INTEGRATED WATER MANAGEMENT

IRRIGATION METHODS

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Irrigated agriculture faces a number of difficult problems in future. One of the major concerns is the generally poor efficiency with which our water resources are being used for irrigation. A relatively safe estimate is that about 40 per cent or more of the water diverted for irrigation is wasted at the farm level through either deep percolation or surface run-off. The other evident problem in future is the growth of alternative demands of water for urban and industrial needs. These uses place a higher value on water resources and, therefore, tend to focus attention on wasteful practices. Irrigation science in future will, thus, face the problem of maximizing the efficiency of our irrigation systems. Efficient utilization of irrigation water is, therefore, the most important factor in irrigated agriculture. It involves several practices like conveying water from the source to the field without seepage losses, following the right method of irrigation consistent with the topography, soil characteristics and other local conditions and applying water to the crop at the right time and in proper amounts.

Efficient irrigation systems apply right amount of water to the crop at the right time and ensure its uniform distribution in the field. The method of irrigation determines greatly the duty of water and the profitableness of irrigation. The considerable labour which always attends the application of water to land is one of the big charges to be made against irrigation and one that must be made as low as possible. Besides, the method of irrigation frequently affects directly the degree to which plants may use the water applied. The technology of agricultural water management is situation specific and the choice of a right irrigation method will depend on its economics and the performance requirements. The factors influencing the selection of an irrigation method are the soil characteristics, cropping system, land topography, quantity and quality of irrigation water and the nature and availability of inputs like labour and energy.

There are recurrent discussions on the pros and cons of different irrigation methods. Especially controversial are the arguments about the choice between open gravity as opposed to sprinkling methods. Unfortunately, opinions are often based on limited local experience where a method has been employed which may have been utterly unsuitable to existing conditions and should never have been chosen. Success is often taken for granted and receives little publicity; on the other hand, one who fails in a certain endeavour is likely to broadcast the shortcomings of a method, rather than question his own merits.

The broad terms in which articles and papers usually describe irrigation methods as gravity or surface irrigation make the analysis of the different claims still more difficult. These articles may include methods and applications of the most inefficient and outdated types, some probably dating back thousands of years. This fact may give the explanation for the extreme variety of findings, depending on where and by whom the experience has been gained.

Every modern irrigation method has both advantages and disadvantages and certainly has a definite place in an irrigation system. The irrigation engineer must, therefore, evaluate the project and choose the method best suited to local conditions. An irrigation method should fulfill one or more of the following requirements:

1. To afford a uniform water distribution with a small depth of application for light irrigations.
2. To allow a heavy and uniform application of water and under some conditions as much as 25 cm per application for salt leaching in problem soils.
3. To allow use of large concentrated water flows for reduction of conveyance losses, network and labour cost.

4. To be suitable for use with economic conveyance structures.

5. To facilitate mechanized farming.

There are only two general methods of applying irrigation water: irrigation above ground and irrigation below ground. Each of these two methods appears under several variations and possesses a special advantage. The water at the surface may be applied by flooding it on the field surface or in small channels, by spraying it under pressure overhead and by applying it in drops. The terms subsurface, surface or gravity, overhead or sprinkler and drip irrigation are used to describe these four methods of irrigations, respectively. The use of sub-surface method is very limited. The drip method and sprinklers have certain advantages but their initial high cost of installation and some other limitations make them suitable only for specific conditions. Surface irrigation methods are, therefore, the most commonly used methods of irrigation across the world.

1. SURFACE IRRIGATION

In the surface methods of irrigation, water is applied by a channel located at the upper reach of a field. Water may be distributed to the crops in smaller rectangular basins, in long parallel strips or in small channels between crop rows. Two general requirements of prime importance to obtain high efficiency in surface irrigation are, properly constructed water distribution systems and proper land preparation to permit the uniform distribution of water over the field. Surface irrigation is the method generally adopted in all countries.

The methods of surface irrigation may be classified as flooding method and furrowing methods. The flooding method covers all the soil with water but the water applied by the furrowing method covers only a part of the soil surface. Both flooding and furrowing are used extensively in all irrigated regions. The adoption of one or the other of these two methods depends sometimes upon careful trials, but more often upon custom following the practices. The chief factors determining the choice between flooding and furrowing are:

**Nature of the soil:** Furrowing is normally preferred for light and erodible soils. On such soils, the soil erosion due to flooding often results in large channels, gullies or eroded soil. On heavier soils, flooding may be practised safely, as far as erosion is concerned. Many soils, after having been wetted, bake and form a hard crust, which is injurious to the soil and to the plants. On such soils the furrowing method is advisable, for by that method only a part of the surface is covered with water and that part may be covered with loose earth by cultivation soon after irrigation. Other soils, after having been wetted, as they dry, fall apart, forming natural mulches. On these soils, flooding is safe.

**Contour of the land:** On relatively level land, either flooding or furrowing may be adopted. Flooding is best done when the slope of the land is not steep, especially in the soil that tends to erode easily. On steeper lands, furrowing must be employed. The heavier the soil, the steeper may be the grade.

**Head of the water stream:** The "head" indicates the volume of water supplied to the unit of time. Under some systems of canal management, farmers are given large streams of water for short times; under other systems, small streams are available for longer periods. The total quantity of water at the end of the period may in either case be the same. A high head of water moves rapidly over the land. Loose, sandy soils that absorb water rapidly must be
irrigated with a high head of water, especially under the flooding method, or the water may all be drawn into the soil, before the lower end of the field is reached. Under the flooding method, a high head of water may be used on nearly all soils, but a low head is suitable only for heavier soils. It follows that the furrowing method is best adapted where the head of water is low; the flooding method where the head is high. This deduction has found practical expression over the whole irrigated area.

**Quantity of water available:** If irrigation water is abundant, and a high head may consequently be secured, the flooding method is usually employed. If water is scarce, the main consideration is to make the total supply cover the largest area and the furrowing method is ordinarily employed, since by this method, a small quantity of water may be made to cover much land. It has been shown that the productive power of water decreases, as the total quantity applied to a given area is increased. That is, with each additional centimetre of water, less dry matter is produced. Consequently, where water is scarce, it is more profitable to spread the small quantity of water over a large area of land. To do this, the furrow method is indispensable. In irrigation practice, therefore, although the reason is not always understood, the furrowing method is invariably used wherever the supply of water is low.

**Nature of the crop:** The nature of the crop also determines the method of irrigation. There are certain crops that are sensitive to the inundation of water around their roots. Furrowing is the most suited method for these crops.

**1.1 Hydraulics of Surface Irrigation**

Efficient water application by surface irrigation depends on the knowledge of the hydraulic characteristics of the irrigation stream. The flow in surface irrigation is a case of spatially varied unsteady open channel flow with decreasing discharge. The discharge rate decreases downstream due to infiltration. The flow phenomenon is affected by several variables that must be determined before proper criteria for the design of surface irrigation system are developed. The dominant variables influencing the hydraulics of surface irrigation are elapsed time, size of irrigation stream, slope of the land surface, infiltration characteristics of the soil and the hydraulic resistance to flow offered by the soil surface and vegetative covers.

Careful consideration, however, shows that the effect of slope, hydraulic resistance offered by the soil surface roughness and vegetative retardance and the size of the irrigation stream is reflected in their influence on the depth at which the water flows. If the vegetation or the size of the irrigation stream are increased, or the slope is decreased, the water will slow up until a great enough depth of water has accumulated to overcome these factors. Reverse conditions will result in flow taking place at a shallower depth. Thus, the prediction of advance rate of the irrigation stream consists of finding the advance of the water front as a function of the elapsed time $t$, when the infiltration-time function $Y(t)$, the size of entrance stream, $q$ and the depth of flow, $h$ are known.

As irrigation water flows into a field and progresses down its length, an ever-decreasing portion of the total volume of water applied flows above the ground, while the remainder infiltrates into the soil and composes the subsurface storage. Any rational approach to predict surface irrigation flows must equate the total volume of water discharged at the supply channel to the sum of surface storage and subsurface storage; moreover, this volume balance is obtained at every instant of time, subsequent to the initial turning of water on to the land.

The hydraulics of surface irrigation consists in developing equations relating the flow phenomena. It represents a complex problem in theoretical analysis, owing to the varying intake rate of soil both with respect to time and distance. While several developments in
hydraulics of surface irrigation are available in literature, some fundamental aspects are presented here.

Surface irrigation is composed of four phases as illustrated graphically in Fig.1. When water is applied to the field, it advances over the surface until the water covers the entire area. It may or may not directly wet the entire surface, but all the flow paths are completed. Then the irrigation water either runs off the field or begins to pond on the surface if a dyke is provided at the downstream end of the field. The interval between the end of advance and when the inflow is cut off is called the wetting or the ponding phase. The volume of water begins to decline when no water is being applied. It either drains from the field or infiltrates into the soil. For the purpose of describing the hydraulics of surface irrigation, the drainage period may be segregated into the depletion phase (vertical recession) and the recession phase (horizontal recession). Depletion is the interval between the cut-off time and the appearance of the first bare soil under the water. Recession begins at that point and continues until the entire surface is drained.

In plotting advance and recession curves, the distance down the field is plotted on the x-axis and the elapsed time on the y-axis. Both the advance and the recession curves are plotted on the same graph (Fig.2). Parallelism of advance and recession curves ensures uniform distribution of water throughout the field.

It is useful to note here that in practising surface irrigation, one may not observe a ponding, depletion or recession phase. On basins, for example, the post-cut off period may only involve a depletion phase as the water infiltrates vertically over the entire field surface. Likewise, in the irrigation of a paddy crop, irrigation very often adds to the already ponded field, so there is neither advance nor recession - only wetting or ponding and the part of depletion phase occur. In furrow systems, the volume of water in the furrow is very often a small part of the total supply for the field and it drains rapidly. For practical purposes, there may not be a depletion phase and recession may be ignored. Thus surface irrigation may appear in several configurations and operate several regimes.

**Recession of Flow Infiltration and Opportunity Time**

After the irrigation stream is cut off the tail water recedes downstream. The rate of recession of the tail water is determined by noting the times at which water just disappears from the upstream end and recedes downstream past the field. An accurate description of flow involves the use of unsteady state flow equations. Rational formulae to predict the recession flow under field situations have not yet been developed.

The difference between the time the water front reaches a particular point along the field and the time at which the tail water recedes from the same point is the infiltration opportunity time, or the time of ponding. The infiltration opportunity time at any point along the field is the vertical distance (in time scale) between the advance and recession curves at the point.

**1.2. Design of Surface Irrigation Systems**

The surface irrigation system should be able to apply an equal depth of water all over the field without causing any erosion. After the water is allowed to enter the plot it will advance towards the end of the field. Recession of the water starts from the beginning of the plot after the water is shut off. Most of the time it becomes necessary to stop the inflow of water when the water front reaches a particular length of the plot, so that the irrigation of the remaining length is completed with the water already introduced. The reduction of the stream size partially or fully is known as cut-back. To minimize the percolation losses, a surface
irrigation system should be designed such that the opportunity time is uniform all throughout
the plot and also equal to the time required to put the required depth of water into the soil
(Fig. 2).

In every irrigation system, a particular size of stream is available to irrigate the land with a
known topography and soil characteristics. They should be matched in such a way that the
required amount of water is applied all over the field as uniformly as possible at the same
time no soil losses occur during irrigation. The data required for design of surface irrigation
systems may be broadly grouped as follows:

**Soil characteristics:** Soil properties required are the infiltration rates as a function of time
and expected variability between irrigations, field capacity, wilting point and bulk density. Other
information on salt content, effects of surface flooding such as crusting and cracking is
also useful for designing a suitable and efficient surface irrigation system.

**Crop data:** Types of crops proposed to be raised in the area, their agronomical requirement
like ridging etc., rooting habits, allowable soil water deficits at various stages of growth and
relative sensitivity to inundation are the information needed on the crop side.

**Water availability:** Stream size available at the field to be irrigated, quality of irrigation
water, expected amount and distribution of rainfall are the needed data.

**Field topography:** Slope of the area to be irrigated, size and shape of the field are the
factors that influence the design of surface irrigation system.

### 1.3 Depth of Irrigation

The information obtained from the soil moisture characteristics can be used in calculating the
depth of water to be applied in irrigation. Whenever a crop is irrigated, the governing
principle is to bring the moisture content of the soil in the root zone of the crop to field
capacity. Depending on the root zone of the crop, the depth of the soil to be irrigated is
known. Let this depth be denoted by D. Considering a soil column of unit area and depth D,
moisture content of the soil can be represented as depth 'd' obtained by multiplying the
percentage volume $P_v$ by the depth of soil $D$; or

$$d = P_v \times D / 100 \quad \ldots \quad (1)$$

Noting $P_v = P_w \cdot A_s$, where $P_w$ is the percentage of moisture to be added to the field by weight
and $A_s$ is the apparent specific gravity of the soil,

$$d = P_w \times A_s \times D / 100 \quad \ldots \quad (2)$$

If the moisture content at field capacity is $P_f$ and the actual moisture content in the soil $P_a$, both
expressed as percentages by weight, the depth of irrigation $d$ is given by,

$$d = (P_f - P_a) \times A_s \times D / 100 \quad \ldots \quad (3)$$

Since, $P_f, P_a$ and $A_s$ are dimensionless, $d$ will have the same dimensions as $D$. When the soil
profile is layered and information is available for each layer, $d$ is calculated separately for
each layer and summed up to determine the depth of irrigation.
1.4 Evaluation of Surface Irrigation Methods

Many irrigation systems are poorly adapted to the soils and topography. Intake rates and water holding capacities of the soils are not known before a field is laid out for irrigation. Little effort is made to learn how much water is needed to replenish the soil water reservoir. These parameters are determined in the field evaluation of an irrigation system. There are various methods of water application, each one having merits and demerits. The suitability of each method to the existing soil and crop conditions can be determined only when its performance is evaluated by measuring certain parameters and analyzing them. In evaluating an irrigation method, the basic variables influencing the hydraulics of flow in the method are determined and the characteristics of flow measured. Proper evaluation of irrigation methods under representative soil and crop management practices provides data and criteria for the design of efficient irrigation systems.

1.4.1 Collection of Data

Field studies are necessary to define quantitatively the irrigation system performance in relation not only to its physical features but also to its design and management. Field analysis of a single irrigation event may not clearly establish these relationships and, therefore, should be repeated at times when the soil, crop or operational characteristics have changed sufficiently to reveal other facets of the irrigation systems. In order to collect the data for evaluation of a surface irrigation system, the first step is to determine the effective depth of the root zone of the crop. The determination of this depth is very important, as the plants take water only from this depth. Any amount of water below this depth is of no use to plants. If there is enough moisture within this depth, the plans will uptake both the moisture and nutrient as per their requirement, resulting in higher yields. If the water available in this zone is inadequate, it will be difficult for the plants to uptake water to meet their consumptive water requirements, giving low yields. The moisture extraction patterns by plants in a soil are shown in Fig. 3. This depth is, therefore, very important from irrigation point of view and required to be determined first before irrigation to ascertain how much water is needed in the crop root zone and how much is lost as deep percolation below this dept out of the total water applied to the field. This depth of the root zone is determined by removing the soil around the roots of the plants and studying the development of the roots of the plants during different growth stages of the crop. Based on the depth of the root zone, the quantity of water to be applied in irrigation to an area is determined by multiplying irrigation depth with the area of the field.

After having determined the effective depth of the root zone, the permanent wilting coefficient, field capacity and apparent specific, gravity as mentioned in equation (3) are determined from soil samples and their analysis. This is followed by determining the moisture content of the soil in the root zone before irrigation by taking soil samples from various places at different points along the length of the flow. The equivalent depth of water present before irrigation is then calculated by using equation (2). The net depth of water to be added to the root zone is obtained from equation (3). The total volume of water to be applied to an area is calculated by multiplying this irrigation depth by the area of the field. The irrigation time to apply the required depth of irrigation is then computed by dividing the quantity of water by the available stream size for irrigation. In order to apply the required depth of irrigation as mentioned above, the opportunity time is determined from the infiltration characteristics of the soil developed separately for the field of irrigation.

After having obtained the required information as mentioned above, the predetermined and constant inflow stream with non-erosive velocity is diverted to the field and the advance time of water front to reach the selected stations is monitored till the water reaches the tail end of
the field. The irrigation stream is cut off after the irrigation stream has run for the full irrigation time as calculated above. This is followed by observing and recording the recession time at all the selected points for which the advance time has already been recorded. The opportunity time at each point is obtained by subtracting the advance time from the recession time for the point.

Soil samples are taken from all the stations, after the excessive water or free water is drained from the root zone. This situation normally occurs 24 hours or more after the irrigation water is applied to the field. Two or more days may be required for type free moisture to be drained in fine-textured soils.

The samples thus collected are dried in an oven and the moisture could at each station is determined to determine the actual moisture added by using equation (2). The moisture actual added to the field through is determined by subtracting the initial depth of moisture at the time of irrigation from the depth of moisture as calculated from equation (2). The adequacy, deficit or open irrigation is obtained by comparing these two values of moisture depths.

1.4.2 Analysis of Data

The performance of surface irrigation is then evaluated based on the analysis of data obtained from observations made and soil samples collected before and after irrigation. The first and foremost information is to determine the average depth of irrigation achieved. The average depth of irrigation is the average value of the depths added at each point as discussed above. The average depth may also be represented by the average value of depth infiltrated at each of the selected points, which is obtained by substituting the opportunity time in the infiltration equation. The moisture added to the root zone is either the average value of observed observations or the value of depth obtained from equation (3), whichever is minimum, as the soil cannot retain water more than that required at the field capacity. If the field is open or not dyked at the lower end, arrangements are also made to measure the surface runoff losses at the tail end and the total surface water loss is thus determined. The volume of deep percolation losses is determined by subtracting the water depth required or stored in the root zone from the average depth of irrigation, as calculated above. If the average depth of irrigation comes out to be less than the moisture to be stored in the root zone, there is no deep percolation and the entire amount of water infiltrated in the soil profile has been stored in the root zone. Based on this information various performance parameters defined in the subsequent sub section are determined to assess the performance of a surface irrigation system.

Example 1  Soil samples were taken from different depths in a wheat field. Based on the analysis of the samples, moisture contents before irrigation and at field capacity and apparent specific gravity of the soil at different depths are given in the following Table. Determine the depth of irrigation to be applied to the field.

<table>
<thead>
<tr>
<th>Root zone depth (cm)</th>
<th>Moisture content before irrigation (%)</th>
<th>Moisture content at field capacity (%)</th>
<th>Apparent specific gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-30</td>
<td>8.20</td>
<td>15.20</td>
<td>1.70</td>
</tr>
<tr>
<td>30-60</td>
<td>10.50</td>
<td>15.80</td>
<td>1.62</td>
</tr>
<tr>
<td>60-90</td>
<td>12.40</td>
<td>16.20</td>
<td>1.45</td>
</tr>
</tbody>
</table>
Solution

Using equation (3), the depth of irrigation to be applied to the field is calculated in the following table

<table>
<thead>
<tr>
<th>Root Zone depth (cm)</th>
<th>Moisture Content Before irrigation (%)</th>
<th>Moisture Content at field capacity (%)</th>
<th>Moisture to be added %</th>
<th>Apparent Specific gravity</th>
<th>Depth of water to be applied cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-30</td>
<td>8.20</td>
<td>15.20</td>
<td>1.70</td>
<td>3.57</td>
<td></td>
</tr>
<tr>
<td>30-60</td>
<td>10.50</td>
<td>15.80</td>
<td>1.62</td>
<td>2.58</td>
<td></td>
</tr>
<tr>
<td>60-90</td>
<td>12.40</td>
<td>16.20</td>
<td>1.45</td>
<td>1.65</td>
<td></td>
</tr>
<tr>
<td>Total depth of irrigation to be applied</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.80</td>
</tr>
</tbody>
</table>

Fig. 1 Graphical illustration of water application during surface irrigation, showing its advanced, wetting, depletion and recession phases (Walker, 1989)

1.4.3 Performance Parameters

A number of parameters have been defined in the multitudes of ways and named in various manners. They have been designated as the performance parameters, as they are used to assess the performance of an irrigation method. There is no single parameter that is sufficient to define a surface irrigation system's performance. The efficiency and the uniformity of water application are, however, the most common ones among the several indices used to judge the performance of a surface irrigation system or its management. Conceptually, the adequacy of an irrigation event depends upon how much water is stored within the root zone
of the crop, losses percolating below the root zone, losses occurring as surface run-off, the uniformity of applied water and the remaining soil moisture deficit or under irrigation within the crop root zone following the irrigation. Ultimately, the measure of performance is to see whether the system has enhanced production and profitability on the farm and minimized the losses at the same time. The following parameters are generally determined to assess the performance of an irrigation system:

**Application Uniformity**

When a field with uniform slope, soil and crop density receives steady flow at its upper end, the water front advances at decreasing rate until it reaches the lower end of the field. If the end is not dyked, run-off occurs for a time before recession starts following shut off of the flow. Fig. 4 shows the distribution of applied water along the field length. The differences in intake opportunity time produce applied depths that are non-uniformly distributed with a characteristic shape skewed toward the inlet end of the field.

![Fig. 2 Variation in opportunity time in along the length of the field in surface irrigation (Murty, 1998)](image1)

![Fig. 3 Moisture extraction patterns by plants growing in a soil with an adequate availability of water (Michael, 1978)](image2)
Application uniformity is concerned with the distribution of water over the entire field. A number of technical sources suggest the Christiansen coefficient as a measure of uniformity of application. Others propose distribution uniformity as the average infiltrated depth in the low quarter of the field divided by the average infiltrated depth over the whole field. The same authors also suggest an absolute distribution uniformity which is minimum depth divided by the average depth. Thus, the evaluator can choose one that fits his perceptions, but it should be clear as to which one is being used. The following definition of distribution efficiency may, however, be used to describe the application uniformity of a surface irrigation system.

\[ E_d = 100 \left(1 - \frac{y'}{d'}\right) \]  
\[ \text{Where,} \]
\[ E_d = \text{distribution efficiency} \]
\[ d' = \text{average infiltrated depth along the field} \]
\[ y' = \text{average numerical deviation of the measured depths from } d' \]

**Application Efficiency**

Application efficiency \( (E_a) \) is defined as the volume of water added to the root zone divided by the volume of water applied to the field, i.e.

\[ E_a = \frac{\text{Volume of water added to the root zone}}{\text{Volume of water applied to the field}} \]  
\[ \text{where,} \]
\[ E_a = \text{application efficiency} \]

**Storage Efficiency**

This is also referred to as the water requirement efficiency and is defined as

\[ E_s = \frac{\text{Volume of water added to the root zone}}{\text{Potential soil moisture storage volume}} \]
The storage efficiency is an indicator of how well the irrigation meets its objective of refilling the root zone. The value of the storage efficiency is important when either the irrigation tends to leave major portions of the field under-irrigated or where under irrigation is purposely practised to use the precipitation as and when it occurs. This parameter is the most directly related with the crop yield since it reflects the degree of soil moisture stress. Usually, under-irrigation is a good practice in highly probability rainfall areas to conserve water but the degree of under-irrigation is a difficult question to answer at field level.

**Deep Percolation Losses**

The loss of water through drainage beyond the root zone is reflected in the deep percolation losses, DPL. It is defined as

\[
DPL = \frac{\text{Volume of deep percolation}}{\text{Volume of water applied to the field}} \times 100 \quad \ldots \ldots (4 \text{ d})
\]

High deep percolation losses aggravate water logging and salinity problems and leach valuable crop nutrients from the crop root zone. Depending upon the chemical nature of the ground water basin, deep percolation may cause a major problem of water quality on the regional basis. These losses can return to receiving streams heavily laden with salts and other toxic elements and thereby degrade the quality of water to be used by others.

**Tail Water Losses**

Losses of irrigation water from the irrigation system through surface run-off from the end of the field are indicated in the tail water losses, TWL. This is defined as

\[
TWL = \frac{\text{Volume of surface run-off}}{\text{Volume of water applied to the field}} \quad \ldots (4 \text{ e})
\]

Run-off losses pose additional threats to irrigation systems and regional water resources. Erosion of the top soil on a field is generally associated with the run-off. The sediments can then obstruct conveyance and control structures downstream, including dams and regulating structures.

With the five measures of the performance defined above, a broad ranges of assessment is possible and specific remedies are identified. Application efficiency is the most important parameter in terms of design and management since it reflects the overall beneficial use of irrigation water (Walker, 1989). A design and management study may, therefore, be proved to maximize application efficiency, maintaining the storage efficiency at 95-100 per cent. This approach eliminates the storage efficiency from an active role in surface irrigation design and management and simultaneously maximizes application uniformity. If the analysis tends to maximize $E_a$, distribution uniformity is not qualitatively important and may primarily be used only for illustrative purposes.

Three typical results of a surface irrigation are illustrated in Fig. 5. When the flow is cut off too soon after the advance phase completes, the depth of application of water at some of the points in the field may be inadequate to refill the root zone (curve a) or the application may just satisfy the need in the least watered area (curve b). But most often, the applied depths exceed the target depth, at all locations (curve c). Large differences in economic, physical,
social and operational conditions occur in surface irrigation systems. Consequently, it is
impractical to judge any of these three cases as good or bad, since situations like the need for
conservation of water or rainfall expectations make a regime one to utilize when the time calls for it. The
suggested evaluation of performance is the numerical definition of the efficiency parameters.

Example 2  If a stream of 0.085 cubic metres/sec is delivered to the field for 2 hours, run-
off averaged 0.0475 m$^3$/sec for one hour and the depth of penetration of
water measured at certain points in the field is 1.68, 1.53, 1.45, 1.25 and
1.07 m at the lower end, determine the water application efficiency and
uniformity coefficient. If the root zone depth of the crop is 1.68 m,
determine (a) water application efficiency, (b) water storage efficiency, (c)
Water distribution efficiency, deep percolation ratio and (e) tail water ratio.

Solution

(a) Water application efficiency

\[
\text{Water delivered to the field} = 0.085 \times 2 \times 60 \times 60 = 612 \text{ m}^3
\]

\[
\text{Runoff losses} = 0.0476 \times 1 \times 60 \times 60 = 171 \text{ m}^3
\]

\[
\text{Water stored in the root zone} = 612 - 171 = 441 \text{ m}^3
\]

Using equation (4b), water application efficiency, $E_a$, may be determined as

\[
E_a = \frac{441}{612} \times 100 = 72.06\%
\]

(b) Water storage efficiency

Average depth of penetration in the root zone,

\[
d' = \frac{1.68 + 1.53 + 1.45 + 1.25 + 1.07}{5} = \frac{6.98}{5} = 1.40 \text{ m}
\]

Using equation (4c), storage efficiency in this case may be defined as the ratio of the
average depth of water penetration in the root zone to the root zone depth, i.e.

\[
E_s = \frac{1.40}{1.68} \times 100 = 83.00\%
\]

(c) Water Distribution efficiency

After having determined the average depth of water penetration in the root zone, the
numerical deviation of an observed value of the depth from the average depth of penetration
of 1.4 is calculated. The average value of the deviations, $y'$, is then determined as follows:

\[
y' = \frac{(1.68 - 1.40) + (1.53 - 1.40) + (1.45 - 1.40) + (1.40 - 1.25) + (1.40 - 1.07)}{5} = \frac{0.94}{5}
\]

\[
= 0.188 \text{ m}
\]
Using equation (4 a), water distribution efficiency, $E_d$ is calculated as

$$E_d = 100x \left( 1 - \frac{y'}{d} \right) = 100x \left( 1 - \frac{0.188}{5} \right) = 86.60\%$$

Fig. 5 Three typical irrigation applications patterns under surface irrigation (Walker, 1989)
(d) Deep percolation Losses

As the depth of maximum penetration is equal to the depth of the root zone, there are no deep percolation losses and hence, deep percolation losses, which is the ratio of the deep percolation to the water delivered to the farm, is zero.

(e) Tail water losses

As defined in equation (4e), tail water loss (TWL) is the ratio of the surface runoff to the water applied to the field, i.e.

$$TWL = \frac{171}{612} \times 100 = 28\%$$

1.5 Methods of Surface Irrigation

The classification of surface methods of irrigation is perhaps arbitrary in technical literature. This has been compounded by the fact that a single method is often referred to with different names. In this chapter, surface irrigation methods are being classified by the slope, the shape and the size of the field, the end conditions and how water flows into and over the field. Each method has unique advantages and disadvantages depending upon (1) initial cost (2) shape and size of the field, (3) soil characteristics, (4) nature and availability of water supply, (5) climate, (6) cropping patterns, (7) social preferences and structures, (8) historical experiences and (9) influences external to surface irrigation system. Based on these considerations, surface irrigation has been divided into border, check basins, basin and furrow irrigation methods.

1.5.1 Border Irrigation

Border method of irrigation is a method of surface flooding wherein the water is applied to the field divided into strips separated by parallel ridges (Fig.6). The ridges are spaced about 15-20 m apart and are 275 m long. The parallel ridges are meant to guide a sheet of flowing water as it moves down the slope. This enables the irrigator to watch the water more closely. When the water reaches the lower end of the strip, it may be shut off and another strip is irrigated. Each strip is levelled transversely, but has the natural slope in the longitudinal direction so that the water turned at the upper end of each strip; moves down the slope in the form of a thin sheet. Border strips may be designed either to allow runoff at the tail end or to retain the entire amount of water introduced into the strip. Border method of irrigation is suited to a wide variety of crops and soils. The method can be designed to suit different soil types. The border method is suitable to irrigate all close-growing crops like wheat, barley, groundnut, barseem, fodder crops and legumes. Border irrigation can also be used for irrigating orchards where topography and soils are suitable. It permits efficient, rapid and relatively easy irrigation, if the borders are properly constructed. Labour requirements are low. Relatively large streams of water are required. The layouts must have nearly flat, uniform grades and good land preparation. It is, however, not suitable for crops like rice which requires standing water during most parts of its growing season.
The essential feature of border irrigation is to provide an even surface over which the water can flow down the slope with a nearly uniform depth. Each strip is irrigated independently by turning in a stream of water at the upper end. The water spreads and flows down the strip in a sheet confined by the border ridges. The irrigation stream must be large enough to spread over the entire width between the border ridges without overtopping them. When the advancing water front either reaches the lower end or a few minutes before or after that, the stream is turned off. The water temporarily stored in the border moves down the strip and infiltrates, thus completing the irrigation.

The border method of irrigation is adapted to most soils where depth and topography permit the required land levelling at a reasonable cost and without permanent reduction in soil productivity. It is, however, more suitable to soils having moderately low to moderately high infiltration rates. It should not be used in coarse sandy soils that have very high infiltration rates because of the stringent limitations in design. It is also not well suited to soils having a very low infiltration rate, since to provide adequate infiltration opportunity time, without surface runoff at the lower end; the irrigation stream may be too small to completely cover the border strips.

1.5.1.1 Advantages and Disadvantages of Border Irrigation

The border method has a number of advantages. They include: (i) border ridges can be constructed economically with simple farm implements like a bullock-drawn frame ridger or bund former or tractor-drawn disc ridger, (ii) labour requirement in irrigation is greatly reduced as compared to the conventional check basin method of irrigation, (iii) uniform distribution and high water application efficiencies are possible if the system is properly designed, (iv) large irrigation streams can be efficiently used, (v) operation of the system is simple and easy and (vi) adequate surface drainage is provided if outlets are available.

The application of border method, however, requires skill and can only be applied after a painstaking investigation of soil, topography and water conditions. Otherwise, this method, which is one of the most efficient methods of irrigation, may become a severe liability and create both drainage and salinity problems. The stream size per unit width must be large, particularly following a major tillage operation, but not as large as for basins owing to the slope effects. The precision of the field topography is also critical.
1.5.1.2 Types of Border Irrigation

Borders may be laid along the general slope of the field or may be laid across the general slope of the field. When they are laid along the general slope, they are called straight borders and when they are laid across the general slope, they are termed as contour borders. The straight borders are further classified as graded and level borders.

**Graded borders:** The graded borders have some slope in the direction of irrigation. The slopes generally range from 0.1 per cent to 0.5 per cent, but higher slopes are used under unavoidable conditions. The slope selected should not cause soil erosion problems. Each strip is irrigated by turning in the stream of water at the upper end. The stream size, dimensions of the border, time of irrigation are so adjusted as to get uniform application of water throughout the strip. When fields can be levelled to desirable land slopes economically and without affecting its productivity, graded borders (Figs. 7 and 8) are easier to construct and operate.

**Level Borders:** These borders have no slope in the direction of irrigation and are closed at ends. Water is ponded until it infiltrates into the soil. Level borders are the same as the checks or the beds as will be described later.

![Infiltration, Wetting front, Soil](image)

**Fig. 7** Schematic sketch illustrating the layout of an impounding type of border irrigation system (Michael, 1978)

![Uniform growth of wheat](image)

**Fig. 8** Uniform growth of wheat in a straight border strip in an experimental field. The space between adjacent strips is provided for movement while collecting experimental data (Michael, 1978)
**Contour borders:** While irrigating steep lands (greater than 2 to 3 per cent slope), if borders are made longitudinally, it is difficult to get uniform application of water. Such borders also cause severe soil erosion problems. In such cases, the land is converted into a series of borders in the transverse direction. The borders are given the required grade in the transverse direction. Such borders are referred to as contour borders (Fig. 9). The design criteria of a contour border are the same as a straight border. Each contour border is level crosswise and has a uniform longitudinal gradient as in a border. The width and length of a contour border are identical to a straight border for a particular set of conditions. Because of land topography sometimes it may not be possible to get uniform width in case of contour borders.

![Fig. 9 Field laid out for contour border irrigation](image)

In laying contour borders, the field is divided into a series of strips on the approximate contour, and each strip is levelled as an independent area. Thus, a series of steps are formed in successive elevations around the slope. The vertical interval between adjacent borders should, as far as possible, be limited to 30 cm, but should not exceed 60 cm. The height of bund (ridge) should be sufficient to contain both the normal irrigation stream and storm runoff. Since the earthwork involved is often large, the contour borders should be laid out as closely to the original topography of the land as farming operations and other considerations permit. In laying out contour borders the irrigation channel is laid down the land slope, providing sufficient number of drop structures. At the downstream end of borders, a drainage channel is provided to drain away storm runoff. The drainage channels, which run down the land slope, should be provided with erosion control structures.

### 1.5.1.3 Border Specifications and Stream Size

Successful operation of the border method requires that the system is designed and operated properly. Proper design requires consideration of the hydraulics of flow in borders which is similar to that described in Article 1.1. However, some general suggestions on width, length and slope of borders and size of irrigation streams are presented in this article.

The design of the border irrigation consists in deciding (1) width of the border, (2) length of the border, (3) slope (4) duration of irrigation and (5) stream size. All these factors are
interrelated. The width of the border should be such that there should be no cross slope within the width and the stream size available should flow with non-erosive velocity and at the same time it should give the desired advance rate. The length should be such that a uniform intake opportunity is obtained all along the border. When the field sizes are small, the field size may govern the length.

**Width of border strip:** The width of a border usually varies from 3 to 15 metres, depending on the size of the irrigation stream available and the degree of land levelling practicable. When the size of the irrigation stream available is small, the width is reduced. It is, however, not economical to keep the width less than three metres; as otherwise, too many ridges will have to be formed per unit area of the field surface.

**Border length:** The length of the border strip depends upon how quickly it can be wetted uniformly over its entire length. This in turn depends on the infiltration rate of the soil, the slope of the land, and the size of the irrigation stream available. For moderate slopes and small to moderate irrigation streams, the following border lengths are normally suggested:

- Sandy and sandy loam soils: 60 to 120 metres
- Medium loam soils: 100 to 180 metres
- Clay loam and clay soils: 300 to 500 metres

**Example 3** A stream of 20 litres per second is applied to a border strip 6 m wide, such that the average depth of water flow is estimated to be 7.5 cm while the soil has an average infiltration rate of 2.5 cm/hr. Determine the maximum distance up to which water will advance.

**Solution**

It has already been pointed out that the flow in surface irrigation is a case of spatially varied unsteady open channel flow with decreasing discharge. The discharge rate decreases downstream due to infiltration. As a result, when irrigation water flows into a field and progresses down its length, an ever-decreasing portion of the total volume of water applied flows above the ground, while the remainder infiltrates into the soil and composes the subsurface storage. Any rational approach to predict surface irrigation flows must equate the total volume of water discharged at the supply channel to the sum of surface storage and subsurface storage; moreover, this volume balance is obtained at every instant of time, subsequent to the initial turning of water on to the land. When this water inflow at the inlet of a basin just equals the sub-surface storage, there is no surface storage and water no longer advancing further. The length of advance by which water front has moved up to this instant is the maximum distance of advance. This may be determined by the following equation:

\[ q = IA_{\text{max}} = IWL_{\text{max}} \]

Where,

- \( Q \) = stream size, 20 lps,
- \( I \) = infiltration rate, 2.5 cm/hr,
- \( A \) = Maximum area irrigated.
- \( W \) = width of the border, 6 m and
- \( L_{x} \) = maximum length of advance
Substituting the given values in the above-mentioned equation, we get

\[ L_{\text{max}} = \frac{20 \times 100 \times 3600}{1000 \times 6 \times 2.5} = \frac{1200}{2.5} = 480m \]

**Border slope:** The borders should have a uniform longitudinal gradient. Excessive slopes will make the water run to the lower end quickly, causing insufficient irrigation at the upstream end and deep percolation losses and breach the field at the downstream. They also cause soil erosion in borders. On the other hand, too flat slopes will result in the very slow movement of the border stream, causing deep percolation losses at the upper reaches and inadequate wetting downstream. Recommended safe limits of land slopes in borders are given below:

- Sandy loam to sandy soils: 0.25% to 0.60%
- Medium loam soils: 0.20% to 0.40%
- Clay to clay loam soils: 0.05% to 0.20%

The slope of the border conforms to the land slope and as such cannot be changed like other parameters. The land slope is provided at the time when land grading operations are carried out. The general recommended land slope for different soil types and the maximum length of borders are given in Table 1.

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Optimum grade (Per cent)</th>
<th>Maximum Length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>0.05</td>
<td>500</td>
</tr>
<tr>
<td>Clay loam</td>
<td>0.10</td>
<td>330</td>
</tr>
<tr>
<td>Silt loam</td>
<td>0.20</td>
<td>270</td>
</tr>
<tr>
<td>Loam</td>
<td>0.30</td>
<td>170</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>0.40</td>
<td>130</td>
</tr>
<tr>
<td>Sand</td>
<td>0.50</td>
<td>100</td>
</tr>
</tbody>
</table>

(Minehart, 1976).

**Irrigation duration:** The duration of irrigation depends upon the depth of water to be applied. As the depth of water to be applied could change with different irrigations, the design of the border should consider all the possible depths to be applied.

**Size of irrigation stream:** The size of the irrigation stream needed depends on the infiltration rate of the soil and the width of the border strip. Coarse textured soil with high infiltration rates require large streams to spread water over the entire strip rapidly and avoid excessive losses due to deep percolation at the upper reaches. Fine textured soils with low infiltration rates require smaller streams to avoid excessive losses due to runoff at the downstream end and deep percolation at the lower reaches.

The size of the stream delivered into each border is the controlling factor in border irrigation which can be varied after the irrigation system has been installed. It can, therefore, be used to partly compensate for inadequacies in width or length of borders which have been selected.
and for changes which might take place in soil infiltration rates or depths of rooting of crops. The size of the stream required, however, should be determined as accurately as possible as a part of the design of the system.

It is often convenient to express the requirement of the irrigation stream in terms of the rate of water flow per unit width of the border, such as in litres per second per metre of border width. This value multiplied by the width of the border is the size of the irrigation stream that should be delivered into each border.

The depth of water applied to the soil can be regulated by the size of the irrigation stream. A larger stream is used to apply a shallower depth and a smaller stream to apply greater depth of water. This is because the amount of water entering the soil is related to the infiltration opportunity time which, in turn, is related to how fast the entire area of the border can be covered with the flow of water. Thus, by varying the size of the irrigation stream, it is possible to vary the depth of water applied. As a light irrigation is more frequently required in a sandy soil than that in clay, the stream size per unit of border has to be selected more for a sandy soil than that for clay. Table 2 presents some typical values of stream sizes for different soil types and slopes.

Table 2  Some typical values of stream sizes to suit varying soil characteristics and border slopes

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Infiltration rate, cm per hr</th>
<th>Border slope, Per cent</th>
<th>Flow per metre width, Litres/second</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy soil</td>
<td>2.5</td>
<td>0.2-0.4</td>
<td>0.4-0.65</td>
</tr>
<tr>
<td>Loamy sand</td>
<td>1.8 to 2.5</td>
<td>0.2-0.4</td>
<td>0.4-0.6</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>1.2 to 1.8</td>
<td>0.2-0.4</td>
<td>0.4-0.6</td>
</tr>
<tr>
<td>Clay loam</td>
<td>0.6 to 0.8</td>
<td>0.15-0.3</td>
<td>0.3-0.4</td>
</tr>
<tr>
<td>Clay</td>
<td>0.2 to 0.6 to</td>
<td>0.1-0.2</td>
<td>2-4</td>
</tr>
</tbody>
</table>

(Michael, 1978)

1.5.1.4 Design of Border Irrigation Systems

A well designed border irrigation system provides for the application of the desired amount of water nearly uniformly throughout the field. To obtain the maximum water application efficiency, the water should remain on the surface sufficiently long to allow just the desired amount of water to infiltrate into the soil. The required infiltration opportunity time is obtained, using the accumulated infiltration-time relationship for the soil in question. Water distribution efficiency is governed mainly by the uniformity of the infiltration opportunity time obtained throughout the border length. When the behaviour of the irrigation system can be predicted from the measurable characteristics of the site, it is possible to obtain a nearly uniform infiltration opportunity time throughout the border by suitably adjusting the entrance stream size, the length of run or slope of the border. In an existing field layout, where the
length or slope of the borders cannot be altered, the main controllable variable is only the entrance stream size.

The following procedure is suggested for the design of an efficient border irrigation system:

1. The length, width and slope of the border strip are determined.
2. The depth of water required to replenish the soil moisture in the root zone of the crop to field capacity is estimated. This may be done by actual measurement of the soil moisture content in the root zone before irrigation or predicted from the consumptive use requirements of the crop under the prevailing agro-climatic conditions.
3. The accumulated infiltration-time relationship of the soil under the existing soil conditions and vegetation is determined. The relationship can be established by actual measurements with cylindrical irifiltrometers before each irrigation, but it can also be obtained from previously established relationships.
4. The desired infiltration opportunity time is determined. It is the time necessary for the soil to absorb the estimated depth of irrigation water. It is obtained from the accumulated infiltration-time relationship of the soil as determined in item (3).
5. The hydraulic resistance is estimated on the basis of the soil surface roughness and the hydraulic characteristics of the crop. The hydraulic resistance, expressed as the Manning’s n, may be estimated by the Manning’s formula. An approximate value of the stream size is selected first and the value of n is calculated. More accurate values of n are obtained by successive approximations on the basis of the stream size ultimately selected.
6. The average depth of flow is estimated. For a given entrance stream size, q, hydraulic resistance, n, water surface slope, s, a depth, do, will be reached at the upstream end of the border. This depth represents the minimum steady state flow depth. The water depth is a function of the distance down the border. The stream size, q0 at any point down the border is equal to the difference between the entrance stream size, q, and the average rate of the volume of water, qi infiltrating over the area upstream from the point under consideration.
7. The water front advance is predicted. The water front advance-time relationship as a function of the entrance stream size, average depth of flow, and infiltration characteristics, may be predicted with reasonable accuracy using any equation of advance developed for predicting water front movement. To arrive at an efficient irrigation system design, it is necessary to calculate a family of advance curves using different values of q and possible border lengths.

1.5.1.5 Evaluation of Border Irrigation

Field tests of the designed border strips should be carried out in order to evaluate the performance of border irrigation. Such evaluation helps in suitably improving the system. The procedure consists in determining the intake rate by the ring infiltrometer for determining the time required for a particular depth to infiltrate into the soil. With a given stream, the advance and recession curves are plotted as in Fig. 2. A critical examination of the advance and recession curves indicates the necessary changes. The intake opportunity time for all points should be nearly equal and should be enough to infiltrate the required
depth of water. For example, if the depth absorbed at the end is too much a cut-back stream is desirable.

If the intake opportunity time is not enough, the stream size may be reduced or the length of the field increased. To assess the soil moisture distribution in the field, soil sampling before and after irrigation are desirable.

The first step in evaluating border irrigation is to determine the infiltration characteristics and water-holding capacity of the soil in the root zone. Then release a stream of predetermined size into a border strip and measure both advance and recession times at different places along the length of the border. Compare the depth of water applied at different places and determine the uniformity with which it is absorbed by the soil. Repeat the process one or more times, if the stream is not found to be of the proper size.

Recording advance and recession time at different places requires a good judgment. On slopes above 0.5 per cent, a large part of the water in the border strip, when the supply is shut off, may move down slope in a fairly uniform manner. On such fields, record recession time at each station when the water has disappeared from the area above it. If the recession line across the border strip is irregular, record the time when there is about as much cleared area below as there is water-covered area above the station. On slopes below 0.5 per cent, a smaller proportion of the water moves down the strip. Some may be trapped in small depressions and may not be absorbed for some time after surrounding areas are clear. Since the important thing is to determine when the uptake opportunity is essentially gone, the recession time may be recorded for a station when 80-90 percent of the area between it and the next station upstream has no water in the surface. The following step-by-step procedure is used in evaluating a border irrigation system.

i) Choose a border strip with a constant and non-erosive stream and measure the length and width of the border strip.

ii) Determine the average slope and variations in slope of the border and set stakes at an interval of 10 or 20 metres along the length of border strip, leaving a distance of 50 cm from the border ridge.

iii) Set a weir or other water measuring device at the upper end of the border strip and at the lower end, if surface run-off is expected.

iv) Determine the depth of the root zone of the crop, determine moisture content in the root zone of the soil at 15 cm depth increments and estimate the amount of water needed to fill the root zone.

v) Determine the infiltration characteristics of the soil by using a concentric cylinder infiltrometer tests.

vi) Turn water on to make sure that the stream size does not fluctuate. If the strip is wide, more than one opening from the head ditch to the border strip may be required to avoid erosion near the turnout and ensure uniform movement of water front across the border.

vii) Record the time when water starts flowing into the border strip and the time when the water front reaches each station. If the front is an irregular line across the border strip, use the average of the times that different parts reach each station.
viii) Record the time when the waste stream, if any, starts moving and measure the flow periodically until it stops.

ix) Record the time when water is turned off at the head of the field and the time when the sheet of water recedes past each station.

x) Check the adequacy of the irrigation at a number of places with an auger 24 hours or more after the water is turned off. Two or more days may be required for the free moisture to be distributed in the fine-textured soils.

xi) Plot the ‘rate of advance' and the recession curves of the sheet of water, compute performance parameters and determine the average depth of water absorbed by the soil and uniformity of distribution.

xii) If the analysis of data indicates that some adjustments are desirable, make them and repeat the entire process.

### 1.5.2 Check-basin Irrigation

The check basin method of irrigation consists in dividing the area into square or rectangular plots and irrigating each plot (Fig. 10). The field is laid off into compartments or checks wholly surrounded by ridges or levees. The plots are generally level or have a very mild slope. The terms flat bed method, check borders, border checks and level borders are also used to describe this method of irrigation. The levees or ridges constructed around the checks control irrigation water. The basins are filled to the desired depth and the water is retained until it infiltrates into the soil. When applying water for irrigating rice or leaching salts from the soil, the depth of water may be maintained for a considerable period of time by allowing water to continue to flow into the basins. The water admitted at the upper end completely fills the compartments until, in many cases; it overflows at the lowest point of the levee. This method of irrigation has been practised from the earliest antiquity. Check basin irrigation is the most common method of irrigation in India and in many other countries, including Europe, Asia and Africa.

![Fig. 10 Schematic sketch of a typical layout of a check basin method of irrigation](Michael, 1978)
The compartments may be laid off in various ways. If the land does not slope too much, the whole farm is laid off into square or rectangular checks, into which water is admitted in succession. Where the land is uneven or the slope steep, the checks are made to conform to the contour of the land. In either case, water must be admitted at the highest point and be brought rapidly into the compartment so that the ground may be covered thoroughly and in a short time. At times a depression is made in the lower levee over which the excess of water passes into the next lower check.

1.5.2.1 Basic Details of Check Basins

The distinguishing features of the various uses of the check basin method of irrigation involve the size and shape of the basins and whether irrigation is accomplished by intermittent or continuous ponding of water in the basins. The ridges or bunds may be temporary for a single irrigation as in the pre-sowing irrigation of seasonal crops, or may be for a cropping season as in post-emergence irrigations. They may be semi-permanently constructed for repeated use as in the case of paddy fields. The size of the ridge will depend on the depth of water to be impounded as well as on the stability of the soil when wet.

Water is conveyed to the field by a system of supply channels and lateral field channels. The supply channel is aligned on the upper side of the area and there is usually one lateral for every two rows of check basins (Fig. 10). Water from the laterals is turned into the beds and is cut off when sufficient water has been admitted to the basin. Water is retained in the basin until it soaks into the soil. The size of the irrigation stream is not critical as long as it is sufficient to provide coverage of the entire strip in a relatively small portion of the time required to apply the desired amount of water into the soil. As the infiltration rate of the soil increases, the stream size must be increased or the size of the basins reduced in order to cover the area within a short period of time. A large size irrigation stream will permit a comparatively larger size of the basin.

Types of check basins: The size of check basins may vary from one metre square, used for growing vegetables and other intensive cultivation, to as large as one or two hectares or more, used for growing rice under wet land conditions. When the land can be graded economically into nearly level fields, the basins are rectangular in shape. In rolling topography, the ridges follow the contours of the land surface (Fig. 11). The contour ridges are connected by cross ridges at intervals. The vertical interval between contour ridges usually varies from 6 to 12 cm in case of upland irrigated crops like wheat and 15 to 30 cm in case of low land irrigated crops like rice.

Fig. 11 Schematic sketch of the layout of a contour basin for irrigating big rice fields
(Michael, 1978)
The size of basins in rice fields varies with the size of the irrigation stream available and the size of the land holding. Large irrigation streams and large holdings permit large basins. The size also depends on the infiltration characteristics of the soil. Sandy and sandy loam soils with high infiltration rates permit only small size basins while clay soils having low infiltration rates allow large basins.

In rice fields, water is held at the desired level in the basins by check gates. The height of the shutter of the check gate is equal to the depth of submergence desired. Drainage may be provided by placing pipe outlets in the levels, allowing excess water from one area to spillover into the area immediately below.

**Adaptability:** Check basin irrigation is suited to smooth gentle and uniform land slopes and for soils having moderate to slow infiltration rates. Steep slopes require complex layouts and heavy land levelling. The method is especially adapted to irrigation of grain and fodder crops in heavy soils where water is absorbed very slowly and is required to stand for a relatively long time to ensure adequate irrigation. It is also suitable in very permeable soil which must be covered with water rapidly to prevent excessive deep percolation losses at the upstream end. This method can be adopted either when the soils are having high infiltration rates or low infiltration rates. In case of high infiltration rates the soils are to be quickly covered to avoid deep percolation losses and in case of soil of low infiltration rates the water is to be allowed to stand for the required time to enable the water to penetrate to the desired depth.

The check basin method is used to irrigate a wide variety of crops. Both row crops and close growing crops are adapted to be used with basins as long as the crop is not affected by temporary inundation or is planted in beds so that it will remain above the water level.

Many different kinds of crops can be grown in sequence in the same field without making major changes in the design, layout or operating procedures. Practically all irrigated paddy is grown in basins. Check basins are extremely useful when leaching is required to remove salts from the soil profile. The method also enables the conservation of rainfall and reduction in soil erosion by retaining a large part of the rain in the basin to be infiltrated gradually without loss due to surface runoff.

Evidently it is adapted only to comparatively level land; if the slope is great, the lower levee must be made too high for practical purposes. A large head is always necessary; for, if the head is small, the land, especially if sandy, is likely to absorb the water so fast at the upper end that the lower end receives only a small part of water intended to cover the whole check. In the older countries, the checks are usually small. In America, the checks are often very large-from 4 to 8 or more hectares. The check method of irrigation, to be really successful, must be practised with small checks.

**1.5.2.2 Advantages and Disadvantages**

The check method of irrigation has some advantages. The quantity of water applied can be very accurately gauged and evenly distributed by this method. The check method of irrigation is indispensable for crops such as rice, which demand that the soil be kept moist or even submerged for long periods throughout the year. Such crops are few, and the check method is, in fact, used more extensively for other crops. The method usually results in high water application and distribution efficiencies if the desired net depth of irrigation can be estimated adequately and if the size of the irrigation stream is measured properly. The low efficiencies
obtained in check basin irrigation in India are due to inadequate land levelling and uncontrolled water application.

The check method of irrigation also has many disadvantages. If the soil bakes, this method should not be employed at all, since water covers, for some time, the whole area. It is impossible by this method to keep water from touching the crop. The relatively large quantities of water that must be used by this method tend to keep the root very near the surface, and the crop will be more intensely affected by adverse conditions of heat or cold. The principal disadvantage of the check basin method of irrigation is that the ridges interfere with the movement of animal-drawn or tractor-drawn implements for inter-culture or harvesting of crops. Considerable land is occupied by ridges and lateral field channels and crop yields are substantially low on the ridge and in the lateral channels. The method impedes surface drainage. Precise land grading and shaping are required. Labour requirements in land preparation and irrigation are much higher in check basin irrigation as compared to other methods, except when the basins are very large. The method is not suitable for irrigated crops which are sensitive to wet soil conditions around the stems of plants. Plants which are damaged by these conditions are usually irrigated by furrows.

1.5.2.3 Hydraulics of Check Basin Irrigation

The hydraulics of flow in check basins may be considered to comprise of four stages: (i) initial spreading of the entrance stream to cover the full width of the basin and simultaneous advance of the irrigation stream, (ii) advance of the water front after the initial spreading, (iii) rise of water level after the advancing stream reaches the downstream end and (iv) subsidence of water after the irrigation stream is stopped. The variables influencing the hydraulics of check basin irrigation are, in general, the same as in border irrigation. The essential differences in the phenomenon are in the initial spreading of the entrance stream to cover the full width of the basin and in the characteristics of the recession flow.

Initial spreading of the entrance stream: The water front advance in a check basin differs from that in borders in the initial stages at the upstream end of the basin. The entrance stream spreads on either side as it advances forward till the entire width of the basin is covered. When water is introduced into a check basin from an orifice or other inlets, the flow is non-linear. In non-linear flow, the paths of flow may diverge or converge along the flow line. Check basins are, therefore, evaluated by observing the spreading pattern in the field. Desired water distribution efficiency is obtained by adjusting the entrance stream size or the size of the check basin or both. In long basins, the initial spreading time is very small as compared to the total time required for the water front to reach the downstream end of the basin.

Water front advance: The dominant variables, controlling the water front advance in check-basin irrigation, are the same as in borders, namely, entrance stream size, infiltration characteristics of the soil, hydraulic resistance offered by the soil surface and vegetation, water surface slope and elapsed time. Fig. 12 shows the pattern of water spread in a check basin. The water spread pattern is shown by drawing iso-time lines at uniform time intervals based on field data of the measured values of time when the water front reaches each station.
Water storage and ponding: Ponding occurs after the water front reaches the downstream end of the check basin and continues until the inflow stream is cut off. The volume of storage above the soil surface in a given time period is equal to the difference between the volume of water admitted into the basin during the period and the volume infiltrated into the soil.

1.5.2.4 Design of Check Basin Method

If the check basin irrigation system is properly designed, it is possible to apply the right amount of water nearly uniformly throughout the basin. The problem of efficient irrigation by check basin consists essentially of having the right size of basin to suit the available stream size for a particular set of soil and crop conditions.

The design of check basin system of irrigation consists in determining the size of the plot suitable for a particular stream size and also finding out the duration of irrigation in order to replenish the moisture in the root zone of the crop. As water is introduced into the check, it starts advancing and ultimately reaches the tail end. The bund at the lower end prevents any runoff. Water surface and infiltration profiles in check basin irrigation at different stages are shown in Fig. 13.
The amount of water theoretically required to irrigate a particular size of the check can be obtained using the formula:

\[ qt = \frac{Ad}{6} \]  \hspace{5cm} (5)

Where
- \( q \) = stream size, lps
- \( t \) = time for which water is to flow, min
- \( A \) = area of the check, m\(^2\) and
- \( d \) = depth of irrigation, cm.

The quantity of water calculated by the above formula will irrigate the entire check uniformly, if the opportunity time is same all over the check. In a check as some time is required for the water to spread, the opportunity time and consequently the depth absorbed will not be same over the entire area. The opportunity time available at the tail end of the check basin is less to an extent of the time required for the water to spread and advance all over the check. As such, if the area is to be fully irrigated, an additional opportunity time equal to the time of spread should be allowed at the end. It is assumed that after the water has spread all over the check basin initially, the rest of the water introduced into the check is uniformly available over the entire area. The advance and recession curves are shown in Fig. 14.

**Example 4** An irrigation stream of 15 litres/sec is delivered to a check basin of size 10 m x 15 m. The moisture contents of soil at field capacity and permanent wilting coefficient are 20 and 2 per cent, respectively. Irrigation is to be applied to the field when 50 per cent of the available moisture is depleted. Assuming no surface and deep percolation losses, determine how long the irrigation stream should be applied to the basin to replenish the soil moisture to its field capacity.
The average depth of the crop root zone is 1.2 m. The apparent specific gravity of the root zone soil is 1.5.

**Solution**

Using equation (3), the net depth of irrigation, \( d \), is computed as follows

\[
d = \frac{(pf - pa)x A x x D}{2x100}
\]

\[
= \frac{(20 - 2)x1.5x1.2x100}{2x100} = 16.2cm
\]

The time of irrigation, \( t \), may be calculated by using equation (5), i.e.

\[
t = \frac{Ad}{6q} = \frac{10x15x16.2}{6x15} = 27 \text{ min}
\]

**Example 5** Determine irrigation time of a check basin with 12 m x 50 m size which is irrigated with a stream size of 25 lps to achieve an irrigation depth of 8 cm at the tail end of the basin in a soil with cumulative infiltration of \( Y = 1.1 t^{0.45} \), where \( Y \) is the depth of infiltration in centimeters and \( t \) is the elapsed time in minutes. The advance function of the water front for the given stream size is represented by \( l = 7.5 t^{0.6} \), where \( l \) is the advance length in metres and \( t \) is the time of advance in minutes.

**Solution**

Opportunity or ponding time, \( t_d \) to apply the required irrigation depth of 8.00 cm at the tail end of the basin is calculated by using the infiltration equation as follows:

\[
t_d = \left( \frac{8.0}{1.1} \right)^{0.45} = (7.27)^{2.22} = 82.13 \text{ min}
\]

Our next step is to calculate the time of advance to reach the tail end of the check-basin. This may be computed from the given advance equation as follows:

\[
t_l = \left( \frac{50}{7.5} \right)^{1/6} = (6.67)^{1.67} = 23.80 \text{ minutes}
\]

Total recession time, \( T = t_d + t_l = 82.13 + 23.80 = 105.93 \text{ min} \)

As the water starts infiltrating at the upstream end of the basin immediately after the water enters the head of the basin, the opportunity time available at the head end of the basin is the sum of the advance time, \( t_l \), and the opportunity time, \( t_d \), required to apply the desired depth of irrigation at the tail end of the basin, i.e. 105.93 minutes. The depth of infiltration during this time is, therefore, computed as follows:

\[
Y_0 = 1.1(105.93)^{0.45} = 8.97 \text{ cm}
\]
Since there is a linear variation of depths of infiltration from the upstream and downstream ends, the average depth of water applied to the field is the average value of these two depths, i.e., 8.49 cm

Water application efficiency,

\[ E_a = \frac{\text{Water stored in her rootzone}}{\text{Water applied to the field}} = \frac{8.00}{8.49} \times 100 = 94.22\% \]

Time of application is then calculated by equation (3), after considering the application efficiency, i.e.

\[ \text{Time of irrigation} = \frac{Ad}{6q} = \frac{12 \times 50 \times 8.0}{6 \times 25 \times 0.94} = 34 \text{ minutes} \]

1.5.3 Basin Irrigation

The basin method of irrigation is a modification of the check basin method used for irrigation of orchards. Basins are generally squares or rings around the tree. Basins are constructed for each tree or a group of trees (Fig. 15). Water is conveyed to each basin, either by flowing through one basin into another or through a channel separately constructed. It refers to checks in orchards with a tree in the centre of each, and with temporary levees. Earth is heaped around the tree trunks to keep the water away from the bark. This method is used especially in mild climates where fall or winter irrigation is practised. The use of this method is also rapidly decreasing, and is likely soon to pass out of practice. The advantages and disadvantages of this method of irrigation are those discussed under the check method.

In irrigating orchards, square or contour basins may be used as in other crops. When the plants are widely spaced, the ring method of basin irrigation (Fig. 16) may be adopted. The rings are circular basins formed around each tree. The ring basins are small when the plant is young. The size is increased as the plant grows. An advantage of the ring method is that the entire area is not flooded, thus obtaining high Water use efficiency. Usually there is one basin
to a tree. In rectangular and Contour basins however, there may be one basin to a single tree or two or more trees.

![Fig. 15 Surface irrigation through basin method for irrigating small plants (Murty, 1998)](image)

### 1.5.4 Furrow Irrigation

The furrow irrigation is used for irrigating row crops with furrows developed between the crop rows in the planting and cultivating processes. The size and shape of the furrow depends on the crop grown, equipment used and spacing between crop rows. Water is applied by running small streams in furrows between the crop rows. Water infiltrates into the soil and spreads laterally to irrigate the areas between the furrows (Fig. 17). The length of time the water is to flow in the furrows depends on the amount of water required to replenish the soil moisture in the root zone and the infiltration rate of the soil and the rate of lateral spread of water in the soil). Both large and small irrigation streams can be used by adjusting the number of furrows irrigated at any one time to suit the available flow. In areas where surface drainage is necessary, furrows can be used to dispose of the runoff from rainfall rapidly.

In furrow irrigation, water is delivered to a head ditch or pipeline along the upper edge of the field. It is then diverted into furrows running down or across the slope. Furrows should be long enough to permit economical handling of farm equipment between head ditches but not too long for safe irrigation.

![Fig. 16 Surface irrigation through basin method for irrigating large trees in an orchard. It is to be noted that a field is laid in between the two rows of trees and the link channels are connecting the basins around each tree in the orchard (Michael, 1978)](image)
1.5.4.1 Advantages and Disadvantages: As compared with other methods of surface irrigation, the furrow method has several distinct advantages: (i) Water in the furrows contacts only one-half to one-fifth of the land surface, thereby reducing puddling and crusting of the soil, and evaporation losses, (ii) earlier cultivation is possible which is a distinct advantage in heavy soils, (iii) the method reduces labour requirements in land preparation and irrigation and (iv) there is no wastage of land in field ditches as compared with check basin method.

The furrow method is in many ways an ideal method of irrigation. It enables the farmer to control the quantity of water added to a soil. It makes it possible to spread a small quantity of water over a relatively large area of land. It prevents the washing and consequent destruction of the light soils characteristic of arid regions. It reduces evaporation, tends to prevent over-irrigation and, because of the ease with which the furrow may be covered soon after irrigation, the rise of alkali is delayed. There is, little disturbance of the top soil, and baking is largely eliminated.

The furrow method of irrigation also has some disadvantages. Large heads of water cannot be used in the small furrows. It may be desirable, especially in the spring, to apply quickly a large quantity of water to a given field. This is practically impossible with the furrow method of irrigation. It is difficult to admit the same quantity of water to each of the many furrows. Special attention must, therefore, be given to establishing checks in the supply ditch at suitable intervals, to force, as nearly as may be, the same quantity of water into each furrow. Tubes or lath boxes, connecting the furrows with the supply ditch, are helpful in establishing a steady flow in each furrow (Fig. 18). The uniform use of water throughout the length of the furrow is very difficult. On sandy soils, especially, the upper end of the furrow absorbs so much water that little is left for the lower end. In fact, when the furrow is long, it frequently happens that the water disappears before the lower end is reached. The best way to overcome this difficulty is probably to shorten the furrows, and to have a series of temporary supply ditches for each series of furrows.

Furrow irrigation requires proper land grading. The land must be graded so that water can travel the entire length of the row without ponding. This means that the high and low spots must be removed and the land given enough slope to let the water flow down the furrows. Once level, care in tillage operations can keep the land levelled.
1.5.4.2 Basic Details of Furrow Irrigation

Furrow irrigation consists in making the land into ridges and furrows and irrigating the area through the furrows (Fig.19).

When furrow irrigation is practised under saline and alkaline conditions, the lateral movement of soil moisture coupled with evaporation causes salt accumulation in the ridges or beds between furrows. If the salt concentrations reach harmful proportions, planting is done in the relatively salt free bottoms of the furrows following pre-irrigation. Other ways consist of pre-irrigation by the furrow method, removal of the top parts of the ridges where salt accumulates and seeding the crop in the middle of the reduced ridges.

Adaptability: Furrows are used nearly for all row crops that are irrigated by surface methods. Close-growing crops such as small grains hay and pasture on slopes and on soil bakes and crusts badly after being wet may also be irrigated with small furrows. These are sometimes called corrugations or rills. Crops like potato, maize, sugarcane, etc., which are grown on ridge are suited for this method of irrigation. Furrow irrigation can be used to irrigate all cultivated crops planted in rows, including orchards and vegetables, to replenish the water in the root zone of the crops. Both the downward movement and later spread of water are accomplished in this method (Fig. 20). Amongst the common cultivated crops of India, the method is suitable for irrigating maize, sorghum, sugarcane, cotton, tobacco, groundnut, potatoes and other vegetables. Furrows can be spaced to fit the crops grown and the standard machines used for planting and cultivating them. Crops like potatoes, maize and cotton have furrows between all rows (Fig.21). Vegetable crops such as lettuce, carrots, and onions often have two or more rows between furrows. Wide spaced crops, like melons, fruits trees and berries generally require more than one furrow between crop rows. Furrows are
particularly well adapted to irrigating crops which are subject to injury from ponded surface water or susceptible to fungal root rot. Furrow irrigation is suitable to most soils except sands that have a very high infiltration rate and provide poor lateral distribution of water between furrows. The furrow method may be adapted to, without erosion, a wide range of natural slopes by carrying the furrows across a sloping field rather than down the slope.

Fig. 20 Furrow profile showing the downward and lateral movement of water into a soil (Michael, 1978)

Fig. 21 Furrow irrigation of a vegetable crop, illustrating the crop grown on the top of two rows with one furrow irrigating both the rows by diverting water through siphon tubes from a field channel (Michael, 1978)

Furrows may also be adapted to irrigate heavy black soils in combination of border strip irrigation. These soils crack badly, so it is desirable to have furrows within the border strips, so cracking will not allow the water to escape from furrow to furrow. The border ridges are sufficiently large to confine the flow within the strip and the furrows distribute it uniformly. Another advantage is that the furrows provide uniform drainage during heavy monsoon rains and erosion is kept at a minimum.

Characteristics: In soils that absorb water slowly, a wide, relatively shallow furrow is preferable since it gives more area for the water to infiltrate. Where furrows are long and soil is quite permeable, narrow deep furrows may be used to discourage excessive percolation at the upper end. A wide and shallow furrow is normally preferable. In general, small plants require small furrows and large plants permit larger furrows. Furrows of 1.5 to 12.5 cm depth are, therefore, appropriate for vegetables, while some row crops and orchards require much deeper furrows.

Types of furrow irrigation: Irrigation furrows may be classified into two general types based on their alignment. They are: (a) straight furrows and (b) contour furrows. Based on their size and spacing, furrows may be classified as deep and corrugations.
The furrow irrigation systems based on their specifications and adaptability can be further classified into five systems. Their principal characteristics and adaptability are given in Table 3.

Table 3 Types of furrow irrigation systems

<table>
<thead>
<tr>
<th>Type of System</th>
<th>Principle features</th>
<th>Where Adaptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Flat land furrows</td>
<td>Slopes less than 0.1 per cent and essentially straight</td>
<td>Best suited for row crops</td>
</tr>
<tr>
<td>2. Corrugation type furrows</td>
<td>Moderate to steep slopes small U-shaped or V-shaped closely spaced grooves</td>
<td>Suitable to irrigate close growing crops in areas where the topography is steep and uneven.</td>
</tr>
<tr>
<td>3. Contour furrows</td>
<td>Follows contours on steep lands and hill sides</td>
<td>Suitable to irrigate steep and uneven slopes. Hazardous in high rainfall areas</td>
</tr>
<tr>
<td>4. Furrows of miscellaneous shapes</td>
<td>Special cross-section like V-shaped or broad base</td>
<td>Adapted for special soil slope and crop production problems.</td>
</tr>
<tr>
<td>5. Furrows of miscellaneous arrangements</td>
<td>Circuitous or straight</td>
<td>Used in orchards for wetting the soil. Also used for vegetable crops</td>
</tr>
</tbody>
</table>

(Murty, 1998)

(a) Straight furrows: Straight furrows, like borders, are laid down the prevailing land slope (Fig. 22). They are best suited to sites where the land slope does not exceed 0.75 per cent. In areas of intense rainfall, however, the furrow grade should not exceed 0.5 per cent so as to minimize the erosion hazard. The ranges in furrow slopes for efficient irrigation in different soil types are the same as those recommended for borders.

In fine textured soils having very low infiltration rates, the furrows are usually level lengthwise. With level furrows, the same stream size is maintained until the required amount of water is applied. The water is ponded in the furrows until it is absorbed by the soil.

(b) Contour furrows: Contour furrow method is similar to the graded and level furrow methods in that the irrigation water is applied in furrows; but the furrows carry water across a sloping field rather than down the slope. Contour furrows are curved to fit the topography of the...
the land (Figs. 23 and 24). The furrows are given a gentle slope along its length as in the case of graded furrows. Field supply channels run down the land slope to feed the individual furrows and are provided with erosion control structures.

![Fig. 23 Configuration of contour furrow irrigation (Walker, 1989)](image)

![Fig 24 Contour furrow layout in cotton in a black cotton soil area (Michael 1978).](image)

The limitations of straight furrow irrigation are overcome by contouring to include sloping lands. Light soils can be irrigated successfully across slopes up to 5 per cent. Where the soils are stable and will not be cultivated (as in orchards), slopes up to eight to ten per cent can be irrigated by contour furrowing. All row crops, including grains, vegetables and various cash crops, are adapted to this method.

Contour-furrows for row crops are installed annually. But in orchards and other permanent contour plantings, the same furrows and ditches are used every year, and they may be considered as a permanent part of the water handling system. Furrows and waste ditches should be cleaned out and prepared for the rainy seasons immediately after crops are harvested.

Contour furrows may be used on most soil types, except on light sandy soils and soils that crack. The ridges between furrows in sandy soils may break and wash out, overloading the
furrow below, which also breaks. This may continue all the way down the slope causing
heavy erosion damage. Soils that crack provide channels for water, causing similar down
slope furrow breaks. Hence their use is limited on steep slopes in sandy soils and heavy black
soils.

(c) Corrugation method: Corrugation irrigation consists of running water in small furrows,
called corrugations which direct the flow down the slope. Corrugations are U-shaped or V-
shaped channels about 6 to 10 cm deep, spaced 40 to 75 cm apart. The entire soil surface is
wetted slowly by the capillary movement of the water which flows in the corrugations. It is
commonly used for irrigating non-cultivated, close-growing crops such as small grains and
for pasture growing on steep slopes. Corrugations may be used in conjunction with border
irrigation on lands with relatively flat slopes to help in obtaining uniform coverage with
water. This method of wetting the soil minimizes the crusting effect on the surface soil which
may be a problem when the entire surface is flooded. For this reason, corrugation irrigation is
sometimes used for germinating seeds which have been drilled or broadcast. Border or check
basin methods are used later, after the plants have become established. Corrugations or rills
are shallow furrows running down the slope from the irrigation channel. Water moves down
through several corrugations at a time. Unlike in deep furrows, water in corrugations overtops
them during flow. Corrugation irrigation is well adopted for medium and heavy textured
soils, particularly if the soil tends to bake and crust after irrigations. Corrugation method is
useful in irrigation of small grain crops especially wheat.

The corrugations can be constructed with simple bamboo corrugators or cultivators equipped
with small furrows or other similar implements (Fig.25). They usually made in the direction
of the steepest slope. They may also be laid across the slope as in contour furrow. They often
become blocked by soil or plant debris, causing the water to overflow the corrugations. If the
corrugations are placed across the land slope, the overflowing water may move down into the
lower corrugations and may cause severe soil erosion. The maximum slope of the
corrugations depends on the erodibility of the soil and the type of crop being grown. The
permissible length of corrugations varies from about 50 m in light textured soils with slopes
of two to four per cent to about 150 m in heavy textured soils up to two per cent slope.

Corrugations should be spaced such that the lateral movement of water will provide an
adequate irrigation between the corrugations by the time sufficient water has been added to
refill the soil profile.

Corrugation irrigation is most suitable in loamy soils in which the lateral movement of water
takes place readily. Clay soils with low infiltration rates are difficult to irrigate by this
method, unless the slopes are quite flat, or water can be held in the corrugations for a
considerable length of time. The method is also not suitable in deep sandy soils because of
the excessive loss of water by deep percolation before the entire soil surface is wetted.
The corrugation method is not recommended on saline soils or when the irrigation water has a high salt content. The capillary movement and subsequent evaporation of the water will tend to concentrate the salts in the surface soils.

1.5.4.3. Hydraulics of Furrow Irrigation

Efficient water application in furrow irrigation depends on the knowledge of the hydraulics of flow in furrows. Like in borders, the flow phenomenon in furrow irrigation is a case of unsteady open channel flow with decreasing discharge (Fig. 26). Furrow irrigation, however, differs from borders and basins in the pattern of wetting the soil, because the water which soaks into the soil spreads laterally to the adjacent areas. The dominant variables influencing the rate of flow in furrows are the entrance stream size, infiltration rate, size and shape of wetted section of furrow, furrow slope and hydraulic resistance. The hydraulic resistance to flow may be due to the combined effect of the roughness offered by the wetted surface of the furrow and the resistance offered by the crop.

As in borders the time of ponding or infiltration opportunity time in a furrow should be the time period required for the net depth of water to infiltrate so that the crop root zone is filled to its field capacity. The criterion for providing uniformity in moisture penetration is the value of the time of ponding and should, as far as possible, be uniform throughout the length of the furrow. The time of ponding is demarcated by the difference between the advance and recession times in the furrow.
Rational procedures for predicting the water front advance and tail water recession in furrows which are applicable to field designs have not been adequately developed. A number of quasi-rational procedures have been proposed by various workers with varying degrees of adaptability. In the absence of more precise information on predicting the water front advance and tail water recession in furrows, general principles regarding stream size, furrow length and furrow slope to obtain efficient irrigation are followed in field design.

1.5.4.4. Design of Furrow Irrigation

The topography must be uniform enough to permit a head ditch that can feed the entire area of contour-furrow. It must also be regular enough to permit installing a waste ditch to carry off surplus irrigation water and rain water. Fields should be smoothed as much as possible by land grading and by using a float, or land plane, before contour plantings are laid out.

The design of the furrow irrigation system consists in deciding (i) spacing of furrows, (ii) shape and size of the furrows, (iii) stream size, (iv) furrow slope, (v) furrow length, (vi) advance time and (vii) average depth of irrigation. Efficient irrigation by the furrow method is, therefore, obtained by selecting proper combinations of spacing, length and slope of furrows and determining a suitable size of irrigation stream and duration of water application to achieve the required depth of application along the length of the furrow.

**Furrow spacing:** The spacing of the furrow depends upon the row spacing required for the particular crop to be grown and the type of machines used for planting and cultivation. Crops like potatoes, maize and cotton are planted 60 to 90 cm apart and have furrows between all rows. Vegetable crops such as lettuce, carrots and onions are spaced 30 to 40 cm and often have two rows between furrows. Wide spaced crops like melons, fruit trees and berries, generally, require more than one furrow between crop rows.

It is also desirable that the spacing is such that the lateral movement of the soil moisture wets the ridges by the time irrigation is complete. Furrows should be spaced close enough to ensure that water spreads to the sides into the ridge and root zone of the crop before it moves down below the root zone to replenish the soil moisture uniformly. The lateral movement of water from the furrow in soils with uniform profiles depends primarily upon the texture of the
soil, with a broader wetting pattern occurring in clays than in sandy soils. The wetting patterns of different soils being irrigated by furrow methods are shown in Fig.27. As such sandy soils which tend to have vertical wetting patterns should have closer furrow spacing than clayey soils. To obtain complete wetting of sandy soils to depths of 1 to 1.5 metres, the furrows should not be spaced more than 50 to 60 cm apart. In uniform clay soils complete wetting to the same depth may be obtained with a furrow spacing of one metre or more.

![Wetting pattern during furrow irrigation in different soils](image)

Fig.27 Wetting pattern during furrow irrigation in different soils (Murty 1998)

**Shape and size:** Furrow shapes depend upon soil stability, slope of the land and type of the implements used for making the furrows. For steeper slopes (slopes beyond 0.5 per cent) broad based furrows are recommended as steeper slopes cause larger flow velocities and less depth of flow. Conversely, for shallower slopes steep sided furrows are useful as the furrow capacities will be less. The shape of the furrow and position of planting has special significance in irrigating crops with saline water as illustrated in Fig. 28. The height of the ridge and the land slope determine the water carrying capacity of the furrow. Too high ridges are advantageous in areas where excess rain water is to be disposed but require large stream sizes to irrigate the top parts of the ridges.

![Evaporation](image)

(a) Salt accumulation in furrows irrigated with saline water  
(b) Furrow shape and planting to reduce salinity effect

Fig.28 Furrow irrigation with saline water (Murty 1998)

**Furrow stream:** The size of the furrow stream can be varied after the furrow irrigation system has been installed. The size of the furrow stream usually varies from 0.5 to 2.5 litres per second. The largest stream of water with non-erosive velocity is used in each furrow at the beginning of irrigation to obtain the most uniform irrigation. As the large stream size wets the furrow length very quickly, it enables the soil to absorb water evenly through the entire furrow length. After the water reaches the lower end of a furrow, the stream is reduced or cut back so that it just keeps the furrow wet throughout its length with a minimum water at the end. This cut back stream flows until the required depth of water has been applied. The initial stream in level furrows is, however, continued from the beginning to the end of irrigation. The water is ponded in the furrow until it is absorbed by the soil.
The maximum size of the irrigation stream that can be used at the start of the irrigation is limited by considerations of erosion in furrows, overtopping of furrows and prevention of runoff at the downstream end. The stream size of the furrow selected should be non-erosive within the capacity of the furrow. The maximum non-erosive flow rate in furrows as proposed by Criddle et al., (1956) is estimated by the following empirical equation:

\[ q_m = 0.75/s \]  

Where,

- \( q_m \) = maximum non-erosive stream, litres per second
- \( s \) = slope of furrow, per cent

**Furrow slope:** The slope or grade of the furrow is important because it controls the speed at which water flows down the furrow. A minimum furrow grade of 0.05 per cent is needed to ensure surface drainage. In general, the ranges in slope recommended for borders apply to furrows also.

As the furrow grade increases, both the vertical movement and the side spread of water into the crop ridge decrease, so that wastage may occur at the end of the furrow. With highly permeable soils, these factors may not be limiting. However, steeper grades lead to higher water velocities and more erosion.

As with border irrigation, a uniform slope in furrows is desirable. Uniform wetting of the soil and maximum efficiency of irrigation are impossible unless the grade is uniform. However, some deviation from perfection is tolerable with large furrows, and the efficiency of water use may frequently be improved by the use of furrow irrigation.

In order to minimize the land grading operations, longitudinal and cross-slopes used should be adapted to natural topography. The slope of the furrow should be such that it should not cause erosion problems and at the same time help in efficient irrigation. Some general values of furrow slopes are given in Table 4. When the land slope exceeds the safe limits for furrows, the furrows can be laid across the slope on the contour with desired slopes.

**Furrow length:** The optimum length of a furrow is usually the longest furrow that can be safely and efficiently irrigated. Long furrows are an advantage in inter-cultivation. If the length is too long, water soaks in too deep at the head of the furrow by the time the stream reaches the lower end. This results in over-irrigation at the upper end or under-irrigation at the lower end. Short furrows require field supply channels to be spaced too close with consequent loss of land and increase in labour requirement.

![Table 4. Furrow slopes for different soil types](image)

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Max. Slope (Per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>0.25</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>0.40</td>
</tr>
<tr>
<td>Fine sandy loam</td>
<td>0.50</td>
</tr>
<tr>
<td>Clay</td>
<td>1.50</td>
</tr>
</tbody>
</table>

(Murty, 1998)
Proper furrow length depends largely on the hydraulic conductivity of the soil. Furrows must be shorter on a porous sandy soil than on a tight clay soil. The length of furrow which can be efficiently irrigated may be as short as 45m on soils which take up water rapidly, or as much as 300 m or longer on soils with low infiltration rates. The length of furrow is also limited by the size and shape of the field. If only a small area is to be irrigated, the length of furrow may be determined by the length of the field. If the area is large, it may be desirable to have the furrow lengths equal to an even fraction of the total length of the field.

With flat slopes (less than 0.3 per cent) the length of the run can usually be increased with the increase in the furrow slope. Furrow lengths can be increased as the average depth of water to be applied increases. Since the depth of irrigation needed is related to the water holding capacity of the soil and the depth of rooting of the crop, much longer furrows can be used with deep rooted crops growing on clay soils than for shallow rooted crops growing on sandy soils.

In heavy rainfall areas, the length of furrows should be short enough to dispose of the runoff safely without breaking the furrows. Erosion control structures are needed to carry the surplus water down the slope. Contour furrow irrigation used in conjunction with contour bunding and terracing provides an insurance against furrow breaks. Land which is too steep for contour furrows may sometimes be graded to leveled strips (bench terraces) across the slope on which the furrows can be constructed. Land with slopes up to 25 per cent or more can be benched to permit the production of irrigated crops.

The furrow length is influenced by the slope, rate of advance and the depth of application. The stream size, slope and furrow length should be so adjusted that the deep percolation losses are minimum. Table 5 can be used as a rough guide for selecting the furrow length.

**Time of advance:** The time of advance of the water should be such that minimum percolation losses are caused at the head of the furrow. Criddle *et al.*, (1956) suggests a value of T/4 as the time of advance for the stream to reach the end of the furrow, where T is the time required to infiltrate the required depth of water. In such a system, it is assumed that the water flows out at the end of the furrow and the water is used subsequently. In South East Asian Countries almost all the furrow irrigation systems are designed not to allow runoff at the tail end.

**Average depth of irrigation:** The average depth of water applied during irrigation can be calculated from the following relationship

\[ d = q \times \frac{360 \times t}{W \times L} \quad \ldots \ldots \quad (7) \]

Where,
- \(d\) = average depth of water applied, cm
- \(q\) = stream size, litres per second
- \(t\) = duration of irrigation, hours
- \(W\) = furrow spacing, metres
- \(L\) = furrow length, metres
Table 5 Typical furrow lengths for various soils

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Application depth (mm)</th>
<th>Slope (%)</th>
<th>Discharge lpm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.25</td>
<td>0.50</td>
</tr>
<tr>
<td>Coarse</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
<td>150</td>
<td>120</td>
</tr>
<tr>
<td>100</td>
<td></td>
<td>210</td>
<td>150</td>
</tr>
<tr>
<td>150</td>
<td></td>
<td>260</td>
<td>180</td>
</tr>
<tr>
<td>Medium</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
<td>250</td>
<td>170</td>
</tr>
<tr>
<td>100</td>
<td></td>
<td>375</td>
<td>240</td>
</tr>
<tr>
<td>150</td>
<td></td>
<td>420</td>
<td>290</td>
</tr>
<tr>
<td>Fine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
<td>300</td>
<td>220</td>
</tr>
<tr>
<td>100</td>
<td></td>
<td>450</td>
<td>310</td>
</tr>
<tr>
<td>150</td>
<td></td>
<td>530</td>
<td>380</td>
</tr>
</tbody>
</table>

(Withers and Vipond, 1974)
(Application depth includes water for leaching)

**Example 6** Furrows 90 m long and spaced 75 cm apart are irrigated by an initial furrow stream of two litres per second. The initial furrow stream reached the lower end of the field in 50 minutes. The size of the stream was then reduced to 0.5 litres per second. The cut back stream continued for 1 hour. Estimate the average depth of irrigation.

**Solution**

Average depth of irrigation by the initial furrow stream = \( q \times 360 \times t / W \times L \)

\[
= 2 \times 360 \times 50 / 0.75 \times 90 \times 60 = 8.88 \text{ cm}
\]

Average depth of irrigation by the initial furrow stream = \( 0.5 \times 360 \times 1 / 0.75 \times 90 \)

\[
= 2.66 \text{ cm}
\]

Net average depth of irrigation = 8.88 + 2.66 = 11.54 cm.

**1.5.4.5. Evaluation of Furrow Irrigation**

Evaluations of furrow irrigation systems and practices are extremely important, especially where slopes are rather steep. Erodability of the soil, size of the stream, steepness of the slope and shape of the furrow are factors involved. Increasing the land slope or stream size tends to increase erosion. Decreasing stream size and slope and using wide, shallow furrows tend to decrease erosion.

Increasing the size of stream in a bare, V-type furrow on the steeper grades does not materially increase the rate at which the water enters the soil. A furrow stream, of 3.785 litres per minute will put about as much water into the soil per metre of furrow as will a
stream 10 times as larger. This is generally not the case on the gentler slopes or where the furrows are broad or grass covered. By using smaller streams, however the irrigation usually can save both water and soil, but with little more time spent in irrigation if lengths of run are correct.

Flow into furrows can be carefully regulated for uniform water distribution and efficient irrigation. In the absence of satisfactory rational equations to predict advance and recession in furrows, furrow specifications and stream sizes are selected on the basis of field evaluation data obtained under representative field conditions.

Infiltration of water into the furrow is the most important variable affecting the characteristics of flow in furrows. The infiltration rates in furrows may be determined by the gravimetric method, by specially designed furrow infiltrometers, or, more commonly, by the ponded and the inflow outflow methods. However, the ring infiltrometer data will not be applicable to furrows as in case of furrows, only a part of the soil is exposed to the water. In the gravimetric method the difference in moisture content in the soil before and after irrigation is determined by soil sampling and moisture determination. The method, though accurate, is time consuming as it involves sampling at many locations. The furrow infiltrometer technique consists of blocking the furrows at their two ends so as to assess the volume storage difference in the furrow in relation to time. The instrument includes a float mechanism and a water stage recorder. In the ponding method a section of three consecutive furrows are selected and mild steel plates are driven to create buffer around the control portion of the furrow under observation. The results are plotted just like the ring infiltrometer test. The inflow-outflow method, also known as volume balance method, is considered to be the most satisfactory one because it averages infiltration value by compensating various errors, inherent in furrow, arising out of soil heterogeneity, furrow cross-sectional difference, cracks and puddling effects. In this method, a 30 m reach of the furrows is selected. Water is allowed to flow in three consecutive furrows. The inflow and outflow rates in the control furrow are measured. The outer furrows are known as guard furrows and they help in obtaining a representative value of the furrow infiltration in the central furrow.

The procedure for gathering data to evaluate a furrow irrigation system is to divert different sized streams into several furrows and check the rate at which the stream fronts advance down them. Each stream is measured at the head of the furrow and at one or more points down the furrow to determine how much water enters the soil. The following is the step-by-step procedure for evaluating a furrow irrigation system:

1. Choose several uniform furrows for testing.
2. Set stakes at 15 m or 30 m stations down the field.
3. Determine the average slope and variation in slope.
4. Measure the stream size at both the ends of the furrow. Set constant but different size flow stream for each furrow. Analysis will be easier if the spread in stream sizes is rather large. This is done to distinguish between the largest stream causing erosion and the smallest one too small to advance to the end of the furrow. The size of the medium stream may be estimated from the formula \( q = 38/s \), where \( q \) is the stream size in litres per minute and \( s \) is the slope of the furrow in per cent.
5. Estimate how much water can be stored in the crop root zone. Conduct the test when the crop is to be irrigated or the land is not cropped, when soil moisture is relatively low.

6. Record the time when water starts to flow into each furrow and when it reaches the stations. Record the recession time when the stream is cut off.

7. Measure streams, periodically at the stakes and record results.

8. Inspect each furrow for erosion or overtopping and estimate the maximum allowable stream. Flowing water near the intake point causes some erosion. So cloudiness in the water for the first 5 minutes after a stream passes a point may be permissible. Obvious movement of soil particles and vertical cutting or undercutting along the furrow banks after the initial wetting would be serious erosion. This indicates the need for using a smaller stream.

9. Periodically measure flows in the furrows at the outflow-measuring points. Continue these measurements until flows become practically constant. This may not happen on the fine-textured soils for several hours.

10. Cut a trench across and at right angles to the furrows at several places after the irrigation to examine the wetting pattern.

11. Check the adequacy of irrigation 24 hours or more after the water is turned off. In the fine textured soils, 2 or 3 days may be required for all the free moisture to be drained.

12. Collect the soil samples after the free moisture is drained and compute the performance parameters as defined earlier.

13. Determine what adjustments, if any, are needed for safe and efficient irrigation.

Example 7: An irrigation stream of 0.12 m$^3$/min was diverted to apply 9.5 cm depth of water to bring the moisture to the field capacity in a field having uniform slope with 200 m long furrows spaced at 75 cm intervals across the field. The water supply to the field was a large tube-well capable of supplying water on demand.

The soil was a sandy loam of which cumulative infiltration was represented by $Z = 0.55 T_0^{0.532}$, where $Z$ = depth of infiltration in cm and $T_0$ = opportunity time, in minutes. The inflow into the furrow was cut off 390 minutes after irrigation. The surface runoff was measured as 16.7 m$^3$ during the test. The advance and recession times measured during the test points are given in the following table. Assess the performance of this system. Also suggest remedies to improve the system.

<table>
<thead>
<tr>
<th>Advance distance (m)</th>
<th>Advance time (min)</th>
<th>Recession time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
<td>390</td>
</tr>
<tr>
<td>47</td>
<td>6.0</td>
<td>396</td>
</tr>
<tr>
<td>112</td>
<td>18.0</td>
<td>402</td>
</tr>
<tr>
<td>151</td>
<td>30.0</td>
<td>405</td>
</tr>
<tr>
<td>200</td>
<td>54.8</td>
<td>408</td>
</tr>
</tbody>
</table>
Solution

The performance of the system may be assessed by determining the performance parameters defined in Sub-section 1.4. We first determine the depth of infiltration at each of the five points along the length of the furrow by using the given infiltration equation and measured values of advance and recession times at these points. The infiltration depth at any point is computed by substituting in this equation the value of opportunity time at the point, which is obtained by subtracting the advance time from the recession time at the point. The calculation procedure is given in the following table:

<table>
<thead>
<tr>
<th>Advance distance (m)</th>
<th>Advance time (min)</th>
<th>Recession time (min)</th>
<th>Opportunity time (min)</th>
<th>Depth of Infiltration (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
<td>390</td>
<td>390.00</td>
<td>13.15</td>
</tr>
<tr>
<td>47</td>
<td>6.0</td>
<td>396</td>
<td>390.00</td>
<td>13.15</td>
</tr>
<tr>
<td>112</td>
<td>18.0</td>
<td>402</td>
<td>384.00</td>
<td>13.04</td>
</tr>
<tr>
<td>151</td>
<td>30.0</td>
<td>405</td>
<td>375.00</td>
<td>12.88</td>
</tr>
<tr>
<td>200</td>
<td>54.8</td>
<td>408</td>
<td>352.20</td>
<td>12.47</td>
</tr>
</tbody>
</table>

The next step is to compute the performance parameters from the equations presented in the Sub-section. They are calculated as follows:

(a) Water application efficiency, $E_a$

Volume of water applied to the field = $0.12 \times 390 = 46.80 \text{ m}^3$

Water added to the root zone = $0.095 \times 200 \times 0.75 = 14.25 \text{ m}^3$

$$E_a = \frac{14.25}{46.80} \times 100 = 30.45\%$$

(b) Water storage efficiency

We see here that the depth of infiltration (applied water depth) at each of the five points from the upstream to the downstream ends of the furrow is more than the depth added to the root zone. In other words, the root zone along the entire length of the furrow is completely saturated with water. As a result, the water storage efficiency is 100 per cent.

(c) Distribution efficiency, $E_d$

(i) Average depth of infiltration, $d'$

$$d' = \frac{13.15 + 13.15 + 13.04 + 12.88 + 12.47}{5} = \frac{64.69}{5} = 12.94$$
(ii) Average numerical deviation, \( y' \)

\[
\frac{(13.94 - 12.94) + (13.15 - 12.94) + (13.04 - 12.94)(12.94 - 12.88) + (12.94 - 12.47)}{5} = \frac{1.05}{5} = 0.21
\]

Hence,

\[
E_d = 100 \times \left(1 - \frac{0.21}{12.94}\right) = 100 \times (1 - 0.016) = 98.38\%
\]

(d) Tail water losses, TWL

(i) Volume of surface runoff = 16.70 \( m^3 \), as given in the example
(ii) Water applied to the field = 46.80, as calculated above

Hence,

\[
TWL = \frac{16.70}{46.80} \times 100 = 35.68\%
\]

(e) Deep percolation losses, DPL = 100 - \( E_a \) – TWL = 100-30.45-35.68 = 33.87%

Performance of the System

The performance of the system during the evaluation was poor, about 70 percent of all water applied was wasted from the field as runoff or deep percolation. In order to identify improvements, these losses must be separated, either by integrating the applied distribution and computing the deep percolation ratio or by integrating the runoff hydrograph and computing the tailwater ratio. For this example, the latter is chosen to reflect more confidence in measured runoff than calculated infiltration. Losses during the irrigation were almost evenly split between tailwater and deep percolation.

Measures to Improve Performance

The most obvious way to improve the performance of this system would be to cut the inflow off-when the application at the lower end of the field was approaching the required depth. If the required intake opportunity time at the end of the field is calculated and added to the advance time, the cutoff time represented by their sum is approximately 180 minutes. If this would have happened, the total water applied to the field would have been reduced from 46.8 \( m^3 \) to 21.6 \( m^3 \). The soil moisture deficit would still have been completely replenished (\( E_s = 100 \) percent), but the application efficiency would have been increased to about 66 per cent. The DPL and TWL values would have been reduced to 11 percent and 20 percent respectively. Further improvements could be made by utilizing a cutback flow after the advance was completed or by adjusting the inflow rate (reducing it in this case would improve performance).
1.5.5 Surge Irrigation

Excessive water intake and deep percolation losses are the major limitations in water application through surface methods of irrigation. Surge flow irrigation or the intermittent application of water in a series of ‘on’ and ‘off’ modes during constant or variable time spans has the potential to increase irrigation efficiencies of surface methods. The system consists of applying an irrigation stream along the length of the field at a very high advance rate. When the water reaches the end of the field, it is stopped either manually or by using automatic devices. Irrigation is completed in the second cycle with the reduced irrigation size. This irrigation system pioneered by the scientists of Utah State University (Walker and Skogerboe, 1987) is popular in the furrow irrigated areas in USA.

When the water is applied in surges, the downward movement of water during the first surge takes place at the same rate as that in a continuous flow. Afterwards, the infiltration rate in the upper layer of the soil increases in the subsequent surges. This infiltration rate following the ‘off-time’ cycle is higher than that at the end of preceding surge. This is due to the fact that, during the ‘off-time span’, the moisture content at the soil surface is redistributed itself in various downward layers and brings the top surface to a moisture content less than that would have been under the continuous flow. This makes the top soil to absorb more water and the lower layer less water as compared with that under continuous flow. As a result, the total water infiltrated per unit of time under the irrigated area of water front movement is less than that under continuous flow. This increases the rate of movement of water front.

Surge irrigation reduces intake and percolation losses and conserves irrigation water. The degree of water conservation depends upon the stream size, ‘on-time’ and ‘off-time’ cycles and number of surges. These parameters affect the opportunity time, depth and uniformity of infiltration along the length of water front movement, which in turns improve the overall efficiency of the irrigation system. Water distribution efficiency as high as 92 per cent has been reported in surge irrigation as compared with that of 79 per cent in surface irrigation with continuous flow (Visalakshi and Rajput, 1998).

2. SUB-SURFACE IRRIGATION

Sub-surface irrigation consists of applying water from below the ground surface by maintaining an artificial water table at some depth depending upon the soil texture and the depth of the plant roots. Water reaches the plant roots through capillary action. Water may be introduced through open ditches (Figs. 29 and 30) or underground pipelines such as tile drains or mole drains. The depth of open ditches or trenches varies from 30 to 100 centimetres and they are spaced about 15 to 30 metres apart. The water application system consists of field supply channels, ditches or trenches suitably spaced to cover the field adequately and drainage ditches for the disposal of excess water.
2.1 Advantages and Disadvantages

The sub-surface method of irrigation requires special site conditions to have a complete control of water table through water application and drainage. Each site requires special investigations to determine its adaptability to sub-surface irrigation. The method is suited to soils having reasonably uniform texture and permeable enough for water to move rapidly both horizontally and vertically within and for some distance below the crop root zone. The soil profile must also contain a barrier against excessive losses through deep percolation, either a nearly impermeable layer in the substratum or a naturally high water table on which a perched or artificial water table can be maintained throughout the growing season. Topography must be smooth and nearly level or the slopes very gentle and uniform. It has the following advantages and disadvantages:

1. The water is not subjected to direct evaporation from the soil surface. When water is scarce, it is of great importance to reduce such evaporation.
2. It is possible to maintain the water level at optimum depths for crop needs at different growth stages.
3. The system installed once requires little further attention; whereas surface irrigation requires a large annual cost for the upkeep of ditches and the actual spreading of water over the land.
4. The successive wetting and drying of the top soil through surface irrigation, however, benefits crops to enable them to produce more dry matter. This benefit overshadows the loss by evaporation through surface irrigation. Studies indicate that much larger quantities of water evaporate when the water is applied to the surface of the soil than when applied by sub-surface irrigation, but a unit of water applied to the surface produces as much dry matter as when applied below the surface. The value of sub-surface irrigation has been considerably exaggerated only because of decreased evaporation losses (Widtose, 2001).
5. Sub-surface irrigation implies underground water channels, opened at various places for the escape of water to the crop. These underground channels are usually pipes of iron or concrete or wood. The cost of installing such a system is very great and adds immensely to the initial cost of irrigation.

6. Leaks more often occur in the underground system which are located with great difficulty and remedied at large expenses.

7. Plant roots, always in search of water, are gradually directed to the openings in the underground pipes and fill them so completely that the flow of water is either greatly diminished, or entirely stopped.

8. Since the method requires an unusual combination of natural conditions, it can be used in only a few areas. Water having a high salt content cannot be used.

Fig. 30 Sub-surface irrigation of coconut palms through an open ditch in the organic soils reclaimed from lake-bed, Kerala (Michael, 1978)

2.2 Adaptability

Sub-surface irrigation can be used for soils having a low water holding capacity and a high infiltration rate where surface methods cannot be used and sprinkler irrigation is expensive. In India sub-surface irrigation is practised to a limited extent for growing vegetable crops around 'Dal' lake in Kashmir and for irrigation coconut palms in the organic soils or Kuttanad area in Kerala (Michael, 1978).

The best that can be said about sub-surface irrigation is that the method has not yet been perfected and that it offers a fine field for the agricultural inventor. One kind of sub-irrigation of extremely limited application has proved successful. In certain localities are found somewhat sandy soils, 30 cm to 1.5 m in depth, under laid by almost impervious clay. Ditches are dug at intervals of 800 to 1200 m. The water flowing through these ditches sinks until it reaches the clay bottom, along which it travels for great distances within reach of
plant roots. Some of the finest fields in western America are supplied with water by this inexpensive process of natural seepage. Clearly, this method is so limited in extent that it deserves only a passing notice (Widtose, 2001). Attempts should, therefore, be made to irrigate crops by natural sub-irrigation, whenever the conditions appear to be suitable. Except in greenhouses and under natural systems, sub-irrigation may be eliminated from consideration.

3. SPRINKLER IRRIGATION

The method of applying water to the plant on the ground surface through spraying it overhead, somewhat resembling rainfall, is known as sprinkler irrigation. The spray is obtained by applying water under pressure through small orifice nozzles referred to as sprinklers. A pump is used for developing the required pressure. The required pressure may also be developed by gravity, when the source of water is high enough above the area to be irrigated. A typical sprinkler system is shown in Fig. 31. Irrigation water through sprinkler required to refill the crop root zone can be applied more uniformly than that in surface irrigation and at a rate to suit the infiltration rate of the soil. The careful selection of nozzle sizes, operating pressures and sprinkler spacing result in more efficient irrigation.

![Fig. 31 Typical setup of a sprinkler system (Murty 1998)](image)

3.1 Adaptability of Sprinkler Irrigation

Sprinkler irrigation can be used for almost all crops, except rice and jute, and on most soils. It is, however, not suitable in very fine textured soils, where the infiltration rates are less than about 4 mm per hour. The method is particularly suited to sandy soils that have high infiltration rates. Soils too shallow to be levelled properly for surface irrigation methods; can safely be irrigated by sprinklers. This method is also adaptable to adverse topographic conditions of steep and irregular slopes. Sprinkler irrigation can also be used in conjunction with contour bunding, terracing, mulching and strip cropping, if soil erosion is a hazard. Though land levelling is not essential for sprinkler irrigation, some smoothing or grading is required in areas with poor surface drainage.

Sprinkler irrigation can also be used to apply soluble fertilizers, herbicides and fungicides with irrigation water without much extra equipment cost. Penetration of fertilizers into the soil can be controlled by applying the fertilizer at selected times during the application of
water. Sprinkler irrigation can further be used to protect crops against frost and high temperatures that reduce the quantity and quality of harvest.

The introduction of sprinkler irrigation in India was initiated in the mid nineteen fifties, when the plantation owners in the hills introduced sprinkler irrigation to irrigate tea, coffee and cardamom crops during dry season and dry spells of the monsoon period. In mid seventies, progressive farmers in Narmada valley in Madhya Pradesh, southern part of Haryana and north-east part of Rajasthan started using sprinkler system to overcome problems of water shortage, particularly during summer. The adoption of the system gradually spread to large area in the states of Haryana, Rajasthan, Madhya Pradesh, Maharastra and Karnataka. The spread and popularization of the sprinkler irrigation method with farmers has received significant support thereafter through various schemes involving subsidy from the Central and State governments in the recent years. It is estimated that the total area under sprinkler irrigation in India is about 0.7 M ha out of the total irrigated area of 99.39 M ha in the country (Sharma et al, 2006). All out efforts are being made at present to cover more and more area under sprinkler irrigation in India. The Ministry of Agriculture, Government of India and different state governments have been providing subsidy support to propagate the sprinkler irrigation with a view to encouraging second green evolution through increased water use efficiency in irrigation sector (INCID, 1995).

Sprinkler irrigation is becoming increasingly popular in India in regions of water scarcity where available water is insufficient to irrigate the command area by surface irrigation. In such regions, by adopting suitable cropping patterns consisting of crops having high water requirements like wheat and those having low water requirements like mustard and gram, much higher area can be brought under irrigation and farm income increased substantially by adopting sprinkler irrigation. Sprinklers are increasingly being used for irrigating high valued plantation crops like tea, coffee, cardamom and orchards.

3.2 Advantages and Disadvantages

Well-designed sprinklers distribute water better than surface methods. Surface runoff of irrigation water is totally eliminated. The amount of water can be controlled to meet crop needs and light application can be made efficiently on seedlings and young plants. Sprinkler irrigation may be advantageously used under the following conditions:

1. Land is unsuitable or uneconomical for levelling.
2. Soils are too porous and highly erodible.
3. Stream size is too small to distribute water efficiently by surface irrigation methods.
4. Effective control of water application is convenient for applying light and frequent irrigation with higher water application efficiency.
5. Areas located at a higher elevation than the source of water.
6. Labour costs are usually less than those for surface methods.
7. More land is available for cropping, since field supply channels and bunds or ridges are not required.
8. The irrigation method does not interfere with the movement of farm machinery.
Sprinkler irrigation system, has, however, the following disadvantages:

1. Wind distorts sprinkler patterns and causes uneven distribution of water.
2. Evaporation losses are high when operating under high temperatures. This becomes more harmful when the irrigation water has larger amounts of dissolved salts.
3. Initial investment and continued operating costs are much higher than those in case of surface irrigation methods.
4. Power requirements are usually high, since sprinklers operate with a water pressure of 0.5 to more than 10 kilograms per square centimetre.
5. Fine-textured soils that have a slow infiltration rate cannot be irrigated efficiently in hot windy areas. If water applied at the low rate required for these soils, the percentage of water lost by evaporation and wind drift increases.
6. Ripening soft fruits are damaged from the spray.
7. A stable and continuous water supply is needed for the most economical use of the equipment. This is not possible in rural areas due to erratic power supply.
8. The system cannot be used in areas with water containing sand, debris and large amounts of dissolved salts.

3.3 Components of a Sprinkler System

A typical sprinkler system consists of a pumping unit, main line, laterals, risers and sprinkler heads. Additional devices consist of debris screens, desilting devices, flow regulators and fertilizer applicators (Fig. 32). The parts of all sprinkler systems are similar in most respects.

**Pumping unit:** The pump lifts water from the source and pushes it through the distribution system of the sprinklers. It may also be used to boost the water in an existing water distribution line to force it through the sprinkler system at the desired pressure. In all cases, it is important that the pump should be designed to lift the required amount of water from the source of supply to the highest point in the field and maintain an adequate operating pressure.

The type of pumping unit is decided depending on the source of water supply. Both vertical turbine pumps and centrifugal pumps can be used for the purpose. In order to develop required pressure, booster pumps may sometimes be needed. The centrifugal pump, which is more popular, is usually used when the source of water is an open well or any other shallow water source. The turbine pump is used to pump water from deep tube-wells. It is generally set at a fixed location. But, centrifugal pumps are either portable or permanently installed. The pumps can be driven either by electric motors or internal combustion engines. Electric motors are better for fixed installations. They have low initial and running costs and are easier to maintain. Engines are used when the pumping unit is to be portable and at places where electricity is not available.
Main lines: Main lines may be permanent or portable depending upon the situation. Permanent mains are used on farms where field boundaries are fixed and where crops require full-season irrigation. Portable mains are used when a sprinkler system is to be used on any one of a number of fields. Steel pipes are used for most permanent main lines. Asbestos-cement and PVC pipes are also used, but concrete pipelines are not adapted to use in high pressure sprinkler systems. The permanent lines should be buried so as to be out of the way of farming operations. Lightweight aluminium pipes with quick couplers are used for most portable main lines.

Movable mains generally have a lower initial cost and do not provide obstruction to field operations. Water is taken from the main either through a valve placed at each point of junction with a lateral or in some cases through an L or a T section that has been supplied in place of one of the couplings on the main.

Lateral lines: The lateral lines are usually portable. Buried permanent laterals are, however, used for some orchards, tree nurseries and for other special sites. Quick-coupled aluminium pipe is best for most portable laterals. The lateral pipes are usually available in lengths of 5, 6 or 12 m. Each length has quick couplings. The rubber gasket in the female portion of these couplings has a U-shape. The water pressure forces the outside of the 'U' to form a water tight seal. When the water is turned off, the seal is broken and water drains from the pipe, making it easier to uncouple and move the laterals.

Sprinkler heads: The sprinkler head is the most important component of a sprinkler irrigation system (Fig.33). Its operating characteristics under optimum water pressure and climatic conditions, mainly the wind velocity, determine its suitability and the efficiency of the system. The two principal methods used to develop the spray required for sprinkling are: (i) revolving head sprinklers having one, two or more nozzles, depending primarily on the
diameter of the wetted circle and (ii) pipe containing lines of small perforation along its top and sides. Most agricultural sprinklers are of the slow rotation type. They may range from small single-nozzle sprinklers to giant multiple nozzle sprinklers that operate at high pressures.

The combination of pressure and slow rotation results in the jet of water thrown to a considerable distance. This is necessary so that the sprinklers can be spaced farther apart and the water application rates with overlapping pattern can be low enough to be commensurate with the infiltration capacity of the soil. Further, it permits the use of larger orifices to minimize problems of clogging caused by any debris in the water.

The operating characteristics of a rotating sprinkler head determine the rate, amount and distribution of water. Most of the sprinklers used for field crops in India are of the slowly rotating type with either one or two nozzles. The most commonly used types are the small to medium sprinklers with capacities ranging from 7.5 to 75 l/min and which operate at pressures from 1.4 to 4.2 kg/cm². They cover an area of 10 to 40 m in diameter. These sprinklers rotate around a vertical axis. The rotation is caused either by the torque produced by the reaction of the water leaving a nozzle or by the impact of a spring-loaded arm that periodically interrupts the jet from one of the nozzles. Some rotating sprinklers can be adjusted to irrigate a particular segment of a circle. Sprinkler heads commonly used have two nozzles, one to cover the farther area from the sprinkler and the other to cover the area near the sprinkler. Single nozzles are used for low application rates. There are several variations in the design and operating characteristics of the rotating sprinkler to suit different field and climatic conditions.

Debris screens and desilting basins: Debris basins and desilting basins are needed to remove any foreign materials and sediment entering the sprinkler system. They are especially needed if water from surface runoff is used through the sprinklers. Sprinkler systems can also be used to apply fertilizers along with water. The fertilizer is applied through the suction side of the pump. This could, however, cause corrosion of the pump parts because of the chemical nature of the fertilizers. Another method to add the fertilizer solution to the sprinkler system is a Venturi fixed in the sprinkler line creating differential pressures and allowing the fertilizer solution to flow into the water line.
3.4 Types of Sprinkler Systems

The sprinkler system consists of the water source, pumping unit, main line, laterals, risers and the sprinkling units. Sprinkler systems are broadly in the following major types: (i) nozzle-line systems, (ii) perforated portable pipe systems, and (iii) revolving sprinkler systems.

In the nozzle-line systems, small bore nozzles are placed in water pipe at uniform intervals along its length. A rectangular strip is usually irrigated. This is the earlier form of the sprinkler systems and its use now is limited to nurseries and small areas.

The perforated pipe system consists of drilled holes in portable thin wall tubing to irrigate about 3 to 15 m wide strip in a fairly uniform distribution pattern. The system is designed for relatively low operating pressure (about 1 kg/cm²). The application rates are usually 1.25 to 5 cm per hour. Because of its limited coverage in one setting, a large number of movements are needed to irrigate even moderately sized areas.

The revolving sprinkler system consists basically of rotating sprinklers either installed on a pipeline, portable quick coupling lateral pipes or with some type of moving device. The system is versatile either for small or large areas. This system can further be classified as: (i) hand move systems, (ii) mechanical move system and (iii) solid set systems.

In the hand move systems, the lateral lines are manually moved across the irrigated areas. The mechanical move systems adopt a variety of devices for moving the lateral lines across the irrigated areas. In the solid set system, the entire irrigated area is equipped by a set of sprinklers operated either simultaneously or in sequence by automatic timed or manual controls.

Sprinkler systems may also be classified as permanent, portable, semi-permanent and semi-portable, depending upon the makeup of the components.

3.5 Layout of Sprinkler Irrigation

Table 6 presents the characteristics and adaptability of different types of rotating head sprinklers. With the type of sprinkler determined, based on pressure limitations, application rates cover conditions, crop requirements and availability of labour. The next step is to determine the location of the pumping unit, the orientation of mains and laterals, sprinkler spacing, operating pressure and nozzle sizes that will most nearly provide the optimum water-application rate with the greatest degree of uniformity of distribution.

Location and nature of water supply: The source of water supply for sprinkler irrigation is usually a tube well or open well located on the farm. Sometimes, however, surface water sources may also be used with sprinkler irrigation system. The well may be located at a high corner or, more likely, at the centre of the farm to minimize the distance the water must be pumped (Fig. 34). The layout of the mains will depend on the location of the well. It is advantageous to design the pump so as to lift water from the well and provide necessary pressure to overcome the friction loss in the pipelines and to operate the sprinklers.

Sometimes, it may be necessary to adopt a sprinkler irrigation system with an already laid underground pipeline water distribution system or field channels. In case of underground pipelines, a portable pumping set can be used with the suction attached to the hydrants.
mounted outlets. In case of field channels running along one edge of the farm, a portable pumping set and sprinkler unit with the lateral to the field may be used to draw water directly from the channel and distribute it through the sprinklers. Alternatively, the channel can be run down the centre of the field. The laterals will then be only half as long so that smaller length laterals could be used, but the channel interfere with tillage operations and may result in some reduction in net area cropped. Another alternative is to have a permanent pumping plant at the source and distribute the water in buried pressure pipelines. These pipelines will usually run down the centre of the field so that outlets will offer little hindrance to tillage and other farm operations.

![Diagram of sprinkler irrigation system](image)

**Fig. 34. Layout plan for sprinkler irrigation system. The laterals are moved to successive positions up on one side of the main and then down on the other (Michael, 1978)**

**Orientation of laterals:** To obtain a reasonable degree of uniformity in the discharge of each sprinkler, the mains should be located in the general direction of the steepest slope, with the laterals at right angles thereto and as close as is practical to the contour. The usual design is
Table 6: Classification of rotating head sprinklers, their characteristics and adaptability

<table>
<thead>
<tr>
<th>Type of sprinkler</th>
<th>Gravity-fed under tree sprinkler</th>
<th>Normal under-tree sprinkler systems</th>
<th>Permanent overhead systems</th>
<th>Small overhead systems</th>
<th>Low pressure systems</th>
<th>Intermediate pressure systems</th>
<th>High pressure systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure range</td>
<td>0.7 to 1.0 kg/sq cm</td>
<td>1 to 2.5 kg/sq cm</td>
<td>3.5 to 4.5 kg/sq cm</td>
<td>2.5 to 04 kg/sq cm</td>
<td>1.5 to 2.5 kg/sq cm</td>
<td>2.5 to 5 kg/sq cm</td>
<td>5 to 10 kg/sq cm</td>
</tr>
<tr>
<td>Sprinkler discharge</td>
<td>0.06 to 0.25 l/sec</td>
<td>0.06 to 0.25 l/sec</td>
<td>0.2 to 0.6 l/sec</td>
<td>0.6 to 2.0 l/sec</td>
<td>0.3 to 1 l/sec</td>
<td>2 to 10 l/sec</td>
<td>10 l to 50 l/sec</td>
</tr>
<tr>
<td>Diameter of Nozzles</td>
<td>1 to 6 mm</td>
<td>1.5 to 6 mm</td>
<td>3 to 6 mm</td>
<td>6 to 10 mm</td>
<td>3 to 6 mm</td>
<td>10 to 20 mm</td>
<td>20 to 40 mm</td>
</tr>
<tr>
<td>Diameter of coverage</td>
<td>10 to 14 m</td>
<td>6 to 23 m</td>
<td>30 to 45 m</td>
<td>25 to 35 m</td>
<td>20 to 35 m</td>
<td>40 to 80 m</td>
<td>80 to 140 m</td>
</tr>
<tr>
<td>Range of sprinkler spacings (square)</td>
<td>-</td>
<td>18 to 30 m</td>
<td>9 to 24 m</td>
<td>9 to 18 m</td>
<td>24 to 54 m</td>
<td>54 to 100 m</td>
<td></td>
</tr>
<tr>
<td>Recommended speed of sprinkler rotations</td>
<td>-</td>
<td>0.5 to 1 rpm</td>
<td>1 rpm</td>
<td>0.67 to 1rpm</td>
<td>0.5 to 1 rpm</td>
<td>0.7 rpm</td>
<td>0.5 rpm</td>
</tr>
<tr>
<td>Adaptability</td>
<td>Usually uses single nozzle sprinkler heads, used as under-tree systems in uplands, has low uniformity of coverage.</td>
<td>Usually used in closely spaced orchards with full low hanging branches, single nozzle slow rotation sprinklers are often used.</td>
<td>Used for orchards</td>
<td>Triangular spacing necessary for low application rates (1.5 to 3 mm/hr)</td>
<td>Commonly used for low rate of application (3.5 mm/hr) and to help reduce the effects of wind. High risers are used for orchards and lower risers for field crops.</td>
<td>Two-nozzle sprinklers can be used with lower pressures than single nozzle sprinklers. More overlap is required. Rate of application tends to be high.</td>
<td>Usually single nozzle sprinklers, rates of application range from 6 to 12 mm/hr, suitable for supplemental irrigation, unsuitable under windy conditions</td>
</tr>
</tbody>
</table>

(Michael, 1978)
based on the lateral being level. If the lateral slopes upgrade appreciably, it is difficult to design for a reasonable length. If it slopes downgrade, the length can be longer than usual, but rarely does the slope remain uniform for each setting.

Any system in which the laterals are moved should be planned for successive irrigations in strict rotation, so that the interval between irrigations is the same for each portion of a field. This means that, with a main located along the middle of a field, a given lateral will normally be moved to successive positions up one side and then down the other. Otherwise, when the irrigation of one side has been completed, the lateral would have to be carried all the way back to the lower end in order to start irrigation of the other side.

The number of possible arrangements for mains, laterals and sprinklers are many. The arrangement selected should provide for a minimal investment in irrigation pipe, have a low labour requirement and provide for an application of water over the total area in the required period of time. The most suitable layout can be determined only after a careful study of the field conditions to be encountered. The choice will depend to a large extent upon the types and capacities of the sprinklers and their operating pressures.

**Height of sprinkler riser pipes:** Sprinklers are located just above the crops to be irrigated and, therefore, the height of the risers depends upon the maximum height of the crop. To avoid excessive turbulence in the riser pipes the minimum height of riser is 30 cm when the riser pipe is of 2.5 cm diameter and 15 cm when it is of 1.8 to 2 cm diameter.

### 3.6 Sprinkler Selection and Spacing

The actual selection of the sprinkler is based largely upon design information furnished by the manufacturers of the equipment. The choice depends mainly on the diameter of coverage required, pressure available and sprinkler discharge. The data presented in Table 6 may serve as guidelines in selecting the pressure and spacing desired. The best combination of sprinkler spacing and lateral moves, suiting the application rate for the soil and wind conditions should be selected.

The required discharge of an individual sprinkler is a function of the water application rate and the two-way spacing of the sprinklers. It may be determined by the following formula:

\[
q = \frac{S_1 \times S_m \times I}{360}
\]

Where,
\(q\) = required discharge of individual sprinkler, litres/second
\(S_1\) = spacing of sprinklers along the laterals, metres
\(S_m\) = spacing of laterals along the main, metres
\(I\) = optimum application rate, cm/hr.
Examples 8 Determine the required capacity of an individual sprinkler spaced at 12 metre on a lateral line to apply water at a rate of 1.25-cm/hr. The spacing between lateral lines is 18 metres. Also compute irrigation time required to apply 5 cm irrigation depth.

Solution

Given

\[ S_l = 12 \text{ m} \]
\[ S_m = 18 \text{ m} \]
\[ I = 1.25 \text{ cm/hr} \]

Substituting the given values in equation (8), we get

\[ q = \frac{12 \times 18 \times 1.25}{360} = 0.75 \text{lit/sec} \]

The distribution pattern of sprinklers is affected by the spacing of the sprinklers, nozzle pressure, speed of rotation and wind velocity. As a single sprinkler does not provide uniform coverage, sprinklers are used with overlapping patterns. The uniformity of distribution obtained with a sprinkler can experimentally be determined. In finally deciding the discharge from an individual sprinkler, the pattern efficiency should be taken into consideration. The overlap increases with the increase in wind velocity. Table 7 may be used as a guide in the design of sprinkler overlap under different wind conditions.

The discharge from an individual sprinkler is given by

\[ q = Ca (2gh)^{1/2} \]  

Where,

- \( q \) = discharge (m\(^3\)/s),
- \( a \) = area of the nozzles (m\(^2\)),
- \( g \) = acceleration due to gravity (m/s\(^2\)),
- \( h \) = pressure head (m), and
- \( C \) = coefficient of discharge.

The coefficient of discharge for the sprinkler nozzles varies from 0.80 to 0.95. Normally, larger the nozzle, lower is the coefficient. This equation is useful in calculating the area of the nozzle of the sprinkler.
Table 7 Maximum spacing of sprinklers under different conditions of wind speeds

<table>
<thead>
<tr>
<th>Sl.No.</th>
<th>Average wind speed, km/hr</th>
<th>Spacing as the percentage of the diameter of the water spread area of a sprinkler</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No wind</td>
<td>65</td>
</tr>
<tr>
<td>2</td>
<td>0-6.50</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>6.50-13.00</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>&gt; 13.00</td>
<td>30</td>
</tr>
</tbody>
</table>

(Michael 1978)

The type of the sprinklers to be selected is related with the operating pressure of the sprinkler, nozzle discharge and sprinkler spacing. Sprinklers are designed to operate under different pressures. Higher the operating pressures, finer will be the spray and larger coverage, but the operating costs will be higher. For field crops the intermediate pressure sprinkler is generally used.

3.7 Design of Sprinkler Systems

The design of a sprinkler system for a given situation needs consideration of the soil, crop, climate and topography besides the equipment availability. A sprinkler irrigation system, to suit the conditions of a particular site, is specially designed to achieve high efficiencies in its performance and economy. The step-by-step procedure in the planning and design of a sprinkler irrigation system is enumerated below.

3.7.1 Inventory of Resources and Local Conditions

This consists in obtaining information about the available land, water and equipments. A topographical map of the area to be irrigated should be prepared. The soil type in the area under consideration should be known. Information about the source of water, quality and its availability during the entire year should be collected. The water available should be of sufficient quantity and its quality should be satisfactory for irrigation. Information on the amount of sediment present in the water is an important consideration in sprinkler system design. Information on the type of sprinkler equipment and its specifications available is also necessary for the proper selection of the equipment.

**Power source:** The source of power to operate the pump is to be known in advance. Electric power is most convenient when the pump is stationary. Electric pumping sets are cheaper both in initial cost and maintenance cost. Portable diesel pumping sets are the most suitable and practical for fully portable sprinkler systems.

**Map of the area:** It is essential that a map of the area concerned is prepared and drawn to scale with sufficient accuracy to show all dimensions so that lengths of main and laterals can be scaled there from. It should be a contour map or, at least, should show all relevant elevations with respect to water supply, pump location, and critical elevations in the fields to be irrigated. The elevation differences, together with friction losses in the mains and laterals and the pressure requirements of the sprinklers, determine the pressure that must be developed by the pump.
Water supply-source, availability and dependability: The quantity of water to be applied and the period of irrigation depend upon the crops, climate and soil. The methods of scheduling of irrigations are also applicable in case of sprinkler systems. The proposed crops, their water requirements along with the water holding capacities of the soils of the area should be known. It is important that an irrigation system of sufficient size is available to meet the maximum demand of crops. The quantity available should also meet the seasonal and annual requirements of the crops and the area to be irrigated. The water should be chemically suitable for irrigating the crops and soils of the area. It should not have any corrosive effect on the equipment. The water should be relatively clean and free of suspended impurities so that the sprinkler lines and nozzles are not clogged.

Climatic conditions: The consumptive use of a crop depends upon the climatic parameters such as temperature, radiation, intensity, humidity and wind velocity. Sprinkler system is designed for the daily peak rate of consumptive use of the crops irrigated by it. Table 8 is a general guide for determining the approximate peak rates of consumptive use on the basis of different climatic conditions. A peak demand in the range of 2 to 10 mm depth per day is equivalent to a continuous flow of 0.23 to 1.16 litres/second/hectare.

Table 8 peak rate of consumptive use by crops under various climatic conditions

<table>
<thead>
<tr>
<th>Climatic conditions</th>
<th>Peak rate of consumptive use, mm/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cool, humid</td>
<td>3</td>
</tr>
<tr>
<td>Cool, dry</td>
<td>4</td>
</tr>
<tr>
<td>Moderate, humid</td>
<td>4</td>
</tr>
<tr>
<td>Moderate, dry</td>
<td>5</td>
</tr>
<tr>
<td>Hot, humid</td>
<td>5</td>
</tr>
<tr>
<td>Hot, dry</td>
<td>8</td>
</tr>
</tbody>
</table>

(Molenaar, 1960)

3.7.2 Net Depth of Irrigation

The net depth of irrigation is calculated by equation (3) on the basis of available moisture holding capacity of the soil, the soil moisture extraction pattern of the crop and the moisture content in different layers of the root zone depth.

3.7.3 Irrigation Interval

From the point of view of sprinkler design, the irrigation interval is the length of time allowable between two successive irrigations during the peak consumptive use of the crop. It is interesting to note that, as the irrigation interval depends upon the depth of root zone, it can be matched by altering the operating hours of set. For instance, a system designed to apply 100 mm with 20-hour sets at 20-day intervals can also apply 50 mm with 10-hour sets at 10-day intervals. Such practices are common during the early stages of crop growth when the root system has not been fully developed.
3.7.4 Capacity of the System

The required capacity of a sprinkler system depends on the size of the area to be irrigated, the gross depth of water applied at each irrigation, irrigation interval and the net operating time of the system per day. The gross depth of water is obtained by dividing the net depth of irrigation by the application efficiency of the system. The capacity of the system may be calculated by the formula

\[ q = \frac{27.8 \times A \times d}{F \times hr \times Ea} \]  

Where,

- \( q \) = capacity of the pump, lps,
- \( A \) = area to be irrigated, hectares,
- \( d \) = net depth of irrigation, cm,
- \( F \) = irrigation period, days,
- \( hr \) = operating hours per day, hrs and
- \( Ea \) = application efficiency expressed as a fraction

**Example 9** Determine the system’s capacity for a sprinkler irrigation system to irrigate 16 hectares of maize crop. Design moisture use rate is 5 mm per day. Irrigation efficiency is 70 per cent. Irrigation period is 10 days in a 12-day interval. The system is to be operated for 20 hours a day.

**Solution**

Moisture used by the crop during irrigation interval of 12 days = 5x12 = 60 mm. Hence the net depth of irrigation to be applied to the crop, \( d \), is 6 cm. Other data to be used in equation (10) are

- Area of the field, \( A = 16 \) ha
- Operating hours, \( hr = 20 \) hours
- Irrigation period, \( F = 10 \) days
- Water application efficiency, \( Ea = 70 \% \)

Substituting these values in equation (10), the capacity of the pumping system, \( q \), is calculated as follows:

\[ q = \frac{27.8 \times 16 \times 6}{10 \times 20 \times 0.70} = 19.06 \text{lps} \]

3.7.5 Application Rate

The rate of water application of the sprinkler system depends on the infiltration capacity of the soil. Application rates in excess of the infiltration capacity of the soils will cause surface
runoff which will result in water loss, poor distribution of water and soil erosion. Table 9 gives the maximum application rates for different soil conditions. These values could be used as a guide, where reliable local information is not available.

Table 9 Maximum application rates for sprinklers under different soil and slope conditions

<table>
<thead>
<tr>
<th>Soil texture and depth</th>
<th>Application rate on different slopes, cm/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-5%</td>
</tr>
<tr>
<td>1. Course sandy soils to 2 m depth</td>
<td>5.0</td>
</tr>
<tr>
<td>2. Course sandy soils over more compact soils</td>
<td>3.7</td>
</tr>
<tr>
<td>3. Light sandy loams up to 2 metres</td>
<td>2.5</td>
</tr>
<tr>
<td>4. Light sandy loams over more compact soils</td>
<td>2.0</td>
</tr>
<tr>
<td>5. Silt loams up to 2 metres</td>
<td>1.3</td>
</tr>
<tr>
<td>6. Silt loams over more compact soils</td>
<td>0.8</td>
</tr>
<tr>
<td>7. Heavy textured clays or clay loams</td>
<td>0.4</td>
</tr>
</tbody>
</table>

(Hurd, 1969)

3.7.6 Design of Laterals

The sprinkler lateral is connected to the main and has the risers and sprinklers located on it. As the flow goes along the lateral, its volume decreases because of the discharge passing through the sprinklers. However, it is inconvenient to design the lateral for a tapering section. A uniform diameter of the lateral is adopted. The rate of flow entering the lateral is calculated and a trial diameter of the pipe is selected. Assuming that the flow is through the entire length without sprinklers, the frictional loss in the lateral is calculated using Scobey's formula

$$H_f = \frac{K_s L q 10^9}{D^{13}} (4.10 \times 10^6)$$  \[11\]

Where,

- $H_f$ = total friction loss in line in m,
- $K_s$ = coefficient of retardation,
- $L$ = length of pipe in m,
- $q$ = total discharge in l/s, and
- $D$ = inside diameter of the pipe in mm.

Based on Scobey's formula, standard tables are available and can be used for determining friction losses for different discharge rates and pipe diameters per hundred metres in a lateral line of portable aluminium pipes with couplings. As a lateral with sprinklers is a pipe with multiple outlets, the frictional loss as determined above is multiplied by a correction factor (F) as given in Table 10 15.13, corresponding to the number of sprinklers on the lateral. To the frictional loss thus calculated, the elevation is added if the lateral goes uphill or the drop is subtracted if the lateral goes downhill. It is recommended that the total pressure variation in the lateral should not be more than 20 per cent of the average pressure.
Table 10 Correction factor ‘F’ for friction losses in aluminum pipes with multiple outlets

<table>
<thead>
<tr>
<th>Number of sprinklers</th>
<th>Correction factor, F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First sprinkler placed at one sprinkler spacing from the main</td>
</tr>
<tr>
<td></td>
<td>m = 1.9 (^a)</td>
</tr>
<tr>
<td>1</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>0.63</td>
</tr>
<tr>
<td>4</td>
<td>0.48</td>
</tr>
<tr>
<td>6</td>
<td>0.43</td>
</tr>
<tr>
<td>8</td>
<td>0.41</td>
</tr>
<tr>
<td>12</td>
<td>0.39</td>
</tr>
<tr>
<td>16</td>
<td>0.38</td>
</tr>
<tr>
<td>20</td>
<td>0.37</td>
</tr>
<tr>
<td>30</td>
<td>0.36</td>
</tr>
</tbody>
</table>

(Schwab et al., 1993)

\(^a\) Exponent m= 1.9 for q in equation 11
\(^b\) Exponent m= 1.75 for q in equation 19

3.8 Uniformity Coefficient

A measurable index of the degree of uniformity obtainable for any size sprinkler operating under given conditions has been adopted and is known as the uniformity coefficient (\(C_u\)). This uniformity coefficient is affected by the pressure-nozzle size relations, sprinkler spacing and wind conditions. The coefficient is computed from field observations of the depths of water caught in open cans placed at regular intervals within a sprinkled area. It is expressed by the equation developed by Christiansen (1942):

\[
C_u = \left(1 - \frac{\sum X}{mn}\right) \quad \cdots \quad (12)
\]

Where,

\(m\) = average depth of all observations, mm
\(n\) = total number of observations
\(X\) = numerical deviation of depth of an observation from the average depth of \(m\), mm.

A uniformity coefficient of 1.00 is indicative of absolutely uniform application, whereas the less uniform water application is reflected by a lower value of this coefficient. A uniformity coefficient of 0.85 or more is considered satisfactory.

**Example 10**  The depths of water collected at catch cans located at 20 grid points in a test for uniformity coefficient of an sprinkler irrigation system were found as follows:

\[
\begin{align*}
18.5 & \quad 35.00 & \quad 27.50 & \quad 22.00 & \quad 49.00 & \quad 32.60 & \quad 26.00 & \quad 14.30 & \quad 35.00 & \quad 43.00 \\
26.00 & \quad 21.00 & \quad 53.00 & \quad 4.50 & \quad 23.00 & \quad 14.50 & \quad 8.50 & \quad 26.00 & \quad 20.00 & \quad 8.00
\end{align*}
\]

Determine the uniformity coefficient of the system.
**Solution**

The computation is given in the following table:

<table>
<thead>
<tr>
<th>Sl.No.</th>
<th>Depth of observation, mm</th>
<th>Deviation from average depth, mm</th>
<th>Sl.No.</th>
<th>Depth, mm</th>
<th>Deviation from , m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18.50</td>
<td>9.50</td>
<td>11</td>
<td>26.00</td>
<td>2.00</td>
</tr>
<tr>
<td>2</td>
<td>35.00</td>
<td>7.00</td>
<td>12</td>
<td>21.00</td>
<td>7.00</td>
</tr>
<tr>
<td>3</td>
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</tr>
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<td>14</td>
<td>4.50</td>
<td>23.50</td>
</tr>
<tr>
<td>5</td>
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<td>21.00</td>
<td>15</td>
<td>23.00</td>
<td>5.00</td>
</tr>
<tr>
<td>6</td>
<td>32.60</td>
<td>4.60</td>
<td>16</td>
<td>14.50</td>
<td>13.50</td>
</tr>
<tr>
<td>7</td>
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<td>2.00</td>
<td>17</td>
<td>8.50</td>
<td>19.50</td>
</tr>
<tr>
<td>8</td>
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<td>13.70</td>
<td>18</td>
<td>26.00</td>
<td>2.00</td>
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<tr>
<td>9</td>
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<td>7.00</td>
<td>19</td>
<td>20.00</td>
<td>8.00</td>
</tr>
<tr>
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<td>43.00</td>
<td>15.00</td>
<td>20</td>
<td>8.00</td>
<td>20.00</td>
</tr>
<tr>
<td>Total</td>
<td>-</td>
<td>-</td>
<td></td>
<td>507.40</td>
<td>211.80</td>
</tr>
</tbody>
</table>

Average depth, \( m = \frac{507.40}{20} = 28.00 \text{mm} \)

Some of deviations, \( \sum X = 211.80 \)

Substituting these values in equation (12), we have

\[
Cu = (1 - \frac{\sum X}{mn}) = \left(1 - \frac{211.80}{28 \times 20}\right) = (1 - 0.378) = 0.622
\]

**4. Drip Irrigation**

Drip irrigation, also referred to as trickle irrigation or micro irrigation, is one of the latest methods of irrigation which is becoming increasingly popular in India in areas with water scarcity and salt problems. It is a method of watering plants frequently with a volume of water approaching their consumptive use, thus minimizing losses due to deep percolation, surface runoff and soil surface evaporation. This method uses small diameter plastic lateral lines with devices called "emitters" or "drippers" at selected spacing to deliver water to the soil surface near the base of the plants. The system applies water slowly to keep the soil moisture within the desired range for plant growth. Perforations known as emitters are designed to emit water in a trickle rather than a jet of water. The emitters are placed so as to produce a wet strip along the crop row or a wetted bulb of soil at every plant. All the field pipes are left in place for the duration of the growing season of the crop. Fertilizers are usually applied in solution along with the water. The lay-out of a drip irrigation system is shown in Fig. 35.
4.1 Advantages and Disadvantages of Drip Irrigation

The trickle irrigation system has the following advantages:

1. Water distribution occurs in close proximity to plant roots, resulting in uniform and controlled water distribution.
2. Land levelling for irrigation on steeper slopes is eliminated.
3. No surface flow, no tail water loss or soil erosion occurs.
4. The system permits the use of poor quality water.
5. Frequent irrigation is easily accomplished and has the effect of keeping soil moisture tensions low, i.e., between field capacity and saturation. Therefore, the crop is able to withstand the higher osmotic tensions inherent in waters of high salinity.
6. Concurrent application of water and fertilizer is possible.
7. It permits cultural operations during irrigation on trees and vines.
8. It restricts weed growth only to the wetted areas.
9. It results in considerable water saving and increased yields.

The disadvantages of the system include the high initial cost of installation, the requirement of relatively clear water to prevent the blockage of the outlets, the short durability of the components and the poor water distribution efficiency when a low pressure system is installed on steep slopes or uneven land.

The initial cost of the drip irrigation equipment is considered to be its limitation for large scale adoption. Economic considerations, therefore, limit the use of drip irrigation system to orchards and vegetables in water scarcity areas. The cost of the unit per hectare depends mainly on the spacing of the crop. For widely spaced crops like fruit trees, the system may be more economical even than sprinklers. The cost of the unit and the net return from the crop should always be compared before a decision is made on installing the drip system. The main item of expenditure is the cost of the lateral lines. As there is usually one lateral line for each crop row, the wider the crop row spacing, the lesser will be the initial cost on the drip system.
4.2 Adaptability

Israel, a country with acute shortage of fresh water, pioneered extensive use of the system. This system is used with a number of horticultural and vegetable crops. Use of this method of irrigation with other crops is under way in several parts of the world.

Crops like grapes, sugarcane, papayas, banana, guava and most other types of fruit trees and vegetables have been found to respond well to drip irrigation. There is considerable saving in water by adopting this method, since water could be applied almost precisely to the root zone and there is no need to wet the entire area between tree crops. In orchards, it is possible to increase the amount of water applied depending on the stage of the growth of the plant. Substantial increase in the yield of vegetable crops has been observed by adopting the drip method. The method reduces salt concentration in the root zone when irrigated with poor quality water. Like the sprinkler method, drip irrigation permits the application of fertilizers through the system. Drip irrigation can achieve a 90 percent or more application efficiency which can hardly be achieved by other methods of water application. The application efficiency for drip irrigation is based on the water desired in the root zone and is not based on the whole area as in sprinkler or surface methods. The total amount of water used is, therefore, less than the water requirement for the whole area. Substantial water saving can be achieved especially for tree crops where plant spacing is large. When compared with sprinkler system, the drip method operates on much lower pressure, thus reducing energy requirement.

4.3 Components of a Drip Irrigation System

A typical drip system consists of a source of water supply, pumping unit, main lines, sub-mains, laterals and emitters. The main line delivers water to the sub-mains and the sub-mains into the laterals. The emitters, which are attached to the laterals, distribute water for irrigation. Auxiliary components include filters, pressure regulators, valves, pressure gauge and equipment for mixing fertilizers. When the water source is at higher elevation than the field to be irrigated, the drip system can conveniently operate on gravity. The pipe system is usually made of flexible PVC (Poly Vinyl Chloride) material. The emitters are also made of PVC material so that they are not damaged when using saline water or water mixed with fertilizers. Appropriate connections are to be used between the pipelines and other equipments.

Like the sprinkler system, the system consists of a pump to lift water, produce the desired pressure and distribute the water through nozzles or emitters. When a drip irrigation system is designed, the field installation requires the knowledge of the use of different joints and fitting and the understanding of the types of connections for main, sub-main, laterals and other special items. There are, in general, three main connections in a drip irrigation system, namely the main-sub-main connection and sub-main manifold, the sub-main-lateral connection and the lateral end arrangements (Fig. 36). The main-sub main connection is usually a "Tee", either with threads or slips. A sub-main is used to deliver water into laterals and act as a controller so that the field can be irrigated separately under a desired water pressure at any selected time. All the specific items used for control are installed in the sub main, which is called a sub-main manifold. There are a lock sleeve T, a T with insert adapter, a T adapter with insert adapter and a lock sleeve T adapter and micro-tube supply jumper. The ends of lateral lines can be plugged using an insert or simply folding and wrapping. The ends of lateral lines can also be equipped with a drain and flushing valve.
Pump and Prime Mover

The pressure necessary to force water through the components of the system, including the fertilizer tank, filter unit, main line, lateral and the nozzle, is obtained by a pump of suitable capacity. Volute centrifugal pumps operated by engines or electric motors are commonly used. The water pressure required to be developed by the pump should be sufficient to maintain the desired pressure at the laterals. The laterals may be designed to operate under pressures as low as 0.15 to 0.2 kg/cm² and as high as 1 to 1.75 kg/cm². A pressure drop of 0.5 to 1.0 kg/cm² may be anticipated in the head of the drip system, including the filter. There is a further drop of pressure in the lateral and the emitters. The water coming out of the emitters is almost at atmospheric pressure.

Fertilizer Tank

A fertilizer tank is provided at the head of the drip irrigation system for applying fertilizers in solution directly to the field along with the irrigation water. The requirements of the fertilizer applicator in the drip system are the same as in the sprinkler system.

Filter

A filter unit which cleans suspended impurities in irrigation water so as to prevent the blockage of holes and passages of drip nozzles is an essential part of the drip irrigation system. The efficient performance of drip nozzles lies in the effective performance of the filter unit. The filter system may consist of valves and a pressure gauge for regulation and control. A two-stage filter unit is usually provided. It consists of one coarse filter containing pea gravel (0.3 to 0.5 mm size gravel) and a fine filter consisting of one or more stages of wire mesh filter. The multi-stage unit filters out the suspended impurities in succession.

Emitters

Drip nozzles, commonly called 'emitters' or 'drippers' are placed at regular intervals on the laterals. They allow the water to emit at very low rates, usually in trickles. Emitters are the
most important component in the drip system. They should supply the water at the desired rate and, at the same time, should not get clogged either due to sediment or due to chemical reaction with water. There are three general types of emitters (i) water seeps out continuously along the lateral line, (ii) water sprays or drips from an emitter and (iii) water sprays or drips from holes punched in the lateral.

**Classification of emitters:** Emitters may be classified according to (i) principle of operation, (ii) flow regime, and (iii) lateral connection. Depending on the principle of operation, emitters could be classified as orifice type, long path, double wall pipe or perforated pipe. Orifice emitters are connected to the lateral and consist of an orifice producing a jet of water. The jet strikes a cap which acts as a pressure dissipater. These are simple but have the problem of clogging due to the silt or dissolved salts. The orifices range from 0.5 to 1.0 mm and operate at pressures of 2 to 5 m.

Long path emitters are long narrow tubes (0.8 to 2.5 mm dia) operating relatively at high pressures (10 to 15 m). Pressure dissipation is obtained by friction during flow. Several types, like the micro-tubes and the screw type emitters, are available. Clogging is not a major problem in emitters. Double-wall pipes are two flexible polyethylene pipes, one within the other. Water flows inside the inner tube at high discharge rate and pressures (3 to 15 m), passes through small perforations in the inner pipe to the space between the two, from where it flows out at low pressure through large perforations in the outer wall.

Perforated pipes are tubes with walls having small pores, through which water is drawn out by the soil suction. These are buried in the soil and deliver water all through their lengths. They are easily clogged unless some filter material is provided around them.

Based on operating pressures, emitters are referred to as low pressure (2 - 5 m) or high pressure (8-15 m) emitters. Discharges below 4 lph are termed as low, 4-10 lph as medium and 15 lph or more as high. Emitters are also referred to as point source or line source emitters, depending on whether the outlet is at one point or all along the line. Pressure or flow compensating emitters are designed to discharge water at a constant rate over a selected range of pressure variation. In these emitters, variation of pressure distorts a flexible membrane which causes the passageway cross-section to decrease as the pressure increases.

Emitters are also classified, depending on the type of connection to the lateral (Fig. 37). The in-line emitter is placed between two lateral sections whereas the on-line emitter is attached to the outer wall of the lateral with an insert into the tube. If the lateral is buried on-line riser is used for connecting the emitter. This is done when the emitters are placed far apart and it is advantageous to bury the lateral from cultivation requirements. Different types of emitters used in drip systems are shown in Fig.38.
Characteristics of emitters: The flow characteristics of emitters can be characterized by:

\[ q = kH^x \]  \hspace{1cm} (13)

Where,

- \( q \) is the emitter discharge
- \( k \) is a constant of proportionality that characterizes each emitter,
- \( H \) is the working pressure head at the emitter, and
- \( x \) is the emitter discharge exponent that is characterized by the flow regime.
The constant k and exponent x in equation 13 may be determined by solving two simultaneous equations, if the discharges \(q_1, q_2\) at two different operating pressure heads \((H_1, H_2)\) are known. The exponent x may be determined by measuring the slope of a log-log plot of H versus \(q\), that is

\[ x = \frac{\log (q_1/q_2)}{\log (H_1/H_2)} \]

The value of \(x\) characterizes the flow regime and discharge versus pressure relationship of the emitter. The lower value of \(x\), the less discharge will be affected by pressure variations. In fully turbulent flow, \(x = 0.5\) and in laminar flow, \(x = 1.0\). Non-compensating orifice and nozzle emitters are always fully turbulent. The exponent of long-path emitters may range anywhere between 0.5 and 1.0. For pressure compensating emitters, the value of \(x = 0\).

**Example 11**  The measured discharge values of drip emitters in a drip irrigation system are 4.75 and 5.25 at operating pressures of 4 and 5 meters, respectively. Determine the constant of proportionality, k and exponent, x in equation (13). Also determine the discharge of emitters at different operation pressures.

**Solution**

Let,

\[ H_1 = 4 \text{ m}, \quad q_1 = 4.75 \text{ litres/hr} \]
\[ H_2 = 5 \text{ m}, \quad q_2 = 5.25 \text{ litres/hr}, \]

Writing equation (13) in the logarithmic form we get

\[ \log q = \log k + x \log H \]

Substituting the values of heads and discharges in the equation (i), we get the following two equations:

\[ \log 4.75 = \log k + x \log 4 \]
\[ \log 5.25 = \log k + x \log 5 \]

The equations are then reduced to the following forms:

\[ 0.677 = \log k + 0.602 x \] \hspace{1cm} (i)
\[ 0.720 = \log k + 0.699 x \] \hspace{1cm} (ii)

Subtracting equation (i) from equation (ii), we get

\[ 0.043 = 0.097 x \]

\[ x = 0.443 \]

Substituting the value of x in equation (i), we get constant k

\[ 0.677 = \log k + 0.602 \times 0.4430 \]

\[ \log k = 0.677 - 0.267 = 0.410 \]
k = 2.57

Hence \( q = 2.57 H^{0.443} \) ........................................ (iii)

Using equation (iii), discharge values of emitters were calculated and presented in the following tabular form:

<table>
<thead>
<tr>
<th>Head, H, m</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge, q, lph</td>
<td>2.57</td>
<td>3.49</td>
<td>4.18</td>
<td>4.75</td>
<td>5.24</td>
<td>5.68</td>
<td>6.09</td>
<td>6.46</td>
<td>6.80</td>
<td>7.13</td>
</tr>
</tbody>
</table>

**Discharge through an emitter:** In a nozzle or orifice emitter water flows through a pore or opening of small diameter, where most of the head loss takes place. The flow regime is fully turbulent and the discharge of the emitter is given as:

\[
q = a.C(2gH)^{\frac{1}{2}} \]

Where,
- \( a \) is the flow cross-sectional area,
- \( C \) is the coefficient that depends on the characteristics of the nozzle,
- \( g \) is the acceleration due to gravity and
- \( H \) is the working pressure head of the emitter.

Equation 15 may be used to calculate the orifice cross-sectional area necessary to provide the desired head loss and discharge.

**Flow in long-path emitters:** Head loss in a long-path emitter occurs in the long-flow path. Length of the path needed for required loss of head and a known discharge is given by the Darcy-Weisbach equation.

\[
l_c = H g d^5 \pi^2 / 8f q^2 \]

where, \( l_c \) is the length of the flow path in the emitter, \( d \) is the diameter of the emitter and \( f \) is the friction coefficient.

Equation 16 shows that \( H \) is directly proportional to \( l_c \) and is inversely proportional to the fifth power of \( d \), or conversely, \( l_c \) depends on the fifth power of \( d \). Hence, any change in the flow cross section diameter, considerably influences the head loss \( H \) and the length of the flow path \( l_c \).

**Clogging of emitters:** Clogging of emitters is one of the main causes of failure of drip systems. Clogging could occur due to suspended particles carried in water. The suspended particles may be organic moss, aquatic plants or soil particles. Chemical precipitation could occur at the emitter outlets due to salts present or when fertilizers are mixed with irrigation water. Biological deposition like algae could also clog the emitters. Apart from using filters, injection of acids, oxidants, algacides and bactericides are treatments used to control chemically and biologically caused clogging.
4.4 Emission Uniformity along Laterals

As with sprinkler irrigation laterals, head loss due to pipe friction and changes in ground surface elevation cause variation in emitter discharges. In case of drip systems, water temperature could also cause variation in emitter discharges. Uniformity of water application may be measured, as in sprinkler irrigation by means of Christiansen's coefficient of uniformity, Cu defined by:

\[
Cu = \left[1 - \frac{1}{n} \sum_{i=1}^{n} \left| d_i / n q \right| \right] \quad ......................................... (17)
\]

Where,

\[ | d_i | = \text{the absolute difference between the discharge } q_i \text{ of the emitter and the average discharge } q \text{ of all the } n \text{ emitters.} \]

A uniformity coefficient of 0.90 and above is considered to be acceptable. The acceptable values of coefficient of uniformity in drip irrigation are higher than those in case of sprinkler systems.

In order to ensure the manufacturing quality, the manufacturer's coefficient of variation, \( C_v \) is determined from flow rate measurements for several identical emitters and is computed with the following equation:

\[
C_v = \left( q_1^2 + q_2^2 + ... + q_n^2 - nq^2 \right)^{\frac{1}{2}} / (n-1)^{\frac{1}{2}} \quad .................. (18)
\]

Where,

\[ q_1, q_2, \ldots, q_n \] are the discharge values of emitters, \( n \) is the number of emitters in a lateral and \( q \) is the average value of the \( n \) emitters.

\( C_v \) values less than 0.05 are considered to be good, whereas values greater than 0.15 are considered as unacceptable.

4.5 Design of Drip Irrigation Systems

The design of a drip irrigation system consists of the system layout and the determination of the number of laterals to be operated during irrigation. The emitter specifications are decided and laterals, sub-mains and mainlines are designed. Equipment for filtration and chemical injection is selected as required. Pumping plant specifications are finally worked out.

The friction loss for mains and sub-mains can be computed from the Hazen-Williams or Darcy-Weisbach equation. Darcy-Weisbach equation for smooth pipes in micro-irrigation systems when combined with the Blasius equation for the friction factor is given by (Schwab et al., 1993)

\[
H_f = KLq^{1.75} D^{4.75} \quad ............................................. (19)
\]
Where,

\[ H_f = \text{friction loss in m}, \]
\[ K = \text{a constant} = 7.89 \times 10^5 \text{for SI units for water at } 20^\circ\text{C}, \]
\[ L = \text{pipe length in m}, \]
\[ q = \text{total pipe flow in lps and} \]
\[ D = \text{inside pipe diameter in mm}. \]

Equation (19) applies for continuous sections of plastic pipe. For in-line emitters, on-line emitters and other connectors, the head loss should be increased. Such losses may be expressed as equivalent length of lateral pipe, \( L_e \). This increase in length \( L_e \) can be estimated as follows (Karmeli and Keller, 1975):

\[ L_e = 1.0 \text{ to } 3.0 \text{ m for each in-line emitter}, \]
\[ L_e = 0.1 \text{ to } 0.6 \text{ m for each on-line emitter and} \]
\[ L_e = 0.3 \text{ to } 1.0 \text{ m for a solvent-welded Tee connector}. \]

4.5.1 Selection of Emitters

The type of emitter to be selected depends on factors like availability, precision required, type of crop to be irrigated, etc. Different arrangements like double lateral, zigzag, pigtail, multi-exit and other configurations (Fig. 39) are used to enlarge the irrigated area in soils with poor lateral transmission properties and where crops with widely aerial root distributions are to be irrigated.

4.5.2 Chemical Injection Equipment

Fertilizers and chemicals are sometimes directly injected into the drip systems as such application is very effective. Chemical injection requires that the pressure acting on the chemical is greater than the operating pressure in the system. Fig. 40 shows some typical arrangements for this purpose. Chemicals are to be injected upstream of the filters so that any precipitates are removed before they could enter the main system.
4.6 Evaluation of Drip Irrigation Systems

Drip irrigation research is associated with the following studies:

1. Optimal soil moisture for crop growth
2. Water use by different crops under drip irrigation
3. Improved crop yield and quality
4. Interaction of irrigation and application of fertilizer on crop growth
5. Unsaturated soil water movement
6. Irrigation water quality and the movement and distribution of salt in the root zone
7. Irrigation system design and management

The wetting pattern in the soil profile of an individual nozzle is determined by operating a nozzle under actual field conditions for various time periods. The moisture penetration pattern in the soil is determined by measuring the soil moisture \textit{in situ}. The moisture measuring instruments should be installed at different depths and preferably in a radial pattern, away from the drip nozzle. The effective area of coverage of the nozzle will determine the spacing of the nozzles and the number of nozzles required to wet the root spread area of the crop.

While evaluating crop response to water under drip irrigation, the crop parameters such as growth, maturity, produce and disease and weed infestation are recorded. Detailed account of salt movement in the soil is maintained by periodical soil sampling and testing. Soil samples are taken from different soil depths and locations away from the nozzles. Graphical representation of salt concentration is maintained to evaluate the movement and concentration of salts.
5. SUMMARY

Numerous irrigation methods are applied the world over. These differ in different places from the most primitive wild flooding to the very sophisticated ones. Regardless of their construction cost, which is very low in the former or very high in the latter, irrigation by most methods suffers from one or several of the following shortcomings: very high labour requirements, very low irrigation efficiency, low net land utilization and very high operational and maintenance costs.

Based on considerations from the civil and mechanical engineering point of view, out-dated methods are still predominant in many regions and ironically are employed in many new development projects and have been found much better than the most sophisticated and expensive structures and equipment. Other regions rely on sprinkling, which is in many circles considered as the ultimate option for the progressive farming. This is due to the fact that too little attention is paid to the economic and often most promising furrow and corrugation methods, which have been revived from their earlier disrepute to compare, under suitable conditions, favorably with any other methods. This is, contrary to sprinkling, partly because there is little incentive for advertising gravitational irrigation methods, partly, because there are few people with enough specialized knowledge to insure a successful surface irrigation system and partly because sprinkler design is erroneously considered by many to require only simple engineering considerations. The latter has often resulted in the waste of large amounts of money, due to incompetently designed sprinkler systems. Such failures are not always immediately apparent, to enable us to correct the shortcomings, and this has brought sprinkling into disrepute in some places, even where it was earlier considered to be the most suitable method and should have been a grand success. The fact cannot be overstressed that all the irrigation methods described above are good and economical, if properly employed where they apply. The water supply, the type of soil, the topography of the land and the crop to be irrigated ultimately determine the correct method of irrigation to be used. Whatever the method of irrigation, it is necessary to design and operate the system for the most efficient use of water by the crop (Zimmerman, 1966).

References


