SURFACE IRRIGATION

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Surface Irrigation

1. Introduction

In recent years, there has been a rapid increase in the use of sprinkler and micro-Irrigation. However, the most popular irrigation method is still traditional surface irrigation, whereby water is spread across the land using basin, border and furrow techniques. More than 90 % of all irrigation involves the use of surface irrigation and it is unlikely that this will change in the foreseeable future.

Many types of surface irrigation systems have been developed to suit different agricultural systems and communities. Some are very small covering only a few hectares, others are large, covering many thousands of hectares. However, they all have the following components in common (Figure 1):

- source of water
- distribution system
- irrigation unit
- drainage system
- access

On farm irrigation system will perform well only if farmers know how to manage irrigation water. This includes the selection of water application rate, application time and farm size. All these factors are interrelated and are related to soil infiltration rate, crop consumptive use, types of crop and field conditions. Properly selected values of these factors will ensure good uniformity of water application and reduce the water losses.

In this chaper, the selection of surface irrigation methods and the basic principles of surface irrigation system design are discussed.

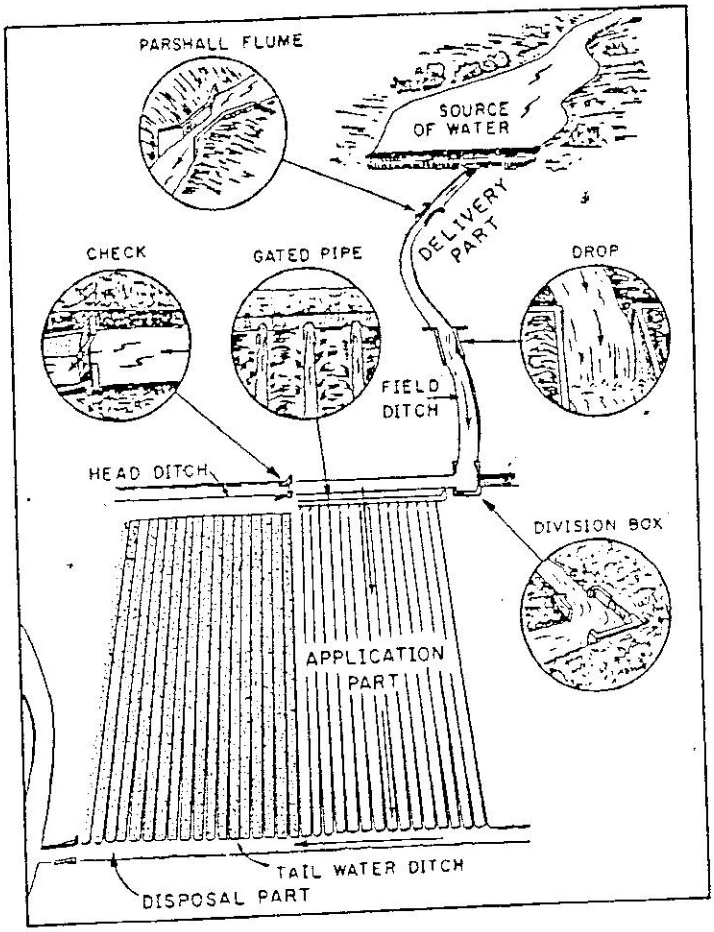
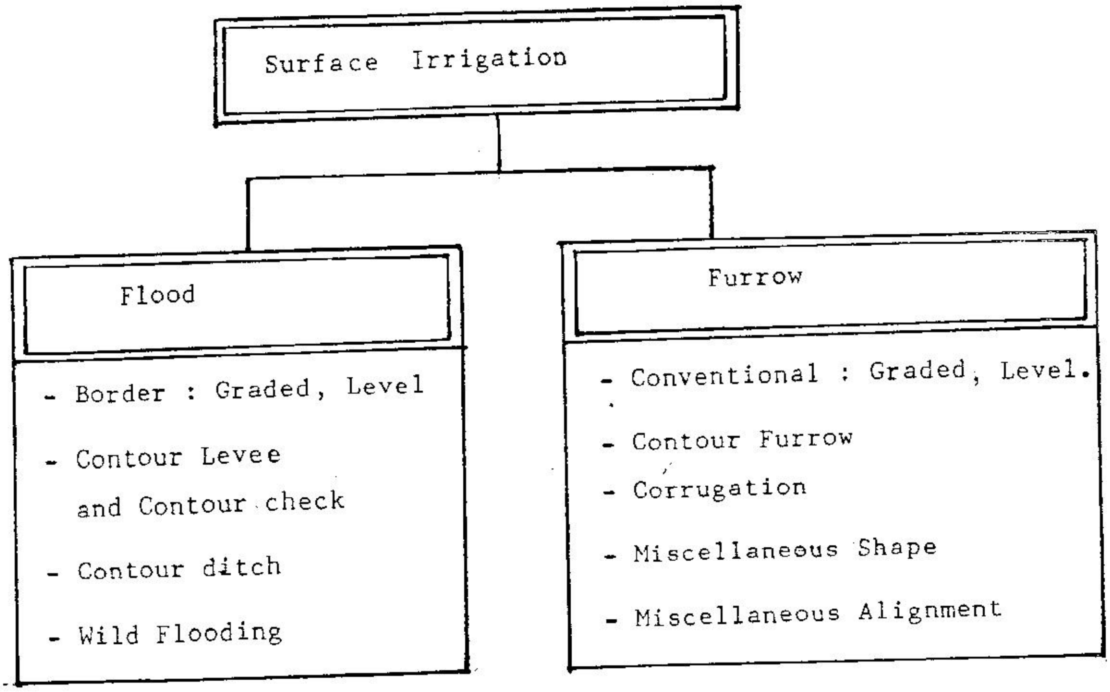


Figure 1 A Farm Surface Irrigation System

2. Surface Irrigation Methods

Surface irrigation is the water application technique where water flows or ponds on the soil surface and gradually infiltrates into the soil. There are many methods of surface irrigation. However in general, surface irrigation can be divided into 2 categories namely flood and furrow. These 2 basic surface irrigation methods can also divided as shown in the following diagram.



Only Graded Furrow, Graded Border and Level Border or Basins are discussed in the next 3 chapters.

Surface irrigation has been known to farmers for more than decades and is still very popular. Greater than 90 % of the whole irrigation in the world are surface irrigation. This is because surface irrigation has several advantages which can be summarized as follow:

(1) It can be applied to almost all kinds of crop and can be modified to suit different sizes and methods of water delivery.

(2) High flexibility. The application time is a lot shorter than others irrigation method. This flexibility is very important for hot and dry climate where crops require increditably large amount of water.

(3) Investment is lower since this method of irrigation let water flows on the soil surface by gravity. In case it requires

pump, it usually requires smaller pumping unit, lower horse power. Becides there is almost no irrigation structures or equipments requiring high degree of maintenance.

(4) Reliable. Since surface irrigation requires a few pieces of equipments. Therefore the damage to crops due to unavailable water is rarely occurred.

(5) Good design and good management can increase irrigation efficiency to as high as other techniques.

The disadvantages of surface Irrigation are:

(1) It requires uniform grade. This limits the application to only level or almost level land. On an undulating topography, the cost of land smoothing and leveling can be very high.

(2) Erosion can take place if the land slope is too steep

(3) Ditch and dike may obstructed the machines operating on farm.

(4) Drainage problems if water is not used efficiently or a proper method is not selected

(5) Require more labor.

3. Design of Surface Irrigation

3.1 Required Data

In design of surface irrigation, it requires a lot of data including water, topography, soil, crops and etc. The data can be classified into 5 groups.

(1) Water. The total amount of water available throughout the year or season, method of water delivery, discharge, water quality, rainfall and effective rainfall and crop and irrigation water requirements.

(2) Topography. Size , shape and slope of land, location of water sources and natural drainage system.

(3) Soil. Soil stability, soil suitability for canal construction, depth of top soil, soil water holding capacity, surface soil property change after flooding such as surface cracking, infiltration rate, salt problems in soil, erodibility and soil drainage capability.

(4) Crops. Types of crop, area to be grown, root zone depth, crop water requirements at different stages throughout the season, farming practices and etc.

(5) Other data. Labor and farm machine availability, financial situation and etc.

3.2 Choosing A Surface Irrigation Method

Choosing a water application method which is suitable to soil, crops and other factors is an outmost important. Otherwise, the cost of surface irrigation can be very high. The method may not be effective and can damage the cultivation area such as eroding soil surface, leaching plant nutrients, increasing groundwater table and causing salinity problem. Therefore, to decide which is the best method of surface irrigation to use, many factors must be considered (Table 1). These include: land togography, soils, field shape, crops and labor.

3.3 Basic Considerations in Design

In order to have good surface irrigation system, many basic considerations have to be made in design of the system. Those are:

(1) the system must be responsive to crop consumptive use,

(2) the system must be able to apply water uniformly throughout the field,

<u>Table 1</u> Factors Effecting Choice of Surface Irrigation Method

Irrigation Method	Land Topography				Soil In-filtration Rate (mm/hr.)	Field Shape	Crops				Labour (hour/ha per irri-gation)
	Humid Regions		Arid Regions				Row crops	Sown drilled crop	Flooded rice	Orchards	
	Bare soil	Good crop cover	Bare soil	Good crop cover							
Basin	Level slope or less than 0.1% (steeper slopes need terracing)				up to 30	Any shape	Yes	Yes	Yes	Yes	0.5 - 1.5
Border	0.5	2.0	2.0	5.0	up to 30	Rectangu-lar	Yes	Yes	No	Yes	1.0 - 3.0
Furrow	0.3 Cross slope 3.0	-	2.0 Cross slope 3.0	-	up to 30	Rows should be equal length	Yes	No	No	Yes	2.0 - 4.0

(3) minimum soil surface erosion,

(4) minimum water losses,

(5) reuse the runoff with minimum extra cost, or provide the drainage system to avoid water logging at the tail end of the field,

(6) minimum labor requirements,

(7) minimum use of land for farm ditch and drainage systems (usually allows 5 % of the area),

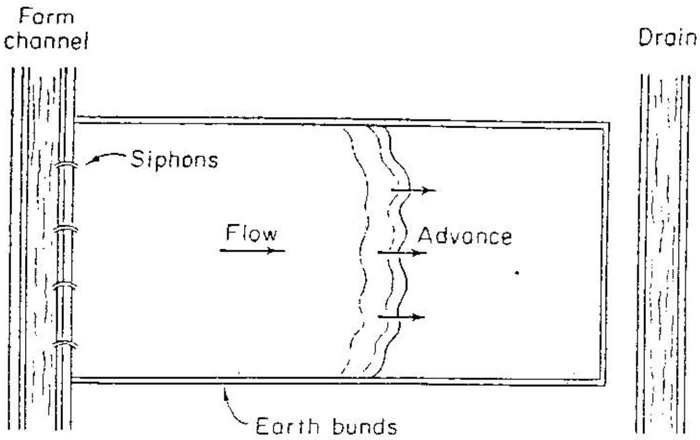
(8) depth of water application to area receiving water at the same time should not be too different, and

(9) requirements for farm machinery.

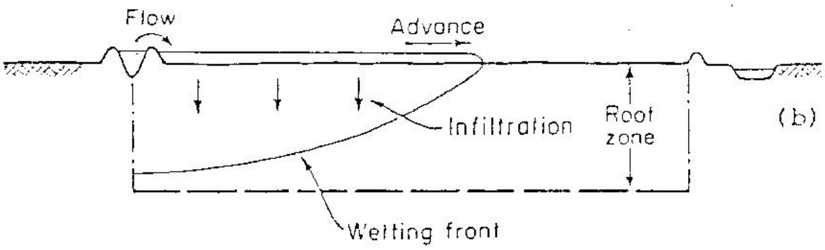
4. Characteristics of Surface Irrigation

As mentioned before, the surface irrigation is the method that allows water flowing on the soil surface and infiltrating into the soil . When water is supplied to the field through siphons or small outlets in the bank of the farm channel, it flows over the soil surface. Some water infiltrates into the soil while some advance along the field as shown in Figure 2. Whenever the size of stream is greater than the soil infiltration rate, water keeps advancing. The time between start of irrigation and water advances to the end of field is called Advance Phase. The graph showing the relationship between the elapsed time (on Y axis) and the advance distance (on X axis) is called Advance Curve.

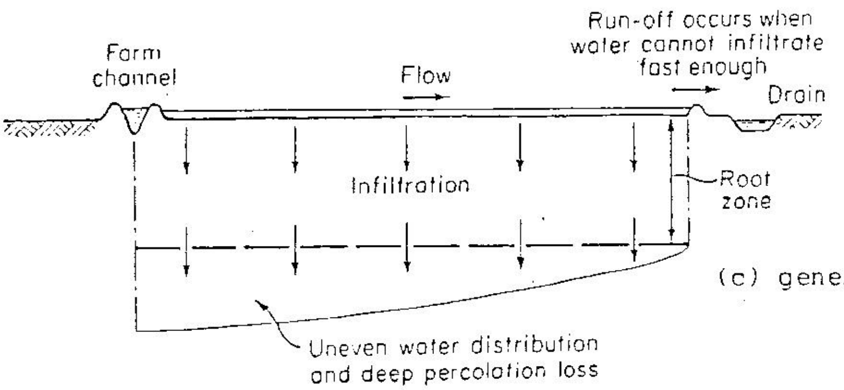
After water flows to the tail end, if water supply is still continued, water floods the whole field, the infiltration is continued and the runoff takes place. The time since water advances to the tail end until stop of irrigation is called Storage Phase.



(a) water moving on soil surface



(b) water moving in soil profile



(c) general problem

Figure 2 Surface Irrigation Characteristics

After stopping irrigation at the head end, Water may be still ponding on the soil surface. Some water infiltrater and some runoffs at the tail end. Finally, Water starts receding from the head end, or from the high spot. The time between stop of irrigation and water starts receding is called Lag Time.

After water starts receding from the head end, it continues to the tail end. This recession process is clearly seen on graded borders than furrows. The time when water starts dissappear at the head end until water receding from the whole field is called Recession Phase. The graph showing the relationship between recession time and distance is called Recession Curve.

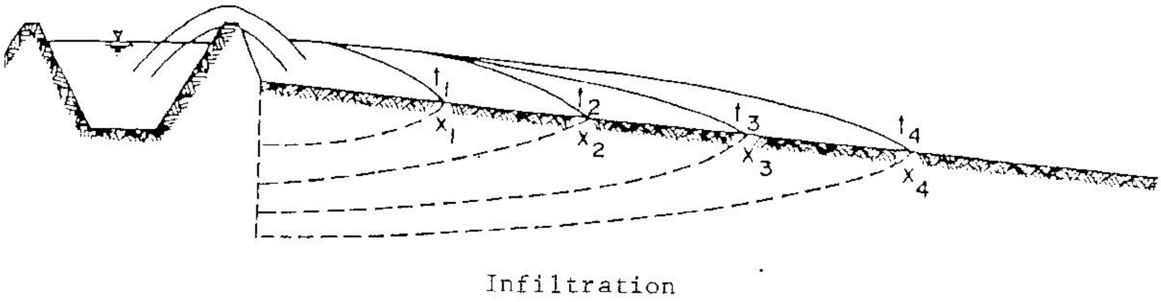
Typical characteristics of advance phase, advance curve and recession curve are shown in Figure 3. The time difference between recession curve and advance curve is called opportunity time or contact time.

4.1 Basin Irrigation

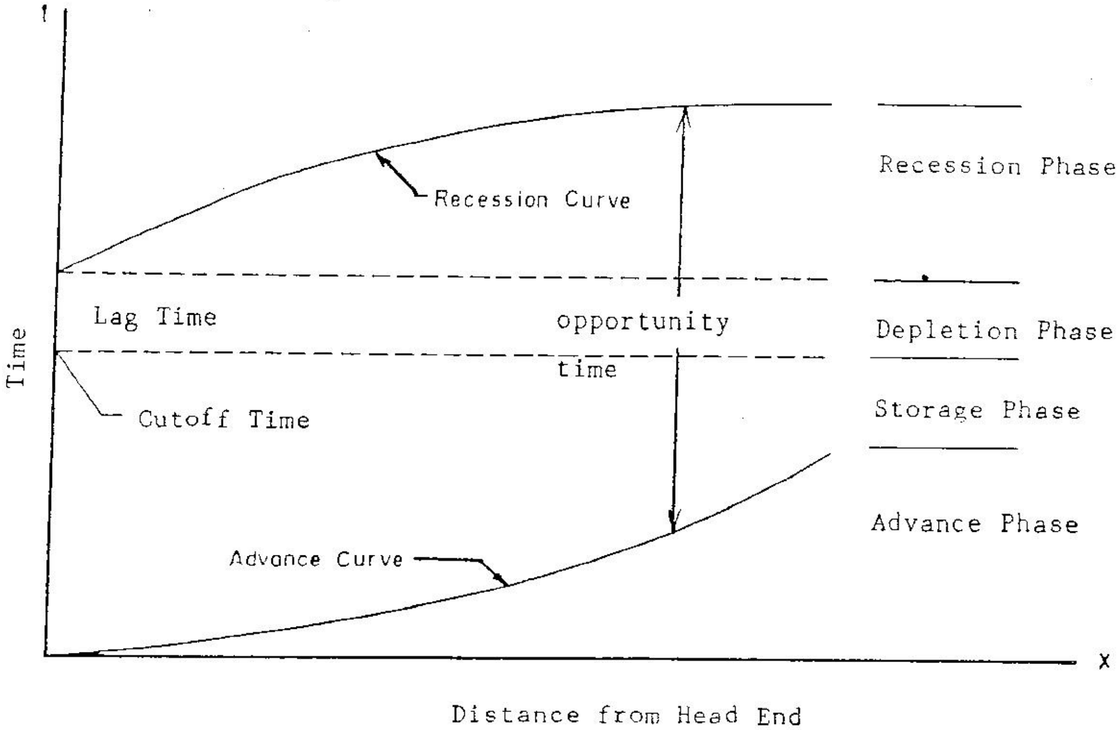
Basin irrigation usually apply with stream size large enough for water to spread to the tail end quickly as shown in Figure 4, because the basin requires level land or less than 0.01 % slope. If water is supplied with too small stream size, water may not be advanced to the tail end or the opportunity time at the head end is too long and the deep percolation takes place.

Normally, a practical guideline is to use a stream size large enough for the flow to reach the tail end of the field in one quarter of the opportunity time. This is called the quarter time rule.

Basin irrigation is one of the most popular method of irrigation because it is simple and suitable to almost all types of crops, soil and topography. The efficiency can be very high if it is properly designed and managed since only deep percolation loss can occur.



(a) Advance Characteristics



(b) Definition Sketch Showing Surface Irrigation Terms

Figure 3 Typical Characteristics of Advance and Recession of Surface Irrigation

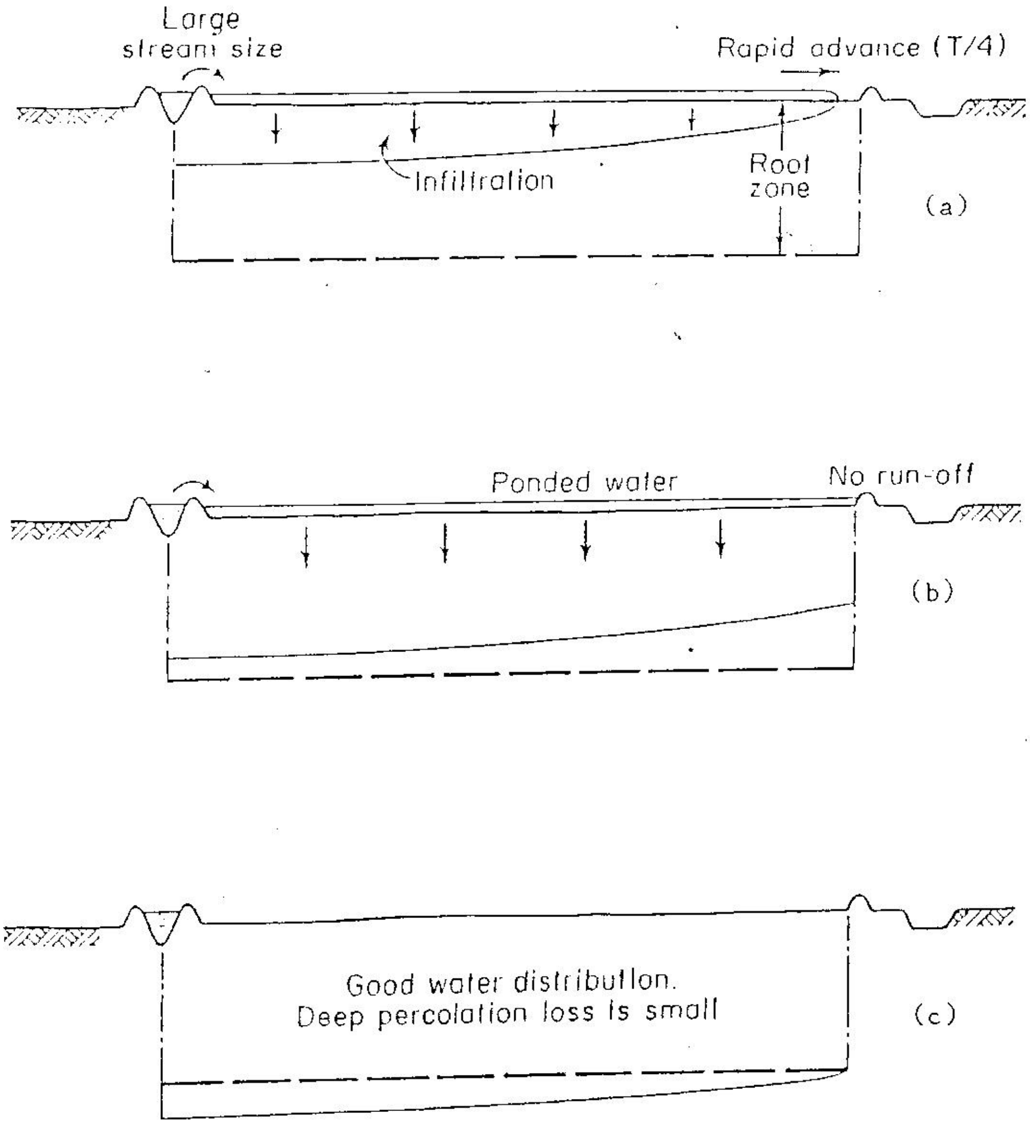


Figure 4 Basin Irrigation (a) Rapid advance-very little infiltration takes place
(b) Water ponded on surface-infiltration occurs over entire basin (c) Completed irrigation

4.2 Border Irrigation

Main differences between bordere and basins are borders have a uniform gradient and usually require a small stream size so that water can advance to the tail end slowly as shown in Figure 5.

The small stream size means that water advances slowly along the field. When sufficient water has infiltrated at the top of the field the inflow is stopped. The flow recedes away from the farm channel stopping any further infiltration. Further along the field there is still a lot of water on the soil surface and so the advance and infiltration continue. All the surface water is gradually absorbed at the tail end of the field.

This method can result in a very uniform irrigation but in practice it is very difficult to achieve. It depends on choosing the right stream size for the soil type, irrigation depth and length of border and stopping the inflow at the right time. If the inflow is stopped too soon water may not even reach the end of the border. If it is stopped too late then deep percolation and runoff can occur.

4.3 Furrow Irrigation

Physically, furrow irrigation is a lot different from basins and borders. Water flows in a small channel, not flooding over the soil surface like the other two.

Furrow irrigation in some ways is very similar to basin irrigation. A large stream size is used to spread water quickly along each furrow to keep deep percolation losses small (see Figure 6). The size of stream required depends on the irrigation depth, soil type, and furrow length. The quarter time rule is often used as a practical guideline for the advance of water down furrows. Unlike basins, however, runoff can be a problem. When the flow reaches the far end of the field it cannot be easily ponded because furrows are usually on

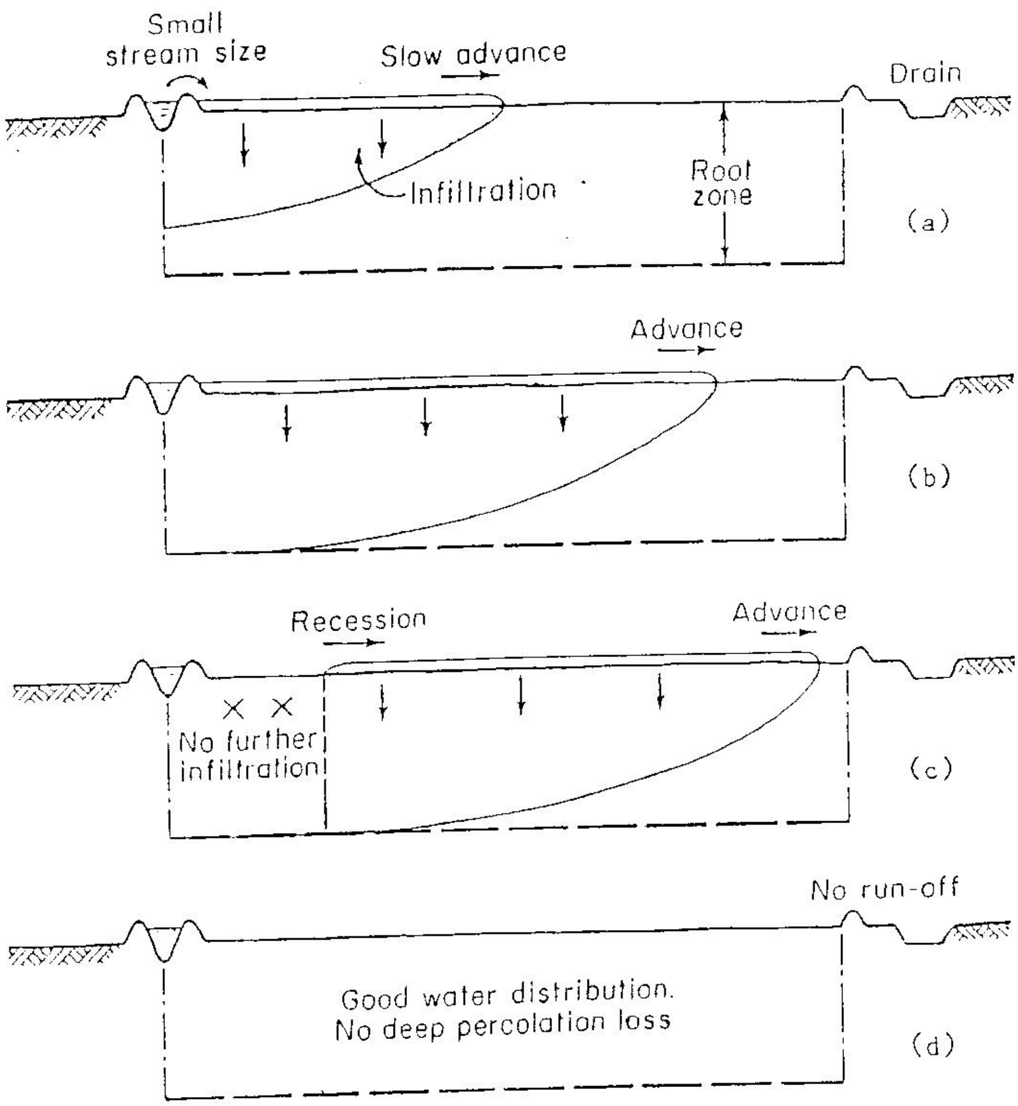


Figure 5 Border Irrigation (a) Advance begins (b) Inflow stopped (c) Advance continues and recession begins (d) Irrigation completed

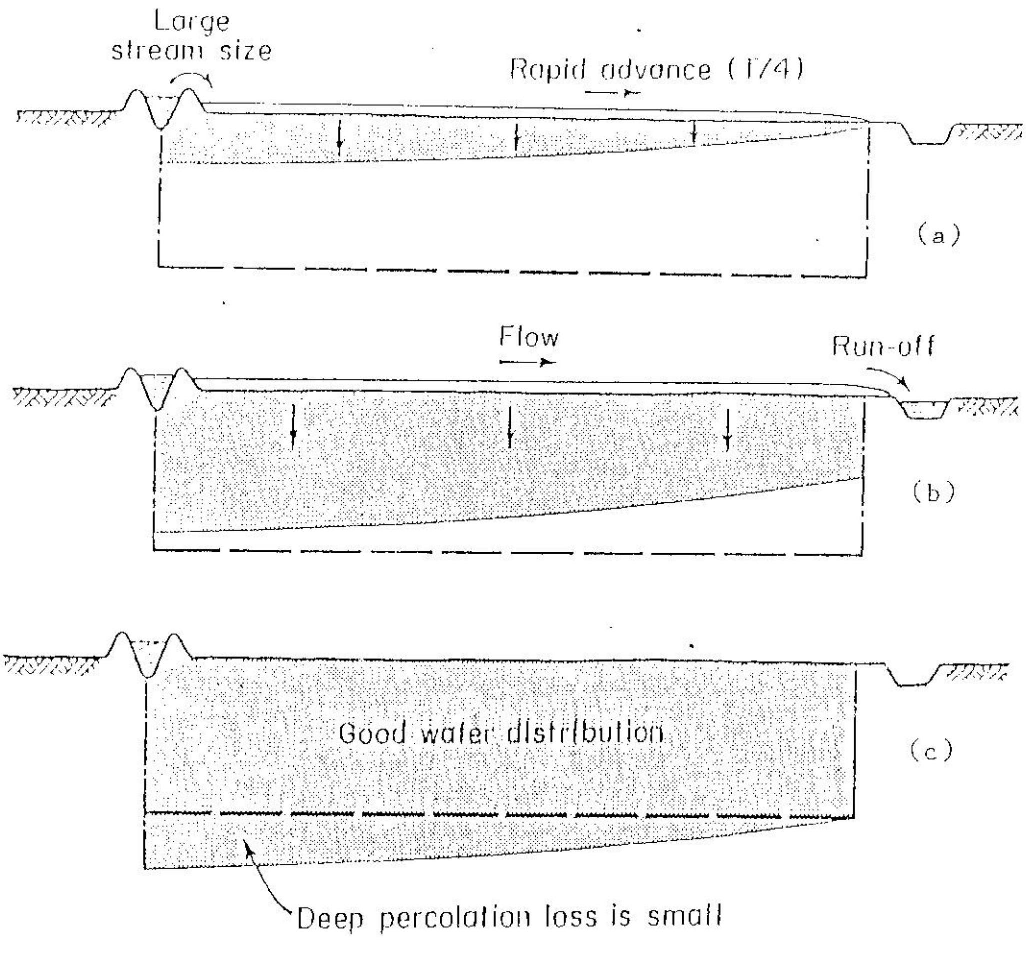


Figure 6 Furrow Irrigation. (a) Rapid advance-very little infiltration takes place (b) Flow continues-water runs off end of furrow (c) Irrigation completed

sloping land and there is very little room to store water. Water that cannot infiltrate fast enough into the soil must be allowed to runoff the end of the field and into a drain. This may seem to be a great waste of water but there are ways in which this loss can be reduced. Those are cutback stream technique and re-use system.

5. Effectiveness (Quality) of Surface Irrigation

The concept of irrigation effectiveness is extremely useful in evaluating designs and management strategies. The effectiveness of surface irrigation can be determined from the 3 following indices.

(1) Uniformity of Application

(2) Application Efficiency

(3) Adequacy of Irrigation.

5.1 Uniformity of Application

The uniformity of application describes how evenly an irrigation system distributes water over a field. Perfect (100 percent) uniformity means that the entire field receives an equal depth of water. Less than perfect uniformities imply that some areas of a field receive more water than the other areas. This may result in "over irrigating" the crop in one portion of the field and "under-irrigating" the crop in another portion.

It is impossible to have perfect uniformity in practice. However with carefully selected stream size and application time, high uniformity can be achieved.

The uniformity of application can be evaluated using the Christiansen Uniformity Coefficient (CU)

$$CU = 100 \left[1.00 - \frac{\sum_{i=1}^{n} | x_i |}{V_T}\right] \qquad \text{...........(1)}$$

Where

$$X_i = D_i A_i - \bar{V}$$

$$\bar{V} = \frac{V_T}{n}$$

$$V_T = \sum_{i=1}^{n} D_i A_i$$

and

D_i = Infiltrated Depth at point i

A_i = Area of point i

n = No. of Infiltration Measured Points

If $A_1 = A_2 = A_3 = \text{-----} = A_i$

Equation 1 can be rewritten as

$$CU = 100 \left[1.00 - \frac{\sum_{i=1}^{n} |d_i|}{n \bar{D}}\right] \quad \text{....................(2)}$$

Where

$$d_i = D_i - \bar{D}$$

$\bar{D}$ = Average Depth Infiltrated

$$= \frac{\sum_{i=1}^{n} |D_i|}{n}$$

An alternative to determine the uniformity of application is to use Distribution Uniformity (DU).

$$DU = \frac{100 \ \bar{D}LQ}{\bar{D}} \quad \text{..............................(3)}$$

Where

$\bar{D}_{LQ}$ = Low Quarter Average Depth

Example I In evaluation of furrow irrigation, the infiltrated depths are given below.

Station (i)	D_i (cm)
1	4.00
2	3.80
3	3.65
4	3.60
5	3.50
6	3.40

Assume each station have the same size of area. Determine CU.

$$\bar{D} = 3.66 \text{ Cm.}$$

$$\sum_{i=1}^{n} | d_i | = 0.97 \text{ Cm.}$$

$$CU = 100 \left[1.00 - \frac{0.97}{6 \times 3.66}\right]$$

$$= 95.6 \%$$

5.2 Application Efficiency

Efficiency in general means

$$E = \frac{\text{Output}}{\text{Input}} \times 100 \% \quad \text{.......................(4)}$$

In surface irrigation system, the output means the portion of water infiltrated into the root zone that is available to crops while the input means the total water applied.

By the above definition, the application efficiency (Ea) is defined as :

$$E_a = \frac{V_{RZ}}{V_T} \times 100 \% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

For the case of complete irrigation,

$$V_{RZ} = \frac{D_{RZ}\ (FC - \theta)}{100} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$V_T = \frac{QT}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

For incomplete irrigation

V_{RZ} = Volume or Depth infiltrated

Where

E_a = Application Efficiency in %

V_{RZ} = Part of water applied that stored in root zone

V_T = Total amount of water applied

D_{RZ} = Root zone depth

FC, θ = Soil moisture content at field capacity and initial soil moisture in % by volume.

Q = Average stream size during irrigation

T = Duration of irrigation

A = Area irrigated.

Alternatively the amount of water stored in the root zone can be determined by the following equation.

$$V_{RZ} = V_T - DP - RO \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where

DP = Deep percolation

RO = Runoff

The amount of deep percolation, runoff and application efficiency depends on the ratio of advance time (Tadv) and the opportunity time (To) or the advance ratio (Tadv/To) as shown in Figure 7.

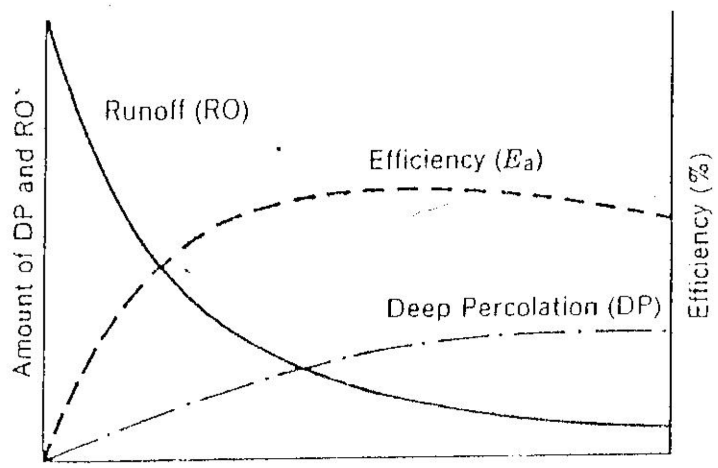


Figure 7 Effect of Advance Ratio on DP,RO and Ea.

Example 2 In irrigating a corn field by furrows, 26 furrows covering 0.6 ha can be irrigated per day, Assume 8 operating hours a day. The size of stream is 1 lps per furrow. The Soil moisture depletion (SMD) is 8 cm. Calculate the application efficiency.

$$V_{RZ} = A.D$$

$$= 0.6 \times 10{,}000 \times \frac{8}{100} = 480 \ m^3.$$

$$V_T = QT$$

$$= 26 \times \frac{1}{1000} \times 8 \times 3600 = 748.8 \ m^3.$$

$$E_a = \frac{480}{748.8} \times 100 = 64.1 \ \%$$

5. Adequacy of Irrigation

In case water application is not uniform. Some portion of the field is inadequately irrigated but some over irrigated. The adequacy of irrigation can be determined from the % of area under complete irrigation.

The percentage area receiving complete irrigation can be determined by the cumulative frequency distribution analysis as shown in Figure 8. From the figure, 50 % is over irrigated indicating the adequacy of irrigation equal to 50 %.

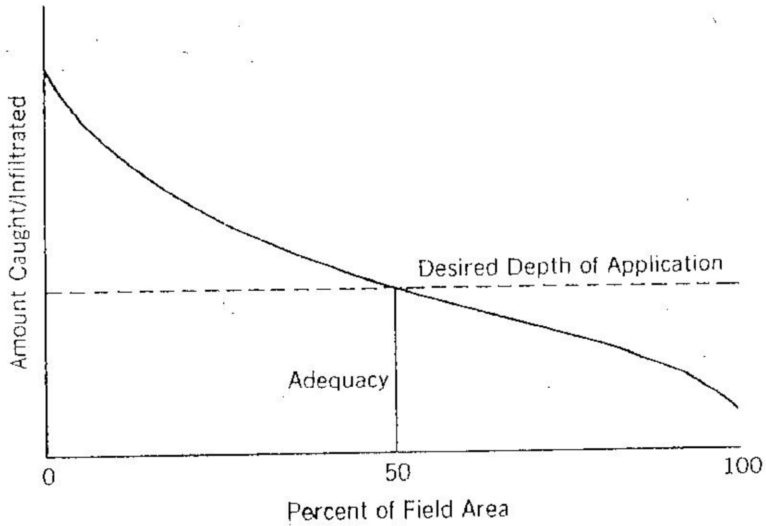


Figure 8 Cumulative frequency distribution pattern for determining the adequacy of irrigation.

Example 3 Determine the adequacy of irrigation from the following data.

1. Irrigation depth = 3.25 cm.

2. Depths infiltrated are given below

(Di = Depth infiltrated in cm.)

Station (i)	Di (cm)	Station (i)	Di (cm)
1	4.0	11	3.4
2	3.9	12	3.4
3	2.6	13	2.7
4	3.7	14	2.8
5	4.0	15	2.2
6	3.5	16	3.7
7	3.3	17	3.5
8	2.8	18	3.2
9	3.0	19	2.6
10	3.5	20	4.3

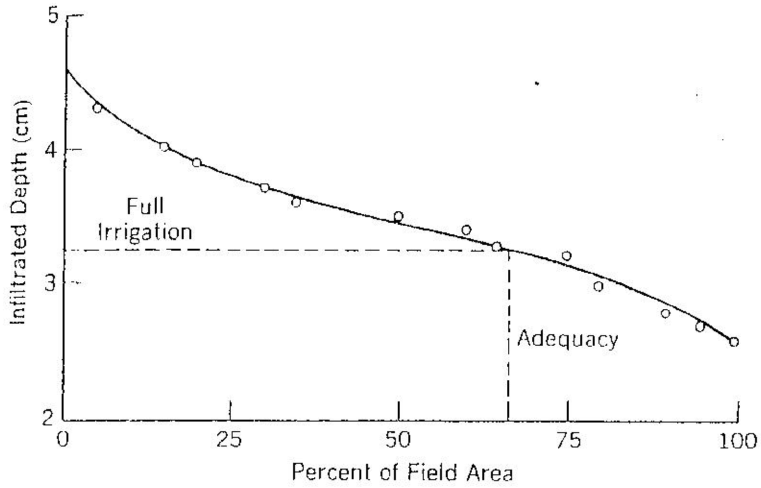
The area of each station (i)

$$= \frac{1}{n} \times 100 = \frac{1}{20} \times 100 = 5 \%$$

The cumulative frequency distribution of the area can be determined below.

Infiltrated Depth Arranged in descending Order	% Area	% Cumulative Area
4.3	5	5
4.0	5	10
4.0	5	15
3.9	5	20
3.7	5	25
3.7	5	30
3.6	5	35
3.5	5	40
3.5	5	45
3.5	5	50
3.4	5	55
3.4	5	60
3.3	5	65
3.2	5	70
3.2	5	75
3.0	5	80
2.8	5	85
2.8	5	90
2.7	5	95
2.6	5	100

The arranged infiltrated depth and % cumulative area are plotted as follow.



The graph indicates the adequacy of irrigation of 67 %

Alternatively the storage efficiency (Es) can be used as an index to the adequacy of irrigation

$$E_S = 100 \frac{V_{RZ}}{SMD} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where

V_{RZ} = The amount of water stored in the root zone.

SMD = Soil moisture depletion.

Example 4 Determine the storage efficiency from the data in Example 3. Given that the root zone depth is 50 cm. The soil moisture contents at field capacity and initial moisture are 25 and 18 % respectively.

$$SMD = \frac{(F_C - \theta)\ D_{RZ}}{100}$$

$$= \frac{(25 - 18)50}{100} = 3.5 \text{ cm.}$$

Only 10 stations got too much water, the less got insufficient water

$$V_{RZ} = 3.27 \text{ cm.}$$

$$E_S = \frac{3.27}{3.5} \times 100 = 93.4 \%$$