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Design of Basin, Border and Furrow Irrigation Systems

DEPARTMENT OF AGRICULTURE PHILIPPINES

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Foreword

The formulation of this national standard was initiated by the Agricultural Machinery Testing and Evaluation Center (AMTEC) under the project entitled "Enhancement of Nutrient and Water Use Efficiency Through Standardization of Engineering Support Systems for Precision Farming" funded by the Philippine Council for Agriculture, Aquaculture and Forestry and Natural Resources Research and Development - Department of Science and Technology (PCAARRD - DOST).

As provided by the Republic Act 10601 also known as the Agricultural and Fisheries Mechanization Law (AFMech Law of 2013), the Bureau of Agriculture and Fisheries Standards (BAFS) is mandated to develop standard specifications and test procedures for agricultural and fisheries machinery and equipment. Consistent with its standards development process, BAFS has endorsed this standard for the approval of the DA Secretary through the Bureau of Agricultural and Fisheries Engineering (BAFE) and to the Bureau of Philippine Standards (BPS) for appropriate numbering and inclusion to the Philippine National Standard (PNS) repository.

This standard has been technically prepared in accordance with BPS Directives Part 3:2003 – Rules for the Structure and Drafting of International Standards.

The word "shall" is used to indicate mandatory requirements to conform to the standard.

The word "should" is used to indicate that among several possibilities one is recommended as particularly suitable without mentioning or excluding others.

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ANNEXES

Design of Basin, Border and Furrow Irrigation Systems

Introduction

Surface irrigation is one of the widely used systems of irrigation in the country. Basin and border irrigation systems are designed for lowland rice irrigation while furrow irrigation is mostly for corn and sugarcane. The methods discussed in this standard are primarily intended for areas for development where irrigation systems do not exist yet. It is also intended to help in improving the traditional way of irrigation especially for those who uses flooding method.

1 Scope

This standard provides selection criteria minimum requirements and procedure for the design of a surface irrigation system specifically for basin, border and furrow.

2 References

The following normative documents contain provisions, which, through reference in this text, constitute provisions of this National Standard:

PNS/BAFS/PAES 217:2017 Determination of Irrigation Water Requirements

3 Definitions

For the purpose of this standard, the following terms shall apply:

3.1
basin
field that is level in all directions, encompassed by a dike to prevent runoff, and provides an undirected flow of water onto the field

3.2
basin irrigation
type of surface irrigation where water is applied to the basin through a gap in the perimeter dike or adjacent ditch as shown in Figure 1; water is retained until it infiltrates into the soil or the excess is drained off.

3.3
border irrigation
method of irrigation which makes use of parallel border strips where the water flows down the slope at a nearly uniform depth (Figure 2)

3.4
border strip
area of land bounded by two border ridges or dikes that guide the irrigation stream from the inlet point of application to the ends of the strip

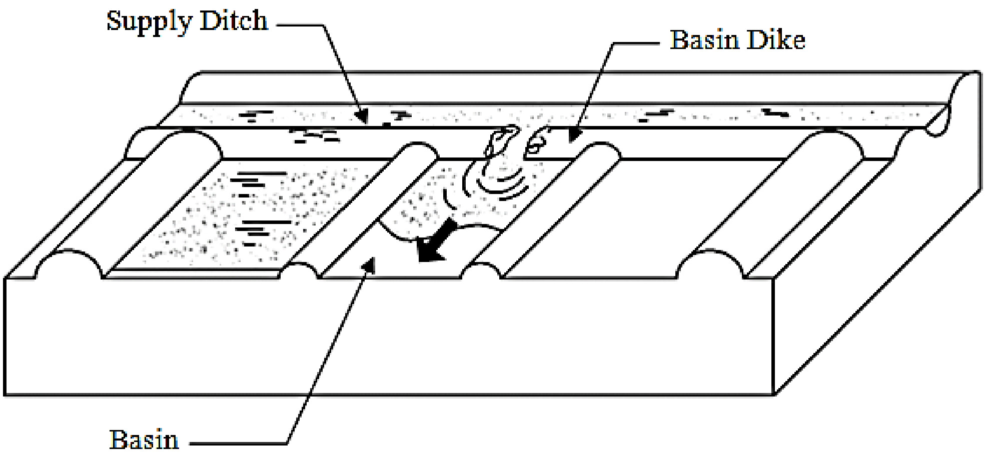

Figure 1. Basin Irrigation
SOURCE: Brouwer, Irrigation Water Management Training Manual No. 5: Irrigation Methods, n.d

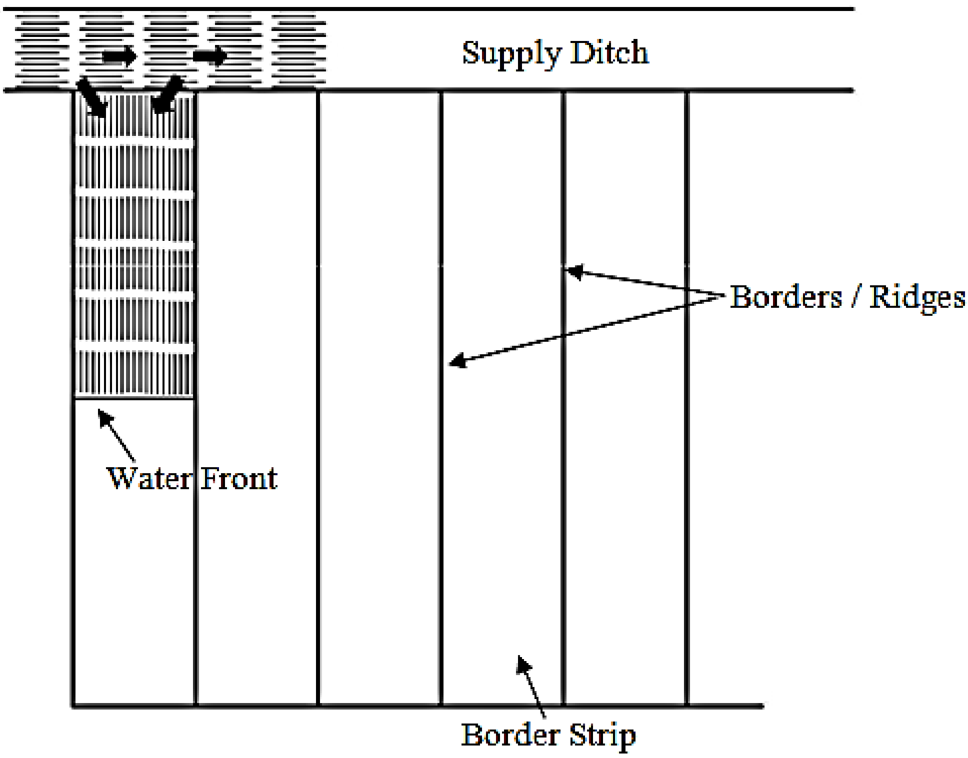

Figure 2. Border Irrigation
SOURCE: Brouwer, Irrigation Water Management Training Manual No. 5: Irrigation Methods, n.d

3.5
furrows
small parallel channels, made to carry water in order to irrigate the crop

3.6
furrow irrigation
method of irrigation where water runs through small parallel channels as it moves down the slope of the field (Figure 3)

3.7
head ditch
supply ditch
small channel along one part of a field that is used for distributing water in surface irrigation

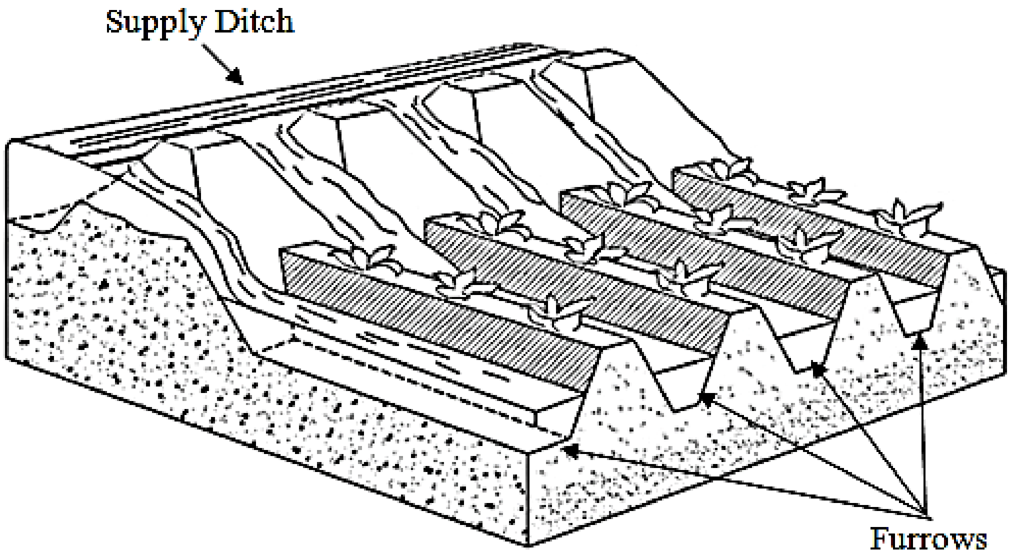

Figure 3. Furrow Irrigation
SOURCE: Brouwer, Irrigation Water Management Training Manual No. 5: Irrigation Methods, n.d

3.8
surface irrigation system
application of water by gravity flow to the surface of the field. Either the entire field is flooded (basin irrigation) or the water is fed into small channels (furrows) or strips of land (borders)

4 Data Requirement

The following data are required in the selection and design of a surface irrigation system

- Slope
- Soil Type
- Type of Crop

- Irrigation Depth
- Stream Size

5 Selection Criteria

The suitable type of surface irrigation system for an area shall be based on the following criteria:

Table 1. Selection of Surface Irrigation System

Selection Criteria	Furrow Irrigation	Border Irrigation	Basin Irrigation
Necessary development costs	Low	Moderate to high	High
Most appropriate field geometry	Rectangular	Rectangular	Variable
Land leveling and smoothing	Minimal required but needed for high efficiency, Smoothing needed regularly	Moderate initial investment and regular smoothing is critical	Extensive land leveling required initially, but smoothing is less critical if done periodically
Soils	Coarse-to moderate-textured soils	Moderate- to fine-textured soils	Moderate- to fine-textured soils
Crops	Row crops (corn, vegetables, tree, sugarcane)	Row/solid-stand crops, annual crops (sugarcane, forage, pasture)	Solid-stand crops (paddy rice and other which can withstand waterlogged conditions
Water supply	Low-discharge, long duration, frequent supply	Moderately high discharge, short duration, infrequent supply	High discharge, short duration, infrequent supply
Climate	All, but better in low rainfall	All, but better in low to moderate rainfall	All
Principal Risk	Erosion	Scalding	Scalding
Efficiency and uniformity	Relatively low to moderate	High with blocked ends	High
Slope	0.05 % to 3.0 %	2.0% to 5.0%	≤ 0.1%

SOURCE: NCRS-USDA, Part 623: Irrigation – National Engineering Handbook, 2012

6 Basin Irrigation

6.1 Types of Basin Irrigation

6.1.1 Closed Single Basin

6.1.1.1 Water applied to an individual basin and all of that applied water is allowed to infiltrate.

6.1.1.2 Each basin in the irrigation block is hydraulically independent.

6.1.1.3 Water advances from the inflow point towards the downstream end of the basin in a regular pattern, which may be distorted by surface irregularities

6.1.1.4 Inflow is normally shutoff before the water reaches the downstream end of the basin

6.1.2 Multiple/ Sequential Basin

6.1.2.1 Each basin is irrigated separately by a supply channel running along the boundary with a number of adjacent basins as shown in Figure 4.

6.1.2.2 In each basin, the water level in the supply channel controls the water application. When a basin is irrigated, the water level in the channel is raised higher than the soil surface elevation and overflows onto the basin.

6.1.2.3 When the irrigation is completed, the water level in the channel is lowered below the soil surface elevation of the basin and supply is diverted to the next basin. The excess water from the first basin drains back to the supply channel.

6.1.2.4 The next basin is irrigated with the supply discharge plus the drainage water from the upstream basin (or basins).

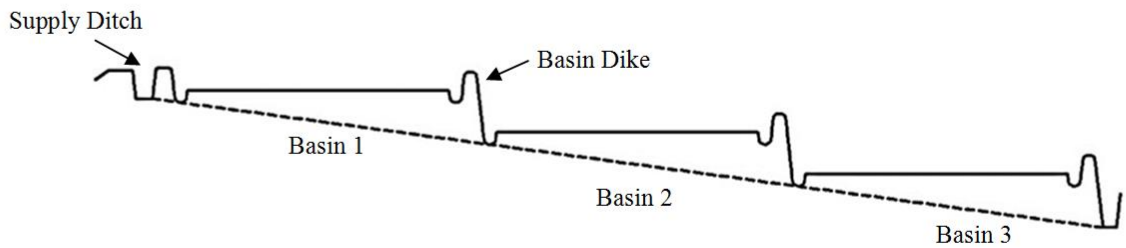

Figure 4. Sequential Basin

SOURCE: Savva and Frenken, Irrigation Manual Volume II Module 7 - Surface irrigation systems: planning, design, operation and maintenance, 2002

6.2 Design Criteria

6.2.1 Topography - The basin shall be nearly if not completely level to prevent tailwater. A difference of 6 cm to 9 cm between the highest and lowest elevations may be allowed such that it is less than one-half of the net depth of application.

6.2.2 Soil type - Sandy soils or fine-textured soils that crack when dry shall be avoided to maintain adequate basin ridge height.

6.2.3 Application rate - Irrigation water shall be applied at a rate that will advance over the basin in a fraction of the infiltration time

6.2.4 Irrigation volume - The volume of water applied shall be equal to the average gross irrigation application.

6.2.5 Intake opportunity time -The intake opportunity time at all points in the basin shall be greater than or equal to the time required for the net irrigation to infiltrate the soil. The longest intake opportunity time at any point in the basin area shall be sufficiently short to avoid scalding and excessive percolation losses.

6.2.6 Depth of water - The depth of water flow shall be contained by the basin dikes.

6.2.7 Design application efficiency - The minimum design application efficiency shall be 70% thus, the minimum time required to cover the basin shall be 60% of the time required for the net application depth to infiltrate the soil.

6.2.8 Basin dikes – Top width of the basin dike shall be greater than or equal to the height of the dike. The settled height shall be at least equal to either the gross application depth or the design maximum depth of flow plus a freeboard of 25%, whichever is greater.

6.2.9 Supply ditches – Supply ditches shall convey the design inflow rate of each basin or multiples of the design flow rate where more than one basin is irrigated simultaneously. The water surface in the ditch shall be 15 cm to 30 cm above the ground surface level in the basin depending on the outlet characteristics. The ditches shall be constructed with a 0.1% grade or less to minimize the number of check structures and labor requirements.

6.2.10 Outlet location – One outlet shall be installed for basin widths of up to 60 m and flow rates up to 0.4 m^3/s. Multiple outlets at various locations may be installed depending on the rate of flow require and the width of the basin.

6.2.11 Drainage – Surface drainage facilities shall be provided for basins with low or moderate intake soils and in high rainfall areas.

6.2.12 Erosion – The maximum water flow velocity into the basin shall be less than or equal to 1 m/s to avoid scouring and erosion.

6.2.13 Agricultural practice – The width of the agricultural machinery or implement to be used in the basin shall be considered in finalizing the width.

6.3 Design Procedure

The design procedure is based on the objective to flood the entire area in a reasonable length of time so that the desired depth of water can be applied with a degree of uniformity over the entire basin. Table 2 shows the suggested basin size for different soil types and flow while Table 3 shows the maximum basin width based on slope. Figure 5 outlines the design procedure.

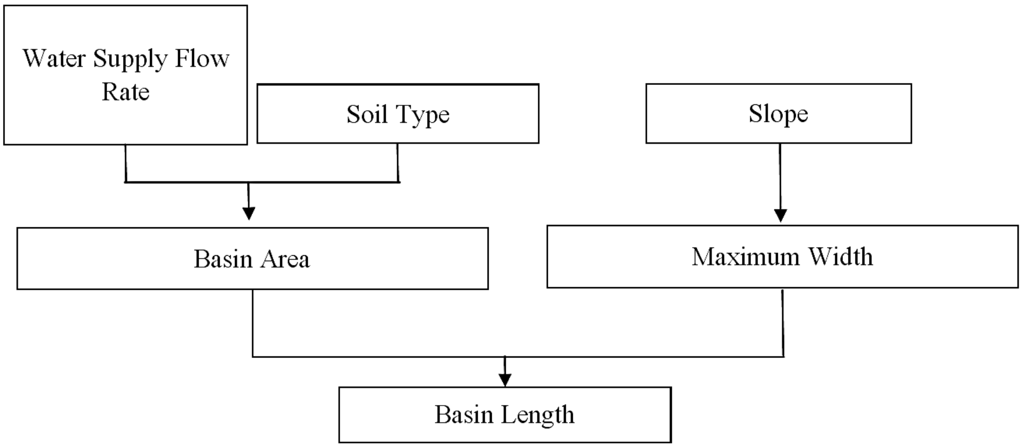

Figure 5. Design Procedure for Basin Irrigation Design

Table 2. Suggested Basin Areas for Different Soil Types and Rates of Water Flow

Flow Rate		Soil Type			
		Sand	Sandy Loam	Clay Loam	Clay
L/s	m^3/s	ha			
30	0.03	0.02	0.06	0.12	0.2
60	0.06	0.04	0.12	0.24	0.4
90	0.09	0.06	0.18	0.36	0.6
120	0.12	0.08	0.24	0.48	0.8
150	0.15	0.10	0.30	0.60	1.0
180	0.18	0.12	0.36	0.72	1.2
210	0.21	0.14	0.42	0.84	1.4
240	0.24	0.16	0.48	0.96	1.6
270	0.27	0.18	0.54	1.08	1.8
300	0.3	0.20	0.60	1.20	2.0

SOURCE: Booher, FAO Agricultural Development Paper 95: Surface Irrigation, 1974

Table 3. Approximate Values for the Maximum Basin Width

Slope (%)	Maximum Width (m)	
	Average	Range
0.2	45	35-55
0.3	37	30-45
0.4	32	25-40
0.5	28	20-35
0.6	25	20-30
0.8	22	15-30
1.0	20	15-25
1.2	17	10-20
1.5	13	10-20
2.0	10	5-15
3.0	7	5-10
4.0	5	3-8

SOURCE: Booher, FAO Agricultural Development Paper 95: Surface Irrigation, 1974

6.4 *Methods of Operation

6.4.1 Direct Method - Irrigation water is led directly from the field channel into the basin through siphons, spiles or bundbreaks.

6.4.2 Cascade Method - Irrigation water is supplied to the highest terrace, and then allowed to flow to a lower terrace and so on.

7 Border Irrigation

7.1 Types of Border Irrigation

7.1.2 Open-end Border System - This is usually applied to large borders where the end borders are provided with openings to accommodate free flow of water for drainage

7.1.3 Blocked-end Border System - This is usually applied to small borders where the end borders restrict the further downward flow of water.

7.2 Design Criteria

7.2.1 Crop – All close-growing, non-cultivated, sown or drilled crops, except rice and other crops grown in ponded water can be irrigated by border irrigation.

7.2.2 Topography – Areas shall have slopes of less than 0.5%. For non-sod crops, slopes of up to 2% may be acceptable and slopes of 4% and steeper for sod crops.

7.2.3 Soil Type – The soil shall have a moderately low to moderately high intake rate which is 7.6 mm/hr to 50 mm/hr. Coarse sandy soils with extremely high and those with etremely low intake rate shall be avoided.

7.2.4 Stream Size – The stream size shall be large enough to adequately spread water across the width of border.

7.2.5 Irrigation Depth – A larger irrigation depth shall be aimed by making the border strip longer in order to allow more time for the water to reach the end of the border strip.

7.2.6 Cultivation Practices – The width of borders shall be a multiple of the farm machinery used in the field.

7.3 Design Procedure

Table 4 provides a guideline in determining maximum border dimensions based on field experience. Figure 6 shows the design procedure.

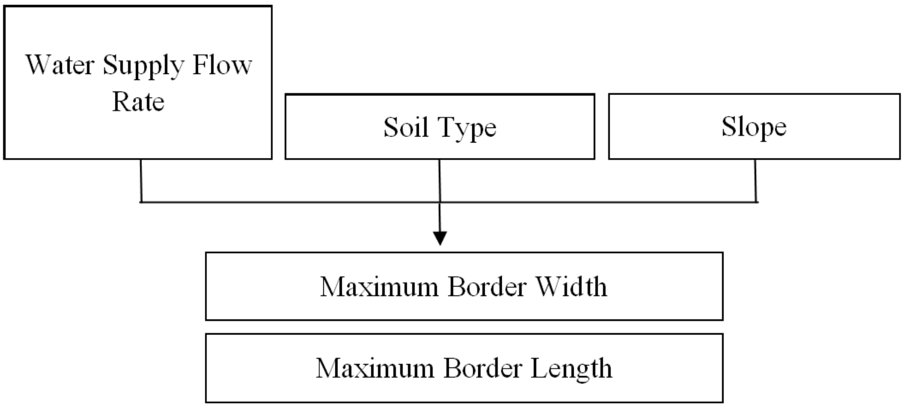

Figure 6. Design Procedure for Border Irrigation Design

Table 4. Suggested Maximum Border Lengths and Widths

Soil Type	Border Slope (%)	Stream Flow (L/s)	Border Width (m)	Border Length (m)
Sand	0.2-0.4	10-15	12-30	60-90
Infiltration rate greater than 25 mm/h	0.4-0.6	8-10	9-12	60-90
	0.6-1.0	5-8	6-9	75
Loam	0.2-0.4	5-7	12-30	90-250
Infiltration rate of 10 to 25 mm/h	0.4-0.6	4-6	6-12	90-180
	0.6-1.0	2-4	6	90
Clay	0.2-0.4	3-4	12-30	180-300
Infiltration rate of less than 10 mm/h	0.4-0.6	2-3	6-12	90-180
	0.6-1.0	1-2	6	90

SOURCE: Brouwer, Irrigation Water Management Training Manual No. 5: Irrigation Methods, n.d

7.4 Operation

Borders are irrigated by diverting a stream of water from the channel to the upper end of the border where it flows down the slope. When the desired amount of water has been delivered to the border, the stream is turned off which may occur before the water has reached the end of the border. The following may be used as guidelines:

7.4.1 On clay soils, the inflow is stopped when the irrigation water covers 60% of the border.

7.4.2 On loamy soils it is stopped when 70 to 80% of the border is covered with water.

7.4.3 On sandy soils the irrigation water must cover the entire border before the flow is stopped.

8 Furrow Irrigation

8.1 Types of Furrow Irrigation

8.1.1 Corrugation Irrigation

8.1.1.1 The water flows down the slope in small furrows called corrugalions or rills which is used for germinating drill-seeded or broadcasted crops.

8.1.1.2 No raised beds are used for crops.

8.1.2 Zigzag Furrow

8.1.2.1 This type of furrow irrigation shall increase the length that the water must travel to reach the end of irrigation run thus, reducing the average slope and velocity of the water.

8.1.2.2 This can be formed down and across the slope by machines.

8.2 Design Criteria

8.2.1 Slope – The minimum grade shall be 0.05% to facilitate effective drainage following irrigation and excessive rainfall. If the land slope is steeper than 0.5%, furrows shall be set at an angle to the main slope or along the contourto keep furrow slopes within the recommended limits.

8.2.2 Soil Type – Furrows shall be short in sandy soils to avoid excessinv percolation losses while furrows can be longer in clayey soils.

8.2.3 Stream Size – If the furrows are not too long, 0.5 L/s of stream flow shall be adequate for irrigation but the maximum stream size shall largely depend on the furrow slope.

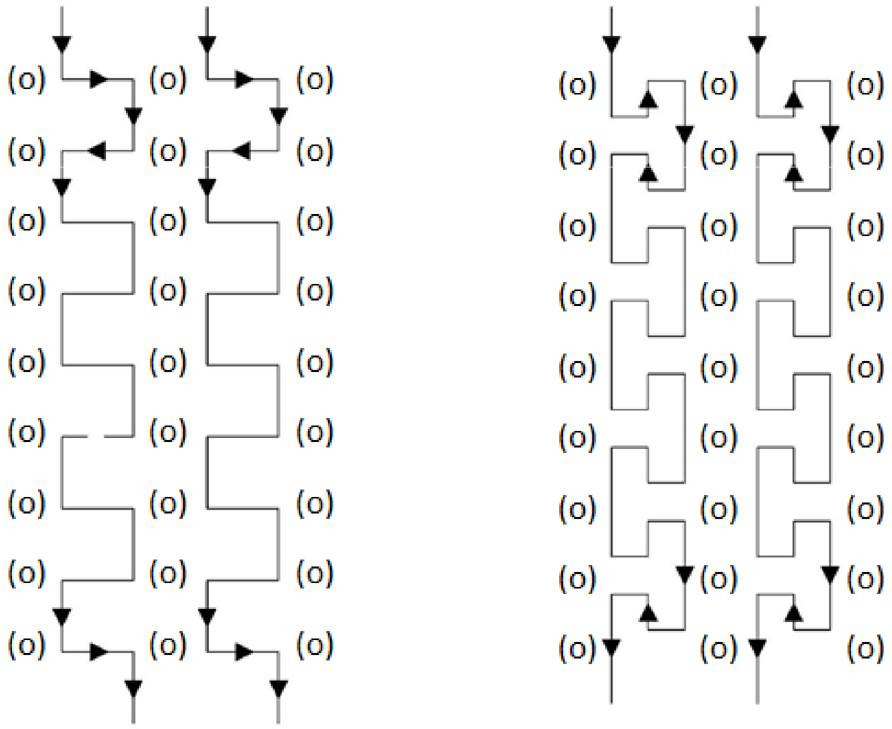

Figure 7. Zigzag Furrow
SOURCE: Brouwer, Irrigation Water Management Training Manual No. 5: Irrigation Methods, n.d

8.2.4 Irrigation Depth – Larger irrigation depths shall allow longer furrows.

8.2.5 Cultivation Practice – Compromise shall be made between the machinery available to cut furrows and the ideal plant spacing while ensuring that the spacing provides adequate lateral wetting on all soil types

8.3 Design Procedure

Figure 8 outlines the design procedure.

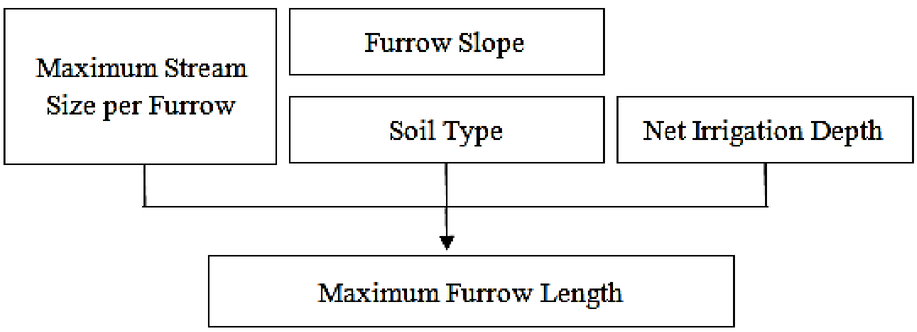

Figure 8. Design Procedure for Furrow Irrigation Design

8.3.1 Furrow Length

The recommended furrow length based on different parameters are shown in Table 5. However, it may be practical to make the furrow length equal to the length of the field in order to avoid leftover land.

Table 5. Practical Values of Maximum Furrow Lengths (m) Depending on Slope, Soil Type, Stream Size and Net Irrigation Depth

Furrow Slope (%)	Maximum Stream Size (l/s) per furrow	Clay		Loam		Sand	
		Net Irrigation Depth (mm)					
		50	75	50	75	50	75
0.0	3.0	100	150	60	90	30	45
0.1	3.0	120	170	90	125	45	60
0.2	2.5	130	180	110	150	60	95
0.3	2.0	150	200	130	170	75	110
0.5	1.2	150	200	130	170	75	110

SOURCE: Brouwer, Irrigation Water Management Training Manual No. 5: Irrigation Methods, n.d

8.3.1.1 Gross Depth of Irrigation

$$d_{gross} = \frac{\text{Stream Size} \times \text{Time Water Applied}}{\text{Furrow Length} \times \text{Wetted Furrow Spacing}}$$

8.3.1.2 Required Discharge from Source

$$\text{Discharge from Source} = \text{Stream Size} \times \text{Number of Furrows Flowing}$$

8.3.2 Furrow Shape

8.3.2.1 The furrow shall be large enough to contain the expected stream size.

8.3.2.2 Narrow, deep V-shaped furrows as shown in Figure 9 shall be made in sandy soils in order to reduce the area through which water percolates.

8.3.2.3 Wide, shallow furrows as shown in Figure 10 shall be made in clay soils in order to obtain a large wetted area

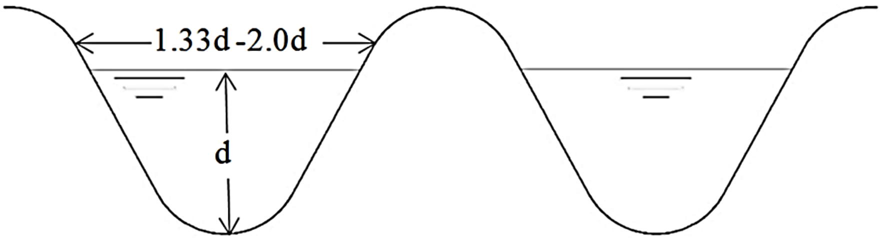

Figure 9. Furrows for Sandy Soils
SOURCE: Savva and Frenken, Irrigation Manual Volume II Module 7 - Surface irrigation systems: planning, design, operation and maintenance, 2002

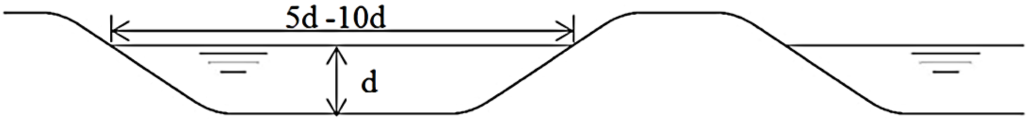

Figure 10. Furrows for Clayey Soils
SOURCE: Savva and Frenken, Irrigation Manual Volume II Module 7 - Surface irrigation systems: planning, design, operation and maintenance, 2002

8.3.3 Furrow Spacing

Table 6. Recommended Furrow Spacing Based on Soil Type

Soil Type	Furrow Spacing (cm)
Coarse Sand	30
Fine Sand	60
Clay	75-150

SOURCE: Brouwer, Irrigation Water Management Training Manual No. 5: Irrigation Methods, n.d

8.4 Operation

8.4.1 Direct Application- Water is supplied to each furrow from the field canal, using siphons or spiles. If available, a gated pipe is used. Figure 10 and Figure 11 show the direct application of water into each furrow.

8.4.2 Alternate Furrow Irrigation – It involves irrigating alternate furrows rather than every furrow. Small amounts applied frequently in this way are usually better for the crop than large amounts applied after longer intervals of time.

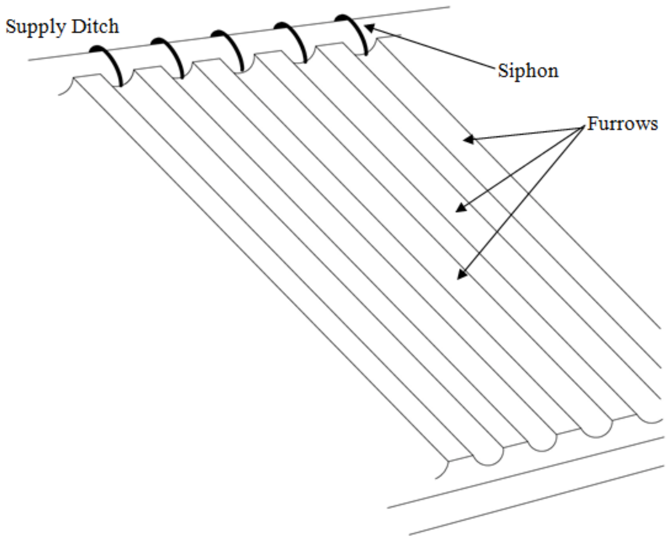

Figure 10. Furrow Irrigation Using Siphons
SOURCE: Brouwer, Irrigation Water Management Training Manual No. 5: Irrigation Methods, n.d

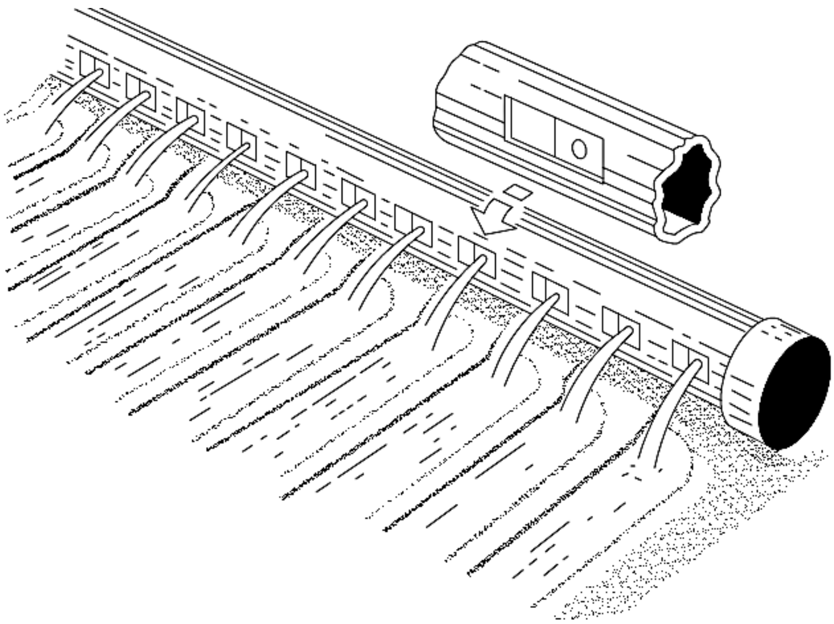

Figure 11. Gated Pipe
SOURCE: Brouwer, Irrigation Water Management Training Manual No. 5: Irrigation Methods, n.d

The procedure for evaluating a furrow irrigation system is shown in Annex A.

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ANNEX A
(informative)

Performance Evaluation of a Furrow Irrigation System

A.1 Materials and Equipment

- Stakes
- Steel Tape
- Timer
- Parshall Flume
- Weir
- Infiltrometer
- Profilometer - a device with individual scales on the rods to provide data to plot furrow depth as a function of the lateral distance where data can then be numerically integrated to develop geometric relationships such as area verses depth, wetted perimeter versus depth and top-width verses depth

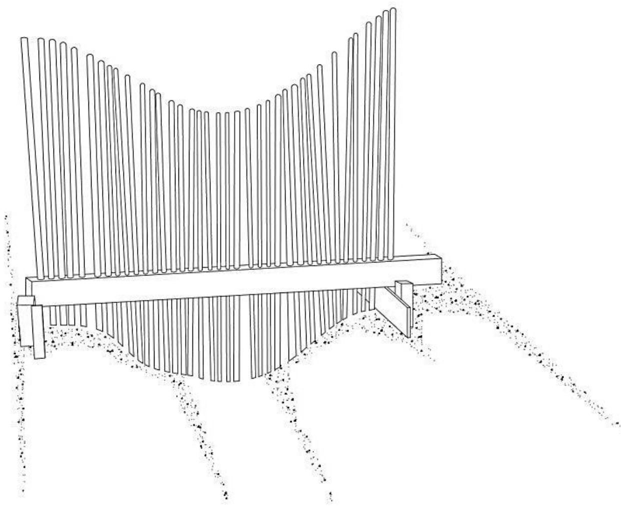


Figure A.1. Profilometer

A.2 Site Selection

A.2.1 The test furrows shall be representative of the irrigated area.

A.2.2 The test furrows shall be of uniform furrow shape and length.

A.2.3 Tests shall be conducted during a normal irrigation period.

A.2.4 There shall be no entry and leakage of water from any other sources.

A.3 Test Set-up

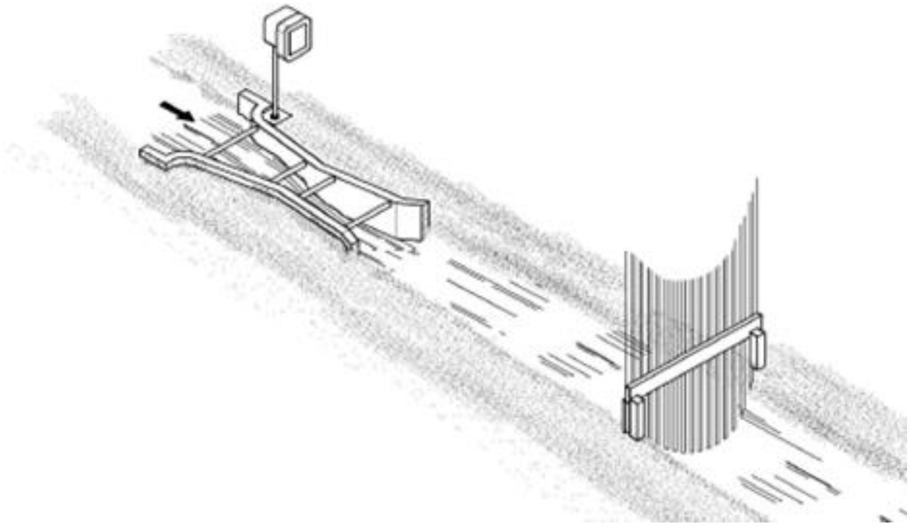


Figure A.2. Test Set-up for Evaluating a Furrow Irigation System

A.3.1 Flow measuring devices shall be installed as close to the beginning of the test furrows.

A.3.2 Stations shall be marked with stakes and shall be assigned at uniform intervals such that measurements will be convenient.

A.3.3 The inlet end of the furrow shall be marked as Station 0+00.

A.4 Preliminary Measurements

A.4.1 Furrow Length – This shall be measured from the furrow intake to the end of the furrow.

A.4.2 Furrow Slope – Any slope variation shall be recorded.

A.4.3 Furrow Spacing – This shall be measured as the distance between the centerlines of the wetted furrows.

A.4.4 Furrow Geometry – The furrow cross-section which includes depth and top width shall be determined using a profilometer.

A.4.5 Soil Type and Condition – The location and extent of major soil types shall be determined

A.4.6 Soil Moisture Depletion – The soil moisture content shall be determined prior to irrigation.

A.4.7 Type of Crop – The type of crop and cultivation practices shall be noted.

A.5 Test Readings and Measurement

A.5.1 Infiltration – The infiltration characteristics of the furrows shall be determined. Various methods such as inflow-outflow measurement, double ring infiltrometer (see Annex C), blocked furrow infiltrometer and recirculation flow infiltrometer can be used. In general, the following conditions shall be considered:

A.5.1.1 Infiltration tests shall be conducted as close as possible to the time of irrigation and under representative conditions.

A.5.1.2 The furrow water depth to be used during the tests shall be as close to the normal irrigation depth.

A.5.1.3 Infiltration characteristics shall be determined during the first, second and another irrigation event if the system will be evaluated for an entire cropping.

A.5.2 Inflow Rate – Inflow rates shall be determined using flumes, orifices or weirs. The following conditions shall be considered:

A5.2.1 For relatively flat slopes where ponding may become a problem, using flumes is recommended.

A.5.2.2 A range of stream sizes, including the normal irrigating stream size, shall be applied to the test furrows.

A.5.2.3 Flow rates shall be measured and recorded periodically along with the time of reading.

A.5.3 Advance Rate – The time at which the waterfront reaches each marked station shall be recorded.

A.5.4 Runoff – The rate of runoff at each test furrow shall be recorded.

A.5.5 Wetted Cross-section – The flow depth and top width of each furrow at each station shall also be recorded.

A.5.6 Recession – The time when inflow to the furrows ceases shall be recorded.

A.5.7 Postirrigation Soil Water – This shall be determined one to three days after the irrigation event.

A.5.8 A data sheet for recordings is provided in Table A.1

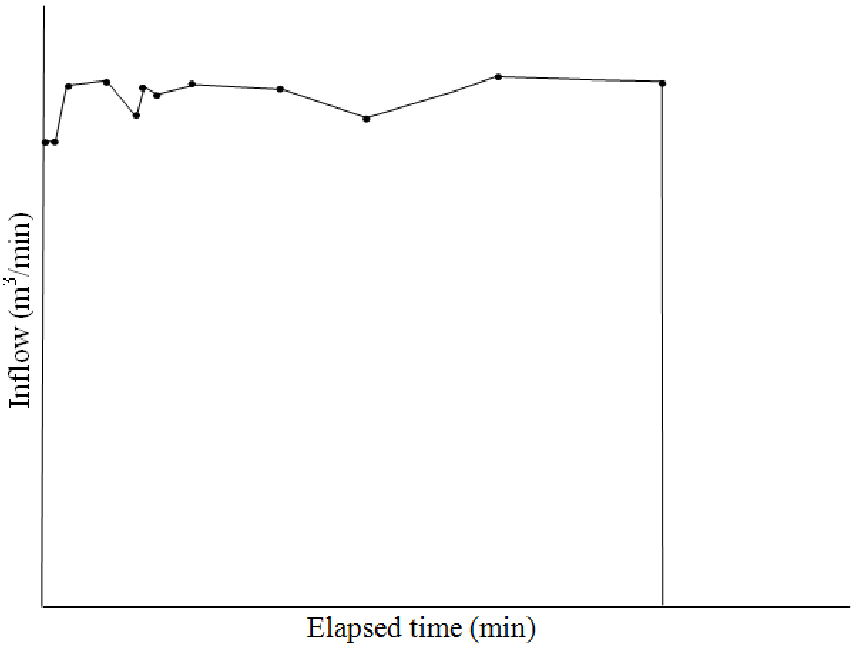
Table A.1. Data Sheet for Furrow Irrigation Evaluation

PRELIMINARY DATA	
Furrow	Length
	Slope
	Spacing
	Top Width
	Depth
Soil	Type
	Condition
	Moisture Depletion
	Type of Crop

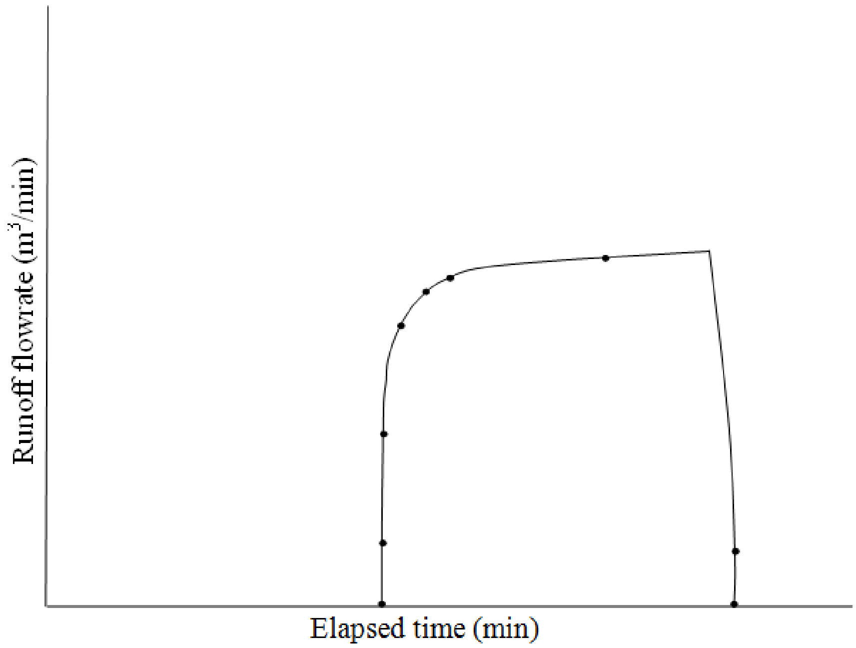
Furrow, Station Number	Inlet Discharge	Distance from Furrow Inlet	Advance Time		Recession Time		Outflow	Time Elapsed
			Clock Reading when Station is Reached	Time elapsed since start	Clock Reading when longitudinal water movement stops	Time elapsed since start		

A.6 Graphs

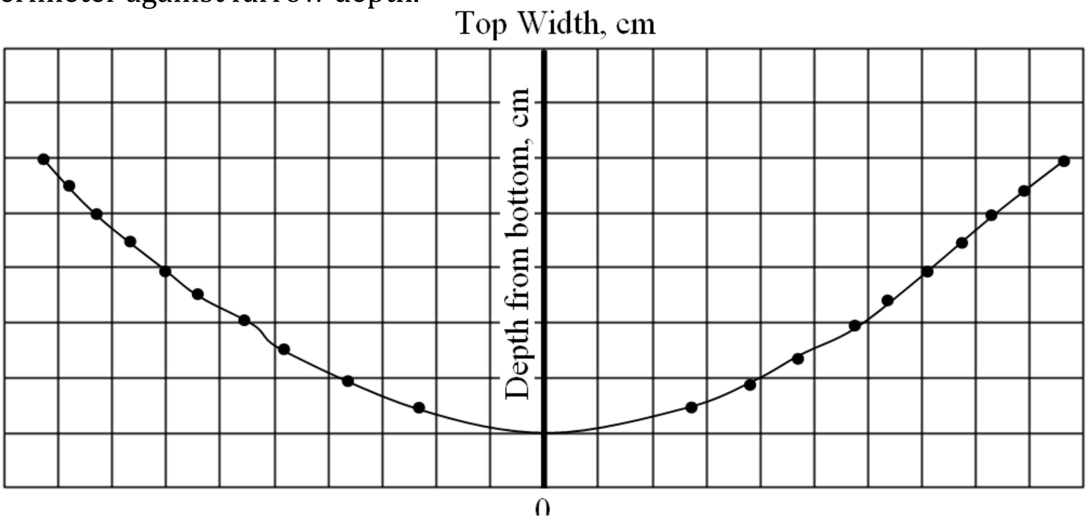
A.6.1 Furrow Inflow Hydrograph – Generate the furrow inflow hydrograph by plotting the inflow to the furrow against time.



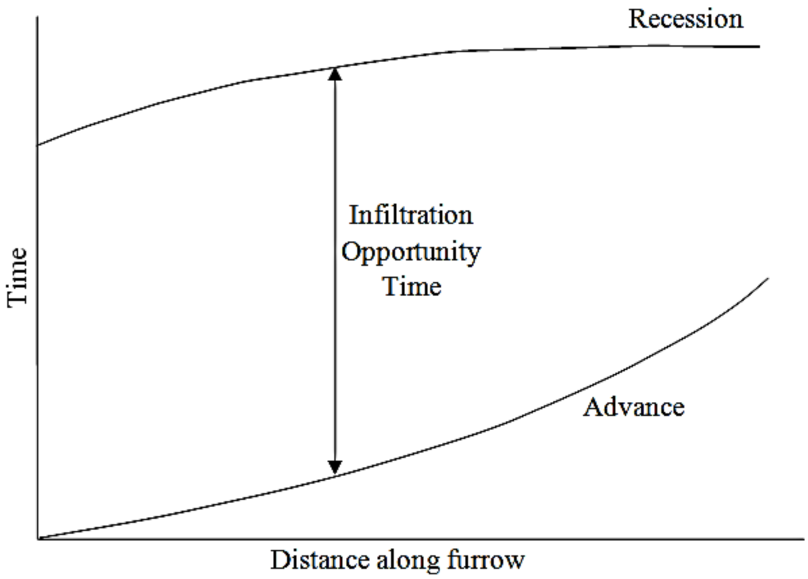
A.6.2 Runoff Hydrograph – Generate the furrow runoff hydrograph by plotting the outflow against time.



A.6.3 Furrow Shape Analysis – Generate the graph of area and wetted perimeter against furrow depth.



A.6.4 Advance and Recession Trajectory - Generate the trajectories by plotting the advance time and recession time against distance.



A.7 Equations

A.7.1 Total volume of infiltration

$$V_z = V_{in} - V_{tw}$$

where:

V_z	is the total volume of infiltration (m^3)
V_{in}	is the volume of inflow (m^3)
V_{out}	is the volume of runoff (m^3)

A.7.2 Basic Intake Rate

$$f_o = (Q_{in} - Q_{out})/L$$

where:

f_o is the basic intake rate (m^3/min/m)
Q_{in} is the flow rate into the field (m^3/min)
Q_{out} is the flow rate out of the field (m^3/min)
L is the furrow length (m)

A.7.3 Advance distance

$$x = pt_x^r$$

$$r = \frac{log(L)/log(0.5L)}{log(t_L)/log(t_{0.5L})}$$

$$p = L/t_L^r$$

where:

x is the advance distance (m)
t_x is the time of inflow from inlet to distance x (min)
$t_{0.5L}$ is the time of advance to a point near one-half the field length (min)
t_L is the time of advance to the end (min)
p,r is the fitting parameters
L is the furrow length (m)

A.7.4 Area wetted

$$A_x = 33.92t_x^{0.74}$$

where:

A_x is the area wetted (m^2)
t_x is the time of inflow from inlet to distance x (min)

A.7.5 Flow geometry

$$Q = \frac{p_1 A^{p_2} S_o^{0.5}}{n}$$

where:

Q is the discharge (m^3/s)
A is the cross-sectional area of the flow (m^2)
S_o is the slope of the hydraulic grade line, assumed equal to the field slope
n is the Manning's roughness coefficient
p_1, p_2 is the geometry parameter determined from furrow cross section analysis (see Annex B)

A.7.6 Cross-Section Area of Flow at the Inlet

$$A_o = \left(\frac{Q_o n}{60 p_1 S_o^{0.5}}\right)^{1/p_1}$$

where:

A_o	is the cross-section area of flow at the inlet, m^2
Q_o	is the inlet discharge, m^3/min/furrow
n	is the Manning's roughness coefficient
p_1	is the geometry parameter determined from furrow cross section analysis (see Annex B)
S_o	is the slope of the hydraulic grade line, assumed equal to the field slope

A.7.7 Subsurface Shape Factor

$$s_z = \frac{a + r(1-a) + 1}{(1+r)(1+a)}$$

$$a = \frac{log(V_L/V_{0.5L})}{log(t_L/t_{0.5L})}$$

$$V_L = \frac{Q_o t_L}{L} - s_y A_o - \frac{f_o t_L}{(1+r)}$$

$$V_{0.5L} = \frac{2Q_o t_{0.5L}}{L} - s_y A_o - \frac{f_o t_{0.5L}}{(1+r)}$$

where:

s_z	is the subsurface shape factor
r	is the fitting parameter (section A.7.3)
Q_o	is the inlet discharge (m^3/min/furrow)
t_L	is the time of advance to the end (min)
$t_{0.5L}$	is the time of advance to a point near one-half the field length (min)
s_y	is the surface storage shape factor (usually 0.7 to 0.8)
A_o	is the cross-section area of flow at the inlet (m^2) (section A.7.6)
f_o	is the basic intake rate (m^3/min/m) (section A.7.2)
L	is the furrow length (m)
r	is the fitting parameter (section A.7.3)

A.7.8 Volume Balance

$$Q_{ot} = s_y A_o x + s_z k t^a x + \frac{f_o t x}{1 + r}$$

$$k = \frac{V_L}{s_z t_L^a}$$

where:

s_y	is the surface storage shape factor (usually 0.7 to 0.8)
A_o	is the cross-section area of flow at the inlet (m^2)
x	is the advance distance (m) (section A.7.3)
s_z	is the subsurface shape factor (section A.7.7)
t	is the elapsed time since the irrigation started (min)
f_o	is the basic intake rate (m^3/min/m) (section A.7.2)
r	is the fitting parameter (section A.7.3)
V_L	parameter determined from section A.7.7
t_L	is the time of advance to the end (min)
a	parameter determined from section A.7.7

A.7.9 Field Evaluated Infiltration Function

$$Z_i = k[t_r - (t_x)_i]^a + f_o[t_r - (t_x)_i]$$

where:

Z_i	is the cumulative intake at each increment of length i (m^3/m)
k	is the parameter determined from section A.7.8
a	is the parameter determined from section A.7.7
t_x	is the recession time (min)

A.8 Evaluation

In evaluating the performance of a furrow irrigation system, the following assumptions were considered:

- the crop root system extracts moisture from the soil uniformly with respect to depth and location
- the infiltration function of the soil is a unique relationship between infiltrated depth and the time water is in contact with the soil
- the objective of irrigating is to refill all of the root zone

A.8.1 Application Efficiency

$$E_a = \frac{Volume\ of\ water\ added\ to\ the\ root\ zone}{Volume\ of\ water\ applied\ to\ the\ field}$$

$$E_a = 100 \times \frac{Z_{req} \times L}{Q_o \times 60 \times t_{co}}$$

where:

E_a	is the application efficiency
Z_{req}	is the soil moisture depletion measured x furrow Spacing (m^3/m)
L	is the length of furrow (m)
Q_o	is the inlet discharge (m^3/min/furrow)
t_{co}	is the cutoff time (s)

A.8.2 Tailwater Ratio

$$TWR = \frac{Volume\ of\ runoff}{Volume\ of\ water\ applied\ to\ the\ field}$$

$$TWR = 100 \times \frac{V_{out}}{Q_o \times 60 \times t_{co}}$$

where:

V_{out}	is the runoff per furrow (m^3/furrow)
Q_o	is the inlet discharge (m^3/min/furrow)
t_{co}	is the cutoff time (s)

A.8.3 Deep Percolation Ratio

$$DPR = \frac{Volume\ of\ deep\ percolation}{Volume\ of\ water\ applied\ to\ the\ field}$$

$$DPR = 100 - E_a - TWR$$

where:

DPR	is the deep percolation ratio
E_a	is the application efficiency (%) (section A.8.1)
TWR	is the tailwater ratio

ANNEX B
(informative)

Furrow Cross-Section Analysis

B.1 Plot or develop the furrow cross section from the profilometer measurements.

B.2 Divide the depth into equal increments.

B.3 Integrate the area and wetted perimeter and generate a table shown in Table B.1.

Table B.1. Furrow Cross-section Data

Furrow Depth (y)	Area (A)	Wetted Perimeter

B.4 Select two points of furrow depth from the table and denote as y_1 and y_2, while the corresponding area and wetted perimeter are A_1, A_2 and WP_1 and WP_2, respectively.

B.5 Assume a power relation between depth and area, and depth and wetted perimeter.

$$A = a_1 y^{a_2}$$
$$WP = b_1 y^{b_2}$$

B.6 At y_1, $A = A_1$, $WP = WP_1$; at y_2, $A = A_2$, $WP = WP_2$, then

$$a_2 = \log\left(\frac{A_2}{A_1}\right) \;;\quad a_1 = \frac{A_2}{10^{a_2}}$$

$$b_2 = \log\left(\frac{WP_2}{WP_1}\right) \;;\quad b_1 = \frac{WP_2}{10^{b_2}}$$

B.7 From the Manning's formula and power relation equations,

$$p_2 = 1.667 - 0.667\frac{b_2}{a_2}$$

$$p_1 = \frac{{a_1}^{1.667-p_2}}{{b_1}^{0.667}}$$

ANNEX C
(informative)

Determination of Infiltration Rate Using Infiltrometer

Infiltration is measured by observing the fall of water within the inner cylinder of two concentric cylinders driven vertically into the soil surface layer. The infiltration measurement in the inner ring is the representative infiltration of the irrigation area.

C.1 Select possible locations for 3-4 infiltrometers spread over the irrigation area. Avoid areas with signs of unusual surface disturbance, animal burrows, stones and others.

C.2 Drive the cylinder into the soil to a depth of approximately 15 cm by placing a driving plate over the cylinder, or placing heavy timber on top, and using a driving hammer. Rotate the timber every few pushes or move the hammer equally over the surface in order to obtain a uniform and vertical penetration.

C.3 Fix a gauge (almost any type) to the inner wall of the inner cylinder so that the changes in water level can be measured.

C.4 Fill the outer ring with water to a depth approximately the same as will be used in the inner ring and also quickly add water to the inner cylinder till it reaches 10 cm or 100 mm on the gauge.

C.5 Record the clock time immediately when the test begins and note the water level on the measuring rod.

C.6 The initial infiltration will be high and therefore regular readings at short intervals should be made in the beginning, for example every minute, after which they can increase to 1, 2, 5, 10, 20, 30 and 45 minutes, for example. The observation frequencies should be adjusted to infiltration rates.

C.7 After a certain period, infiltration becomes more or less constant. Then the basic infiltration rate is reached. After reading equal water lowering at equal intervals for about 1 or 2 hours, the test can stop.

C.8 The infiltration during any time period can be calculated by subtracting the water level measurement before filling at the end of the period from the one after filling at the beginning of that same period.

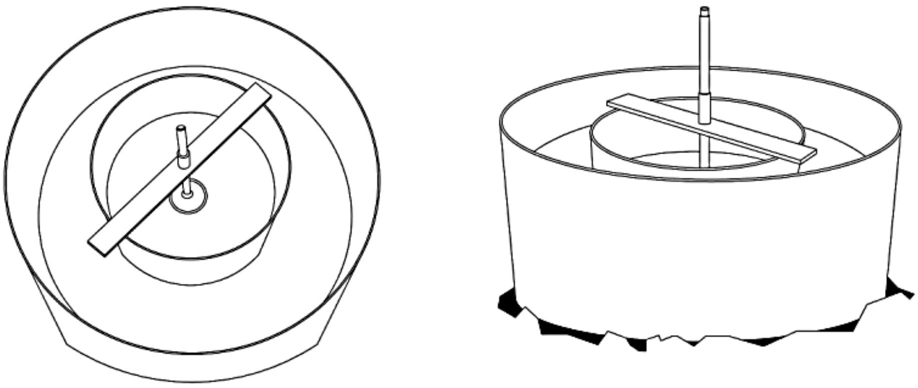


Figure C.1. Double-Ring Infiltrometer

Table C.1. Data Sheet for Infiltrometer Test

Watch Reading (hr:min)	Time Interval (min)	Cumulative Time (min)	Water Level Reading		Infiltration (mm)	Infiltration Rate (mm/min)	Cumulative Infiltration (mm)
			before filling (mm)	after filling (mm)			

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