bar{y}(t)$ will provide the infiltration equation for the basin. In the above equation, the inflow rate Q is known from the inflow discharge measurement device, $V_p(t)$ and $A_p(t)$ can be calculated from the plotted advance contours and the depths of water at the stations recorded at several times during the irrigation event (Tables E-1 and E-2).

In most cases of basin irrigation, the advancing water front is nonuniform across the basin, therefore, a procedure is developed here to estimate the value of $V_p(t)$. The procedure is similar to that of Peri et al. (1979) with some modifications. The reader is referred to Peri et al. (1979) for related discussions.

The basin width, W, was divided into n strips (columns), each of width ΔW_j; where j denotes the strip number (Figure 5.1 (a)). The total length of each strip was considered equal to each other. The ΔW_j values were determined from the total length of the basin and the area of each strip (Tables A-1 and A-4) for the two irrigations (S1 and L1) which were monitored for this purpose. In each strip, there were m stations spaced at equal distance Δx (Figure 5.1(a)). For simplification, it is recommended that the stations are so spaced such that ΔW_j and Δx are equal for all strips.



(b) Cross-sectional view of water front on strip j=1 at $t=t_r$



(a) Schematic description of the grids for the measurement of the advancing water front.

Figure 5.1 Definition sketch for Modified Volume Balance method.

Referring to Figure 5.1(b):

$$x_j = x_{j_1} + x_{j_2} = (k - 0.5)\Delta x + x_{j_2} \qquad (5.2)$$

where,

k = total number of stations within length x_j

x_{j_1} = the wetted strip length up to the last station covered by the water front

$x_{j_2} = x_j - x_{j_1}$.

The average depth of water for length x_{j_1}, $\bar{y}_{j_1}$, was computed by weighting the length represented by each station up to station k (see Figure 5.1(b)). Since the last station k on length x_{j_1} represents a length equal to $\Delta x/2$, then

$$\bar{y}_{j_1} = (2 \sum_{i=1}^{k-1} y_{ij} + y_{kj})/(2k+1) \qquad (5\text{-}3)$$

where,

i = number of stations (or row numbers, used in earlier sections) along the strip

y_{ij} = observed depth of water at station ij (Tables E-1 and E-2)

and the average depth of water for length x_{j_2} was considered as $\bar{y}_{j_2} = 0.75\, y_{kj}$ (5-4)

assuming a shape factor of the surface water profile equal to 0.75.

When the water front advanced only beyond the first station (for k=1), the depth of water at the basin upper end (y_{io}) was estimated considering

$$y_{io} = y_{1j}/0.85 \qquad (5\text{-}5)$$

and

$$\bar{y}_{j_2} = 0.75\ y_{io} = 0.882\ y_{1j} \qquad (5\text{-}6)$$

where $\bar{y}_{j_2}$ is the average depth of water of the longitudinal surface water profile on strip j when the water front advanced only beyond the first station.

When x_j is equal to the length of the basin, L, then (Tables E-5 and E-6)

$$k = m$$

$$a_{j_2} = 0$$

$$\bar{y}_{j_1} = (\sum_{i=1}^{n} y_{ij})/k \qquad (5\text{-}7)$$

The volume of total surface storage, $V_p(t)$, at time t is given by (taking the weighted average of the depths $\bar{y}_{j_1}$ and $\bar{y}_{j_2}$ and summing up the volume of water standing in all strips j=1 to n):

$$V_p(t) = \sum_{j=1}^{n} \frac{1}{x_j}(x_{j_1}\bar{y}_{j_1} + x_{j_2}\bar{y}_{j_2})A_j = \sum_{j=1}^{n} \frac{1}{x_j}(a_{j_1} + a_{j_2})A_j \qquad (5\text{-}8)$$

$$= \sum_{j=1}^{n} V_{p_j}(t)$$

where, A_j is area of the strip j covered by water. The $V_p(t)$ values for irrigation numbers S1 and L1 are presented in Tables E-5 and E-6.

The average depth of infiltrated water, $\bar{y}(t)$, was calculated by Eq. 5-1 (Tables E-7 and E-8) and was plotted as a function of t on log-log paper (Figures E-1 and E-2) and their relationship was established by fitting a straight line through these points. The relationship can be represented by a general form:

$$\bar{y}(t) = KAt^{B} \tag{5-9}$$

where B = slope of the line

KA = the value of $\bar{y}(t)$ at t = 1

The value of K can be estimated by the following expression (Kiefer, 1959):

$$K = \frac{F}{B+1} \approx \frac{(B-1)-r(B-1)+2}{(B+1)(1+r)} \tag{5-10}$$

where r is the exponent of the advance function of the form

$$A(t_a) = pt_a^{r} \tag{5-11}$$

where $A(t_a)$ is the area covered by water at any time of advance, t_a. The relationships of the above form are presented in Figures E-3 and E-4. Thus, the value of K was estimated to calculate A (Table E-9) which could be used in the infiltration equation of the Kostiakov type:

$$y = At_{op}^{B} \tag{5-12}$$

where t_{op} is the infiltration opportunity time.

Irrigation Performance Parameters

The depth of water infiltrated at each station (y_{field}) was estimated by Eq. 5-12 and then the average infiltrated depth for the entire basin, $\bar{y}_{field}$, was calculated (Tables E-10 and E-11) by:

$$\bar{y}_{field} = \frac{1}{A_t} \sum_{i=1}^{m} \sum_{j=1}^{n} (y_{field_{ij}} \cdot a_{ij}) \tag{5-13}$$

where $y_{field_{ij}}$ = estimated depth of water infiltrated at the ijth station and other parameters are defined in Eq. 4-2.

Since the measurement of actual volume of water (inflow) was significantly more reliable and accurate than the water depth measurements at each station, y_{ij}, the depth of infiltration at each station was adjusted by multiplying it by the ratio of average depth of application, $\bar{y}$, to $\bar{y}_{field}$ as in Eq. 4-7 to obtain $y_{ad_{ij}}$ (Tables E-10 and E-11). Also, the value of A in Eq. 5-12 was multiplied by this ratio to adjust the infiltration equation to conform with the actual average depth of application.

The distribution uniformity (U_d) and the Christiansen's Uniformity Coefficient (UCC) values for the two irrigations were calculated using the $y_{ad_{ij}}$ values and are presented in Table 5.1.

Table 5.1 Distribution Uniformity and Christiansen's Uniformity Coefficient using infiltration equations developed by the Modified Volume Balance method.

Irrigation	A_T (sqm)	$\bar{y}$ (mm)	h_c (mm)	U_d (Percent)	UCC (Percent)
S1	643.02	128.77	2.29	98.22	96.44
L1	1334.95	111.97	1.40	97.85	95.67

Section 6

COMPARISON OF INFILTRATION EQUATIONS

The estimation of the basin irrigation performance parameters is guided by the method of calculation of the depth of infiltration at each individual area (y_{ij}) of the basin. In this report, three such methods were considered, viz.,

(1) Adjusted Infiltration Equation,

(2) Split-time Infiltration, and

(3) Modified Volume Balance.

Finally, the Distribution Uniformity (Eq. 4-23) and the Christiansen's Uniformity Coefficient (Eq. 4-24) were determined based on the y_{ij} values estimated by these three methods. These parameters for the two irrigations (S1 and L1) are presented in Table 6.1.

The y_{ij} values estimated by method 1 (Adjusted Infiltration Equation) are basically dependent on the typical infiltration equation, therefore, inherently dependent on the accuracy and reliability of the cylinder infiltrometer tests. Each infiltration equation thus developed represents the soil characteristics of the particular test site and a typical infiltration equation developed from several such tests may serve as a representative infiltration equation for an entire basin when data requirements of a better method cannot be met.

The Split-Time Infiltration method reduces the dependence of water depth estimation (y_{ij}) for the typical infiltration

Table 6.1. Irrigation performance parameters estimated for irrigations S1 and L1 by three methods of calculating infiltration.

Method of Estimating Infiltration	Irrigation Number S1			Irrigation Number L1		
	h_c	U_d	UCC	h_c	U_d	UCC
1	1.76	98.64	98.83	4.64	95.86	92.02
2	2.94	97.72	95.42	5.81	94.81	89.58
3	2.29	98.22	96.44	2.40	97.85	95.67

Method 1: Adjusted Infiltration Equation method.

Method 2: Split-Time Infiltration method.

Method 3: Modified Volume Balance method.

equation by dividing the opportunity time at each station into two parts as explained in Section 4. When the value of y_{co} (Eq. 4-13) is the major portion in the estimation of the y_{ij} value (close to 50 percent of y_{ij}), then the estimation of y_{ij} becomes considerably less dependent on the exponent of the typical infiltration equation (Eq. 4-17). In this case, the estimation is greatly influenced by the accuracy of the water depth measurements at the irrigation cutoff time. Therefore, if such reliable observations can be taken, the irrigation performance should be evaluated by the Split-Time Infiltration method rather than by the Adjusted Infiltration Equation method.

The Modified Volume Balance method is based on measured volumes of inflow and water surface storage at several times during the water front advance. A carefully calibrated inflow measuring device can be extremely accurate and reliable if the device is read frequently and, preferably, maintained at a constant head (constant discharge rate). The volume of storage is calculated from the observed depths of water at each grid station. The accuracy of this estimation is dependent on the visual judgment of the observer, levelness of the basin, and number and extent of depressions and high spots in the basin. When these conditions are reasonably satisfied, the volume of infiltration estimated at several times during advance would provide an infiltration equation that would represent the overall soil and moisture characteristics of the basin, as well as be representative of the irrigation conditions. It should be noted that evaporation during irrigation has not been taken into account in this analysis. Evaporation data, when available, should be incorporated in the analysis whenever possible.

The two basins, leveled by a laser-controlled scraper, resulted in a high degree of levelness with no visible depressions before the first irrigation was applied. Later on, depressions were formed across the basins because of the equipment used for planting and walking inside the basins to collect data during successive irrigations. Though extensive depressions are expected to be a major cause of reduced irrigation uniformity, the effect is apparently not shown in the estimated values of U_d and UCC (see Tables 4.2 and 4.3). These uniformity values calculated by the first infiltration method for irrigation number L1 (Table 4.2) are strangely lower than the L3, L4 and L5 irrigations. Whereas, when they were estimated by the Modified Volume Balance method (Table 6.1) these uniformity values for irrigations S1 and L1 were comparable, even though this method would seem more reasonable. Although only one irrigation event for each basin could be successfully monitored for using the Modified Volume Balance method, which is not sufficient to draw extensive conclusions, the analysis shows that this method is highly reliable in the sense that the infiltration equation thus developed includes all the attributes of the soil (ground surface levelness, variability of soil moisture conditions, and soil physical characteristics) and irrigation (variability of flow rate across the basin width and with time) conditions.

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APPENDIX A

AREA REPRESENTED BY EACH STATION

Table A-1. Area (m^2) represented by the stations of the small basin for irrigation Number S1.

Station Rows \ Station Column	1	2	3	Total Area (m^2)
1	33.54	36.00	36.24	105.78
2	35.16	36.00	36.18	107.34
3	35.16	36.00	36.78	107.94
4	34.86	36.00	36.18	107.04
5	35.10	36.00	36.30	107.40
6	35.52	36.00	36.00	107.52
Total Area (m^2)	209.34	216.00	217.68	643.02

Table A-2. Area (m^2) represented by the stations of the small basin for irrigation number S2.

Station Column / Station Row	1	2	3	Total Area (m^2)
1	35.40	35.92	33.89	105.21
2	36.08	37.16	36.08	109.32
3	36.19	37.16	36.19	109.54
4	35.65	37.16	35.92	108.73
5	36.04	37.16	36.04	109.24
6	34.00	34.53	33.55	102.08
Total Area (m^2)	213.36	219.09	211.67	644.12

Table A-3. Area (m^2) represented by the stations of the small basin for irrigation number S3 to S5.

Station Column / Station Rows	1	2	3	Total Area (m^2)
1	35.33	35.92	33.82	105.07
2	36.08	37.16	36.08	109.32
3	36.23	37.16	36.23	109.62
4	35.61	37.16	35.61	108.38
5	36.08	37.16	36.08	109.32
6	34.04	34.68	33.74	102.46
Total Area (m^2)	213.37	219.24	211.56	644.17

Table A-4. Area (m^2) represented by the stations of the large basin for irrigation number L1.

Station row \ Station Column	1	2	3	4	5	6	Total Area (m^2)
1	37.86	37.47	37.63	36.39	36.39	35.78	221.52
2	37.70	37.16	37.16	37.16	37.16	36.31	222.65
3	37.94	37.16	37.16	37.16	37.16	36.54	223.12
4	38.09	37.16	37.16	37.16	37.16	37.16	223.89
5	38.40	37.16	37.16	37.16	37.16	37.32	224.36
6	36.23	36.77	36.85	37.16	36.62	35.78	219.41
Total Area (m^2)	226.22	222.88	223.12	222.19	221.65	218.89	1334.95

Table A-5. Area (m^2) represented by the stations of the large basin for irrigation number L2.

Station row \ Station Column	1	2	3	4	5	6	Total Area (m^2)
1	37.31	37.47	36.85	37.32	36.70	36.85	222.50
2	38.55	37.16	37.16	37.16	37.16	37.63	224.82
3	37.63	37.16	37.16	37.16	37.16	37.63	223.90
4	37.63	37.16	37.16	37.16	37.16	38.09	224.36
5	38.09	37.16	37.16	37.16	37.16	38.40	225.13
6	37.77	36.85	36.85	37.32	36.70	37.47	222.96
Total Area (m^2)	226.98	222.96	222.34	223.28	222.04	226.07	1343.67

Table A-6. Area (m^2) represented by the stations of the large basin for irrigation number L3 to L5.

Station row \ Station column	1	2	3	4	5	6	Total Area (m^2)
1	37.16	37.47	36.70	37.47	36.70	36.85	222.35
2	37.22	37.16	37.16	37.16	37.16	37.47	223.33
3	37.78	37.16	37.16	37.16	37.16	37.78	224.20
4	38.09	37.16	37.16	37.16	37.16	38.09	224.82
5	38.09	37.16	37.16	37.16	37.16	38.25	224.98
6	37.93	37.01	36.85	37.47	36.70	37.62	223.58
Total Area (m^2)	226.27	223.12	222.19	223.58	222.04	226.06	1343.26

APPENDIX B

INFILTRATION FUNCTIONS DERIVED BY ADJUSTED INFILTRATION EQUATION METHOD

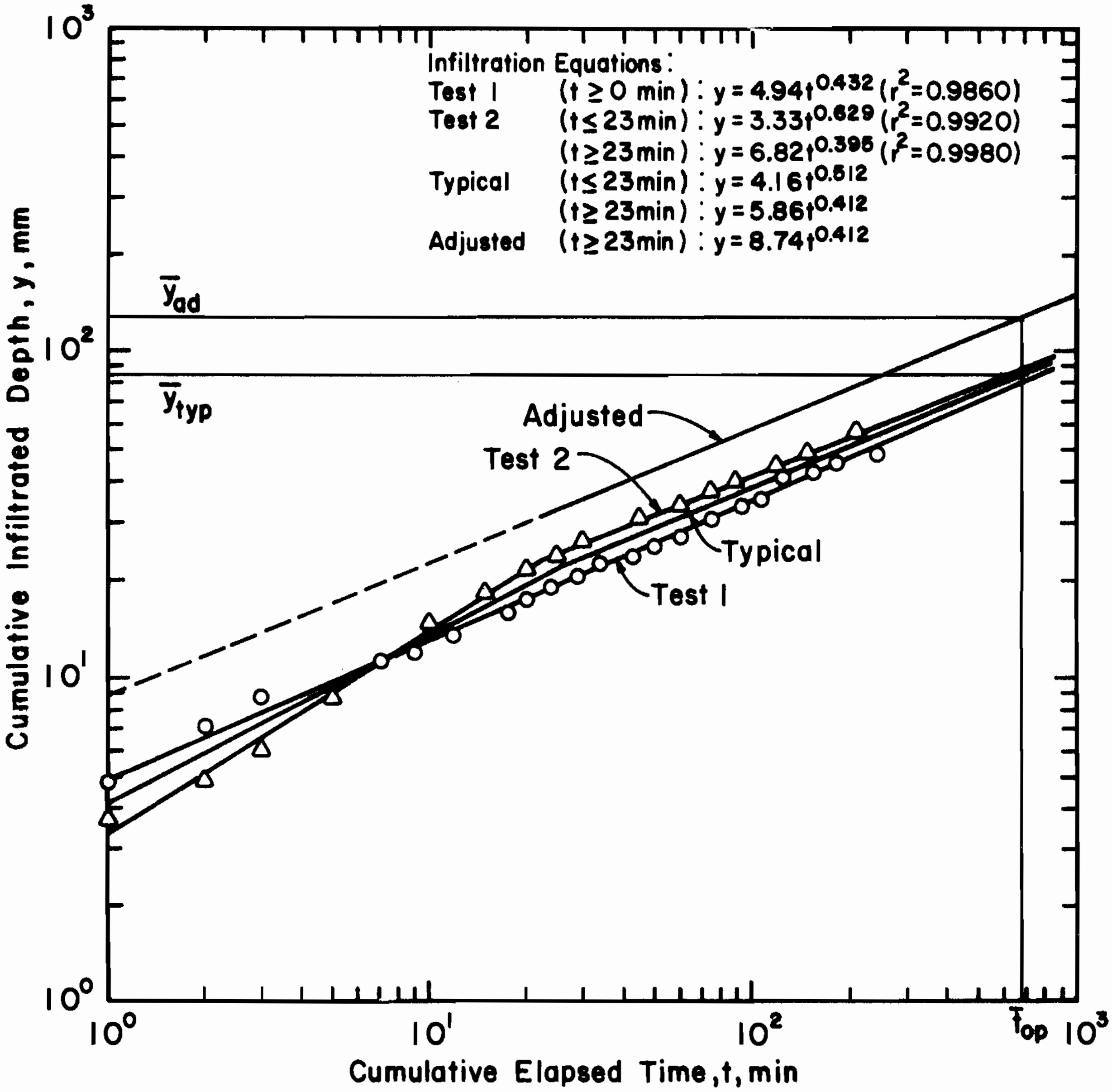


Figure B-1. Cumulative infiltration curves for irrigation S1.

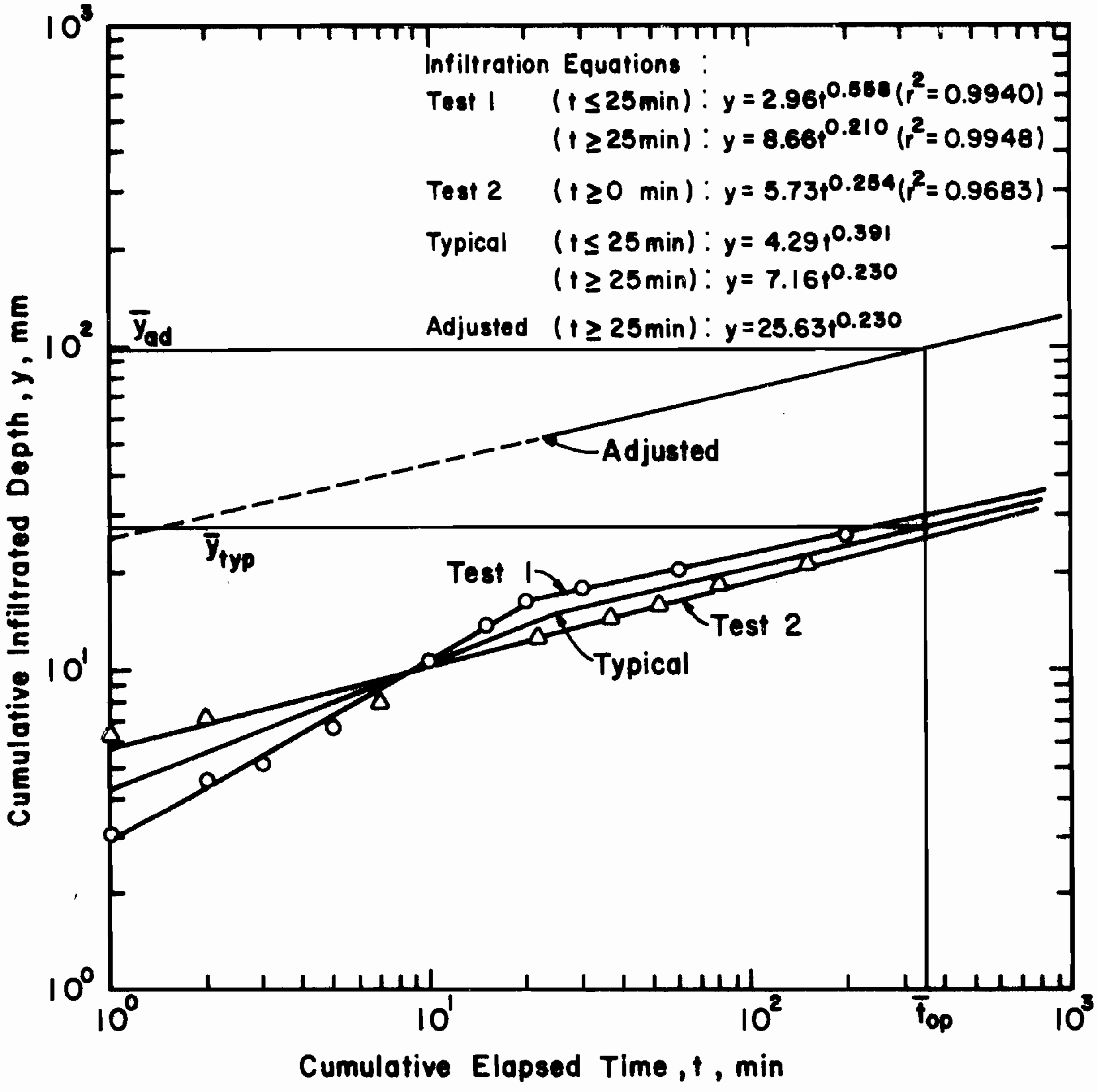


Figure B-2. Cumulative infiltration curves for irrigation S2.

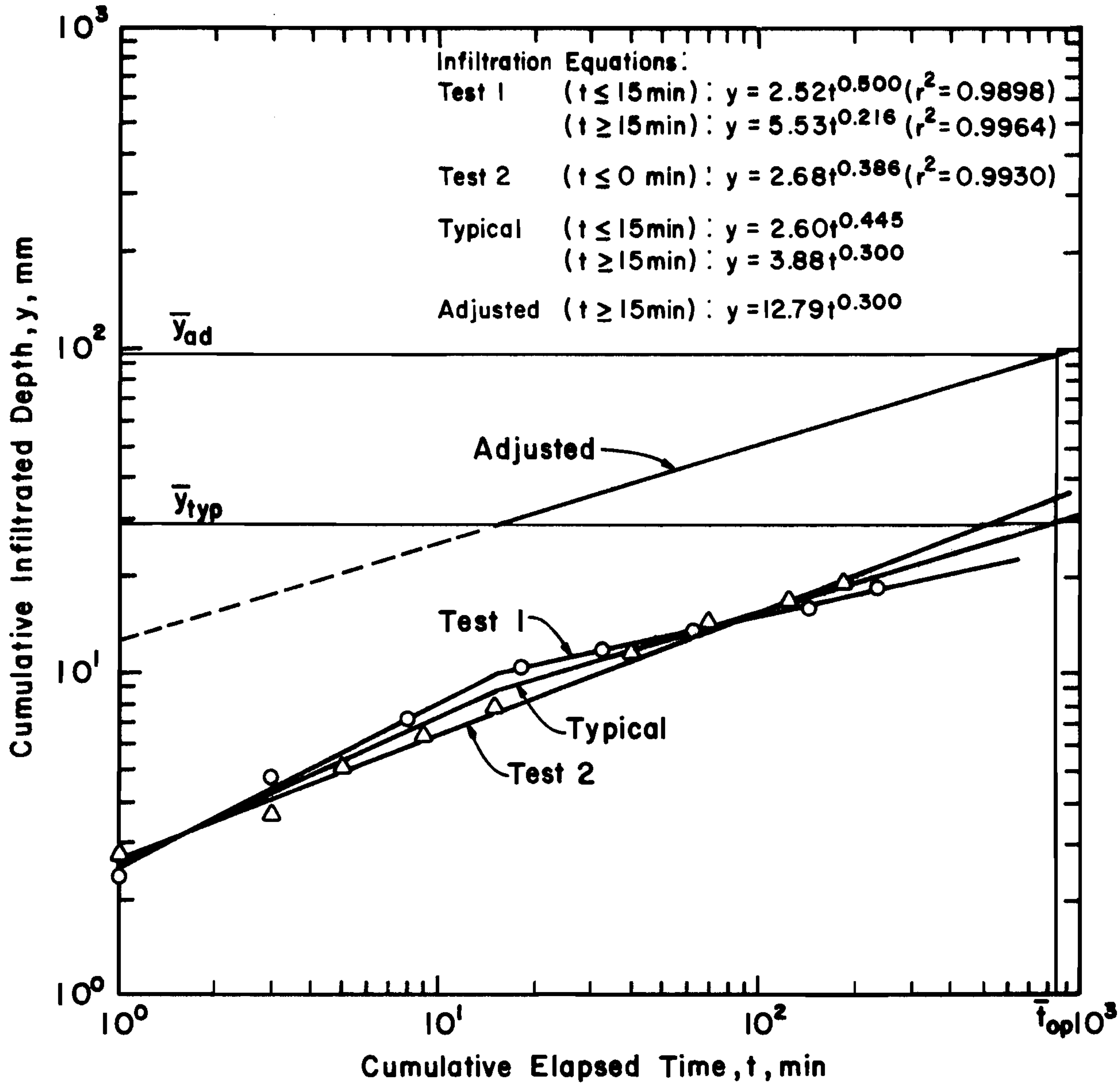


Figure B-3. Cumulative infiltration curves for irrigation S3.

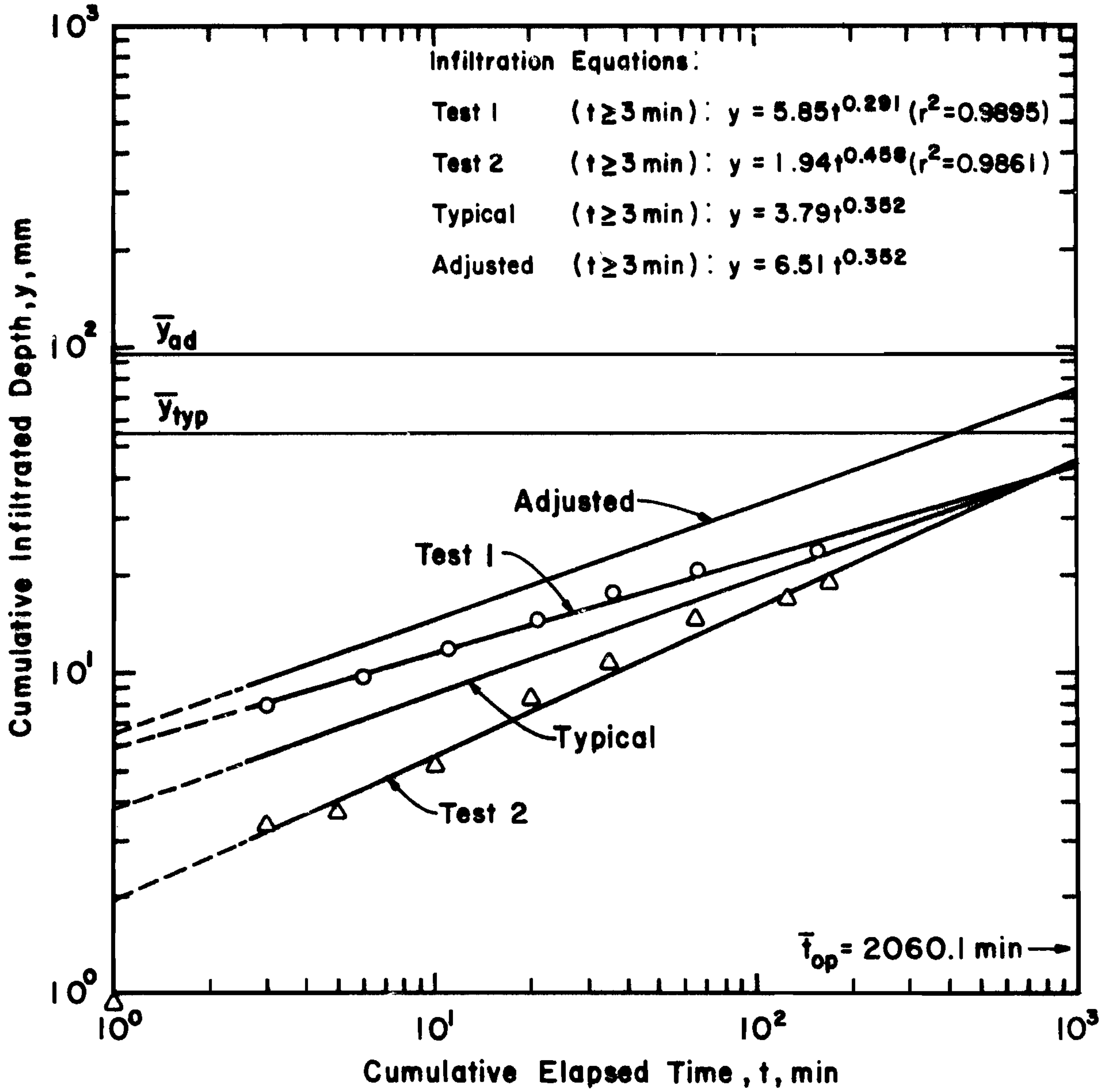


Figure B-4. Cumulative infiltration curves for irrigation S4.

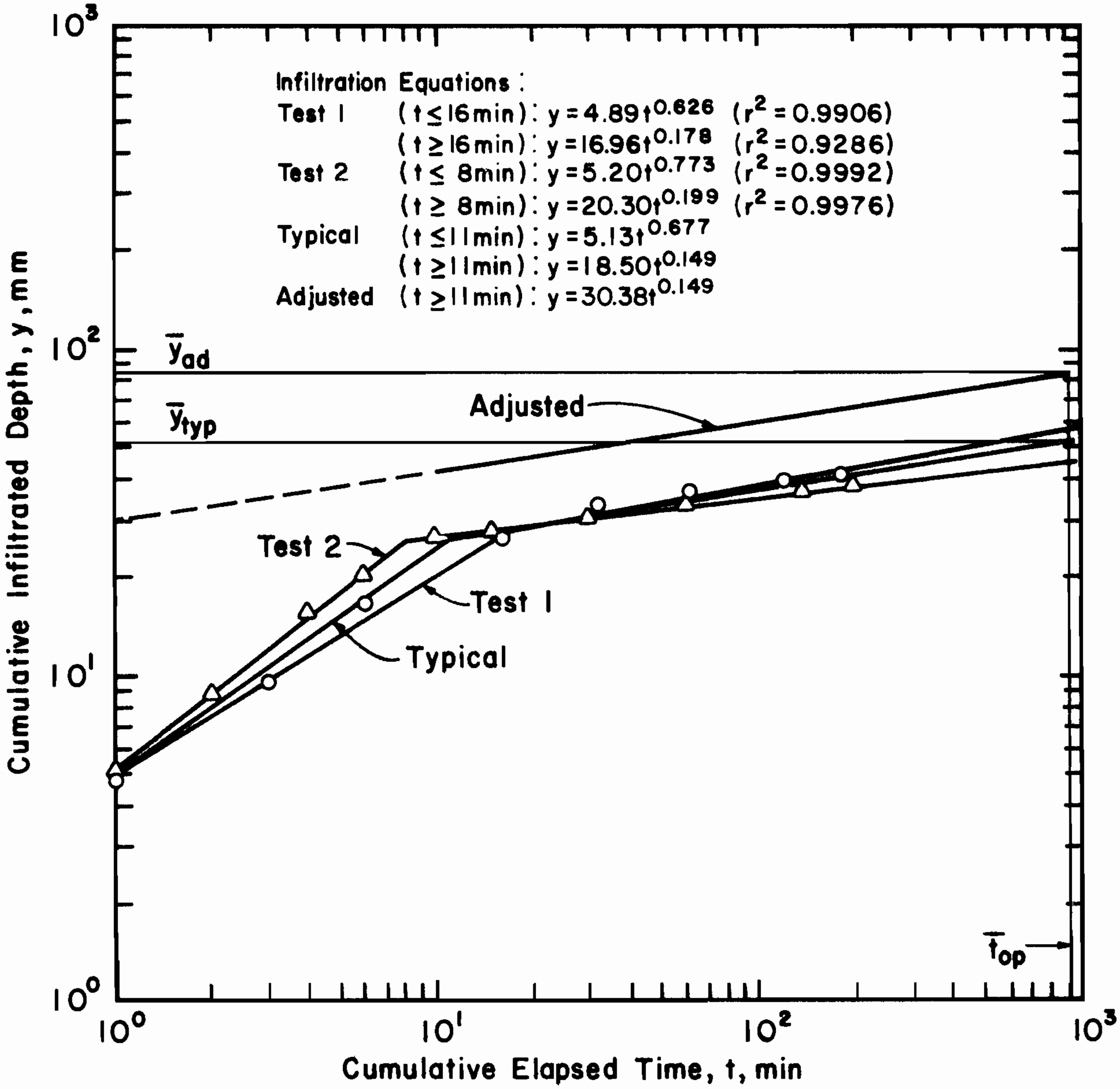


Figure B-5. Cumulative infiltration curves for irrigation S5.

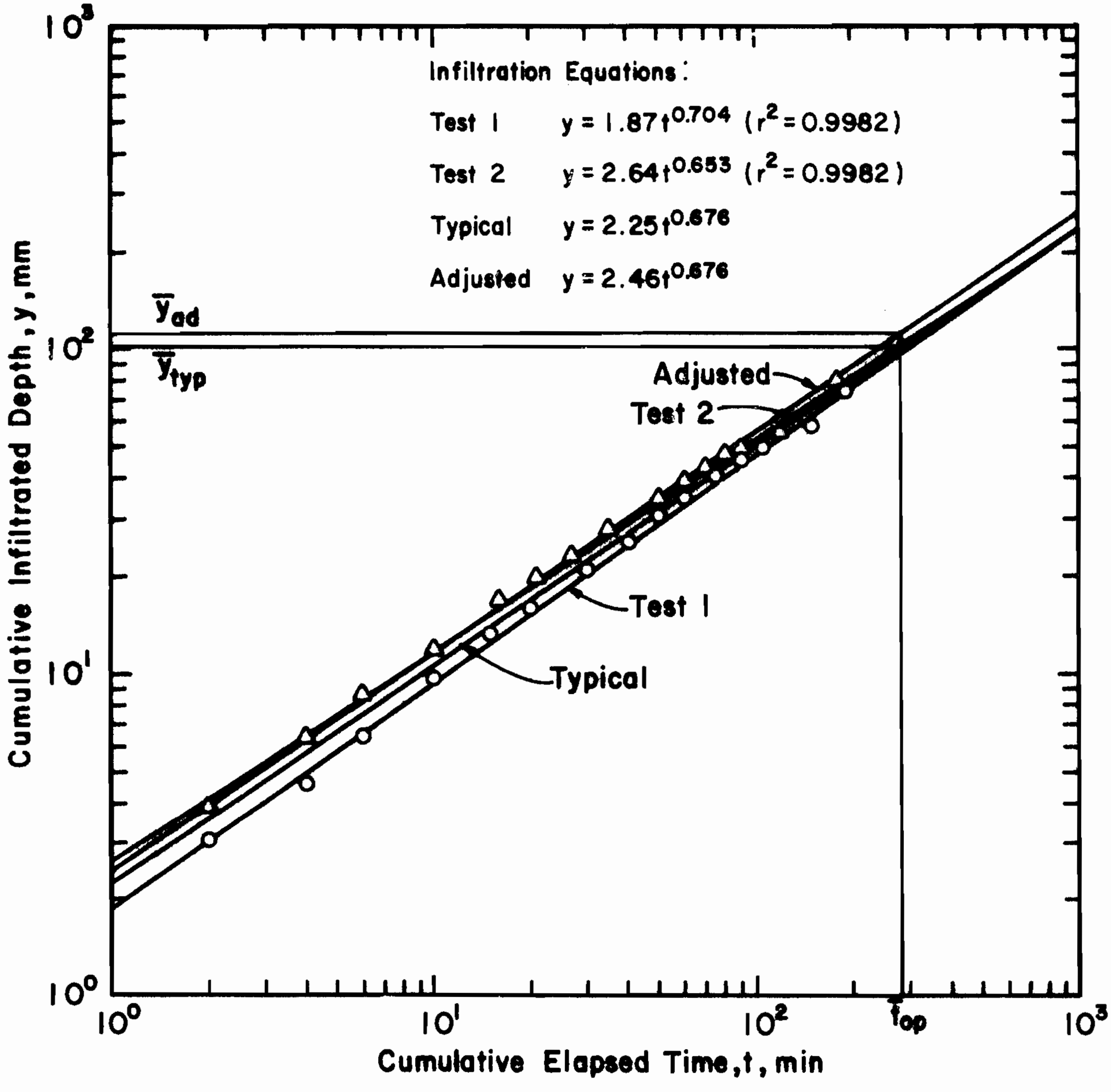


Figure B-6. Cumulative infiltration curves for irrigation L1.

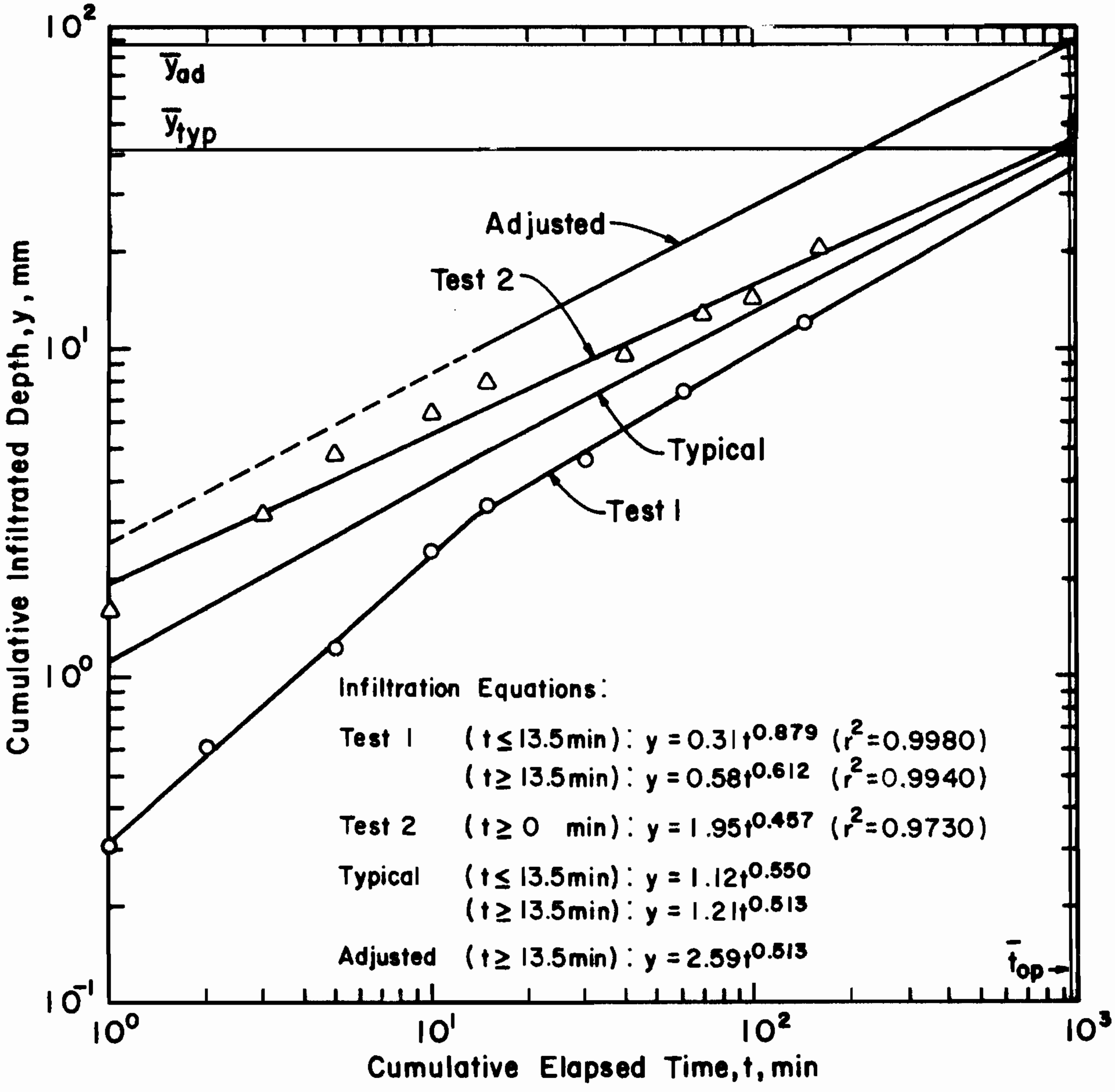


Figure B-7. Cumulative infiltration curves for irrigation L2.

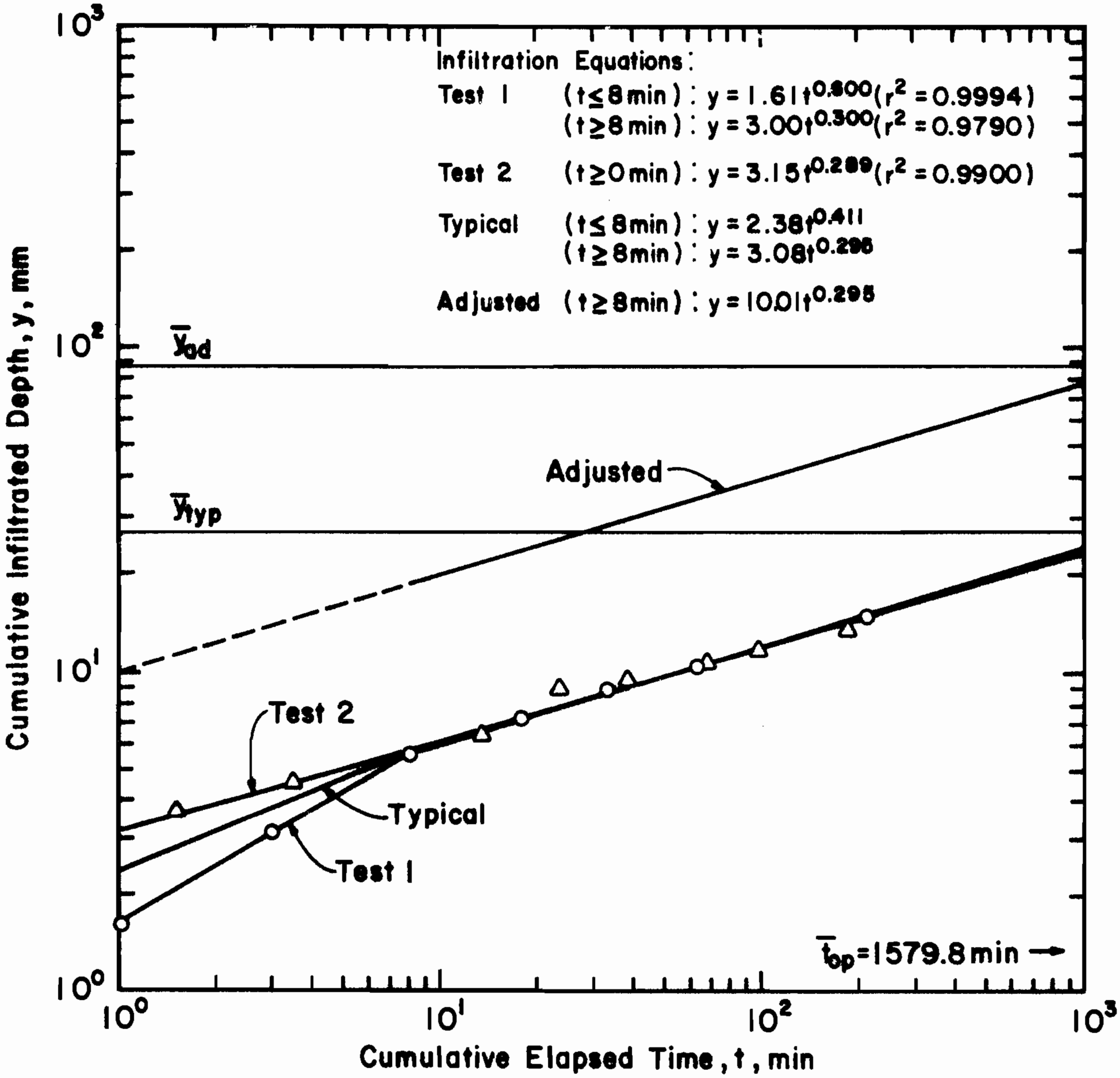


Figure B-8. Cumulative infiltration curves for irrigation L3.

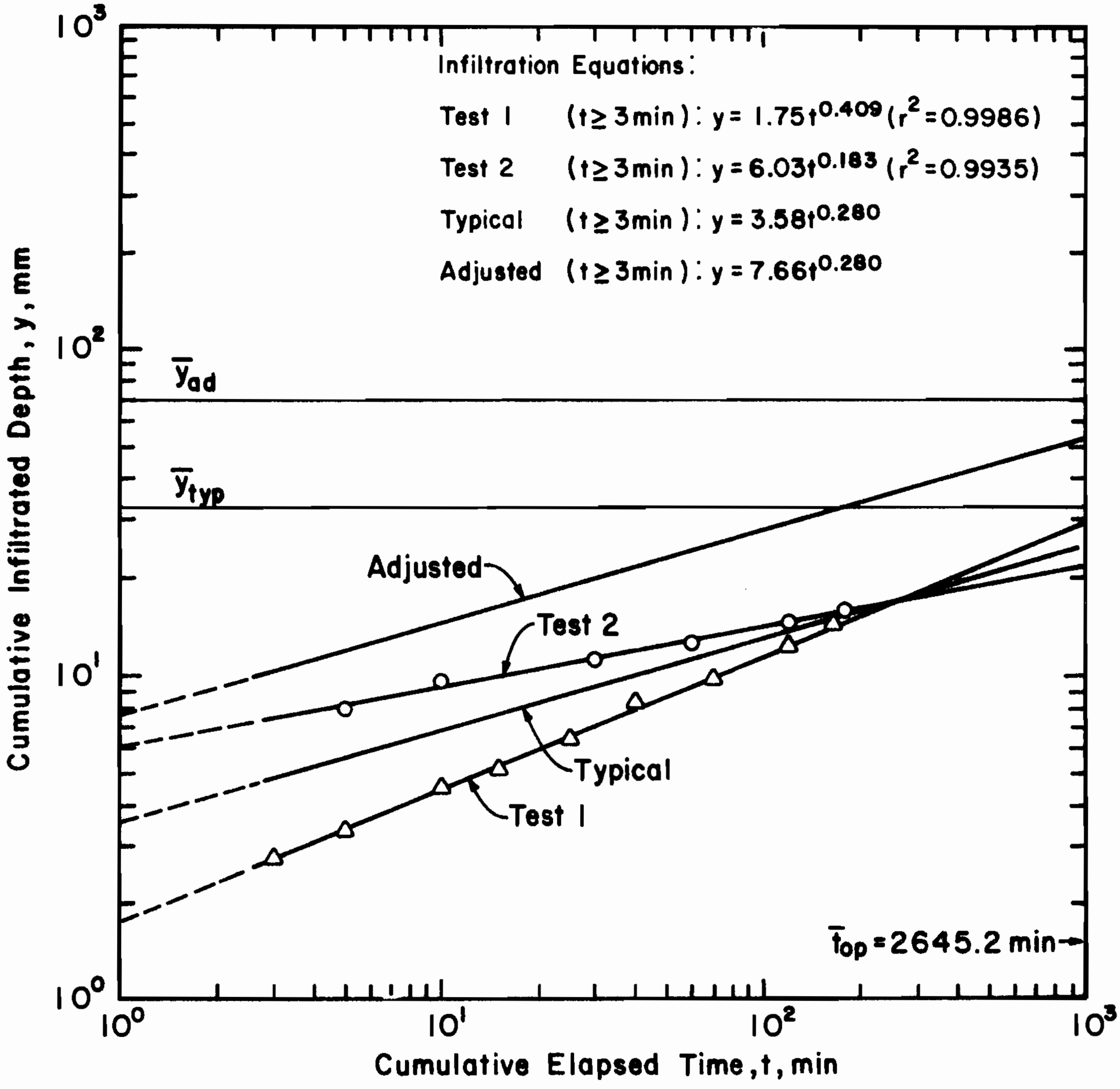


Figure B-9. Cumulative infiltration curves for irrigation L4.

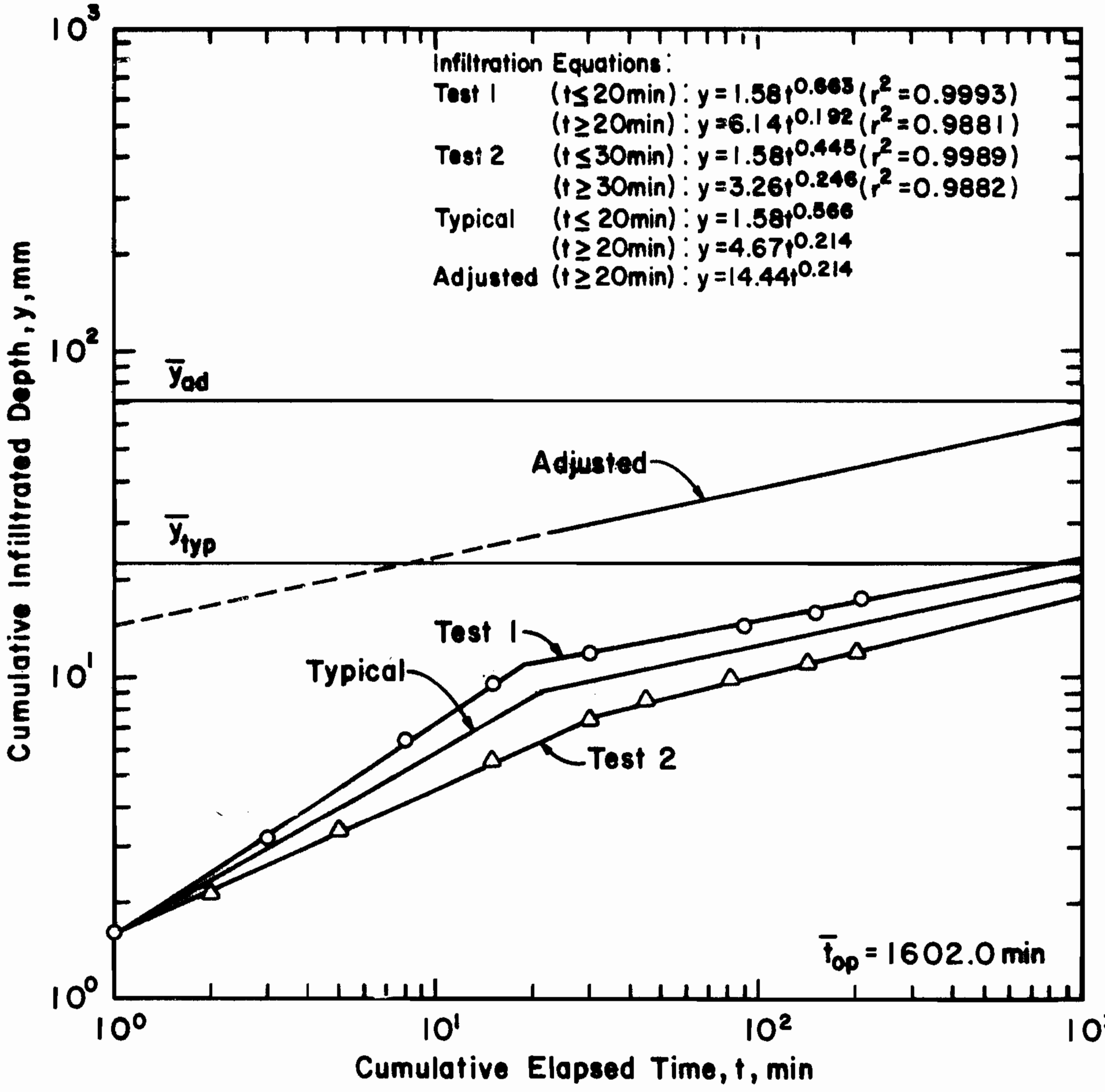


Figure B-10. Cumulative infiltration curves for irrigation L5.

APPENDIX C

ADVANCE AND RECESSION CONTOURS

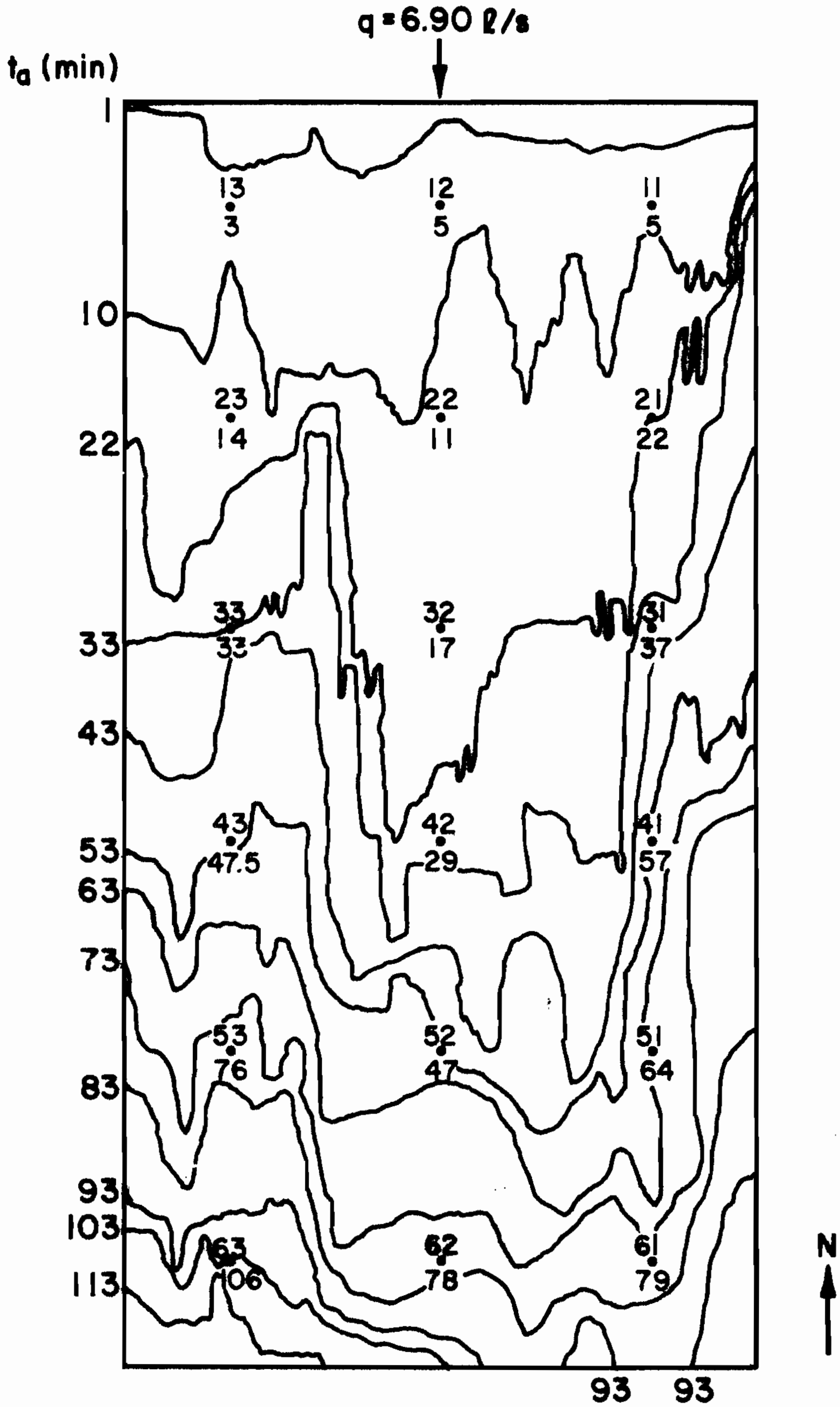


Figure C-1. Advance contours during irrigation number S1 (with station number and advance time (min) to each station shown above and below each station location respectively).

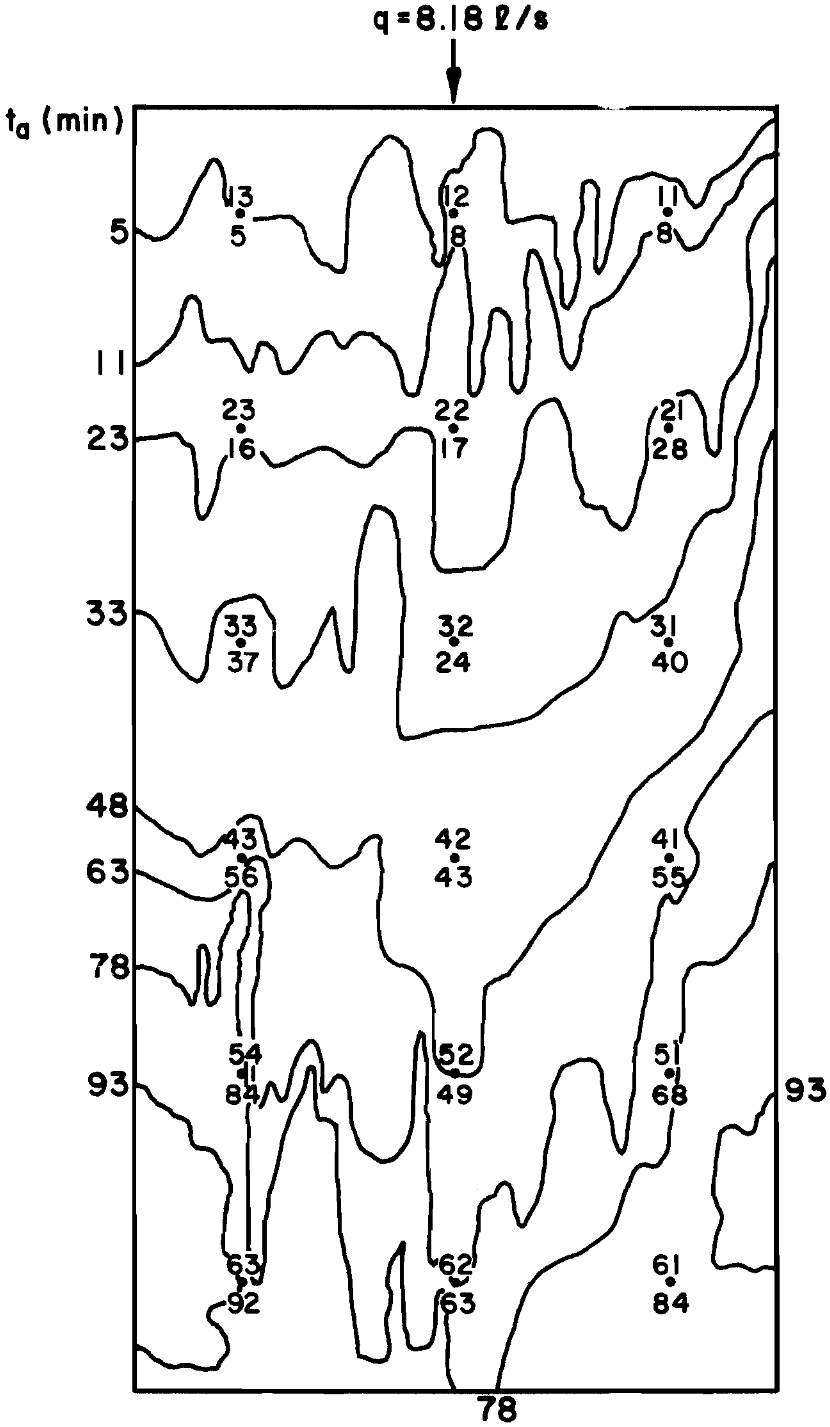


Figure C-2. Advance contours during irrigation number S2 (with station number and advance time (min.) to each station shown above and below each station location respectively).

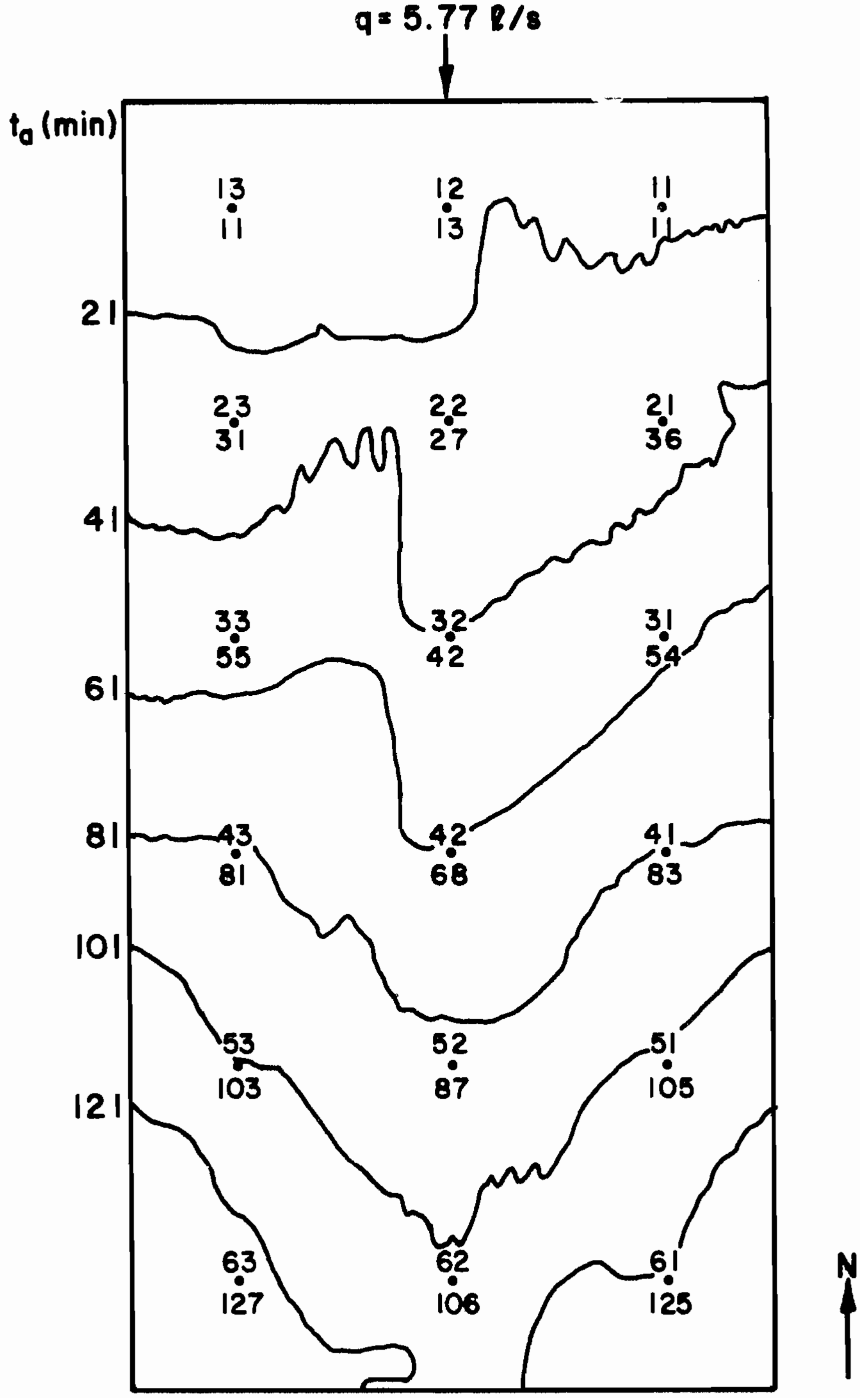


Figure C-3. Advance contours during irrigation number S3 (with station number and advance time (min.) to each station shown above and below each station location respectively).

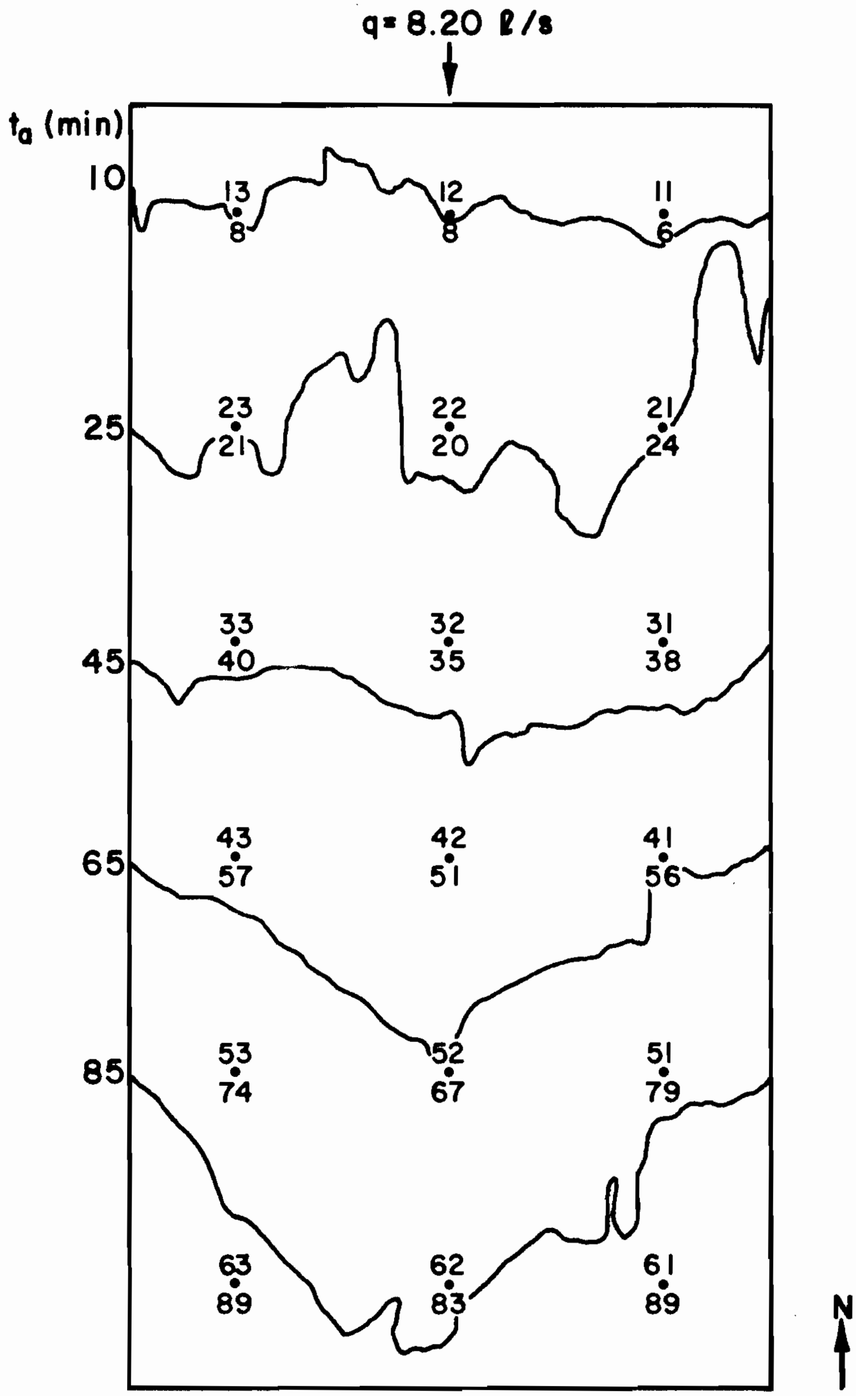


Figure C-4. Advance contours during irrigation number S4 (with station number and advance time (min.) to each station shown above and below each station location respectively).

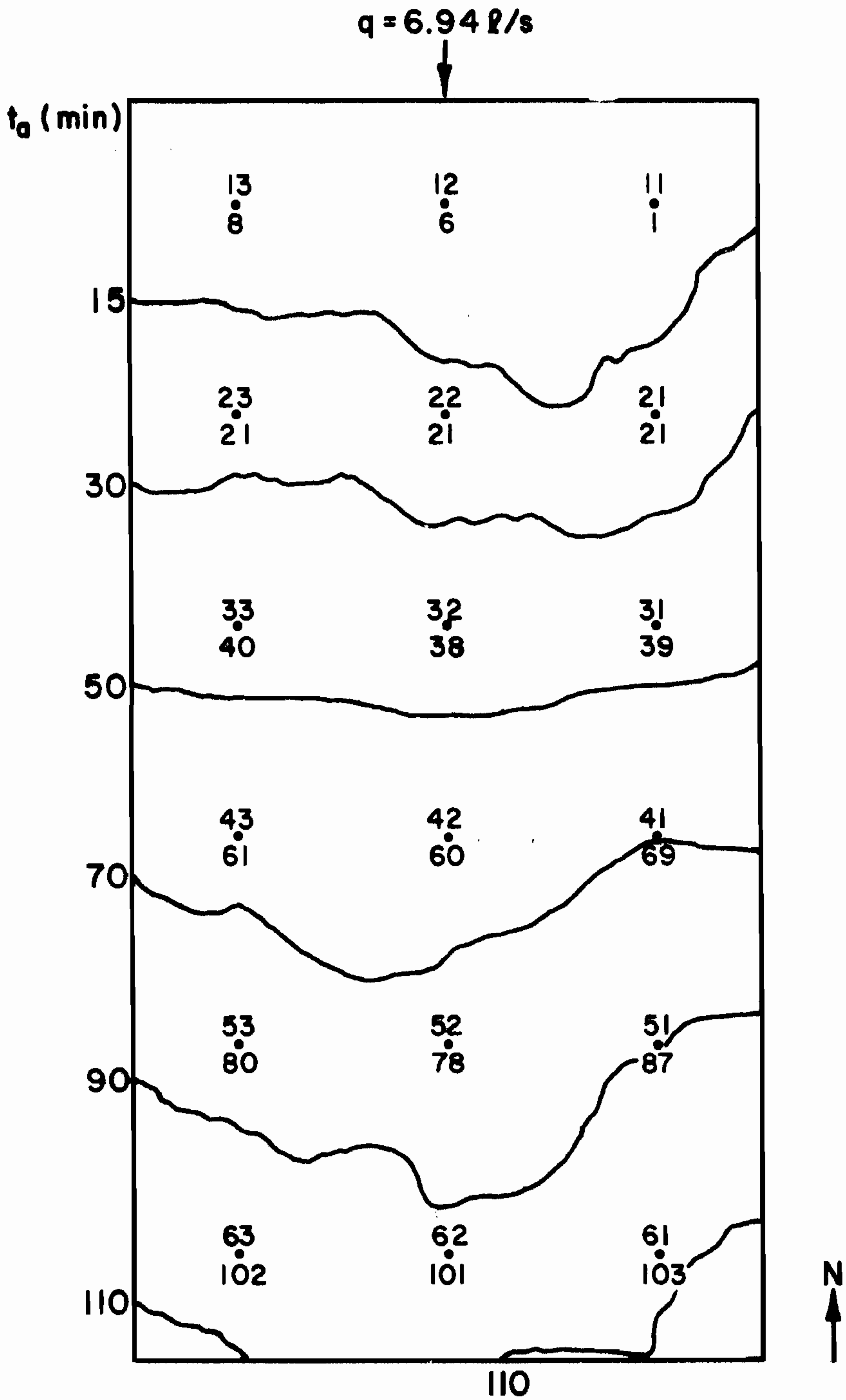


Figure C-5. Advance contours during irrigation number S5 (with station number and advance time (min.) to each station shown above and below each station location respectively).

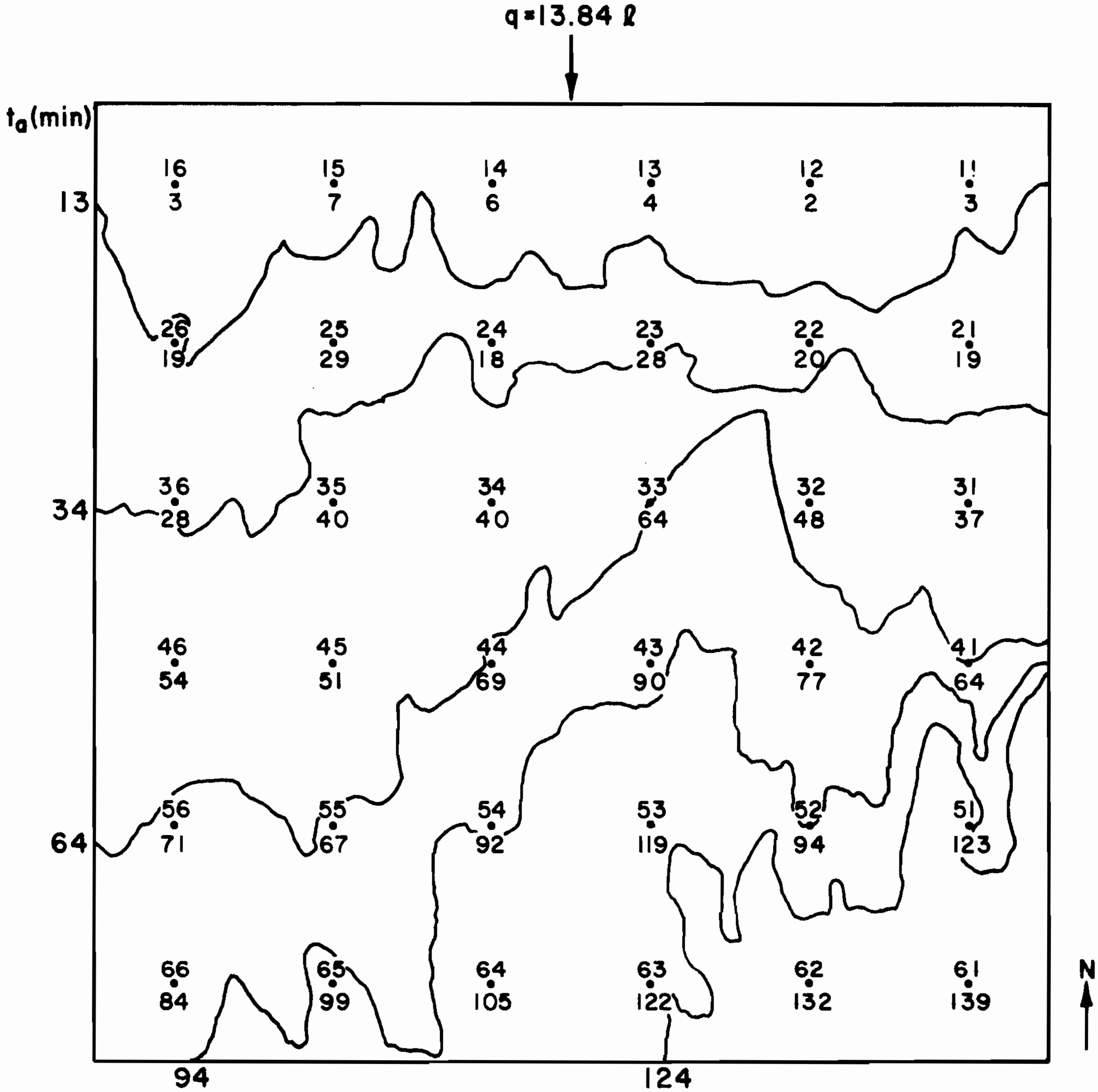


Figure C-6. Advance contours during irrigation number L1 (with station number and advance time (min.) to each station shown above and below each station location respectively).

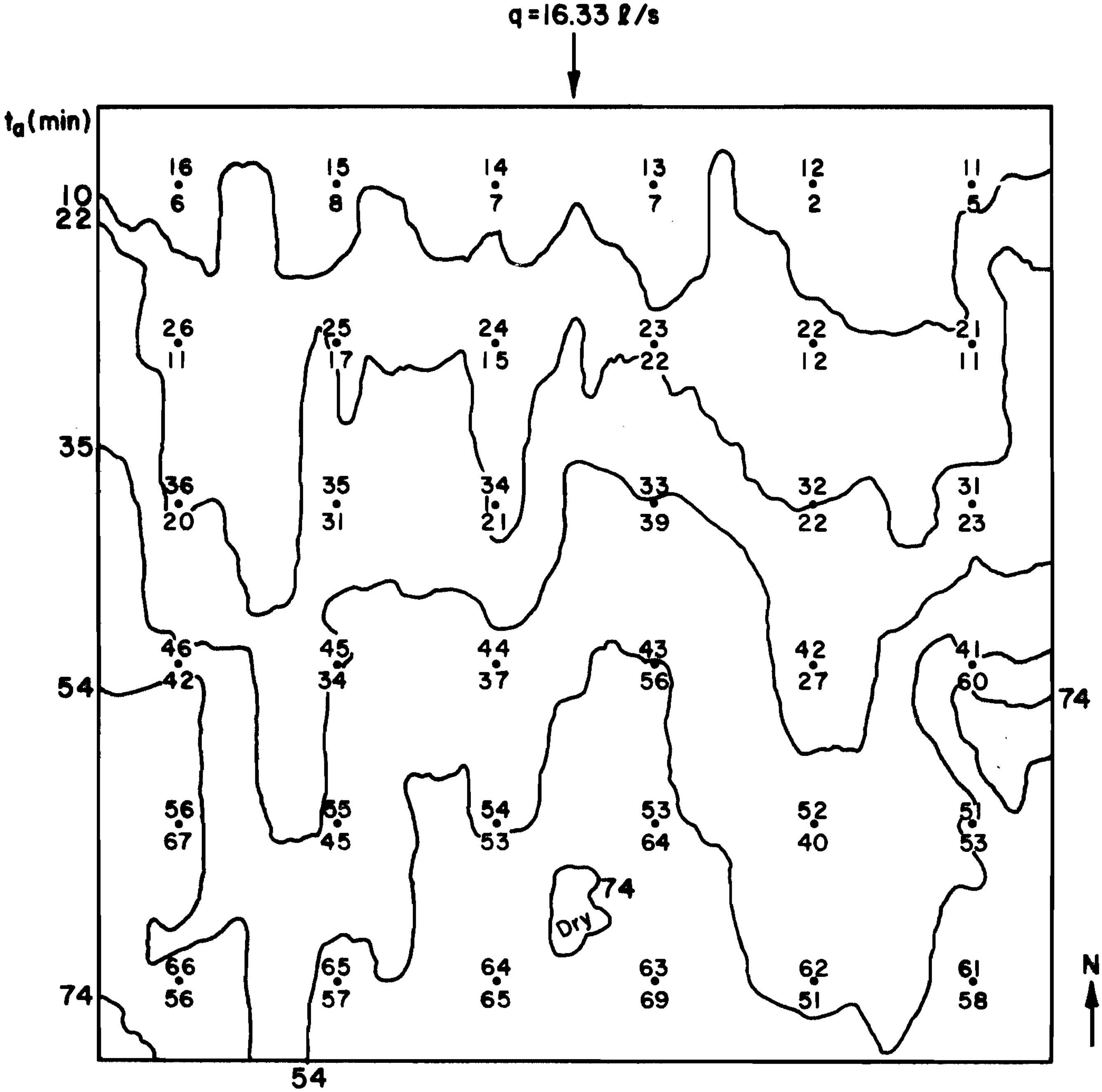


Figure C-7. Advance contours during irrigation number L2 (with station number and advance time (min.) to each station shown above and below each station location respectively).

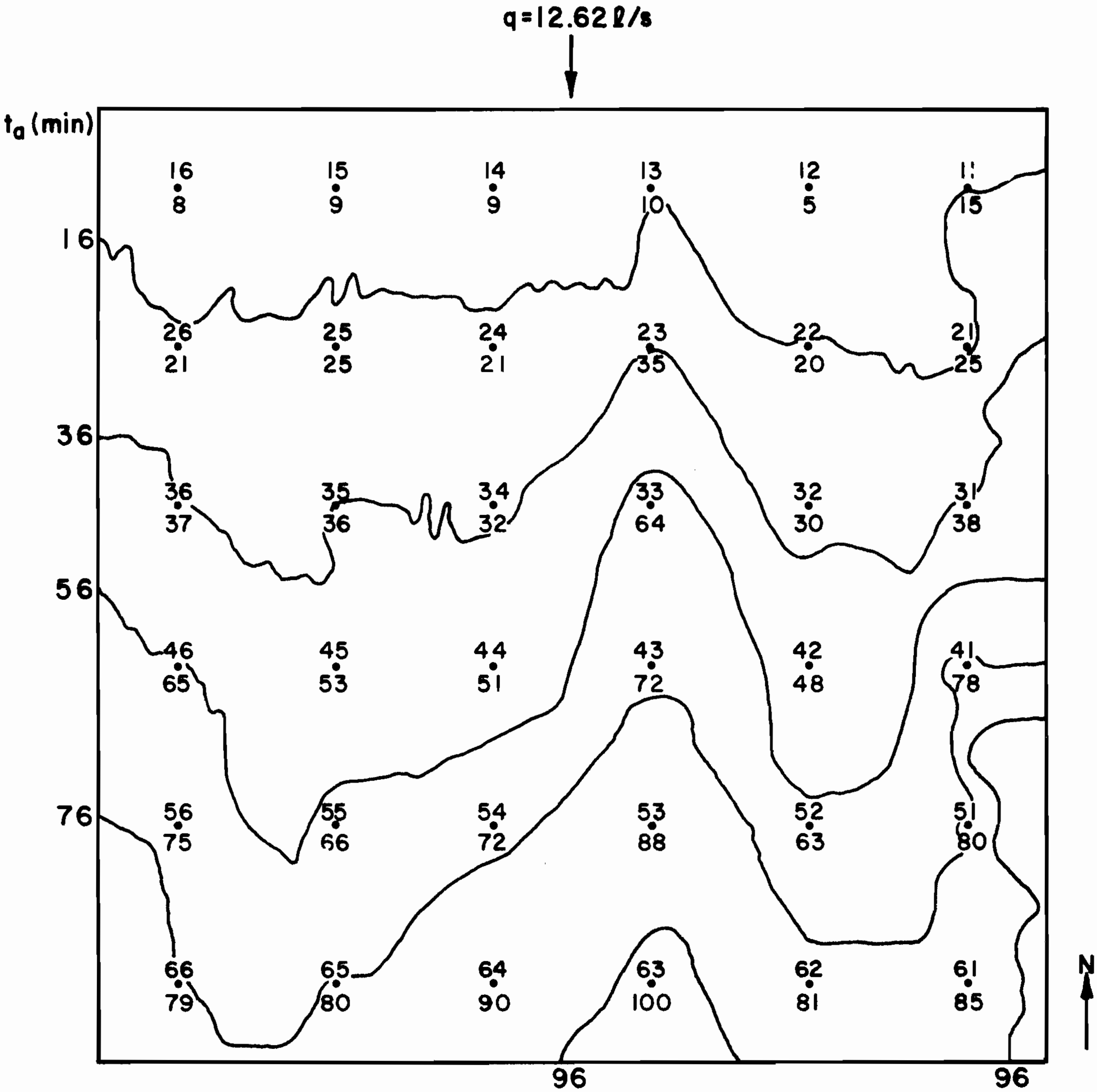


Figure C-8. Advance contours during irrigation number L3 (with station number and advance time (min.) to each station shown above and below each station location respectively).

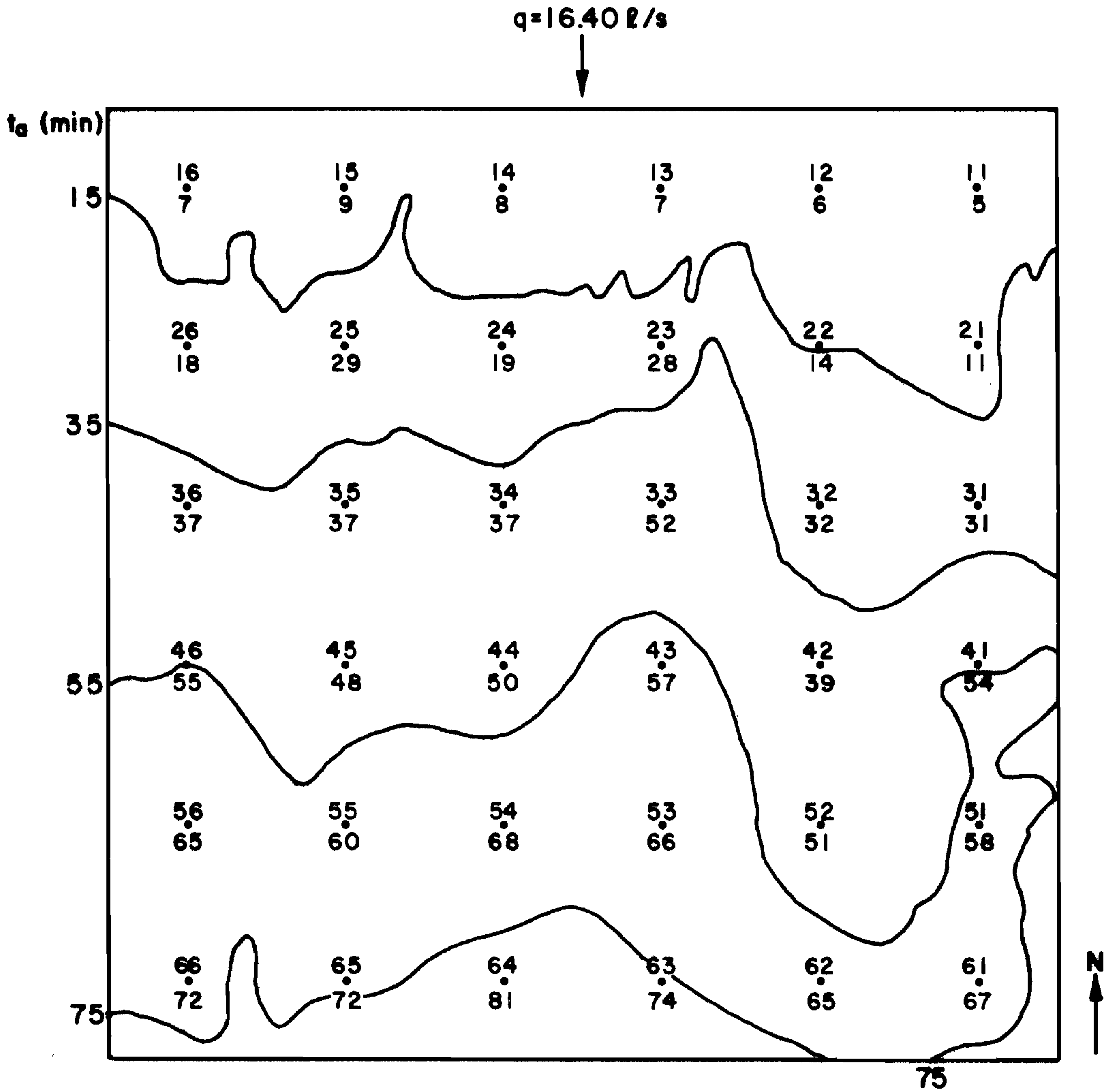


Figure C-9. Advance contours during irrigation number L4 (with station number and advance time (min.) to each station shown above and below each station location respectively).

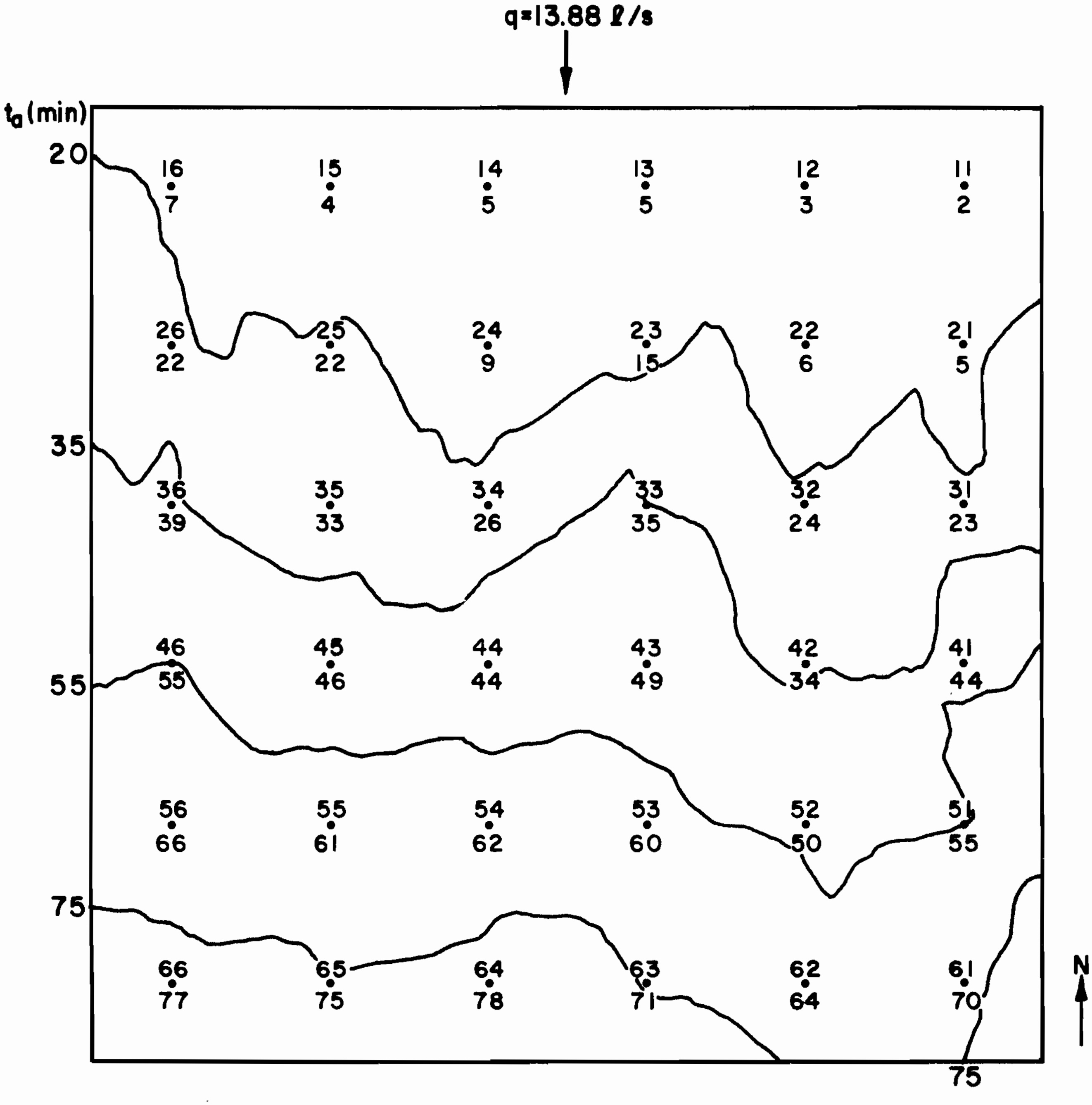
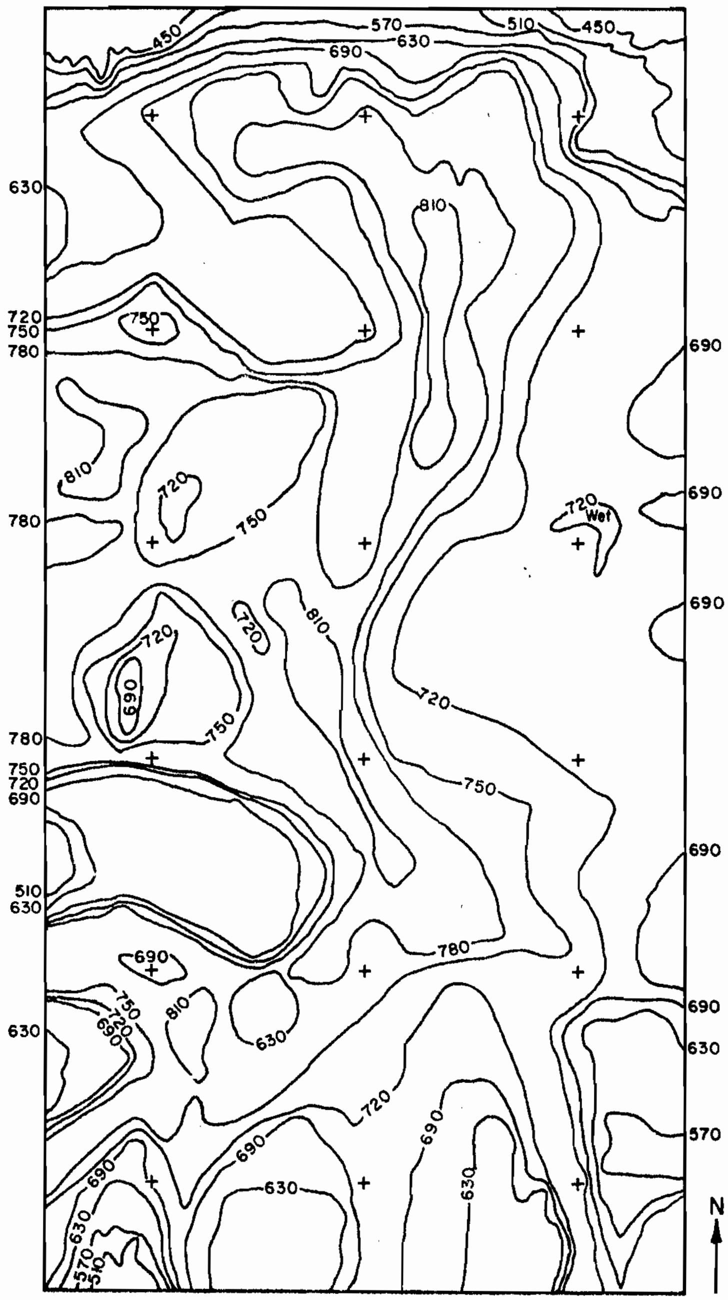


Figure C-10. Advance contours during irrigation number L5 (with station number and advance time (min.) to each station shown above and below each station location respectively).



The Times are in minutes
Recession Completion Time = 820 minutes

Figure C-11. Recession contours of irrigation number S1 (at cumulative time after irrigation started).

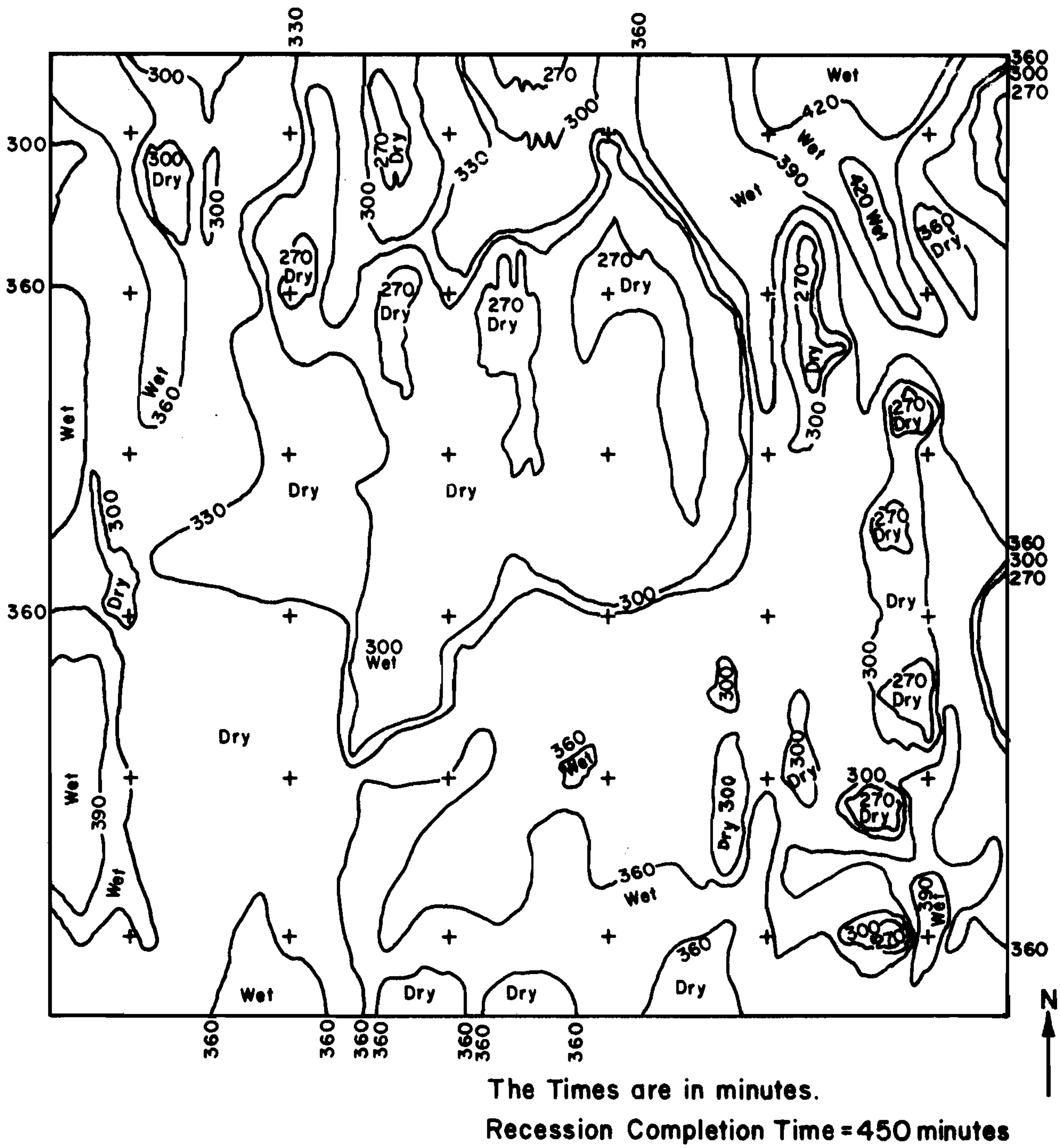


Figure C-12. Recession contours of irrigation number L1 (at cumulative time after irrigation started).

APPENDIX D

APPLIED WATER DEPTHS AND INFILTRATION OPPORTUNITY TIMES

Table D-1. Opportunity time and applied water depths to the Small Basin (18.3 m x 36.6 m) during Irrigation Number S1 (calculated by Method 1).

Station	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63
t_r (min)	630.0	783.0	728.0	714.0	718.5	739.0	708.5	775.0	735.0	715.0	795.0	755.0	735.0	765.0	680.0	730.0	693.0	695.0
t_a (min)	5.0	5.0	3.0	22.0	11.0	14.0	37.0	17.0	33.0	57.0	29.0	47.5	64.0	47.0	76.0	79.9	78.0	106.0
t_{op} (min)	625.0	778.0	725.0	692.0	707.5	725.0	671.5	758.0	702.0	658.0	766.0	707.5	671.0	718.0	604.0	651.0	615.0	589.0
y_{typ} (mm)	83.1	91.0	88.4	86.7	87.5	88.4	85.6	90.0	87.2	84.9	90.4	87.5	85.6	88.0	82.0	84.5	82.6	81.1
y_{ad} (mm)	123.9	135.7	131.8	129.3	130.5	131.8	127.7	134.3	130.1	126.7	134.8	130.5	127.7	131.3	122.3	126.1	123.2	121.0

$\bar{t}_{op}$ = 685.95 min, $\bar{y}_{typ}$ = 86.39 mm, $\bar{y} = \bar{y}_{ad}$ = 128.77 mm

Table D-2. Opportunity Time and Applied Water Depths to the Small Basin (18.3 m x 36.6m) During Irrigation Number S2 (calculated by Method 1).

Station	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63
t_r (min)	421.0	421.0	391.0	411.0	426.0	356.0	416.0	411.0	356.0	386.0	416.0	376.0	411.0	411.0	386.0	456.0	396.0	386.0
t_a (min)	8.0	8.0	5.0	28.0	17.0	16.0	40.0	24.0	37.0	55.0	43.0	56.0	68.0	49.0	84.0	84.0	63.0	92.0
t_{op} (min)	413.0	413.0	386.0	383.0	409.0	340.0	376.0	387.0	319.0	331.0	373.0	320.0	343.0	362.0	302.0	372.0	333.0	294.0
y_{typ} (mm)	28.6	28.6	28.2	28.1	28.6	27.4	28.0	28.2	27.0	27.2	28.0	27.0	27.4	27.8	26.6	27.9	27.2	26.5
y_{ad} (mm)	102.4	102.4	100.8	100.7	102.2	97.9	100.2	100.9	96.5	97.3	100.1	96.6	98.1	99.4	95.3	100.0	97.5	94.7

$\bar{t}_{op}$ = 357.54 min, $\bar{y}_{typ}$ = 27.68 mm, $\bar{y}=\bar{y}_{ad}$ = 99.10 mm

Table D-3. Opportunity time and applied water depths to the Small Basin (18.3 m x 36.6 m) during Irrigation Number S3 (calculated by Method 1).

Station	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63
t_r (min)	881.0	1121.0	851.0	1121.0	866.0	791.0	806.0	1151.0	881.0	851.0	881.0	911.0	761.0	821.0	1031.0	986.0	851.0	1001.0
t_a (min)	11.0	13.0	11.0	36.0	27.0	31.0	54.0	42.0	55.0	83.0	68.0	81.0	105.0	87.0	103.0	125.0	106.0	127.0
t_{op} (min)	870.0	1108.0	840.0	1085.0	839.0	760.0	752.0	1109.0	826.0	768.0	813.0	830.0	656.0	734.0	928.0	861.0	745.0	874.0
y_{typ} (mm)	29.6	31.8	29.2	31.6	29.2	28.4	28.3	31.8	29.1	28.5	29.0	29.1	27.2	28.1	30.1	29.1	28.2	29.6
y_{ad} (mm)	97.4	104.8	96.4	104.1	96.4	93.6	93.3	104.8	95.9	93.9	95.5	96.1	89.5	92.6	99.3	97.1	93.0	97.6

$\bar{t}_{op}$ = 849.54 min, $\bar{y}_{typ}$ = 29.35 mm, $\bar{y} = \bar{y}_{ad}$ = 96.74 mm

Table D-4. Opportunity time and applied water depths to the Small Basin (18.3 m x 36.6 m) during Irrigation Number S4 (calculated by Method 1).

Station	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63
t_r (min)	2210	2285	2115	2285	2285	2315	2045	2285	2165	2060	1805	2015	2015	1805	2015	2285	1850	2195
t_a (min)	6.0	8.0	8.0	24.0	20.0	21.0	38.0	35.0	40.0	56.0	51.0	57.0	79.0	67.0	74.0	89.0	83.0	89.0
t_{op} (min)	2204	2277	2107	2261	2265	2294	2007	2250	2125	2004	1754	1958	1936	1738	1941	2196	1767	2106
y_{typ} (mm)	56.9	57.6	56.0	57.5	57.5	57.8	55.1	57.4	56.2	55.1	52.5	54.6	54.4	52.4	54.5	56.9	52.7	56.0
y_{ad} (mm)	97.8	98.9	96.3	98.7	98.8	99.2	94.6	98.5	96.6	94.6	90.3	93.8	93.4	90.0	93.5	97.7	90.5	96.3

$\bar{t}_{op}$ = 2060.13 min, $\bar{y}_{typ}$ = 55.61 mm, $\bar{y} = \bar{y}_{ad}$ = 95.47 mm

Table D-5. Opportunity time and applied water depths to the Small Basin (18.3 m x 36.6 m) during Irrigation Number S5 (calculated by Method 1).

Station	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63
t_r (min)	975	885	885	1185	1185	1005	885	1215	1185	885	975	885	825	765	885	1185	885	1035
t_a (min)	1.0	5.0	8.0	21.0	21.0	21.0	39.0	38.0	40.0	69.0	60.0	61.0	87.0	78.0	80.0	103.0	101.0	102.0
t_{op} (min)	974	879	877	1164	1164	984	846	1177	1145	816	915	824	738	687	805	1082	784	933
y_{typ} (mm)	51.6	50.8	50.8	53.0	53.0	51.7	50.5	53.1	52.8	50.2	51.1	50.3	49.5	49.0	50.1	52.4	49.9	51.2
y_{ad} (mm)	84.7	83.4	83.4	87.0	87.0	84.9	82.9	87.2	86.7	82.4	83.9	82.6	81.3	80.5	82.3	86.0	81.9	84.1

$\bar{t}_{op}$ = 923.1 min, $\bar{y}_{typ}$ = 51.17 mm, $\bar{y} = \bar{y}_{ad}$ = 84.03 mm

Table D-6. Opportunity time and applied water depths to the Large Basin (36.3m x 36.6m) during Irrigation Number L1 (calculated by Method 1).

Station	11	12	13	14	15	16	21	22	23	24	25	26	31	32	33	34	35	36
t_r (min)	385	410	315	310	335	400	405	365	265	295	265	350	315	340	285	285	322	330
t_a (min)	3	2	4	6	7	3	19	20	28	18	29	17	37	48	64	40	40	28
t_{op} (min)	382	408	311	304	328	397	386	345	237	277	236	333	278	292	221	245	282	302
y_{typ} (mm)	125.2	130.9	109.0	107.3	113.0	128.5	126.1	116.9	90.7	100.8	90.4	114.1	101.0	104.4	86.5	92.7	102.0	106.8
y_{ad} (mm)	136.9	143.1	119.1	117.3	123.5	140.5	137.9	127.8	99.1	110.2	98.9	124.8	110.4	114.2	94.6	101.4	111.5	116.8

$\bar{t}_{op}$ = 283.4 min, $\bar{y}_{typ}$ = 102.34mm; $\bar{y} = \bar{y}_{ad}$ = 111.97 mm

Station	41	42	43	44	45	46	51	52	53	54	55	56	61	62	63	64	65	66
t_r (min)	300	320	335	308	335	295	375	350	350	360	345	360	405	375	405	385	355	355
t_a (min)	64	77	90	69	51	54	123	94	119	92	67	71	139	132	122	105	99	84
t_{op} (min)	236	243	245	239	284	241	252	256	231	268	278	289	266	243	283	280	256	271
y_{typ} (mm)	90.4	92.2	92.7	91.2	102.5	91.7	94.5	95.5	89.1	98.5	101.0	103.7	98.0	92.2	102.2	107.5	95.5	99.3
y_{ad} (mm)	98.9	100.8	101.4	99.7	112.0	100.3	103.3	104.4	97.4	107.7	110.4	113.4	107.2	100.8	111.8	110.0	104.4	108.5

Table D-7. Opportunity time and applied water depths to the Large Basin (36.6m x 36.6m) during Irrigation Number L2 (calculated by Method 1.)

Station	11	12	13	14	15	16	21	22	23	24	25	26	31	32	33	34	35	36
t_r (min)	1230	1170	810	690	1050	1350	1290	930	630	720	810	720	690	810	630	870	720	870
t_a (min)	5.0	2.0	7.0	7.0	8.0	6.0	11.0	12.0	22.0	15.0	17.0	11.0	23.0	22.0	39.0	21.0	31.0	20.0
t_{op} (min)	1225	1168	803	683	1042	1344	1279	918	608	705	793	709	667	788	591	849	689	850
y_{typ} (mm)	46.5	45.3	37.4	34.4	42.8	48.7	47.5	40.1	32.4	35.0	37.2	35.1	34.0	37.0	32.0	38.5	34.6	38.5
y_{ad} (mm)	99.4	97.0	80.1	73.7	91.5	104.3	101.7	85.8	69.4	74.9	79.5	75.1	72.8	79.3	68.4	82.4	74.0	82.4

$\bar{t}_{op}$ = 954.1 min., $\bar{y}_{typ}$ = 40.86mm; $\bar{y} = \bar{y}_{ad}$ = 87.50mm

Station	41	42	43	44	45	46	51	52	53	54	55	56	61	62	63	64	65	66
t_r (min)	675	780	630	1155	1095	1020	840	810	1230	1440	1200	1020	1560	1350	1350	1320	1320	1320
t_a (min)	60.0	27.0	56.0	37.0	34.0	42.0	53.0	40.0	64.0	53.0	45.0	67.0	58.0	51.0	69.0	65.0	57.0	56.0
t_{op} (min)	615	753	574	1118	1061	1078	787	770	1166	1387	1155	953	1502	1299	1281	1255	1263	1274
y_{typ} (mm)	32.6	36.2	31.5	44.3	43.1	43.5	37.0	36.6	45.3	49.5	45.1	40.8	51.6	47.9	47.5	47.0	47.2	47.4
y_{ad} (mm)	69.8	77.5	67.4	94.9	92.4	93.1	79.2	78.4	96.9	106.0	96.5	87.4	110.4	102.5	101.7	100.7	101.0	101.4

Table D-8. Opportunity time and applied water depths to the Large Basin (36.6m x 36.6m) during Irrigation Number L3 (calculated by Method 1.)

Station	11	12	13	14	15	16	21	22	23	24	25	26	31	32	33	34	35	36
t_r (min)	1435	1720	1240	1360	1525	1650	1675	1735	1240	1620	1710	1595	1300	1750	1630	1630	1715	1620
t_a (min)	5.0	5.0	10.0	9.0	9.0	8.0	15.0	20.0	35.0	21.0	25.0	21.0	38.0	30.0	64.0	32.0	36.0	37.0
t_{op} (min)	1430	1715	1230	1351	1516	1642	1660	1715	1205	1599	1685	1574	1262	1720	1566	1598	1679	1583
y_{typ} (mm)	26.3	27.7	25.1	25.8	26.7	27.4	27.4	27.7	25.0	27.1	27.6	27.0	25.3	27.7	27.0	27.1	27.5	27.1
y_{ad} (mm)	85.4	90.1	81.6	83.9	86.8	88.9	89.2	90.1	81.2	88.2	89.6	87.8	82.3	90.1	87.7	88.2	89.5	88.0

$\bar{t}_{op}$ = 1579.8 min., $\bar{y}_{typ}$ = 27.05 , $\bar{y} = \bar{y}_{ad}$ = 87.94

Station	41	42	43	44	45	46	51	52	53	54	55	56	61	62	63	64	65	66
t_r (min)	1150	1770	1740	1740	1740	1480	1660	1795	1740	1840	1570	1630	1960	1780	1810	1810	1615	1930
t_a (min)	78.0	48.0	72.0	51.0	53.0	65.0	80.0	63.0	88.0	72.0	66.0	75.0	85.0	81.0	100.0	90.0	80.0	79.0
t_{op} (min)	1072	1722	1668	1689	1687	1415	1580	1732	1652	1768	1504	1555	1875	1699	1710	1720	1535	1851
y_{typ} (mm)	24.1	27.7	27.5	27.6	27.6	26.2	27.0	27.8	27.4	28.0	26.7	26.9	28.5	27.6	27.7	27.7	26.8	28.3
y_{ad} (mm)	78.4	90.2	89.3	89.7	89.6	85.1	87.9	90.3	89.1	90.9	86.6	87.5	92.5	89.8	90.0	90.1	87.2	92.1

Table D-9. Opportunity time and applied water depths to the Large Basin (36.6m x 36.6m) during Irrigation Number L4 (calculated by Method 1).

Station	11	12	13	14	15	16	21	22	23	24	25	26	31	32	33	34	35	36
t_r (min)	2473	2473	2263	2413	2593	2833	2908	2488	2323	2773	2683	2683	2443	2968	2323	2413	2713	2683
t_a (min)	5	6	7	8	9	7	11	14	28	19	29	18	31	32	52	37	37	37
t_{op} (min)	2468	2467	2256	2405	2584	2826	2897	2474	2295	2754	2654	2665	2412	2936	2271	2376	2677	2646
y_{typ} (mm)	31.9	31.9	31.1	31.7	32.3	33.1	33.4	31.9	31.3	32.9	32.6	32.6	31.7	33.5	31.2	31.6	32.6	32.5
y_{ad} (mm)	68.2	68.2	66.6	67.8	69.1	70.9	71.4	68.3	66.9	70.4	69.6	69.7	67.8	71.6	66.7	67.5	69.8	69.6

$\overline{t}_{op}$ = 2645.2 min. , $\overline{y}_{typ}$ = 32.52 mm, $\overline{y} = \overline{y}_{ad}$ = 69.59 mm

Station	41	42	43	44	45	46	51	52	53	54	55	56	61	62	63	64	65	66
t_r (min)	2383	2938	2323	2473	2698	2608	2758	2938	3028	3028	3028	2683	3028	3028	3028	3028	2773	2743
t_a (min)	54	39	57	50	48	55	58	51	66	68	60	65	67	65	76	81	72	72
t_{op} (min)	2329	2899	2266	2423	2650	2553	2700	2887	2962	2960	2968	2618	2961	2963	2952	2947	2701	2671
y_{typ} (mm)	31.4	33.4	31.1	31.7	32.5	32.2	32.7	33.3	33.6	33.6	33.6	32.4	33.6	33.6	33.5	33.5	32.7	32.6
y_{ad} (mm)	67.1	71.4	66.6	67.9	69.6	68.9	70.0	71.3	71.8	71.8	71.9	69.4	71.8	71.8	71.8	71.7	70.0	69.8

Table D-10. Opportunity time and applied water depths to the Large Basin (36.6m x 36.6m) during Irrigation Number L5 (calculated by Method 1).

Station	11	12	13	14	15	16	21	22	23	24	25	26	31	32	33	34	35	36
t_r (min)	1470	1530	1200	960	1200	1680	1425	1440	1260	1620	1560	1500	1080	1620	1590	1680	1530	1380
t_a (min)	2.0	3.0	5.0	5.0	4.0	7.0	5.0	6.0	15.0	9.0	22.0	22.0	23.0	24.0	35.0	26.0	33.0	39.0
t_{op} (min)	1468	1527	1195	955	1196	1673	1420	1434	1245	1611	1538	1538	1057	1596	1555	1654	1497	1341
y_{typ} (mm)	22.2	22.4	21.3	20.3	21.3	22.9	22.1	22.1	21.5	22.7	22.5	22.5	20.7	22.6	22.5	22.8	22.3	21.8
y_{ad} (mm)	68.8	69.3	65.8	62.7	65.8	70.7	68.3	68.4	66.4	70.1	69.4	69.4	64.1	70.0	69.6	70.5	69.0	67.4

$\bar{t}_{op}$ = 1602.0 min. , $\bar{y}_{typ}$ = 22.7mm ; $\bar{y} = \bar{y}_{ad}$ = 70.06mm

Station	41	42	43	44	45	46	51	52	53	54	55	56	61	62	63	64	65	66
t_{rc} (min)	1080	1590	1600	1650	1530	1500	1470	1650	1860	1740	1710	1500	1800	1830	1890	1830	1830	1830
t_{ad} (min)	44.0	34.0	49.0	44.0	46.0	55.0	55.0	50.0	60.0	62.0	61.0	66.0	70.0	64.0	71.0	78.0	75.0	77.0
t_{op} (min)	1036	1556	1551	1606	1484	1445	1415	1600	1800	1678	1649	1434	1730	1766	1819	1752	1755	1753
y_{typ} (mm)	20.6	22.5	22.5	22.7	22.3	22.2	22.1	22.6	23.2	22.9	22.8	22.1	23.0	23.1	23.3	23.1	23.1	23.1
y_{ad} (mm)	63.8	69.6	69.6	70.1	68.9	68.5	68.2	70.0	71.8	70.7	70.5	68.4	71.2	71.5	72.0	71.4	71.4	71.4

Table D-11. Applied water depths to the Small Basin (18.3m x 36.6m) during Irrigation Number S1 (calculated by Method 2).

Station	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63
t_{op} (min)	195.0	195.0	197.0	178.0	189.0	186.0	163.0	183.0	167.0	143.0	171.0	152.5	136.0	153.0	124.0	121.0	122.0	94.0
y_t (mm)	69.0	69.0	69.3	66.4	68.1	67.7	64.1	67.2	64.7	60.7	65.4	62.3	59.5	62.4	57.3	56.7	56.9	51.1
y_{co} (mm)	69.9	66.7	69.9	66.7	71.4	63.5	63.5	66.7	63.5	66.7	66.7	61.9	60.3	66.7	66.7	63.5	60.3	66.7
y (mm)	138.9	135.7	139.2	133.1	139.5	131.2	127.6	133.9	128.2	127.4	132.1	124.2	119.8	129.1	124.0	120.2	117.2	117.8

t_{co} = 200.0 min, $\bar{y}$ = 128.77 mm

Table D-12. Applied water depths to the Small Basin (18.3 m x 36.6 m) during Irrigation Number S2 (Calculated by Method 2).

Station	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63
t_{op} (min)	122.0	122.0	125.0	102.0	113.0	114.0	90.0	106.0	93.0	75.0	87.0	74.0	62.0	81.0	46.0	46.0	67.0	38.0
y_t (mm)	56.8	56.8	57.1	54.5	55.8	55.9	53.0	55.0	53.4	50.8	52.6	50.6	48.6	51.7	45.4	45.4	49.5	43.4
y_{co} (mm)	57.2	41.3	41.3	34.9	57.2	47.6	41.3	57.8	41.3	53.8	44.5	31.6	53.8	57.2	52.4	55.6	41.3	34.9
y (mm)	114.0	99.7	98.4	89.4	113.0	103.5	94.3	112.8	94.7	104.6	97.1	82.2	102.4	108.9	97.8	101.0	90.8	78.3

t_{co} = 130.0 min, $\bar{y}$ = 99.10 mm

Table D-13. Applied water depths to the Small Basin (18.3 m x 36.6 m) during Irrigation Number S3 (calculated by Method 2).

Station	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63
t_{op} (min)	169.0	167.0	169.0	144.0	153.0	149.0	126.0	138.0	125.0	97.0	112.0	99.0	75.0	93.0	77.0	55.0	74.0	53.0
y_t (mm)	55.7	55.5	55.7	53.1	54.0	53.6	51.0	52.4	50.9	47.1	49.2	47.4	43.6	46.5	44.0	39.8	43.5	39.3
y_{co} (mm)	57.2	44.5	41.3	44.5	47.6	47.6	41.3	50.8	38.1	44.5	38.1	41.3	50.8	60.3	50.8	53.8	60.3	44.5
y (mm)	112.9	100.0	97.0	97.6	101.6	101.2	92.3	103.2	89.0	91.6	87.3	88.7	94.4	106.8	94.8	93.6	103.8	83.8

t_{co} = 180.0 min, $\bar{y}$ = 96.74 mm

Table D-14. Applied water depths to the Small Basin (18.3 m x 36.6 m) during Irrigation Number S5 (calculated by Method 2).

Station	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63
t_{op} (min)	129.0	124.0	122.0	109.0	109.0	109.0	91.0	92.0	90.0	61.0	70.0	69.0	43.0	52.0	50.0	27.0	29.0	28.0
y_t (mm)	52.0	51.7	51.5	50.6	50.6	50.6	49.3	49.4	49.3	46.5	47.4	47.3	44.1	45.4	45.1	41.2	41.6	41.4
y_{co} (mm)	44.5	31.6	31.6	31.6	41.3	31.6	34.9	44.5	28.6	34.9	31.6	28.6	41.3	47.6	38.1	36.5	30.2	33.3
y (mm)	96.5	83.3	83.1	82.2	91.9	82.2	84.2	93.9	77.9	81.4	79.0	75.9	85.4	93.0	83.2	77.7	71.6	74.7

t_{co} = 130.0 min, $\bar{y}$ = 84.03 mm

Table D-15. Applied water depths to the Large Basin (36.6m x 36.6m) during Irrigation Number L1 (calculated by Method 2).

Station	11	12	13	14	15	16	21	22	23	24	25	26	31	32	33	34	35	36
t_{op} (min)	177.0	178.0	176.0	174.0	173.0	177.0	161.0	160.0	152.0	162.0	151.0	163.0	143.0	132.0	116.0	140.0	140.0	152.0
y_t (mm)	82.3	82.6	82.0	81.4	81.0	82.3	77.2	76.9	74.2	77.5	73.9	77.8	71.2	67.5	61.9	70.2	70.2	74.2
y_{co} (mm)	44.5	63.5	47.6	57.2	47.6	57.2	57.2	41.3	31.8	38.1	31.8	41.3	44.5	41.3	50.8	38.1	47.6	55.6
y (mm)	126.8	146.1	129.6	138.6	128.6	139.5	134.4	118.2	106.0	115.6	105.7	119.1	115.7	108.8	112.7	108.3	117.8	129.8

t_{co} = 180.0 min., $\bar{y}$ = 111.97mm

Station	41	42	43	44	45	46	51	52	53	54	55	56	61	62	63	64	65	66
t_{op} (min)	116.0	103.0	90.0	111.0	129.0	126.0	57.0	86.0	61.0	88.0	113.0	109.0	41.0	48.0	58.0	75.0	81.0	96.0
y_t (mm)	61.9	57.1	52.1	60.0	66.5	65.4	38.3	50.5	40.1	51.3	60.8	59.3	30.6	34.1	38.7	46.1	48.5	54.4
y_{co} (mm)	38.1	57.2	47.6	41.3	44.5	39.7	57.2	44.5	55.6	54.0	50.8	57.2	63.5	50.8	60.3	50.8	54.0	50.8
y (mm)	100.0	114.3	99.7	101.3	111.0	105.1	95.5	95.0	95.7	105.3	111.6	116.5	94.1	84.9	99.0	96.9	102.5	105.2

Table D-16. Applied water depths to the Large Basin (36.6m x 36.6m) during Irrigation Number L2 (calculated by Method 2).

Station	11	12	13	14	15	16	21	22	23	24	25	26	31	32	33	34	35	36
t_{op} (min)	115.0	118.0	113.0	113.0	112.0	114.0	109.0	108.0	98.0	105.0	103.0	109.0	97.0	98.0	81.0	99.0	89.0	100.0
y_t (mm)	43.0	43.6	42.6	42.6	42.4	42.8	41.8	41.6	39.6	41.0	40.6	41.8	39.4	39.6	35.9	39.8	37.7	40.0
y_{co} (mm)	66.7	57.2	42.9	33.3	56.3	47.6	44.5	34.9	47.6	27.0	42.9	53.8	38.1	50.8	57.2	57.2	47.6	44.5
y (mm)	109.7	100.8	85.5	75.9	98.7	90.4	86.3	76.5	87.2	68.0	83.5	95.6	77.5	90.4	93.1	97.0	85.3	84.5

t_{co} = 120.0 min., $\bar{y}$ = 87.50mm

Station	41	42	43	44	45	46	51	52	53	54	55	56	61	62	63	64	65	66
t_{op} (min)	60.0	93.0	64.0	83.0	86.0	78.0	67.0	80.0	56.0	67.0	75.0	53.0	62.0	69.0	51.0	55.0	63.0	64.0
y_t (mm)	30.8	38.6	31.8	36.4	37.0	35.2	32.6	35.7	29.7	32.6	34.5	28.9	31.3	33.1	28.3	29.5	31.6	31.8
y_{co} (mm)	44.5	63.5	53.8	53.8	47.6	41.3	44.5	44.5	57.2	69.9	44.5	50.8	69.9	57.2	61.9	69.9	38.1	61.9
y (mm)	75.3	102.1	85.6	90.2	84.6	76.5	77.1	80.2	86.9	102.5	79.0	79.9	101.2	90.3	90.2	99.4	69.7	93.7

Table D-17. Applied water depths to the Large Basin (36.6m x 36.6m) during Irrigation Number L3 (calculated by Method 2).

Station	11	12	13	14	15	16	21	22	23	24	25	26	31	32	33	34	35	36
t_{op} (min)	151.0	151.0	146.0	147.0	147.0	148.0	141.0	136.0	121.0	135.0	131.0	135.0	118.0	126.0	92.0	124.0	120.0	119.0
y_t (mm)	39.5	39.5	39.1	39.2	39.2	39.3	38.7	38.3	37.0	38.2	37.9	38.2	36.7	37.4	34.1	37.3	36.9	36.8
y_{co} (mm)	53.8	57.2	38.1	47.6	53.8	69.9	53.8	41.3	34.9	50.8	34.9	63.5	38.1	47.6	53.8	47.6	47.6	50.8
y (mm)	93.3	96.7	77.2	86.8	93.0	109.2	92.5	79.6	71.9	89.0	72.8	101.7	74.8	85.0	87.9	84.9	84.5	87.6

t_{co} = 156.0 min., $\bar{y}$ = 87.94mm

Station	41	42	43	44	45	46	51	52	53	54	55	56	61	62	63	64	65	66
t_{op} (min)	78.0	108.0	84.0	105.0	103.0	91.0	76.0	93.0	68.0	84.0	90.0	81.0	71.0	75.0	56.0	66.0	76.0	77.0
y_t (mm)	32.5	35.8	33.2	35.5	35.3	34.0	32.3	34.2	31.2	33.2	33.9	32.9	31.6	32.1	29.5	30.9	32.3	32.4
y_{co} (mm)	44.5	60.3	50.8	53.8	50.8	46.0	44.5	46.0	53.8	65.1	47.6	57.2	82.6	57.2	60.3	61.9	55.6	69.9
y (mm)	77.0	96.1	84.0	89.3	86.1	80.0	76.8	80.2	85.0	98.4	81.5	90.1	114.2	89.3	89.8	92.8	87.9	102.3

Table D-18. Applied water depths to the Large Basin (36.6m x 36.6m) during Irrigation Number L4 (calculated by Method 2).

Station	11	12	13	14	15	16	21	22	23	24	25	26	31	32	33	34	35	36
t_{op} (min)	90.0	89.0	88.0	87.0	86.0	88.0	84.0	81.0	67.0	76.0	66.0	77.0	64.0	63.0	43.0	58.0	58.0	58.0
y_t (mm)	36.2	36.1	36.0	35.8	35.7	36.0	35.5	35.1	33.3	34.3	33.2	34.6	32.9	32.8	29.4	32.0	32.0	32.0
y_{co} (mm)	50.8	39.7	34.9	25.4	41.3	41.3	39.7	25.4	34.9	41.3	23.8	36.5	28.6	34.9	50.8	44.5	38.1	38.1
y (mm)	87.0	75.8	70.9	61.2	77.0	77.3	75.2	60.5	68.2	75.8	57.0	71.1	61.5	67.7	80.2	76.5	70.1	70.1

t_{co} = 95.0 min., $\bar{y}$ = 69.59mm

Station	41	42	43	44	45	46	51	52	53	54	55	56	61	62	63	64	65	66
t_{op} (min)	41.0	56.0	38.0	45.0	47.0	40.0	37.0	44.0	29.0	27.0	35.0	30.0	28.0	30.0	19.0	14.0	23.0	23.0
y_t (mm)	29.0	31.7	28.4	29.8	30.2	28.8	28.2	29.6	26.4	25.8	27.8	26.6	26.1	26.6	23.4	21.5	24.7	24.7
y_{co} (mm)	28.6	47.6	41.3	44.5	38.1	34.9	28.6	31.6	38.1	47.6	34.9	38.1	57.2	38.1	44.5	50.8	38.1	50.8
y (mm)	57.6	79.3	69.7	74.3	68.3	63.7	56.8	61.2	64.5	73.4	62.7	64.7	83.3	64.7	67.9	72.3	62.8	75.5

Table D-19. Applied water depths to the Large Basin (36.6m x 36.6m) during Irrigation Number L5 (calculated by Method 2).

Station	11	12	13	14	15	16	21	22	23	24	25	26	31	32	33	34	35	36
t_{op} (min)	111.0	110.0	108.0	108.0	109.0	106.0	108.0	107.0	98.0	104.0	91.0	91.0	90.0	89.0	78.0	87.0	80.0	74.0
y_t (mm)	36.0	35.9	35.8	35.8	35.9	35.7	35.8	35.8	35.1	35.5	34.5	34.5	34.5	34.4	33.4	34.2	33.6	33.0
y_{co} (mm)	41.3	41.3	28.6	34.9	38.1	47.6	31.6	15.9	34.9	19.1	22.2	41.3	38.1	34.9	39.7	41.3	34.9	27.0
y (mm)	77.3	77.2	64.4	70.7	74.0	83.3	67.4	51.7	70.0	54.6	56.7	75.8	72.6	69.3	73.1	75.5	68.5	60.0

t_{co} = 113.0 min., $\bar{y}$ = 70.06mm

Station	41	42	43	44	45	46	51	52	53	54	55	56	61	62	63	64	65	66
t_{op} (min)	69.0	79.0	64.0	69.0	67.0	58.0	58.0	63.0	53.0	51.0	52.0	47.0	43.0	49.0	42.0	35.0	38.0	36.0
y_t (mm)	32.6	33.5	32.0	32.6	32.3	31.4	31.4	31.9	30.8	30.5	30.6	30.0	29.4	30.3	29.3	28.2	28.7	28.3
y_{co} (mm)	28.6	47.6	38.1	41.3	34.9	28.6	31.6	34.9	34.9	47.6	34.9	38.1	53.8	39.7	47.6	52.4	38.1	53.8
y (mm)	61.2	81.1	70.1	73.9	67.2	60.0	63.0	66.8	65.7	78.1	65.5	68.1	83.2	70.0	76.9	80.6	66.8	82.1

APPENDIX E

ESTIMATION OF APPLIED WATER DEPTHS BY MODIFIED VOLUME BALANCE METHOD

Table E-1. Observed depths of water, y_{ij}, at several times during Irrigation Number S1.

Time, t (min)	Station Number					
	11	12	13	21	22	23
10	28.58	31.75	28.58	-	-	-
22	31.75	28.58	31.75	9.53	28.68	22.25
33	31.75	28.58	31.75	19.05	31.75	25.40
43	31.75	28.58	31.75	22.25	33.34	27.62
53	31.75	28.58	31.75	25.40	34.93	28.58
73	31.75	28.58	31.75	28.58	36.52	31.75
83	34.93	31.75	31.75	31.75	38.10	34.93
93	34.93	31.75	34.93	33.34	38.10	34.93
103	34.93	34.93	34.93	34.93	39.69	34.93
120	38.10	34.93	38.10	38.10	42.86	38.10

All depths are in mm.

Table E-1. Observed depths of water, y_{ij}, at several times during Irrigation Number S1 (cont'd).

Time, t (min)	Station Number					
	31	32	33	41	42	43
10	-	-	-	-	-	-
22	-	12.70	-	-	-	-
33	-	22.25	-	-	14.29	-
43	22.25	25.40	19.05	-	22.25	-
53	23.81	26.99	22.25	-	23.81	14.29
73	28.58	33.38	26.99	17.46	30.16	25.40
83	31.75	34.93	28.58	22.25	31.75	28.58
93	33.34	34.93	31.75	28.58	31.75	31.75
103	34.93	38.10	31.75	30.16	33.34	31.75
120	38.10	39.69	34.93	38.10	36.51	34.93

All depths are in mm.

Table E-1. Observed depths of water, y_{ij}, at several times during Irrigation Number S1 (cont'd).

Time, t (min)	Station Number					
	51	52	53	61	62	63
10	-	-	-	-	-	-
22	-	-	-	-	-	-
33	-	-	-	-	-	-
43	-	-	-	-	-	-
53	-	9.525	-	-	-	-
73	9.55	22.25	-	-	-	-
83	19.05	25.40	12.70	9.53	11.11	-
93	22.25	28.58	19.05	20.64	22.25	-
103	25.40	31.75	25.40	25.40	22.23	-
120	31.75	34.93	31.75	34.93	28.58	28.58

All depths are in mm.

Table E-2. Observed depths of water, y_{ij}, at several times during Irrigation Number L1.

Time, t (min)	Station Number					
	11	12	13	14	15	16
13	34.93	3.18	28.58	41.28	28.58	31.75
34	44.45	53.98	41.28	44.45	34.93	38.10
64	41.28	57.15	44.45	47.63	41.28	44.45
94	41.28	57.15	44.45	47.63	44.45	47.63
124	44.45	60.33	44.45	50.80	44.45	47.63
145	44.45	60.33	44.45	50.80	44.45	47.63

All depths are in mm.

Table E-2. Observed depths of water, y_{ij}, at several times during Irrigation Number L1 (cont'd).

Time, t (min)	Station Number					
	21	22	23	24	25	26
13	-	-	-	-	-	-
34	41.28	23.81	15.88	25.40	3.18	20.64
64	47.63	28.58	22.23	31.75	15.88	31.75
94	50.80	31.75	25.40	31.75	22.25	31.75
124	40.80	31.75	25.40	31.75	22.25	31.75
145	53.98	34.93	25.40	31.75	25.40	34.93

All depths are in mm.

Table E-2. Observed depths of water, y_{ij}, at several times during Irrigation Number L1 (cont'd).

Time, t (min)	Station Number					
	31	32	33	34	35	36
13	-	-	-	-	-	-
34	-	-	-	-	-	22.25
64	38.10	23.81	17.46	17.46	30.16	38.10
94	38.10	30.16	30.16	23.81	31.75	44.45
124	38.10	31.75	34.93	25.40	38.10	44.45
145	38.10	31.75	39.69	25.40	39.69	47.63

All depths are in mm.

Table E-2. Observed depths of water, y_{ij}, at several times during Irrigation Number L1 (cont'd).

Time, t (min)	Station Number					
	41	42	43	44	45	46
13	-	-	-	-	-	-
34	-	-	-	-	-	-
64	-	-	-	-	23.81	19.05
94	20.64	31.75	3.18	23.82	31.75	25.40
124	25.40	38.10	26.99	25.40	31.76	28.58
145	25.40	44.45	31.75	30.16	38.10	30.16

All depths are in mm.

Table E-2. Observed depths of water, y_{ij}, at several times during Irrigation Number L1 (cont'd).

Time, t (min)	Station Number					
	51	52	53	54	55	56
13	-	-	-	-	-	-
34	-	-	-	-	-	-
64	-	-	-	-	-	-
94	-	-	-	9.53	31.75	38.10
124	-	19.05	28.58	34.93	34.93	44.45
145	44.45	31.75	41.28	44.45	38.10	47.63

All depths are in mm.

Table E-2. Observed depths of water, y_{ij}, at several times during Irrigation Number L1 (cont'd).

Time, t (min)	Station Number 61	62	63	64	65	66
13	-	-	-	-	-	-
34	-	-	-	-	-	-
64	-	-	-	-	-	-
94	-	-	-	-	-	28.68
124	-	-	34.93	31.75	38.10	38.10
145	50.80	34.93	47.63	41.28	41.28	41.28

All depths are in mm.

Table E-3. Wetted area of strip at several times during Irrigation Number S1.

Time, t (min)	Wetted Area of Strip, Aj (m^2) — Strip (row) Number, j: 1	2	3	$\sum_{j=1}^{3} Aj$ (m^2)	Time, t (min)	Wetted area of Strip, Aj (m^2) — Strip (row) Number, j: 1	2	3	$\sum_{j=1}^{3} Aj$ (m^2)
10	29.129	41.616	41.140	111.885	73	161.796	192.042	165.976	519.814
22	58.107	101.682	67.657	227.446	83	187.573	203.490	177.900	568.963
33	84.867	125.070	86.237	296.174	93	201.471	211.998	194.666	608.135
43	109.707	147.720	105.462	362.889	103	209.340	207.185	201.501	618.026
53	130.525	161.478	132.041	424.044	120	209.340	216.000	217.680	643.020

Table E-4. Wetted area of strip at several times during Irrigation Number L1.

Time, t (min)	Wetted area of strip, Aj (m^2)						$\sum_{j=1}^{6} Aj$ (m^2)
	Strip (row) Number, j						
	1	2	3	4	5	6	
13	34.216	43.833	37.743	36.293	34.263	47.244	233.592
34	73.617	64.542	61.077	61.475	77.393	94.130	432.234
64	125.836	101.603	95.474	126.010	161.159	167.086	777.168
94	139.691	154.623	134.244	169.244	207.704	214.421	1019.825
124	160.050	185.269	209.175	222.190	221.650	218.890	1217.224
145	226.220	222.880	223.120	222.190	221.650	218.890	1334.950

Table E-5. Surface storage volumes at several times during Irrigation Number S1.

Time, t (min)	Strip No. j	x_{j_1} (m)	k	$\bar{y}_{j_1}$ (mm)	$a_{j_1} = x_{j_1}\bar{y}_{j_1}$ (m^2)	x_{j_2} (m)	$\bar{y}_{j_2}$ (mm)	$a_{j_2} = x_{j_2}\bar{y}_{j_2}$ (m^2)	$x_j = x_{j_1} + x_{j_2}$ (m)	A_j (m^2)	$V_{p_j}(t)$ (m^3)	$V_p(t)$ (m^3)
10	1	-	1	-	-	3.70	25.21	0.083	3.70	29.129	0.732	2.932
	2	-	1	-	-	6.00	28.00	0.168	6.00	41.616	1.165	
	3	-	1	-	-	4.65	25.21	0.117	4.65	41.140	1.035	
22	1	9.0	2	24.34	0.219	0.0	0.0	0.0	9.00	58.107	1.414	5.453
	2	15.0	3	25.44	0.382	3.86	9.53	0.037	18.86	101.682	2.259	
	3	9.0	2	28.58	0.257	2.10	16.69	0.035	11.10	67.657	1.780	
33	1	9.0	2	27.52	0.248	5.50	14.29	0.079	14.50	84.867	1.914	7.254
	2	21.0	4	25.64	0.538	0.60	10.72	0.006	21.60	125.070	3.150	
	3	9.0	2	29.63	0.267	6.00	19.05	0.114	15.00	86.237	2.190	
43	1	15.0	3	26.05	0.391	1.00	16.69	0.017	16.00	109.707	2.798	9.569
	2	21.0	4	28.13	0.591	3.00	16.69	0.050	24.00	147.720	3.945	
	3	15.0	3	27.56	0.413	0.90	14.29	0.013	15.90	105.462	2.826	
53	1	15.0	3	27.62	0.414	5.30	17.86	0.094	20.25	103.525	2.597	10.167
	2	27.0	5	26.46	0.714	0.40	7.15	0.003	27.40	161.478	4.226	
	3	21.0	4	25.64	0.538	0.40	10.72	0.004	21.40	132.041	3.344	

Table E-5. Surface storage volumes at several times during Irrigation Number S1 (cont'd).

Time, t (min)	Strip No.	x_{j_1} (m)	k	$\bar{y}_{j_1}$ (mm)	$a_{j_1} = x_{j_1}\bar{y}_{j_1}$ (m^2)	x_{j_2} (m)	$\bar{y}_{j_2}$ (mm)	$a_{j_2} = x_{j_2}\bar{y}_{j_2}$ (m^2)	$x_j = x_{j_1} + x_{j_2}$ (m)	A_j (m^2)	$V_{p_j}(t)$ (m^3)	$V_p(t)$ (m^3)
73	1	27.0	5	24.70	0.667	5.20	7.16	0.037	32.20	161.796	3.537	13.654
	2	27.0	5	31.06	0.839	4.67	16.69	0.078	31.67	192.042	5.561	
	3	21.0	4	29.48	0.619	5.05	19.05	0.096	26.05	165.976	4.556	
83	1	33.0	6	26.56	0.876	1.08	7.15	0.008	34.08	187.573	4.865	15.990
	2	33.0	6	30.31	1.000	0.50	8.33	0.004	33.50	203.490	6.099	
	3	27.0	5	28.93	0.781	0.00	9.53	0.010	28.00	177.900	5.026	
93	1	36.0	6	28.85	1.039	-	-	-	36.00	201.471	5.815	18.066
	2	33.0	6	31.90	1.053	2.20	16.69	0.037	35.20	211.998	6.565	
	3	27.0	5	31.75	0.857	4.60	14.29	0.066	31.60	194.666	5.686	
103	1	36.0	6	30.96	1.115	-	-	-	36.00	209.340	6.484	19.376
	2	33.0	6	34.35	1.135	2.80	16.67	0.047	35.80	207.185	6.841	
	3	27.0	5	32.46	0.876	5.90	19.05	0.112	32.90	201.501	6.051	
120	1	36.0	6	36.51	1.314	-	-	-	36.00	209.340	7.641	22.957
	2	36.0	6	36.25	1.305	-	-	-	36.00	216.000	7.830	
	3	36.0	6	34.40	1.238	-	-	-	36.00	217.680	7.486	

Table E-6. Surface storage volumes at several times during Irrigation Number L1.

Time, t (min)	Strip No. j	x_{j_1} (m)	k	$\overline{y}_{j_1}$ (mm)	$a_{j_1} = x_{j_1}\overline{y}_{j_1}$ (m^2)	x_{j_2} (m)	$\overline{y}_{j_2}$ (mm)	$a_{j_2} = x_{j_2}\overline{y}_{j_2}$ (m^2)	$x_j = x_{j_1} + x_{j_2}$ (m)	A_j (m^2)	$V_{p_j}(t)$ (m^3)	$V_p(t)$ (m^3)
10.0	1	-	1	-	-	4.877	30.81	0.150	4.877	34.216	1.052	5.636
	2	-	1	-	-	6.858	5.80	0.019	6.858	43.833	0.121	
	3	-	1	-	-	5.060	25.21	0.128	5.060	37.743	0.955	
	4	-	1	-	-	6.797	36.41	0.247	6.797	36.293	1.319	
	5	-	1	-	-	5.791	25.21	0.146	5.791	34.263	0.864	
	6	-	1	-	-	8.199	28.00	0.230	8.199	47.244	1.325	
34.0	1	9.144	2	43.39	0.397	2.652	30.96	0.082	11.796	73.617	2.989	13.683
	2	9.144	2	43.92	0.42	1.524	17.86	0.027	10.668	64.542	2.595	
	3	9.144	2	32.81	0.300	0.610	11.91	0.007	9.754	61.077	1.922	
	4	9.144	2	38.10	0.348	2.438	19.05	0.046	11.582	61.475	2.091	
	5	9.144	2	24.35	0.223	2.743	2.39	0.007	11.887	77.393	1.497	
	6	15.240	3	27.95	0.426	0.610	16.69	0.010	15.850	94.130	2.589	
64.0	1	15.240	3	43.18	0.658	6.066	28.58	0.173	21.306	125.836	4.908	24.755
	2	15.240	3	39.05	0.595	1.768	17.86	0.032	17.008	101.603	3.746	
	3	15.240	3	30.17	0.460	0.030	13.10	0.000	15.270	95.474	2.876	
	4	15.240	3	35.24	0.537	5.090	13.10	0.067	20.330	126.010	3.744	
	5	21.336	4	28.35	0.605	5.425	17.86	0.097	26.761	161.159	4.228	
	6	21.336	4	35.38	0.755	4.907	14.29	0.070	26.243	167.086	5.253	

Table E-6. Surface storage volumes at several times during Irrigation Number L1 (cont'd).

Time, t (min)	Strip No. j	x_{j_1} (m)	k	$\overline{y}_{j_1}$ (mm)	$a_{j_1} = x_{j_1}\overline{y}_{j_1}$ (m^2)	x_{j_2} (m)	$\overline{y}_{j_2}$ (mm)	$a_{j_2} = x_{j_2}\overline{y}_{j_2}$ (m^2)	$x_j = x_{j_1} + x_{j_2}$ (m)	A_j (m^2)	$V_{p_j}(t)$ (m^3)	$V_p(t)$ (m^3)
94.0	1	21.336	4	40.14	0.856	1.433	15.48	0.022	22.769	139.691	5.387	31.240
	2	21.336	4	38.55	0.823	6.035	23.81	0.144	27.371	154.623	5.463	
	3	21.336	4	29.03	0.619	1.554	2.39	0.004	22.890	134.244	3.654	
	4	27.432	5	29.28	0.6215	0.427	7.15	0.003	27.859	169.142	3.813	
	5	27.432	5	32.46	0.693	4.907	23.81	0.117	32.339	207.704	5.202	
	6	36.576	6	36.00	1.317	-	-	-	36.576	214.421	7.721	
124.0	1	21.336	4	41.73	0.890	4.298	19.05	0.082	25.634	160.050	6.069	43.793
	2	27.432	5	38.10	1.045	3.536	14.29	0.053	30.968	185.269	6.569	
	3	36.576	6	35.55	1.300	-	-	-	36.576	209.175	7.435	
	4	36.576	6	33.34	1.219	-	-	-	36.576	222.190	7.405	
	5	36.576	6	34.93	1.278	-	-	-	36.576	221.650	7.745	
	6	36.576	6	39.16	1.432	-	-	-	36.576	218.890	8.570	
145.0	1	36.576	6	42.86	1.568	-	-	-	36.576	226.220	9.698	52.874
	2	36.576	6	39.69	1.452	-	-	-	36.576	222.880	8.848	
	3	36.576	6	38.37	1.403	-	-	-	36.576	223.120	8.559	
	4	36.576	6	37.31	1.365	-	-	-	36.576	222.190	8.292	
	5	36.576	6	37.84	1.384	-	-	-	36.576	221.650	8.387	
	6	36.576	6	41.54	1.519	-	-	-	36.576	218.890	9.090	

Table E-7. Cumulative infiltrated depths at several times during Irrigation Number S1.

Time, t (min)	Cumulative inflow volume, Qt (m^3)	Surface storage volume, Vp(t) (m^3)	Cumulative infiltrated volume, V(t) (m^3)	Area of infiltration, ΣA_j (m^2)	Cumulative infiltrated depth, y(t) (mm)
10	4.140	2.932	1.208	111.885	10.80
22	9.108	5.453	3.655	227.446	16.07
33	13.662	7.254	6.408	296.174	21.64
43	17.802	9.569	8.233	362.889	22.69
53	21.942	10.167	11.775	424.044	27.77
73	30.222	13.654	16.568	519.814	31.87
83	34.362	15.990	18.372	568.963	32.29
93	38.502	18.066	20.436	608.135	33.60
103	42.642	19.376	23.266	618.026	37.65
120	49.680	22.957	26.723	643.020	41.56

Table E-8. Cumulative infiltrated depths at several times during Irrigation Number L1.

Time, t (min)	Cumulative inflow volume, Qt (m^3)	Surface storage volume, Vp(t) (m^3)	Cumulative infiltrated volume, V(t) (m^3)	Area of infiltration, Aj (m^2)	Cumulative infiltrated depth, y(t) (mm)
13.0	10.795	5.636	5.159	233.592	22.09
34.0	28.234	13.683	14.551	432.234	33.66
64.0	53.146	23.755	28.391	777.168	36.53
94.0	78.058	31.240	46.818	1019.825	45.91
124.0	102.970	43.793	59.177	1217.224	48.62
145.0	120.408	52.874	67.534	1334.950	50.59

Table E-9. Coefficients and exponents of the advance functions and the infiltration equations.

Irrigation	P	r	B	K	KA	A
S1	24.030	0.710	0.530	0.712	3.205	4.501
L1	33.925	0.743	0.338	0.785	9.523	12,131

Infiltration equations for the Kostiakov type:

Irrigation S1 : $y = 4.501t^{01530}$

Irrigation L1 : $y = 12.131t^{0.338}$

Table E-10. Estimated applied water depths to the Small Basin during Irrigation Number S1 (by Modified Volume Balance method).

Station	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63
t_r (min)	630.0	783.0	728.0	714.0	718.5	739.0	708.5	775.0	735.0	715.0	795.0	755.0	735.0	765.0	680.0	780.0	693.0	695.0
t_a (min)	5.0	5.0	3.0	22.0	11.0	14.0	37.0	17.0	33.0	57.0	29.0	47.5	64.0	47.0	76.0	79.0	78.0	108.0
t_{op} (min)	625.0	778.0	725.0	692.0	707.5	725.0	671.5	758.0	702.0	658.0	766.0	707.5	671.0	718.0	604.0	651.0	615.0	589.0
y_{field} (mm)	136.5	153.3	147.7	144.1	145.8	147.7	141.7	151.2	145.2	140.3	152.0	145.8	141.7	146.9	134.0	139.5	135.3	132.3
y_{ad} (mm)	122.5	137.6	132.6	129.4	130.9	132.6	127.2	135.7	130.4	126.0	136.5	130.9	127.2	131.9	120.3	125.2	121.5	118.8

$\bar{y}_{field} = 143.43$ mm $\bar{y} = \bar{y}_{ad} = 128.77$ mm

Table E-11. Estimated applied water depths to the Large Basin during Irrigation Number L1 (by Modified Volume Balance method).

Station	11	12	13	14	15	16	21	22	23	24	25	26	31	32	33	34	35	36
t_n (min)	385	410	315	310	335	400	405	365	265	295	265	350	315	340	285	285	322	330
t_a (min)	3	2	4	6	7	3	19	20	28	18	29	17	37	48	64	40	40	28
t_{op} (min)	382	408	311	304	328	397	386	345	237	277	236	333	278	292	221	245	282	302
y_{field} (mm)	90.5	92.5	84.4	83.8	86.0	91.7	90.8	87.4	77.0	81.2	76.9	86.4	81.3	82.6	75.2	77.9	81.7	83.6
y_{ad} (mm)	124.2	126.9	115.8	115.0	118.0	125.8	124.6	119.9	105.6	111.4	105.5	118.5	111.5	113.3	103.2	106.9	112.1	114.7

$\bar{y}_{field} = 81.62$ mm $\bar{y} = \bar{y}_{ad} = 111.97$ mm

Station	41	42	43	44	45	46	51	52	53	54	55	56	61	62	63	64	65	66
t_r (min)	300	320	335	308	335	295	375	350	350	360	345	360	405	375	405	385	355	355
t_a (min)	64	77	90	69	51	54	123	94	119	92	67	71	139	132	122	105	99	84
t_{op} (min)	236	243	245	239	284	241	252	256	231	268	278	289	266	243	283	280	256	271
y_{field} (mm)	76.9	77.7	77.9	77.2	81.9	77.4	78.6	79.0	76.3	80.3	81.3	82.4	80.1	77.7	71.8	81.5	79.0	80.6
y_{ad} (mm)	105.5	106.6	106.9	105.9	112.4	106.2	107.8	108.4	104.7	110.2	111.5	113.0	109.9	106.6	112.2	111.8	108.4	110.6

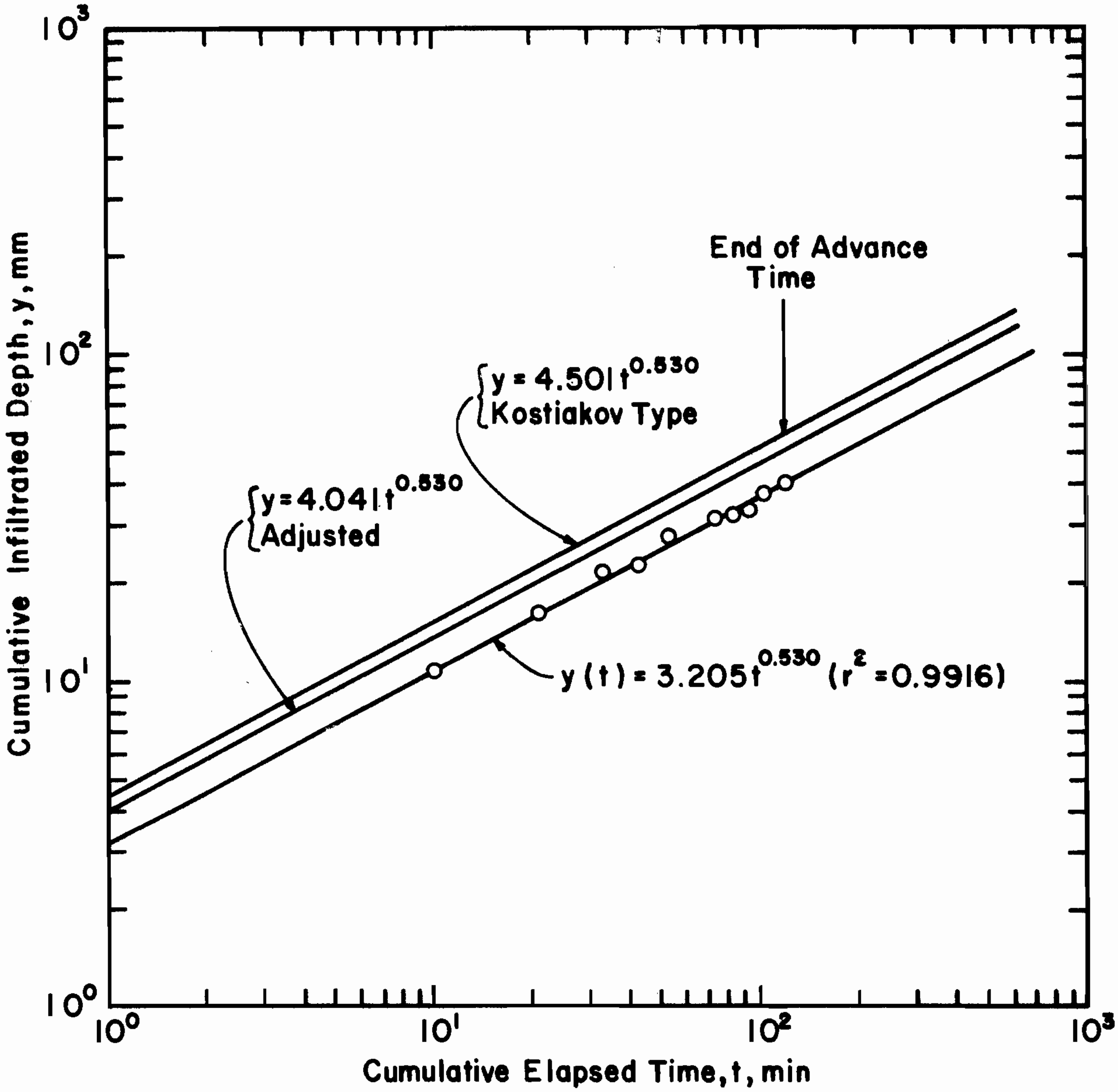


Figure E-1. Infiltration equations developed by modified volume balance method from data of irrigation number S1.

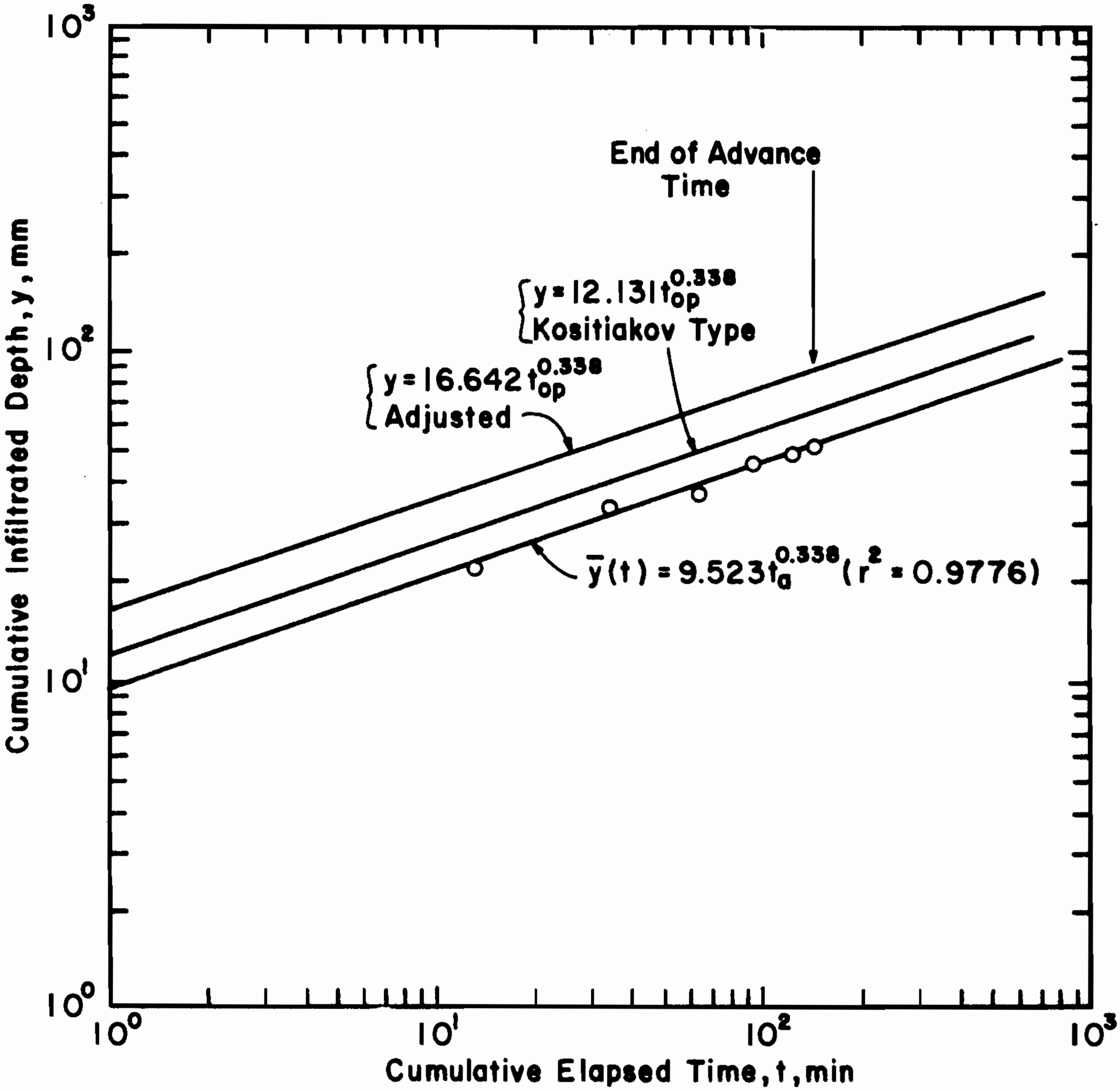


Figure E-2. Infiltration equations developed by modified volume balance method from data of irrigation number L1.

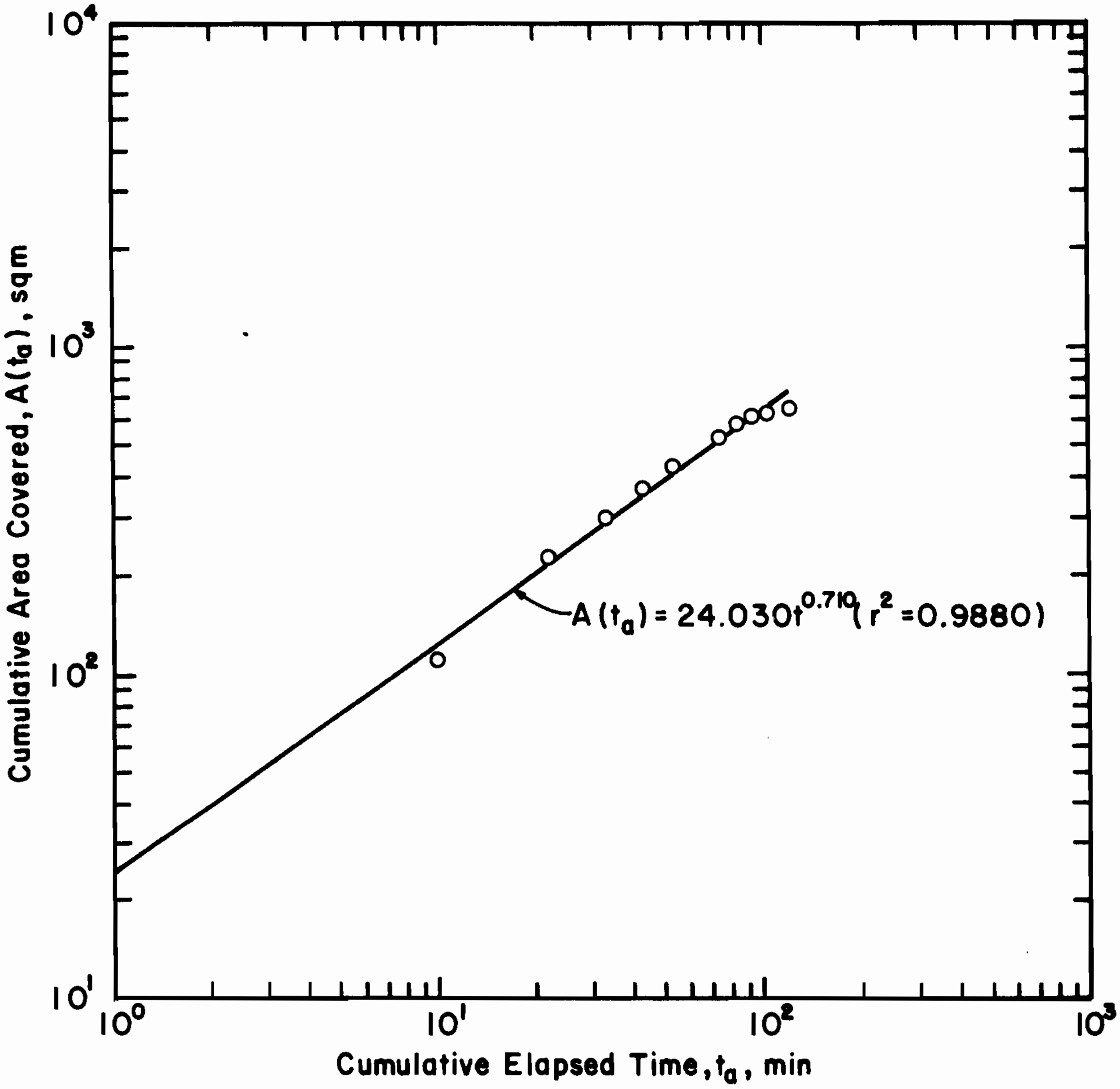


Figure E-3. The advance function of irrigation number S1.

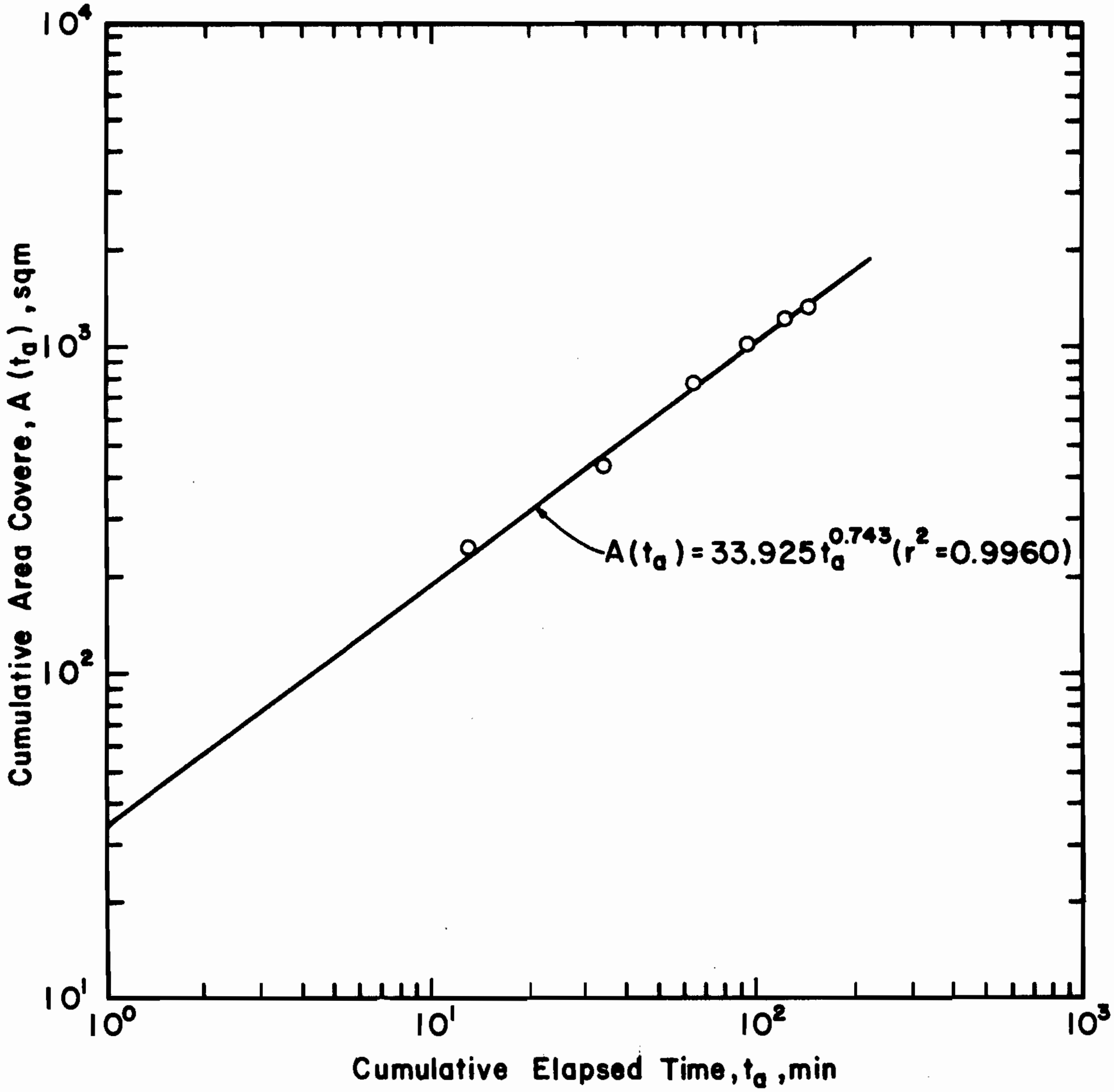


Figure E-4. The advance function of irrigation number L1.

APPENDIX F

YIELD OF SWEET CORN

<u>18.3m x 36.6m Basin (32,117 plants/ha):</u>

Number of ears/ha: 42,920

Grain yield (15.5% moisture content): 1.40 mT/ha

Total dry matter yield: 5.13 mT/ha

<u>36.6m x 36.6m Basin (41,387 plants/ha):</u>

Number of ears/ha: 52,993

Grain yield (15.5% moisture content): 1.36 mT/ha

Total dry matter yield: 5.50 mT/ha