34 Intake Rate: Border and Furrow[1]

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34-1 INTRODUCTION

Water infiltration data which are to be used for evaluation, planning, or management of surface irrigation systems should be obtained by flooding or furrow-flow methods. This chapter describes methods that can be used for determining infiltration rates under actual operating conditions of border or furrow systems.

Volume-balance methods are most often used on low gradient borders and also can be used on level basins and level furrows. The type of irrigation system and slope are the main factors which determine whether the border or furrow method should be used. To achieve high application efficiencies, borders are generally constructed with slopes of 0.005 (m/m) or less. On slopes less than about 0.005, the average depth of water in surface storage is continually changing and can be a significant portion of the applied volume. On furrows having slopes greater than 0.005, the surface storage depth can usually be totally neglected or assumed to be constant. The border method consists of measuring surface storage and inflow volumes, whereas the furrow method consists of measuring inflow and outflow rates. The border method yields intake data applicable to the initial or advance portion of an irrigation, whereas the furrow inflow-outflow method yields data applicable to periods after water has advanced to the outflow station. The recirculating flow method is a modified inflow-outflow method that can evaluate intake rates for a relatively short time span.

The use of laser-controlled scraping equipment to construct level and graded borders has made the surface storage-advance method more practical because soil surface elevations and field slopes are more uniform and fewer measurements are needed to accurately determine surface storage volumes.

Davis and Fry (1963) compared four methods of determining intake

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in furrows. They stated that intake in furrows should be measured with flowing water when possible and that volume balance and inflow-outflow methods were the most accurate. They found that cylinder infiltrometers (Haise et al., 1956) and furrow infiltrometers (Bondurant, 1957; Shull, 1961) tend to overestimate intake rates in coarse-textured soils and underestimate furrow intake rates in fine-textured soils. Gilley (1968) and Kincaid (1979) also found that cylinder infiltrometers tend to underestimate intake rates on borders on fine-textured soils. Fangmeier and Ramsey (1978) found that ponded infiltration tests underestimate infiltration in furrows and that equations developed from advance data underestimate infiltration during the continuing and recession phases. They also found that intake volumes were linearly dependent on the furrow wetted perimeter. Merriam and Keller (1978) described field procedures for evaluating irrigation systems, including measurement of intake rates in furrows and flooded basins.

Erie (1962) gave a review of the factors affecting intake rates under gravity-irrigation conditions. Some of these factors are soil texture and water content, compaction due to tractor traffic, prior tillage, surface soil conditions, cracking of soils, crop cover, and hydrostatic head. Intake rates are often high for the first irrigation and tend to decrease as the growing season advances, but may increase late in the season due to high water use rates or blocking of the furrows by foliage and resultant increases in wetted perimeters of furrows. Intake rates decrease with time when the whole surface is wet, as in border irrigation. Intake from furrows tends to remain more constant with time until wetting zones from adjacent furrows begin to overlap. Under some conditions on medium-to-coarse-textured soils, constant rate furrow streams have been observed to "back up," indicating increased intake rates. Kemper et al. (1982) presented a possible explanation. Furrow streams are often set in the early morning hours when the soil and water temperatures are low, and the backing-up occurs in the latter part of the day when temperatures are high. The increased infiltration rate may be a result of increasing water temperatures and decreased viscosity of the water. This phenomenon deserves further study in the future.

34–2 THE VOLUME BALANCE ADVANCE METHOD

34–2.1 Principles

The volume balance-advance method involves determining of the coefficients for an empirical time-based infiltration function by utilizing data from the advance phase of an irrigation. Authors who have used this type of analysis include Davis and Fry (1963), Christiansen et al. (1966), Gilley (1968), Norum and Gray (1970), Wu (1971), Lal and Pandya (1972), Singh and Chauhan (1973), Kincaid (1979), and Elliot and Walker (1982). All of these methods are similar in principle and differ only in the assumptions made concerning: (i) the shape of the intake function, (ii) the rate of advance, or (iii) the depth of surface storage, i.e, constant or variable.

This section describes the mathematical relationships under one set of assumptions and the procedures used in collecting field data and calculating the resultant values of the intake constants.

Several empirical volume or depth infiltration functions have been used. Perhaps the most widely used is the power function

$$Z = k\tau^{a} \quad [1]$$

where Z is depth of intake, m; τ is intake opportunity time, min; and k and a are coefficients related to soil properties.

More recently, Philip (1954) proposed the equation

$$Z = S\tau^{1/2} + A\tau \quad [2]$$

where S is a constant related to capillarity and A is a constant related to the gravitational effect on infiltration. The USDA-SCS (1974), has adopted the equation

$$Z = k\tau^{a} + c \quad [3]$$

where k, a, and c are empirical constants. Equation [3] reduces to Eq. [1] when $c = 0$.

The basic continuity relationship for border irrigation is

$$Qt = \int_{o}^{s} y\mathrm{d}x + \int_{o}^{s} Zdx \quad [4]$$

where Q is inflow rate per unit width, m²/min; t is elapsed time, min; x is distance from the inflow end, m: y is depth of surface flow, m; s is distance of water front advance, m. The first term in Eq. [4] is the total volume applied, the second term is surface storage volume, and the third term is total infiltrated volume at any time t. Figure 34–1 shows surface storage and infiltrated depth profiles at two different times.

In the following analysis, Eq. [1] will be used to describe infiltration. The intake opportunity time is $\tau = t - t_s$, where t_s is the time necessary for the flow to advance a distance, s. The advance distance can be represented by the power function

$$s = bt^{h} \quad [5]$$

where b and h are empirical constants. Elliot and Walker (1982) recommend the two-point method for determining the advance constants. Advance times to two known distances are substituted into Eq. [5] separately to solve for b and h.

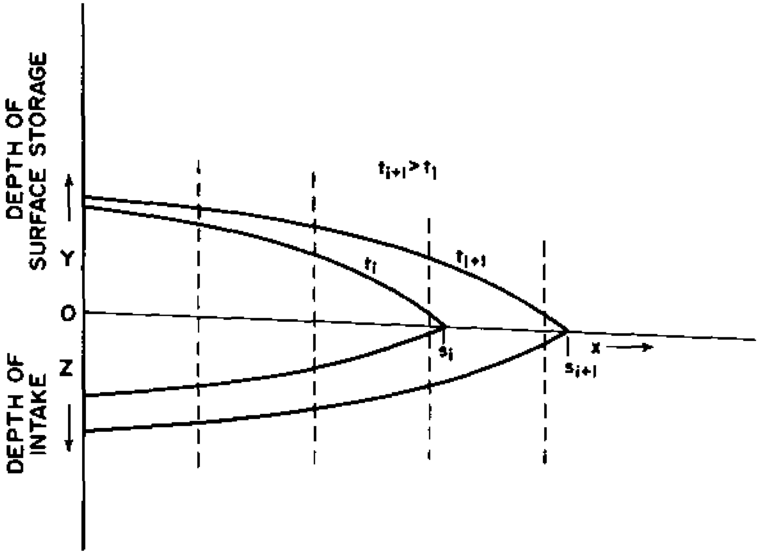

Fig. 34–1. Schematic of water surface and infiltrated depth profiles on a sloping border.

The infiltrated volume integral (last right-hand term of Eq. [4]) can be evaluated by combining Eq. [1] and [5], expanding the result in a binomial series, and integrating term by term from 0 to t. This procedure results in the following relationship for infiltrated volume as a function of time:

$$V_z = f(a,h)\ Pkbht^{a+h} \qquad [6]$$

where V_z is total infiltrated volume, m^3; P is wetted perimeter, m; t is elapsed time, min; b, h, k, and a are constants; and the function $f(a, h)$ is a binomial series as follows:

$$f(a, h) = \frac{1}{h} - \frac{a}{h+1} + \frac{a(a-1)}{2!(h+2)} - \frac{a(a-1)(a-2)}{3!(h+3)} + \ldots . \qquad [7]$$

Equation [6] was developed by Gilley (1968), and also by Christiansen et al. (1966), in a different form. This equation shows that if the intake and advance can be described by power functions, the infiltrated volume will also follow a function of this form. Experimentally, these relationships have been found to work well. The advance constants b and h are evaluated from field advance data. Infiltrated volume is calculated from measurements of inflow and surface storage volume. Values of the intake constants are then determined by Eq. [5] and [6], with known values of b and h. Gilley (1968) used this method on borders having slopes between 0.0002 and 0.005. Kincaid (1979) found the method could be used on zero-slope borders, and extended the method for level furrows by modifying the advance function to describe the total wetted area rather than advance distance.

For borders and furrows of about 0.005 slope or greater, the surface storage depth can be assumed to be constant. The advantage of assuming a constant surface depth is that intake functions other than Eq. [1] may be evaluated. Singh and Chauhan (1973), Christiansen et al. (1966), and others have used this assumption to develop various methods of computing advance or evaluating the intake function. Norum and Gray (1970) proposed a curve matching technique to evaluate the constants of Eq. [1] or [2].

In general, it is best to measure surface storage depths in the field, determine whether or not they can be considered constant, and select an appropriate method of analysis based on the intake function desired. The field procedures described here will provide data necessary for use of any of the analytical methods.

34–2.2 Equipment

1. Flumes (described in detail in the next section) or weirs, orifice plates, or pipeline meters (obtainable in all sizes) for inflow measurement.
2. A surveyor's level, rod, and tape measure.
3. Steel rods approximately 1 m in length for bench-mark stakes.
4. Staff gauges or hook gauges for water surface elevation measurements. Figure 34–2 describes the construction and use of an inexpensive hook gauge.

34–2.3 Procedures

1. Select borders (or furrows) to be tested, with uniform soils and slope if possible.
2. Install inflow measuring equipment.
3. Set six or more bench-mark stakes along one side of the border at about 30-m spacing. It is desirable to space the bench marks closer together near the inflow end. Set the stakes so they can be easily reached from the border dike. Set the tops of the stakes 100 to 150 mm above the border surface.
4. Measure the border bottom width and side slopes of the dike or berm at each bench-mark station. (A method of measuring a furrow profile is given in the next section.)
5. Take level rod readings on the top of each bench-mark stake.
   Take at least six rod readings on the soil surface in a line across the border at each station. On level borders, bench marks may be set to a constant elevation to reduce error and facilitate data reduction.
6. Determine the required inflow rate. (Furrow inflow rates are described in the next section.) Border flows range from 0.05 to 0.2 m^3/min per meter of width, depending upon soil, slope, and surface conditions. Initiate flow.

7. Maintain constant flow rate until water passes the last station.
8. Estimate the advance time to each station as the time when about one-half of the soil surface is covered by water at the station. Record time to the nearest minute.
9. Measure the water surface elevation relative to the top of the stake (bench mark) using a hook gauge and scale preferably reading in millimeters. An accuracy of ±2 mm in water surface measurements is sufficient. Record water surface measurements 1, 2, 5, and 10 min after water reaches the station and at 10- to 30-min intervals thereafter.
10. Shut off the water when water has passed the last station. If recession

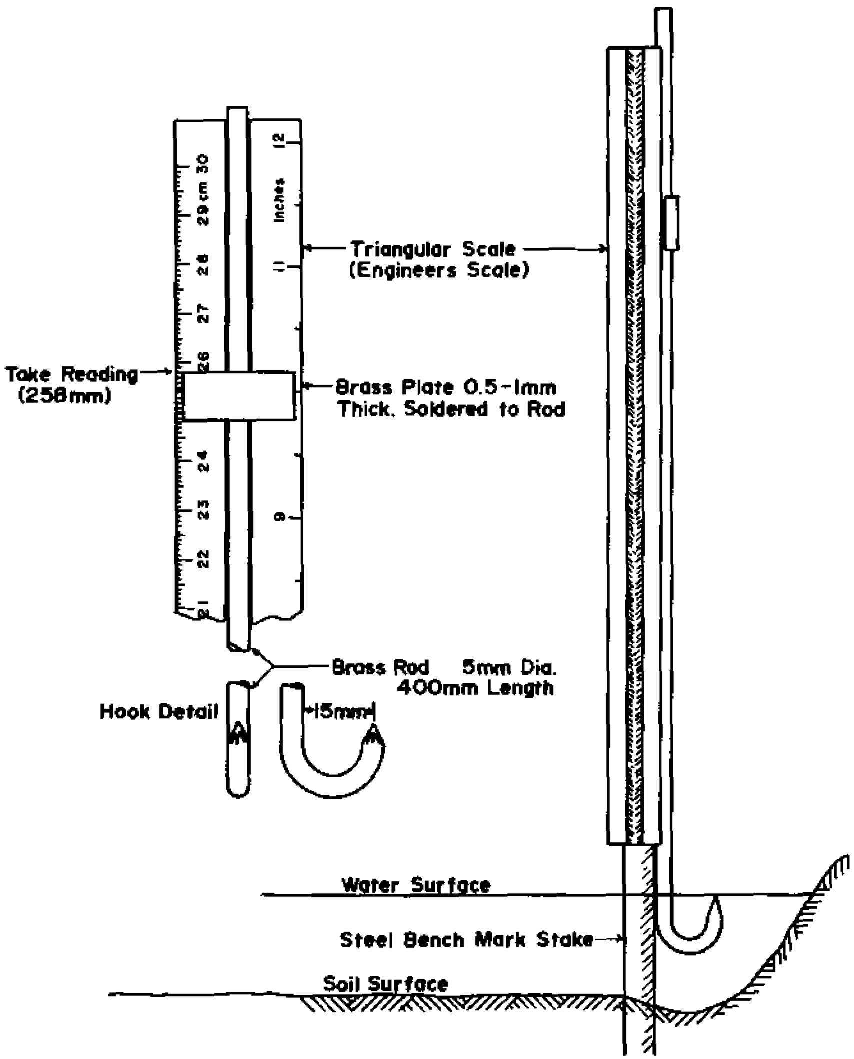

Fig. 34-2. Hook gauge for water surface elevation measurements.

data are desired, record water surface readings immediately before and several times immediately after water is shut off, and then less frequently until all water has infiltrated.

34–2.4 Data Analysis

Tables 34–1 to 34–3 list data from a representative level border advance test (Kincaid, 1979). Table 34–1 gives locations of the bench mark stakes, average soil surface elevations and bottom widths. Table 34–2 lists hydrograph data in the form of water surface elevations computed from hook gauge readings. The actual field readings and bench-mark elevations are not shown. A computer program was written to convert field readings to elevations at the time intervals shown, and compute the total volume in surface storage at any time. The advance distance at any time was computed by log-log interpolation between hydrograph stations. The water surface profile was assumed to be linear between stations. Figure 34–3 shows plotted hydrograph data. A plot of the data is useful in finding and correcting errors and determining whether enough points have been included to accurately describe the hydrographs.

Table 34–1. Dimensions and bench mark stations, Border 5.

Bench mark	Distance	Soil surface elevation	Width
	m	mm	m
1	0.6	165	2.99
2	31.4	156	2.96
3	57.3	147	3.11
4	66.8	130	3.08
5	92.1	160	3.02
6	123.8	165	2.96
Average			3.02

Table 34–2. Hydrograph data—time (min), water surface elevation (mm).

Bench mark											
1		2		3		4		5		6	
min	mm	min	mm	min	mm	min	mm	min	mm	min	mm
1	178	22	174	51	166	62	138	98	179	149	193
3	198	24	185	58	183	65	168	100	183	151	198
6	203	27	189	71	192	69	180	103	185	157	206
9	206	47	199	96	201	98	201	137	203	165	212
20	212	72	208	141	208	139	208	156	210	200	206
43	218	95	210	153	211	153	211	164	212	265	196
73	222	142	217	162	213	163	213	199	206	311	188
94	222	158	217	195	206	198	206	264	196	0	0
143	226	161	216	261	194	262	197	310	188	0	0
158	227	194	207	307	188	309	190	0	0	0	0
160	220	261	197	0	0	0	0	0	0	0	0
193	210	306	188	0	0	0	0	0	0	0	0
260	197	0	0	0	0	0	0	0	0	0	0
305	192	0	0	0	0	0	0	0	0	0	0

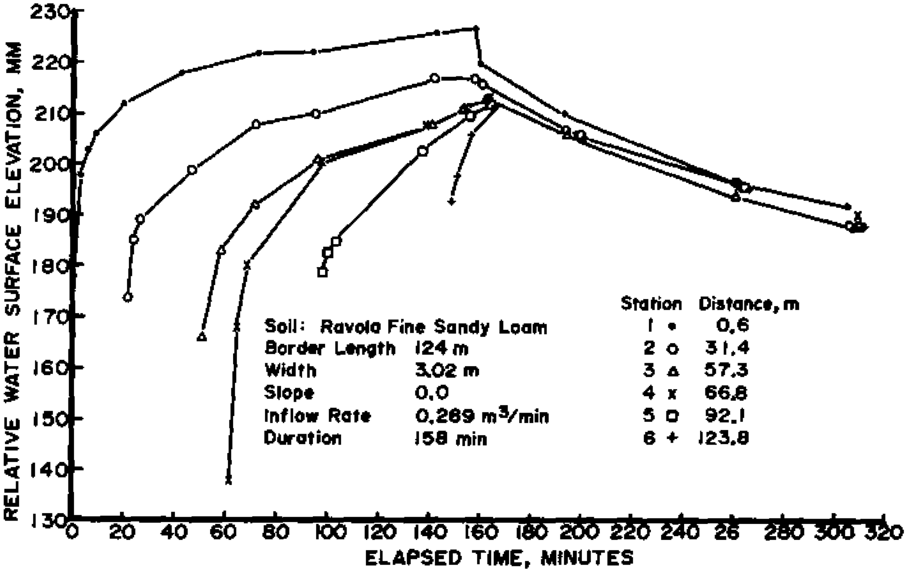

Fig. 34-3. Water surface hydrographs (CSU Farm, Fruita, CO. 5 Sept. 1978).

Table 34-3. Calculated volumes, advance distance, and wetted perimeter.

Time	Inflow	Surface storage	Infiltrated volume	Advance distance	Wetted perimeter
min	m^3			m	
10	2.92	0.91	2.01	11.5	1.98
20	5.75	2.60	3.15	27.8	2.06
30	8.57	4.51	4.06	39.2	2.89
40	11.40	5.68	5.71	48.2	2.75
50	14.18	6.89	7.29	56.5	2.66
60	16.86	8.91	7.95	65.1	3.06
70	19.54	11.06	8.48	72.8	3.13
80	22.19	12.50	9.69	80.0	3.05
90	24.82	14.04	10.78	86.9	2.99
100	27.45	15.52	11.92	93.7	3.22
110	30.07	16.56	13.51	100.1	3.16
120	32.70	17.69	15.01	106.4	3.11
130	35.33	18.94	16.38	112.5	3.06
140	37.95	20.27	17.69	118.5	3.02
150	40.51	22.11	18.41	123.7	3.25
160	42.51	22.89	19.62	123.7	3.26
190	42.51	20.70	21.81	123.7	3.24
220	42.51	18.66	23.85	123.7	3.21
250	42.51	16.77	25.73	123.7	3.19
280	42.51	14.92	27.58	123.7	3.17
310	42.51	13.08	29.42	123.7	3.15

Table 34-3 shows computed volumes, advance distance, and wetted perimeter at 10-min time intervals. The time interval should be small enough to provide at least six points on the infiltrated volume curve. Figure 34-4 shows a plot of the advance and infiltrated volume curves

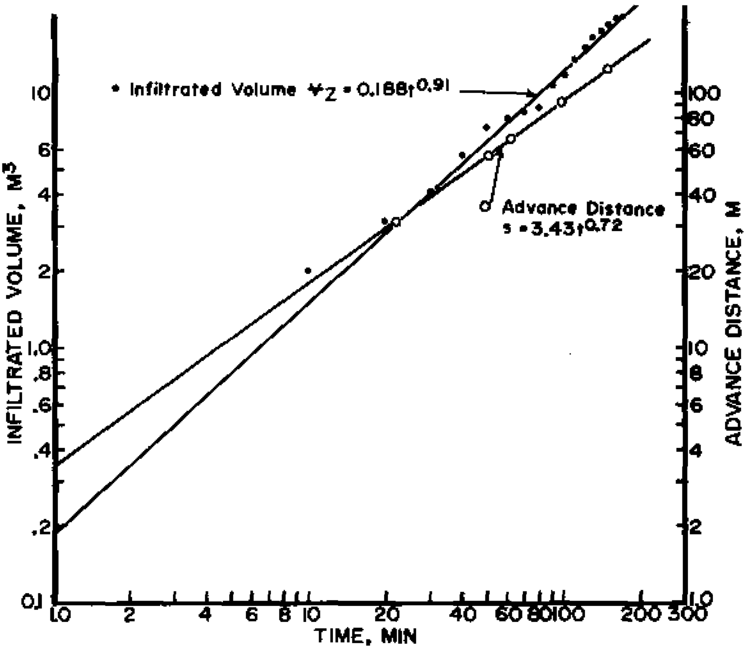

Fig. 34–4. Advance and infiltrated volume curves.

on log-log paper. The advance time to each hydrograph station is plotted and a straight line is fitted to determine the advance constants b and h (h is the slope of the line on the log-log plot, and $b = s$ when $t = 1.0$). The infiltrated volumes are often somewhat erratic at small times, due to the errors in determining surface storage volume for the initial advance. The infiltrated volume data prior to 30 min and after 158 min (the time at which water reached the end of the border) was ignored in fitting a straight line as shown in Fig. 34–4.

The border used in this test was relatively narrow, and the average wetted perimeter was used to determine the intake constants rather than the average bottom width. The surface storage volume and wetted perimeter were computed by assuming a trapezoidal cross section having side slopes of 0.5, vertical/horizontal. The average wetted perimeter was P = 3.14 m.

The value of the constants $b = 3.43$, $h = 0.72$, $a + h = 0.91$ and $Pkbh\,f(a, h) = 0.188$ are obtained from Fig. 34–4. The value of a is $a + h - h = 0.91 - 0.72 = 0.19$, and the value of $f(a, h)$ is calculated by Eq. [6]. By substitution, $k = 0.188/[Pbh\,f(a,h)] = 0.020$ m.

On sloping borders and furrows, the surface flow depths approach a constant normal flow depth, the determination of which is beyond the scope of this chapter. However, if field measurements indicate that a constant flow depth is adequate, the infiltrated volume curve can be constructed by using the assumed surface depth, the advance curve, and inflow rate. The intake constants can then be computed as described above.

34–2.5 Comments

The preceding section describes a method of determining coefficients for equations describing rate of water advance in border ($s = bt^h$) and infiltration ($Z = k\tau^a$). The method assumes that the intake and advance rates can be described by these power functions of time. If the advance or infiltration data cannot be adequately described by a power function, then different intake functions should be used. The reader is referred to the papers previously mentioned which describe other volume balance-advance techniques.

The power function describes intake best on medium- to fine-textured soils where the basic intake rates are relatively small. The intake constants derived from a test may vary with the total time of a test. Intake constants from a relatively short test should not be used to make predictions for longer time spans.

A more general method of using volume balance-advance data for determining infiltration rates is as follows. The measured infiltrated volume curve is contructed as described previously from field data. A predicted infiltrated volume curve is then constructed using the advance data and an assumed infiltration curve. A comparison of the measured and predicted infiltrated volume curves will indicate whether or not the assumed infiltration curve is reasonable. The infiltration curve can be adjusted and a new predicted volume curve calculated. By trial and error, a best-fit infiltration curve can be estimated, or alternative infiltration models can be compared.

34–3 THE INFLOW-OUTFLOW METHOD

34–3.1 Principles

The rate of inflow into an irrigation furrow minus the rate of outflow, at any time, is equal to the furrow intake rate plus the rate at which channel storage is changing. Flow depth is proportional to flow rate at a particular point in a furrow, and since intake rates generally decrease with time, channel storage usually increases with time. However, on furrow slopes greater than about 0.005, the rate of change in surface storage is small (after advance) and may be neglected. The average intake rate can then be taken as the inflow minus outflow rate, and the corresponding time is the average intake opportunity time for the entire furrow. The advance time should be limited to < 25% of the total time span for the test.

To obtain data for the initial part of the intake curve, it would be desirable to test shorter lengths. However, the accuracy of the flow measurements is limited to about ± 3% and sufficient length of furrow must be used to obtain an appreciable flow reduction between the inflow and outflow stations to achieve reasonably good estimates of infiltration. Shockley et al. (1959) gave the following recommendations for furrow test length:

Fine-textured soils	100–300 m
Medium-textured soils	60–150 m
Coarse-textured soils	30–60 m

They also recommend measuring inflow and outflow from two or more adjacent and relatively short furrows to gain a measure of variability. This method reduces the advance time for a given furrow stream size. The maximum recommended nonerosive stream size for each furrow is given by

$$Q = 38/s \qquad [8]$$

where Q is the furrow inflow rate, L/min, and s is the furrow slope in percent. The recommended stream size is one-half to three-fourths of the maximum nonerosive stream.

The flow of water in furrows can be measured either volumetrically or by any of a number of flow-rate measuring devices. Shockley et al. (1959) recommended the volumetric method for flow less than about 80 L/min. Volumetric measurements can be made by collecting the entire flow in a calibrated container and measuring the time to fill the container with a stopwatch. For accurate measurements (± 5%), the container should require at least 4 s to fill. The container is placed in a hole dug in the furrow and the water is run through a tube (approximately 75 mm in diameter) placed in the bottom of the furrow and cantilevered over the container. Inflow measurements can also be made in this manner by using ditch spiles or siphon tubes.

Two types of flumes have been used successfully for direct furrow-flow rate measurement. Small Parshall flumes were described by Robinson (1957), and more recently, small trapezoidal flumes were described by Robinson and Chamberlain (1960). The trapezoidal flumes were also described in ASAE Standard S359.1 (adopted 1975), which gives details on accuracy, construction, and calibration.

The trapezoidal flumes fit furrow channel shapes better than Parshall flumes and can be installed with very little excavation. The V-notch trapezoidal flumes are suitable for flows up to about 150 L/min, and the 50.8-mm (2-inch) throat trapezoidal flumes can be used for larger flows. Fiberglass V-notch trapezoidal flumes can be obtained from the Powlus Manufacturing Co., Inc., Twin Falls, ID 83341.[2]

[2]Mention of trade products or companies in this chapter does not imply that they are recommended or endorsed by the Department of Agriculture over similar products of other companies not mentioned. Trade names are used for convenience in reference only.

The discharge relationship for the V-notch flume of Robinson and Chamberlain (1960) is

$$Q = 0.001281\ h^{2.58} \qquad [9]$$

where Q is flow rate in L/min and h is water depth in the flume inlet in millimeters. The calibration for the Powlus flume is

$$Q = 0.00169\ h^{2.46} \qquad [10]$$

The accuracy of the flow measurement depends on the accuracy of the flume throat dimensions and the accuracy of the stage measurement. To obtain 5% accuracy using the above relationship for the V-notch flume, the stage measurement should be accurate to within ± 1 mm. Materials of construction can have a slight affect on the calibration of a flume and it is recommended that calibration checks be made on new flumes. The errors due to calibration can be reduced by using identical devices to measure both inflow and outflow from furrows and by exchanging the devices between replicated tests.

Flumes should be installed so that the bottom of the flume is flush with or slightly above the furrow bottom. Trapezoidal flumes require very little head loss for free flow conditions and can be used in furrows with slopes as low as 0.002.

Orifice meters are used extensively for flow measurement and are inexpensive to construct. Trout (1983) stated that well-made orifices can measure flows to within $\pm 3\%$ in the field. The basic equation for an orifice is

$$Q = 0.0105\ C\, A\, H^{0.5} \qquad [11]$$

where Q is flow rate in L/min, H is head measured from the water surface to the center of the orifice, mm, A is area of the orifice, mm^2, and C is discharge coefficient which has a value of about 0.65 for freeflow and about 0.61 for submerged flow. Calibration tests should be run to determine the value of C for particular orifices.

For submerged orifices, the head is the difference in elevation between the water surfaces. Submerged orifices measure flow more accurately than the other devices because $H \propto Q^2$ for orifices and the exponent on Q is much lower on the other devices, going down to 0.4 for flumes. This same factor causes more head loss at the orifice, which can increase upstream water levels and cause more infiltration than would occur without the orifice plate in place. This effect on infiltration will be practically negligible if head loss at the orifice is less than 0.05 times the elevation difference between the inflow and outflow orifices. A metal box or large pipe with several orifices can distribute water equally to several adjacent furrows when the head is the same on all orifices. Miller and Rasmussen

(1978) used a 100-mm diameter orifice pipe with constant head control for inflow measurement and regulation. A chassis punch can be used to punch uniform size holes in sheet metal.

Weirs are free overfall devices having characteristics intermediate between flumes and orifices. Commercial propeller-type pipe flow meters are available and are accurate to about ± 3%.

34–3.2 Procedures

1. Select furrows to be tested and determine the locations for measuring devices. At least four furrows or groups of furrows should be tested at a site. Test adjacent furrows and supply water to a buffer furrow on each side of the test furrows if tests are to be of long duration so wetting zones will overlap. Determine, if possible, which of the furrows are traffic furrows.
2. Install the measuring devices and water control facilities.
3. Measure the exact furrow length between inflow and outflow measuring devices.
4. Set stakes at three or more intermediate points equally spaced. If wetted perimeter measurements are to be obtained, at each intermediate point drive a stake in the ridge on each side of the furrow so that a straightedge laid across them will be level.
5. Measure the furrow profile at each intermediate stake. Furrow profiles can be measured by using a graduated straightedge placed on the stakes in a level position across the furrow and measuring from this datum line to the soil surface with an adjustable square or point gauge. The stakes are left in place for later measurement of water flow depth. Take rod readings with a surveyor's level to determine the elevation of the furrow invert and top of the stakes at each intermediate point.
6. Select the furrow stream size, select orifice size or tube size, adjust head controls to maintain constant flow, start the flow, and record the start time.
7. Record the time when the furrow stream reaches each intermediate staked point and the outflow point.
8. Record inflow and outflow rates at 15- to 30-min intervals for the duration of the test. The duration of the test should be sufficient to define the shape of the intake curve, which may be 1 to 2 h on coarse-textured soils and up to 10 h on fine-textured soils. For best results, the test duration should be three or four times the advance time from the inflow to the outflow station.
9. If infiltration per unit area of wetted perimeter is desired, measure water surface levels at the intermediate staked points using the straightedge and point gauge or hook gauge.

34–3.3 Data Analysis

1. Compute inflow and outflow rates and loss rates for each time when outflow measurements were made. Also, compute average elapsed intake opportunity time for each of the loss rates.

2. If rate of loss per unit area of wetted perimeter is desired, compute average total wetted area from the furrow profile and water surface data.
3. Convert loss rates to intake rate per unit length of furrow (L h^{-1} m^{-1}) or infiltration rate (mm h^{-1}) based on wetted furrow area. An equivalent field intake rate (mm h^{-1}) can also be calculated by dividing the intake rate per unit length by the furrow spacing.
4. Calculate furrow slope from furrow invert elevations.

34–3.4 Comments

Intake rates determined by the inflow-outflow method will generally produce a more gradually changing intake rate curve than the volume balance method. The results are most applicable to large intake times and are somewhat dependent on the furrow length and advance rate.

34–4 RECIRCULATING FLOW METHOD

34–4.1 Principles

The recirculation method for measuring furrow infiltration combines some of the advantages of the inflow-outflow method and the furrow blocking method, while maintaining field flow conditions. Tests can be run in off-season and on shorter furrow lengths than is practical with the inflow-outflow method. Basically, the method involves introducing a constant inflow to a furrow from a supply reservoir, collecting the runoff at an outflow weir, and pumping the runoff back to the supply reservoir. The accuracy of this method is potentially high, since the total intake is measured volumetrically, avoiding the errors of inflow-outflow rate measurements. Nance and Lambert (1970) used this method to test 4.5-m (15-ft) furrow lengths. Walker and Willardson (1983) and Wallender and Bautista (1983) described improved versions of the recirculating infiltrometer. In principle, the length of furrow is limited only by the size of the supply reservoir and the total intake volume per unit length. The test section can be long enough to avoid local variations and minimize end effects, and short enough to keep filling time to < 5% of irrigation time. A length of 5 to 50 m would be desirable, requiring approximately 0.5 to 4 m^3 of water. Two or more adjacent furrows can be run simultaneously by dividing the inflow and combining the runoff in one sump. This tends to average the effect of tractor tire compaction in alternate furrows. If the irrigation run is to continue after the wetting fronts meet, water should be maintained in buffer furrows adjacent to the test furrows. The buffer furrows may be ponded rather than flowing, to reduce the water requirement.

34–4.2 Equipment

A cylindrical tank equipped with a float-operated water stage recorder may be used as a supply reservoir. A precision volumetric water meter could be used to refill the reservoir if necessary during a test.

A small reservoir equipped with a float valve serves as a constant-head device for use with a calibrated orifice for flow measurement. A large-diameter pipe with uniform orifices can be used to distribute water to several furrows. Metal plates or boxes are used to block the end of the furrow sections. The inflow boxes should be constructed so that water entering the furrow will not erode the soil. The outflow boxes should be equipped with adjustable weirs and a sump for collecting runoff. A gasoline-engine-powered self-priming pump with a float-controlled throttle provides automatic pump-back regulation.

34–4.3 Procedure

1. Select a test site and construct furrows, if necessary, to the desired length, spacing, and depth.
2. Install the inflow and outflow boxes, being careful not to disturb the furrows in the test sections.
3. Measure the average furrow slope, cross sections, and soil water content if desired.
4. Determine the inflow rate desired and initiate the flow.
5. Record the time of advance and the time at which water begins to flow back into the supply reservoir. Record water levels in the supply reservoir and any additional volumes of water added.
6. Adjust the outflow weir so that the flow depth is nearly constant throughout the test section, and so that the flow near the downstream end neither backs up nor erodes the soil.
7. Measure flow depths in the furrows at several times during the test.

34–4.4 Data Analysis

Calculate and plot cumulative intake volume per unit furrow length vs. average time of intake. Convert data to intake rates if desired.

34–4.5 Comments

The recirculation method can be used to determine infiltration rates for smaller time periods than the inflow-outflow method. It is also applicable to studying the effects of flow rate and depth on infiltration rates. Buffer furrows may not be needed if alternate furrows are tested, if furrow spacing is large, or if relatively short-duration tests are made. Soil probings can be used to determine the extent of the wetting pattern. The wetting pattern can also be observed by cutting a trench across the furrow. Erosion and sediment content of the runoff water can cause problems with recirculation. If sediment concentration is a factor, special sediment handling equipment may be necessary.

34-5 REFERENCES

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