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# IRRIGATION ENGINEERING

[BTAI 2201]

Prepared by:

**Birabhadra Rout**

Assistant Professor

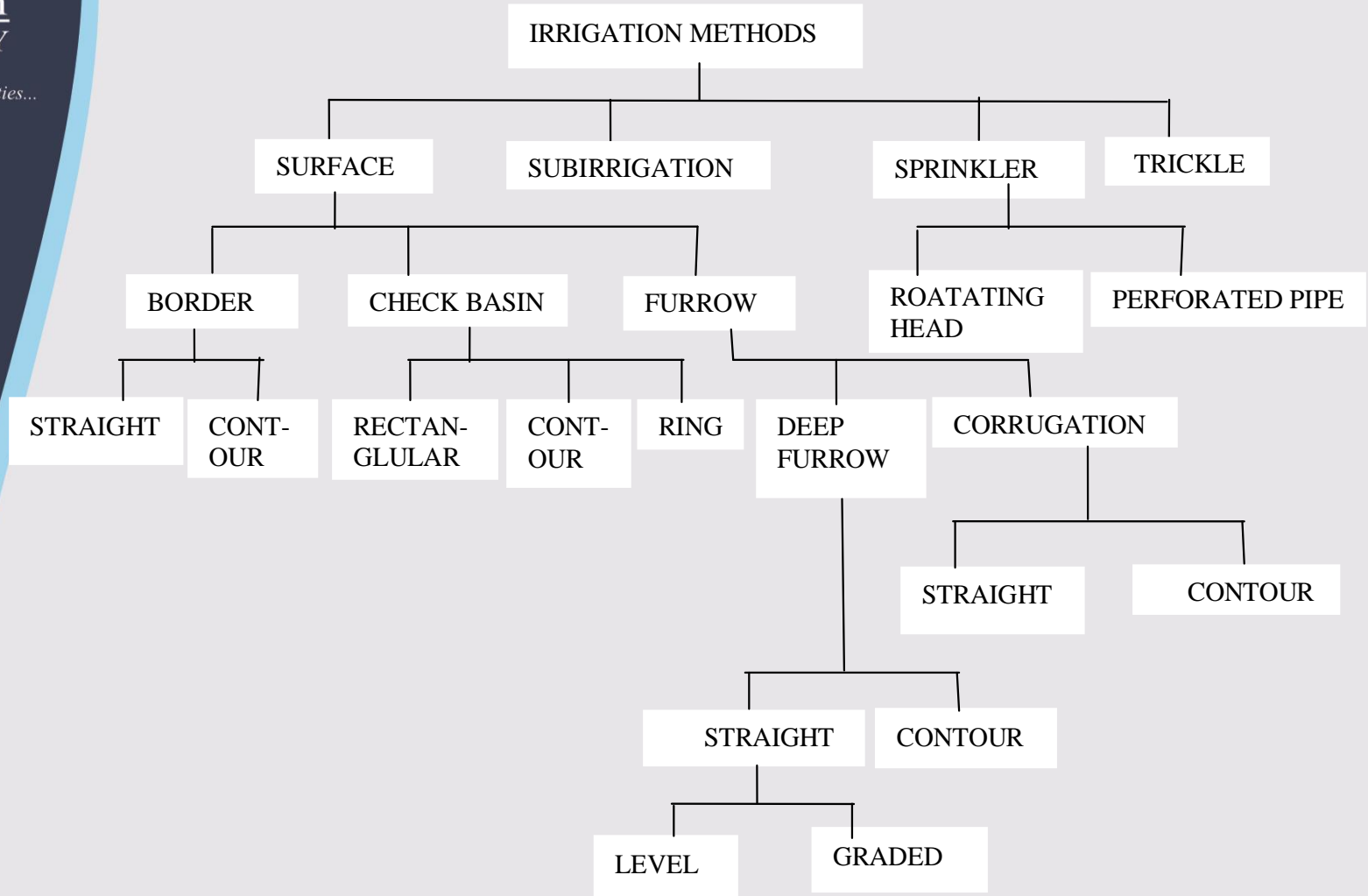
Dept. of Agricultural Engineering  
SoABE, CUTM, Paralakhemundi



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# METHODS OF IRRIGATION





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# Surface Irrigation

Surface irrigation method is most widely practiced. This system is suitable for soil having low to medium infiltration rate & works well for soil having relatively uniform terrain. It also works better for land having less than 2% slopes.

**Surface irrigation**, in general, can be practiced as **uncontrolled or wild flooding & controlled flooding**.

**Controlled flooding can be achieved by**

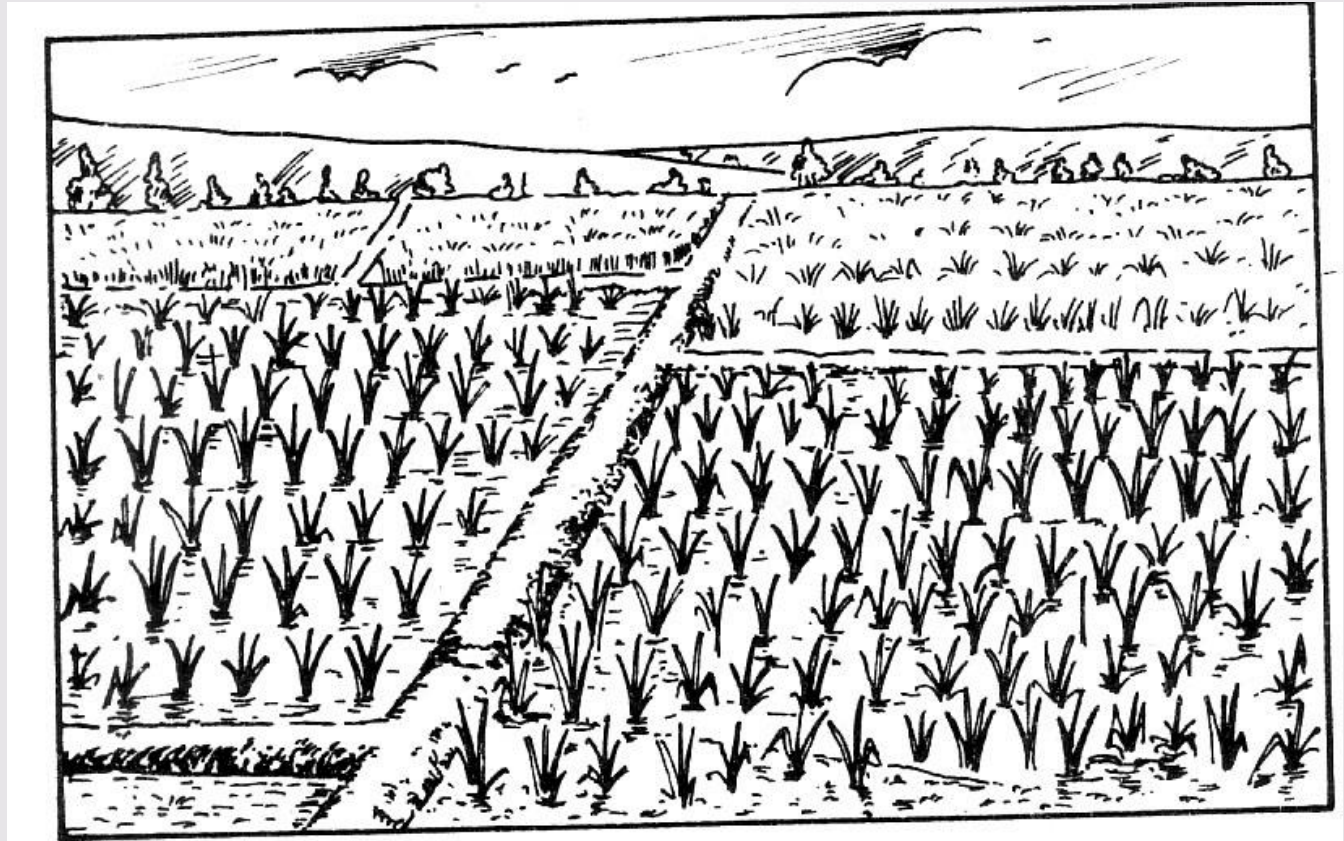
- (i) Free flooding
- (ii) Contour laterals
- (iii) Border strip
- (iv) Checks basin and
- (v) Furrow.



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# Uncontrolled/Wild Flooding

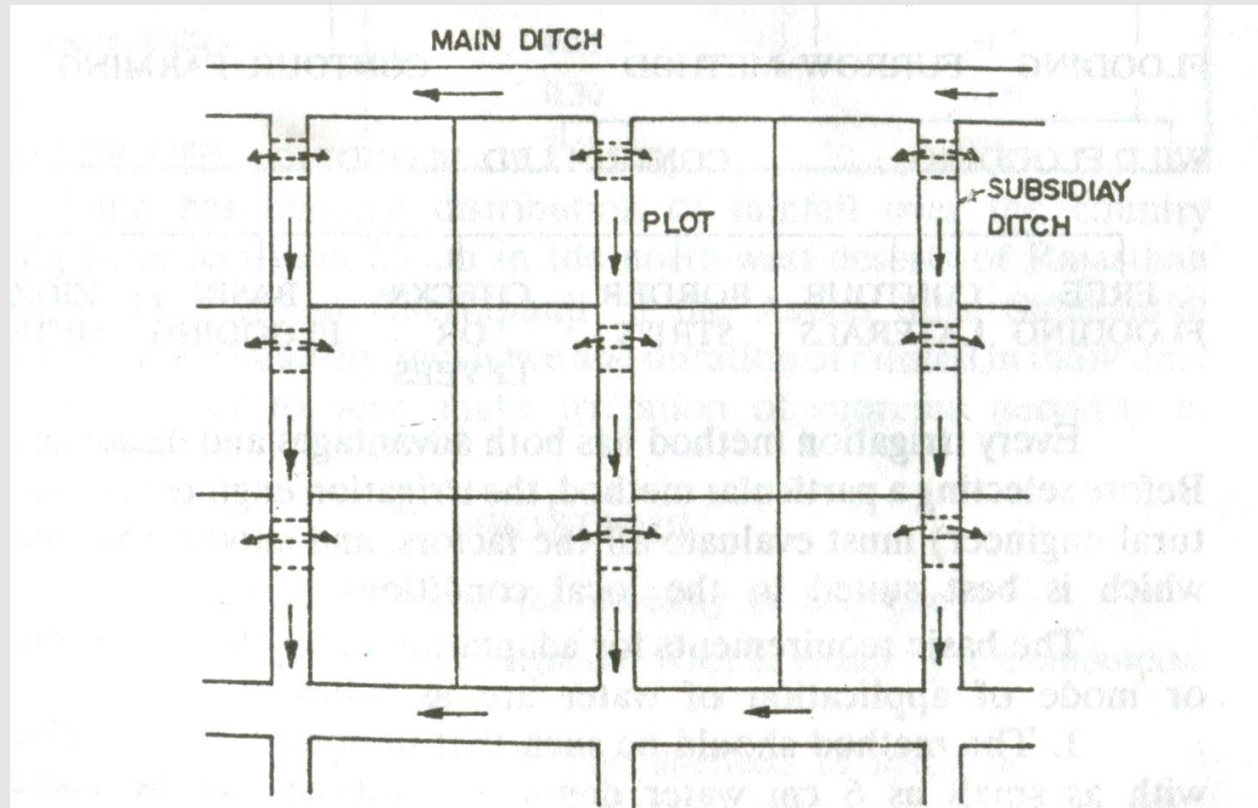




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# Flooding Method



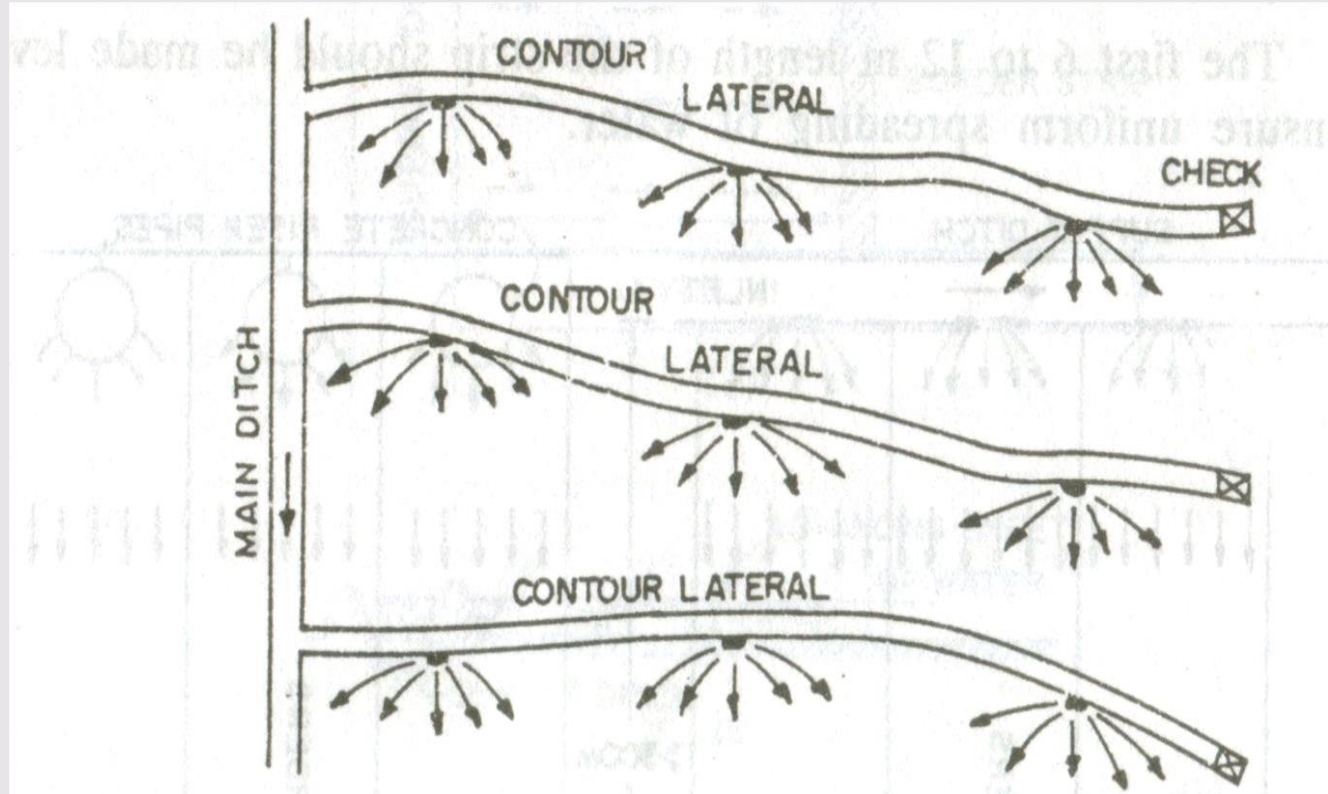
**FIG. 2.1 FREE FLOODING METHOD.**



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# Contour Laterals





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# Border Strip Method

Border method of irrigation makes use of parallel ridges to guide water to move down the slope.

Land is divided in to a number of long parallel strips called borders. These strips are separated by low ridges or levees.

Irrigation water is supplied to the border which is allowed to enter from a supply ditch to the head reach of the strip. Water advances in a form of thin sheet towards the downward direction of the strip along the longitudinal slope.

When the advancing water front either reaches the lower end, or a few minutes before that, the stream is cutoff. Water temporarily stored in the border moves down the strip & infiltrates, thus completing the irrigation.

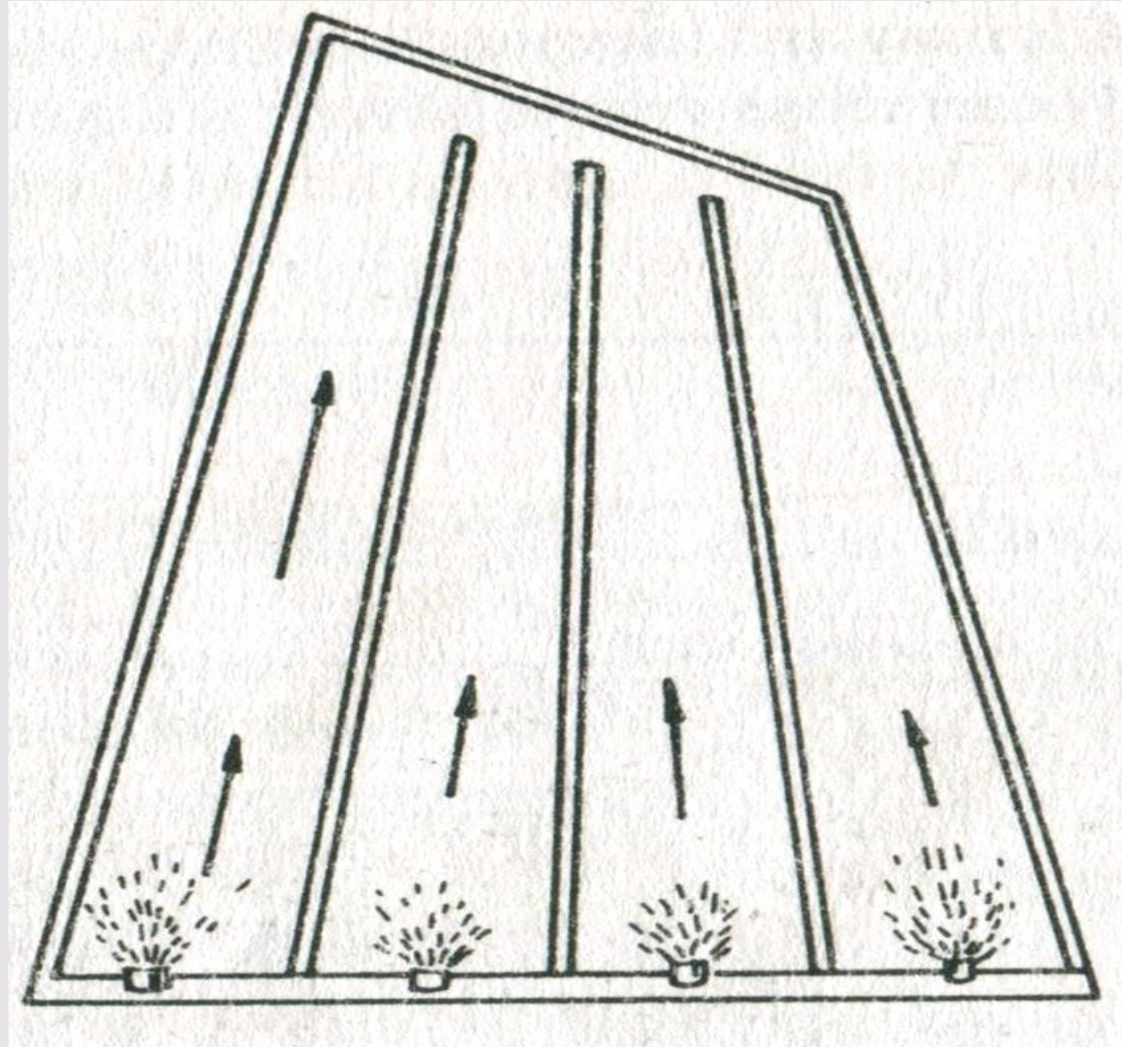
Close growing crops like wheat, pulses, sorghum and forage crops are irrigated by this method.



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## Water Movement along a Border Strip







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# Advantages of Border Irrigation

- Border ridges can be constructed easily and economically with simple farm implements like a bullock drawn A-frame ridger or bund former or tractor drawn disc ridger.
- Labor requirement in irrigation is greatly reduced as compared to the conventional check basin method of irrigation.
- Uniform distribution and high water application efficiencies are possible if the system is designed properly.
- Large irrigation streams can be efficiently used.
- **Operation of the system is easy and simple.**



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## Border Specifications & Stream Size

**Width of a border** usually varies from 3 to 15 m depending on the size of the irrigation stream & degree of land leveling. If the size of the irrigation stream is small, width can be reduced. Reduction of width less than 3 m is not economical.

**Length of the border strip** depends on how quickly it can be wetted over its entire length. This, however, depends on (i) infiltration of rate of the soil (ii) longitudinal slope of the field and (iii) available size of the stream. In general, length of the border strip varies from 60 to 120 m for sandy or sandy loam soil, 100 to 180 m for medium loam soil and 150 to 300 m for clay or clay loam soil.

Borders usually have too little or no cross slope. However, they have some longitudinal slopes which is given as :

0.25 to 0.60 percent for sandy loam to sandy soils.

0.20 to 0.40 percent for medium loam soil and

0.05 to 0.20 percent for clay to clay loam soil.

# Hydraulics of Border Irrigation



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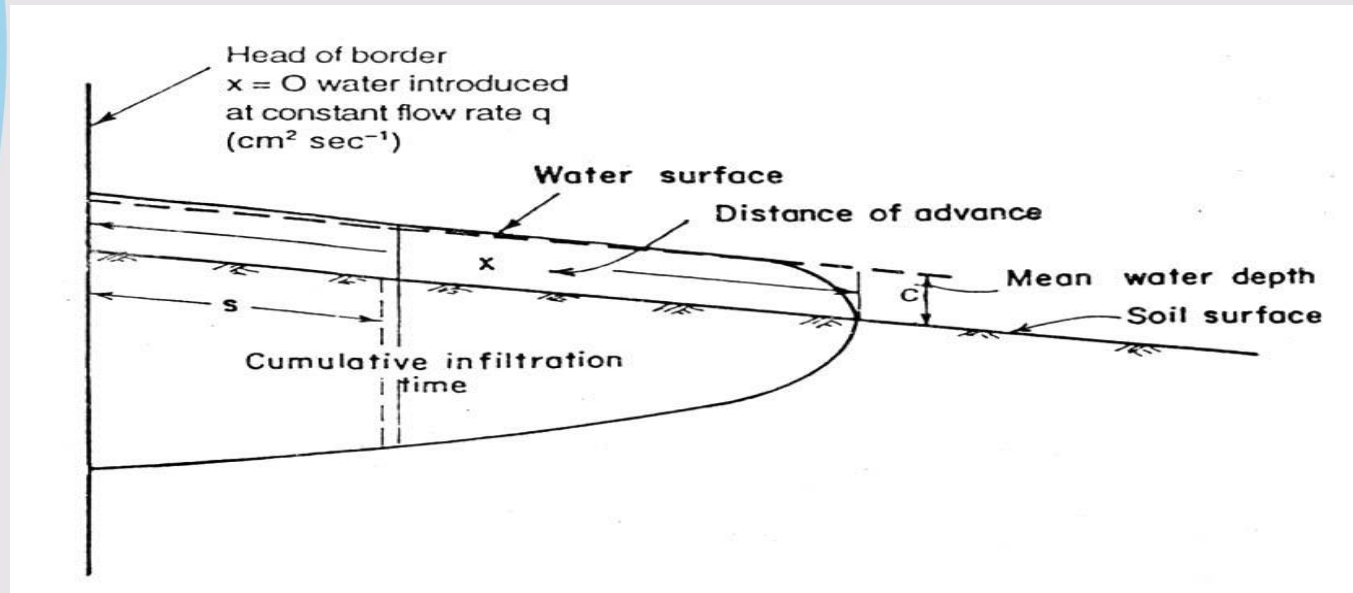
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Hydraulic of border strip can be studied by classical open channel hydraulics approach. Prominent variables that influence hydraulics of border irrigation are stream sizes, slope of land, infiltration of soil, & resistance to flow offered by the soil & vegetative cover



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Let  $q$  = Constant rate of flow per unit width at the upstream end of the border,  
 $\text{cm}^3/\text{min}/\text{cm}$  of border strip

$t$  = Time for which water is applied, min

$d$  = Average depth of water applied, cm

$x$  = Distance, the water front has advanced in time  $t$ , cm

$t_s$  = Time when distance covered  $x = s$ , min

$y$  = Accumulated infiltration depth at point  $x = s$ , when  $t = t_s$



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Now at instantaneous time “dt” the distance of water advancement is “ds”.

The total water admitted in “t” per unit width of border strip =  $q.t$

Volume of water stored on surface of border strip per unit width =  $d.x$

Volume of water infiltrated per unit width at instantaneous time “dt” is “ $y.ds$ ”.

Total volume of water infiltrated over distance  $x$  is

$$= \int_0^x y.ds$$

Using volume balance approach, we get  $q.t = d.x + \int_0^x y.ds$  (Eq. 8.1)



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The accumulated infiltration at any time  $t$  is found to be as:  $y = b + at^\alpha$  (Eq.8.2)

where,  $y$  is accumulated infiltration at time  $t$ , cm;  $t$  is elapsed time, min and  $a$ ,  $b$  and  $\alpha$  are characteristics constants. Value of  $\alpha$  is  $0 \leq \alpha \leq 1$

Putting the value of  $y$  in Eq.8.2 in Eq. 8.1,

$$q.t = d.x + \int_0^x (at^\alpha + b) ds$$

Using convolution theorem of Laplace transformation & gamma function, solution of above eqn. gives water front advancement  $x$  as:



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$$x = \frac{q.t}{b+d} \left[ \frac{1}{\Gamma 2} - \frac{\beta^1 t^\alpha}{\Gamma(2+\alpha)} + \frac{\beta^2 t^{2\alpha}}{\Gamma(2+2\alpha)} - \frac{\beta^3 t^{3\alpha}}{\Gamma(2+3\alpha)} + \dots \right]$$

when  $\frac{\beta^1 t^\alpha}{\Gamma(2+\alpha)} < 1$

$$x = \frac{q.t}{b+d} \left[ \frac{1}{\beta t^\alpha \Gamma(2-\alpha)} - \frac{1}{(\beta t^\alpha)^2 \Gamma(2-2\alpha)} + \frac{1}{(\beta t^\alpha)^3 \Gamma(2-3\alpha)} + \dots \right] \quad (8.5)$$

when  $\frac{\beta^1 t^\alpha}{\Gamma(2+\alpha)} > 1$ .

$$\beta = \frac{\alpha \Gamma(\alpha + 1)}{b + d}$$

$\Gamma(n+1) = n \Gamma(n)$ ,  $\Gamma(1) = 1$ ,  $\Gamma(2) = 1$ ,  $\Gamma(n) = (n-1)!$ ,  $\Gamma(4) = 3! = 6$  etc.



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K	ईK	K	ईK	K	ईK	K	ईK	K	ईK
1.00	1.000000	1.205	0.916857	1.405	0.8870028	1.605	0.894088	1.805	0.932720
1.01	0.994325	1.21	0.915576	1.41	0.886764	1.61	0.894680	1.81	0.934076
1.02	0.988844	1.22	0.913106	1.42	0.886356	1.62	0.895924	1.82	0.936845
1.03	0.983549	1.23	0.910754	1.43	0.886036	1.63	0.897244	1.83	0.939690
1.04	0.978438	1.24	0.908521	1.44	0.885805	1.64	0.898642	1.84	0.942612
1.05	0.973504	1.25	0.906402	1.45	0.885661	1.65	0.900116	1.85	0.945611
1.06	0.968744	1.26	0.904397	1.46	0.885694	1.66	0.901668	1.86	0.948687
1.07	0.964152	1.27	0.902503	1.47	0.885633	1.67	0.903296	1.87	0.951840
1.08	0.959725	1.28	0.900718	1.48	0.885747	1.68	0.905001	1.88	0.955071
1.09	0.955459	1.29	0.899041	1.49	0.885945	1.69	0.906781	1.89	0.958379
1.10	0.951351	1.30	0.897471	1.50	0.886227	1.70	0.908639	1.90	0.961765
1.11	0.947395	1.31	0.896004	1.51	0.886591	1.71	0.910571	1.00	0.961766
1.12	0.943590	1.32	0.894640	1.52	0.887039	1.72	0.912581	1.92	0.968774
1.13	0.939931	1.33	0.893378	1.53	0.887567	1.73	0.914665	1.93	0.972376
1.14	0.936416	1.34	0.892216	1.54	0.888178	1.74	0.916826	1.94	0.976099
1.15	0.933040	1.35	0.891151	1.55	0.888868	1.75	0.919062	1.95	0.979880
1.16	0.929803	1.36	0.890185	1.56	0.889639	1.76	0.912375	1.96	0.983743
1.17	0.926699	1.37	0.889313	1.57	0.890489	1.77	0.923763	1.97	0.987684
1.18	0.923728	1.38	0.888537	1.58	0.891420	1.78	0.926227	1.98	0.991708
1.19	0.920885	1.39	0.887854	1.59	0.892428	1.79	0.928767	1.99	0.995813
1.20	0.918169	1.40	0.887264	1.60	0.893515	1.80	0.931384	2.00	1.000000





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In a border strip experiment the infiltration characteristic is given by the equation  $y = 0.75 t^{0.5} + 0.7$ . The irrigation applied for 2 hr with constant rate of flow per unit width of the channel at the upstream side is  $q = 1.5$  lpm/cm of border strip. The mean depth of flow over the soil surface is 8 cm. Find out the distance of water front advance.



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**Sol.** Given that  $q = 1.5 \text{ lpm/cm} = 1500 \text{ cm}^3/\text{cm}/\text{min}$ ,  
Mean depth of flow  $d = 8 \text{ cm}$  and  
Time of irrigation  $t = 2 \text{ hr} = 120 \text{ min}$   
Accumulated infiltration-time relationship is

$$y = 0.75t^{0.5} + 0.7$$

Which gives values of  $a = 0.75$ ,  $b = 0.7$ ,  $\alpha = 0.5$

$$\beta = \frac{\alpha \Gamma(\alpha + 1)}{b + d} = \frac{0.75 \times \Gamma(0.5 + 1)}{0.7 + 8} = \frac{0.75 \times 0.88622}{0.7 + 8} = 0.076$$

$$\frac{\beta^1 t^\alpha}{\Gamma(2 + \alpha)} = \frac{0.076 \times 120^{0.5}}{\Gamma(2 + 0.5)} = \frac{0.076 \times 10.954}{1.5 \times 0.88622} = 0.626 < 1$$

$$x = \frac{q \cdot t}{b + d} \left[ \frac{1}{\Gamma 2} - \frac{\beta^1 t^\alpha}{\Gamma(2 + \alpha)} + \frac{\beta^2 t^{2\alpha}}{\Gamma(2 + 2\alpha)} \right]$$

$$= \frac{1500 \times 120}{0.7 + 8} \left[ \frac{1}{1} - \frac{0.076 \times 120^{0.5}}{\Gamma(2 + 0.5)} + \frac{(0.076^2 \times 120)}{\Gamma(2 + 1)} \right] = 149 \text{ m.}$$



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**RECESSION FLOW:** After the irrigation stream is cutoff, the tail water recedes downstream. The rate of recession of tail water is determined by noting the time at which water just disappears from the upstream end & recedes downstream past border strip.

In plotting advance & recession curves, distance down the stream is plotted on  $x$ -axis & elapsed time in  $y$ -axis. In same graph, both advance & recession curves are drawn with same scale in an arithmetic graph paper.

Difference of time of recession & advance at any distance from upstream end of the border gives **infiltration opportunity time or time of ponding.**



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# Design of Border Irrigation Systems

The border irrigation system should be so designed that it provides uniform distribution of water over the entire field. To achieve maximum water application efficiency, water should remain on the surface sufficiently long to allow just the desired quantity of water to infiltrate into the soil.

- Length, width & slope of border should be determined.
- Depth of water required to replenish the root zone soil moisture upto FC is estimated. This can be accomplished by determining the root zone soil moisture content before irrigation.
- Accumulated infiltration-time relationship of the soil under the existing soil conditions, & vegetation is determined. This can be done by measuring infiltration amount before each irrigation



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- Desired infiltration opportunity time is determined. It is the time required for soil to absorb the estimated depth of water, It is obtained from accumulated infiltration-time relationship of soil.
- Hydraulic resistance ( $n$ ) is estimated on the basis of the soil surface roughness and the hydraulic characteristics of the crop.
- Average depth of flow is calculated. For a given value of  $q$ ,  $n$  & bed slope, depth of water at upstream end of border is calculated. Then average water depth on the soil surface is calculated from the depth of water at upstream end by multiplying the upstream depth with a constant factor 0.655.
- Water front advance is predicted. Then a water front advance curve is drawn for various values of water front with elapsed time. To arrive at an efficient irrigation system design, it is necessary to calculate a family of advance curves using different values of  $q$  & possible border lengths.

***Finally, irrigation system is designed to obtain optimum water application efficiency & border length.***



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## Check Basin Irrigation

It is the most commonly used method of irrigation in India and in many other countries. This is the simplest method of irrigation & is so popular.

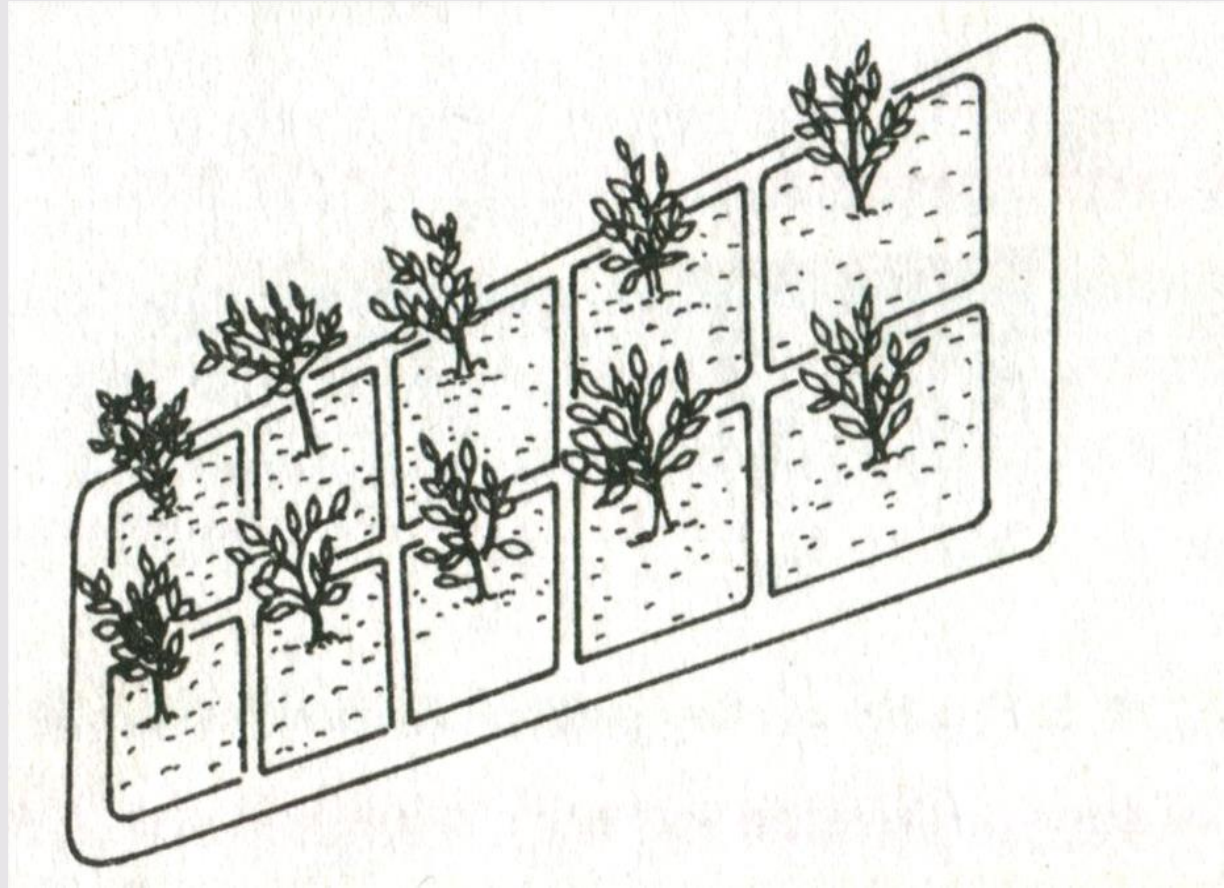
In this method, the entire field is divided into a number of small plots so that each plot has a nearly leveled surface. If the field is very large & it is not easy to level the small plots to one grade, then the field is divided into several small strips & then each strip is divided into several small plots by putting bunds.

Then these bunded small plots are leveled. A common irrigation or drainage line runs in between 2 strips of such small plots. Such a leveled small plot is called as basin.



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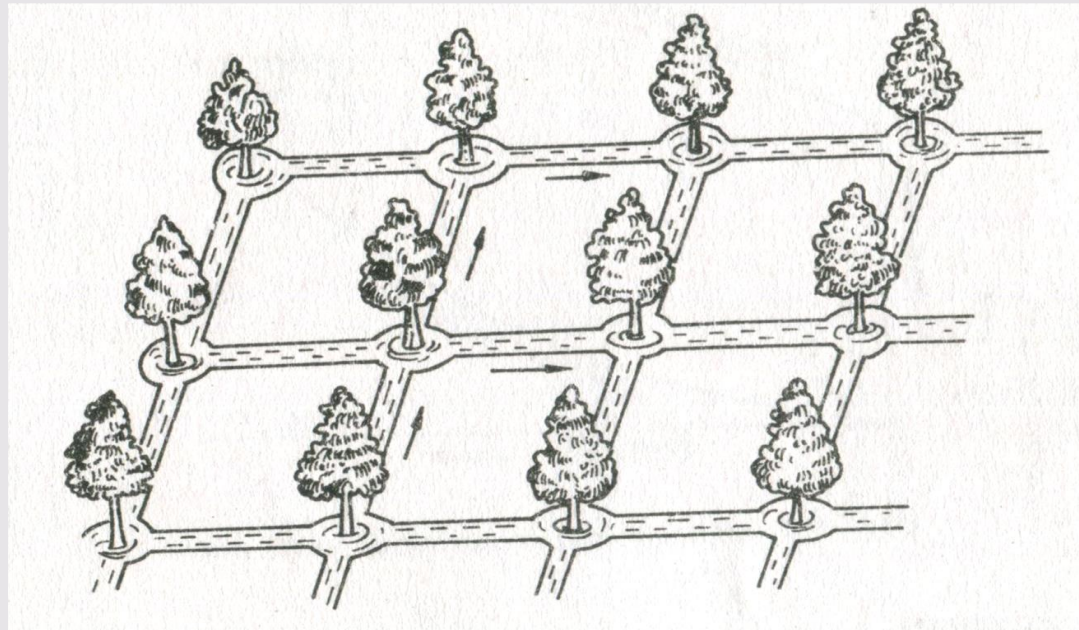
**Basin methods of irrigation**



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In case of orchard crops, ring method of basins may be used.  
The rings are generally circular in shape and surround the tree.  
Fruit trees are irrigated by ring basin



Ring method of irrigation





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Initially when the tree is small, the ring basin is small in size & as the tree grows the size increase. Usually there is one tree in one basin. Sometimes two or more trees are planted in one basin.

The depth of the ring depends on quantity of water to be irrigated. In many cases size of the ring & its distance from the tree depends on the crown of the tree.

In this method, the whole field need not be irrigated. Only two-third of the ring depth becomes enough to irrigate the ring. Thus, this method of irrigation saves a lot of water & hence, increases water use efficiency of the crop. .



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# Adaptability of Check Basin System

Check basin irrigation is suited to smooth, gentle & uniform land slopes & for soils having moderate to slow infiltration rates. Both row & close growing crops are adapted to be used with basins.

The method is especially suitable for irrigation to grains or fodder crops in heavy soils. Practically all irrigated rice is grown in basins.

Check basins are helpful to leach out salts from the fields. They also help in conserving rainfall & reduce soil & water erosion as the basins hold in-situ rainfall because of the levees around it.



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A check basin of size 10 m x 10 m is to be irrigated by a stream of size 10 lit/sec. The depth of the effective root zone is 90 cm. This 90 cm depth of the root zone is divided into 4 profile layers and the following values of soil moisture content and other data of the basin in these four layers are recorded as below.

Depth of profile layer in (cm)	Moisture % on oven-dry basis		Apparent specific gravity, gm/cc
	Field capacity	Actual	
0 – 15	26.0	17.4	1.39
15 – 30	24.0	17.8	1.47
30 – 60	22.3	19.2	1.51
60 – 90	22.2	20.5	1.53

How long should the irrigation stream be applied to the basin to replenish the soil moisture To FC. Assume no percolation & no runoff.



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Moisture deficits in the different layers are as follows:

$$\text{1st layer} = \frac{26.0 - 17.4}{100} \times 1.39 \times 15 = 1.79 \text{ cm}$$

$$\text{2nd layer} = \frac{24.0 - 17.8}{100} \times 1.47 \times 15 = 1.36 \text{ cm}$$

$$\text{3rd layer} = \frac{22.3 - 19.2}{100} \times 1.51 \times 30 = 1.40 \text{ cm}$$

$$\text{4th layer} = \frac{22.2 - 20.5}{100} \times 1.53 \times 30 = 0.78 \text{ cm}$$

So, net quantity of water to be applied is 5.33 cm.

Area of the check basin =  $10 \times 10 = 100 \text{ m}^2$ .

Volume of irrigation water required =  $100 \times 5.33 / 100 = 5.33 \text{ m}^3 = 5330 \text{ lit}$ .

Stream size = 10 lit/sec

Time required for irrigation =  $5330/10 = 533 \text{ sec} \approx 9 \text{ min}$ .

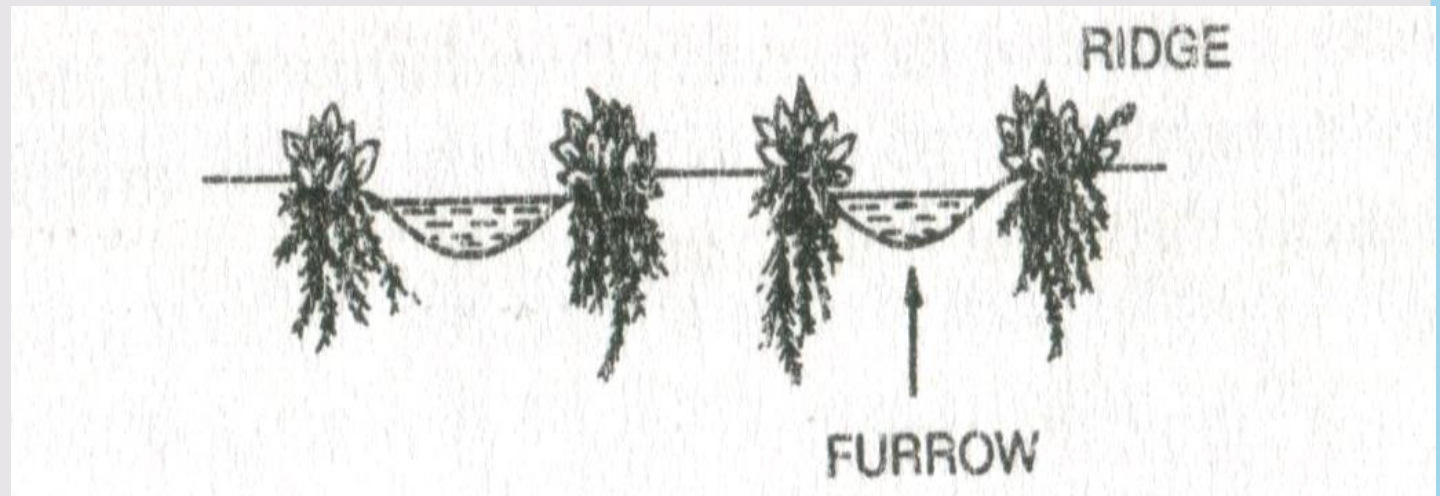


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# Furrow Irrigation

Furrow method of irrigation is used to irrigate row crops with furrows between rows of crops. In this method, small furrows are used to convey water into soil surface in small individual parallel streams. Water infiltrates through sides & bottom of furrows. Water moves both laterally & vertically downward & wet the root zone.





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# Adaptability of Furrow Irrigation System

Furrow irrigation can be used to irrigate all cultivated crops planted in rows, including orchards and vegetables like tomato, potato, brinjal, Ladies finger, chillies, tobacco, groundnut, sugarcane, maize etc.

Furrow irrigation is suitable to most soils except sandy soil that have high infiltration rate and has less lateral distribution of water than vertical distribution between the furrows.

A clay soil has more lateral distribution than vertical one.

If sandy soil is to be used for furrow irrigation, then it should have closer furrow spacing than the clayey soil.



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# Advantages of furrow irrigation

Economic use of water & increased water-use-efficiency is possible due to lateral & downward flow of water in root zone.

Furrows can be used both as irrigation & drainage channel.

Cultural operation in furrows is easy.

Evaporation loss is minimized due to lesser contact zone in the furrow.

Reduces ponding & crusting of the ridge since zone of wetting is only one-third to one-fifth of the total furrow depth.

Irrigation can be practiced in alternate furrows or paired rows to save water & increase water-use-efficiency.

The method reduces labour requirement in land preparation and irrigation.



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# Types of Furrow Irrigation

- Irrigation in each furrow
- Irrigation in alternate furrow
- Alternate irrigation in alternate furrow and
  - Irrigation in furrow in paired rows.

Crops like **potato**, **tomato**, **maize**, **cotton** etc. need irrigation in each furrow whereas crops like **lettuce**, **carrots**, **onions** etc. often need two rows between the furrows which is called as **irrigation in paired rows**. Furrows of depth **7.5 to 12.5** cm are suitable for vegetables while some row crops and orchards require much deeper furrows. But it is advantages to use wide & shallow furrows for a wide range of crops.





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# Design of Furrow Irrigation

The design of furrow irrigation system comprises in deciding:

- i) spacing of the furrows, (ii) shape and size of the furrows, (iii) stream size, (iv) furrow slope and (v) furrow length.

## Furrow Spacing:

Spacing of furrows should fit the crops grown & type of machine used for cultivation. Crops like potato, tomato, maize & cotton are planted at 60-90 cm apart & are irrigated by furrows between all the rows. Vegetables like lettuce, carrots & onions are spaced 30 to 40 cm apart & often have a paired row between furrows.



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## Length of Furrow

Optimum length of furrow is usually the longest furrow that can be safely & efficiently irrigated. Length of the furrow should not be too large. If furrow is of large length, then there will be more accumulation of infiltrated water at upstream end than the downstream end of furrow which will cause non uniform storage of water in the crop root zone. This means, it can be said that upstream end becomes over irrigated whereas downstream end becomes under irrigated.

On the other hand short furrows require more area to be lost to field supply channels causing loss of more valuable crop land & increase in labour cost.

Proper furrow length depends on hydraulic conductivity of soil. Furrows must be shorter in porous sandy soil than on light clay soil. The length of furrows may vary from 45- 300 m or longer depending on the infiltration rate.



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# Furrow Slope

Slope or grade of the furrow controls the speed of flow of water in the furrow in downward direction.

A minimum slope of 0.05 % is needed to enable the furrow to act as drainage channel.

The slope of the furrow should be such that the flow of water in it is non-erosive and at the same time helps in efficient irrigation.



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# Furrow Stream

Size of furrow stream varies from 0.5 to 2.5 lit/sec. In order to achieve the most uniform irrigation, the largest stream that causes no erosion, no overtopping of the furrows and no runoff at the tail end of the furrow is used to irrigate at the beginning in each furrow so that the entire length of the furrow is irrigated. This maximum non-erosive stream is given as:



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$$q_{\max} = \frac{0.60}{s}$$

$q_{\max}$  = maximum non-erosive, lit/sec and  $s$  = slope of furrow, %  
Average depth of water applied during irrigation is given as:

$$d = \frac{q \times 360 \times t}{w \times L}$$

$d$  = average depth of water applied, cm;  $q$  = stream size lit/sec;  $w$  = furrow spacing, m;  $L$  = length of furrow, m and  $t$  = duration of irrigation (cumulative), hr.



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