Border Irrigation Method

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Borders

- It is a strip bounded by low ridges
- A field in divided into strips by constructing parallel ridges along the slope

- Border strips may be:
  - Level border
  - Graded border
- Level borders can be:
  - Open:
  - If the downstream end is open, the water will freely drain from the border
  - Closed (diked):
  - It is diked at the downstream end that leads to higher efficiency and uniformity

Borders (Contd.)

- Borders are constructed on lands that have low grade or are level or that can be leveled economically without reducing field productivity.
- On lands that have excessive slope and undulating topography, lands borders are also laid across the longitudinal slope following contours
- Contour borders have uniform longitudinal slope and no cross-slope.
- The source of water for border irrigation is usually a ditch or channel flowing perpendicular to the borders or low pressure pipeline or tube.
- The border method of irrigation is suitable for close growing crops, such as wheat, barley, legumes and fodder crops, but not for rice that requires standing water
- It is not suitable for soils with very low and very high intake rates.

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Layout of Borders

- A typical border layout, consists of a series of strips that run parallel to the field boundary
- Source of water on the upstream end and drainage ditch at the downstream end
- Contour borders divide the field into a series of strips following contours where each strip is leveled cross-wise, forming a series of benches
- The elevation difference between consecutive benches should be limited to 30 cm and should not exceed 60 cm in any case.

Layout of Borders (Contd.)

- The border layout also depends on the field size, location of water source, and length and width of borders.

  - If a **field is <u>small</u>** and the soil infiltration capacity is low, then borders extend over the full length of the field.
  - If the **field is <u>large</u>** and its soil infiltration capacity is high, then two or more borders across the field may be needed.

- It is desirable to have the source of water supply located that allows all borders to be irrigated by gravity.

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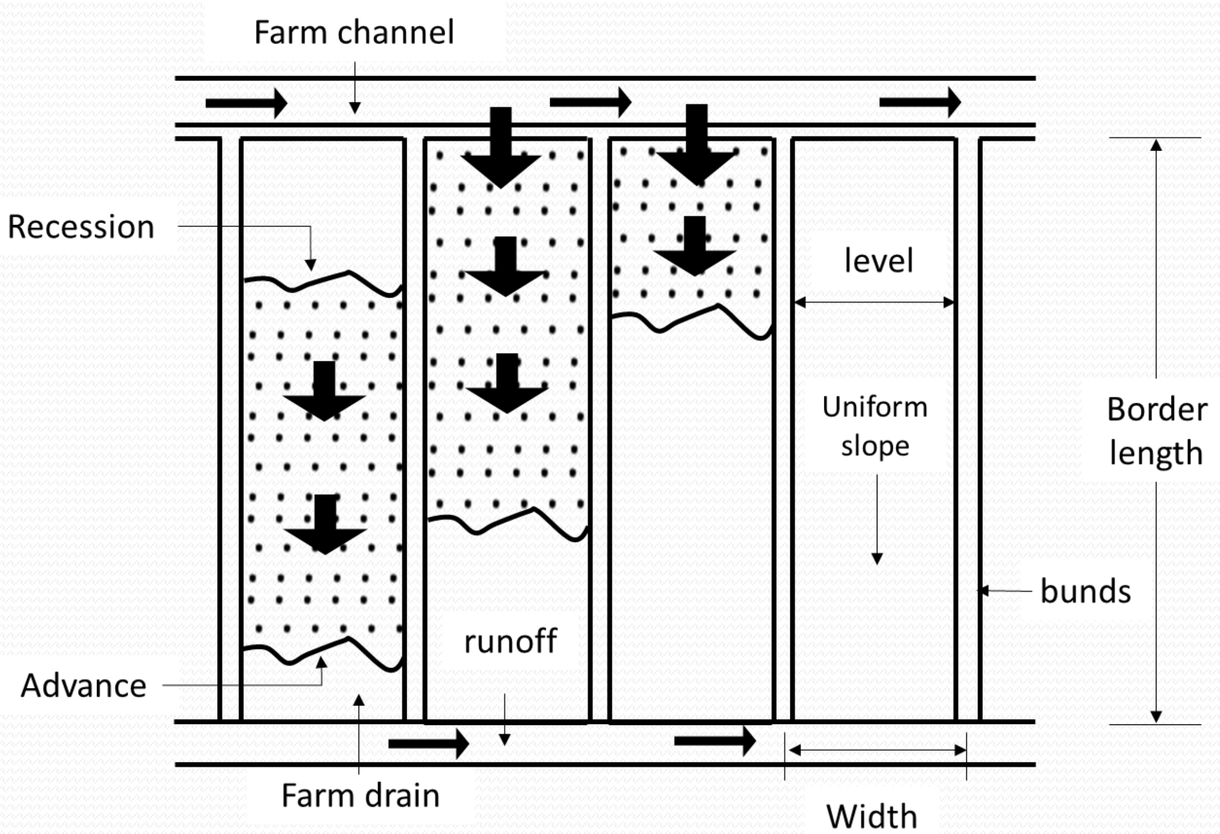

Figure 1. Typical layout for graded border irrigation system (Source: Jurriens et al. 2001)

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- Contour borders divide the field into a series of strips following contours where each strip is leveled cross-wise, forming a series of benches,

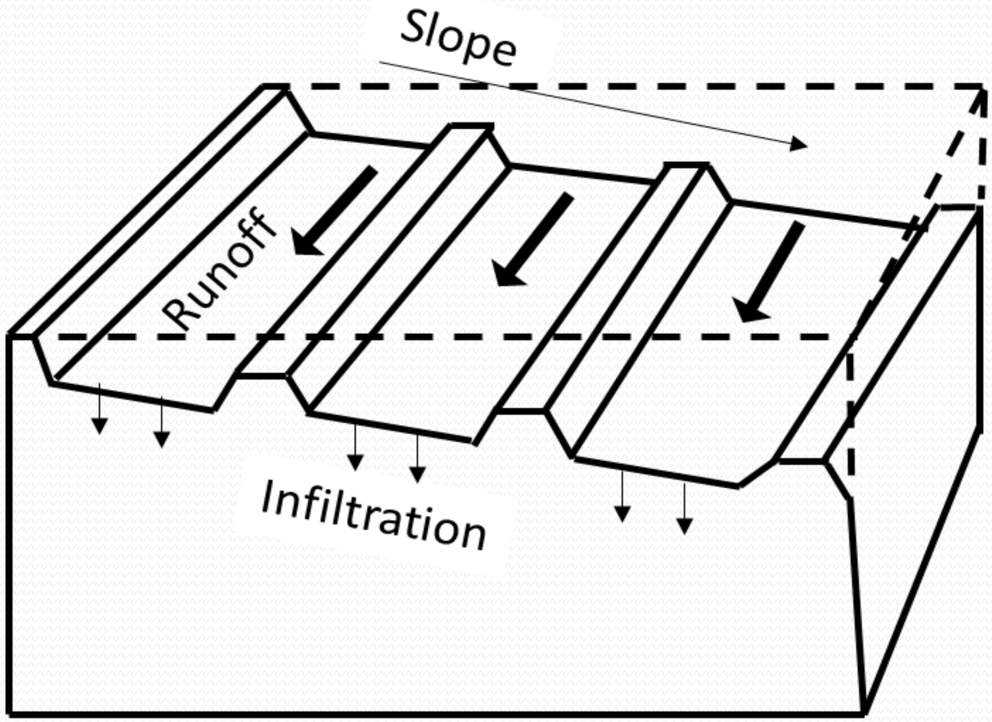

Figure 2. Contour border irrigation

Border Length

- Border Length
  - It depends upon:
    - Field size
    - Soil characteristics
    - Topographic slope
    - Stream size
    - Depth of irrigation required
  - Border length can be longer on heavy soils than on light soils, and can be longer on the same soil with larger stream size.
  - The border can be longer on steeper slopes, but precautions should be taken against erosion.
  - Small basin length may have better irrigation performance but may require more labor and system cost.

Border Length (Contd.)

- Booher (1974) has reported that acceptable irrigation performance can be achieved with border lengths up to 800 m on low intake soils, whereas a length of less than 100 m may be required on high intake soils.

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Border Length (Contd.)

Table 1. Typical border lengths for different soils (Source: Booher, 1974)

Soil	Typical border length	
	(m)	(ft)
Clay	180-350	600-1150
Clay loam	90-300	300-1000
Sandy loam	90-250	300-800
Loamy sand	75-150	250-500
Sand	60-90	200-300

Border Length (Contd.)

Table 2. Typical border strip dimensions in meters as related to soil type, slope, irrigation depth, and stream size (Source: Savva and Frenken 2002)

Savva and Frenken (2002) have presented typical border lengths, as shown in Tables 15.2 and 15.3, for large and small farm sizes, respectively.

Soil type	Slope (%)	Depth applied (mm)	Flow (l/sec)	Strip width (m)	Strip length (m)
Coarse	0.25	50	240	15	150
		100	210	15	250
		150	180	15	400
	1.00	50	80	12	100
		100	70	12	150
		150	70	12	250
	2.00	50	35	10	60
		100	30	10	100
		150	30	10	200
Medium	0.25	50	210	15	250
		100	180	15	400
		150	100	15	400
	1.00	50	70	12	150
		100	70	12	300
		150	70	12	400
	2.00	50	30	10	100
		100	30	10	200
		150	30	10	300
Fine	0.25	50	120	15	400
		100	70	15	400
		150	40	15	400
	1.00	50	70	12	400
		100	35	12	400
		150	20	12	400
	2.00	50	30	10	320
		100	30	10	400
		150	20	10	400

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Border Length (Contd.)

Savva and Frenken (2002) have presented typical border lengths, as shown in Tables 15.2 and 15.3, for large and small farm sizes, respectively.

Table 3. Suggested maximum border widths and length for small holder irrigation schemes (Source: Savva and Frenken 2002)

[The flow is given per meter width of the border. The total flow into a border is equal to the unit flow multiplied by the border width in meters.]

Soil type	Border strip slope (%)	Unit flow per meter width (l/sec)	Border strip width (m)	Border strip length (m)
Sand (infiltration greater than 25 mm/h)	0.2-0.4 0.4-0.6 0.6-1.0	10-15 8-10 5-8	12-30 9.12 6-9	60-90 80-90 75
Loam (infiltration of 10 to 25 mm/h)	0.2-0.4 0.4-0.6 0.6-1.0	5-7 4-6 2-4	12-30 9-12 6	90-250 90-180 90
Clay (infiltration less than 10 mm/h)	0.2-0.4 0.4-0.6 0.6-1.0	3-4 2-3 1-2	12-30 6-12 6	180-300 90-180 90

Border Width (Contd.)

- Booher (1974) has recommended that the difference in elevations of ridges of a border should not exceed 3 cm (1 in.) or the difference between ground surface elevations of uphill and downhill sides of a ridge should not exceed 6 cm (2 in.).
- Thus, the border width should not exceed 9 m (30 ft.) on a 1.0 percent cross slope (9 cm/0.01=9 m).
- Alternatively, the entire field can be graded to a uniform 1 percent slope and the maximum width will then be 3 cm/0.01=3 m. For zero field slope and 1 percent cross slope, the width can be 6 cm/0.01= 6 m (20 ft.).

Border Width

- The width of a border also depends on the stream size and land declivity and can be from 3 to 30 m.
- For small stream sizes, the width can be less but should not be less than 3 m in any case. The width should not be larger than 9 m on 1% cross-slopes (James, 1988).
- If machinery is used for cultivation, then the width should be sufficient to allow one pass. However, the width should be sufficient to allow an even number of passes.

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Border Width (Contd.)

- The values of maximum border width, depending on the slope, have been given by Soil Conservation Service (1974), as shown in Table 15.4.

Table 15.4 Recommended maximum border widths for different slopes in the direction of slope (Source: Soil Conservation Service, 1974)

Slope (%)	Maximum border width	
	(m)	(ft)
Level	60	200
0.0-0.1	35	120
0.1-0.5	20	60
0.5-1.0	15	50
1.0-2.0	12	40
2.0-4.0	9	30
4.0-6.0	6	20

Border Slope

- Three issues should be considered in the slope.
- (1) Borders should have enough slope to permit water to flow downstream over the surface.
- (2) It should allow some water to infiltrate into the soil but prevent deep percolation at the upstream end.
- (3) Flow velocity should not be large to cause significant soil erosion.

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Border Slope (Contd.)

- The maximum slope depends on the potential of soil erosion.
- Savva and Frenken (2002) suggests a minimum slope of 0.05-0.1% needed for water to flow downstream over the border.
- Soil slope is generally greater on coarse textured soils (0.25 to 0.6% for sand) than on fine textured soils (0.05 to 0.20% for clay, 0.20 %- 0.40% for loams) (Michael, 1978).

Border Slope (Contd.)

- The larger slope can be used on sod condition than on non-sod cover conditions.
- In order to improve the application uniformity of border irrigation, land smoothing may be required to remove furrows or depression that concentrate the flow.
- It may be necessary to adjust slopes in order to improve irrigation efficiency.
- Minimum slopes of 0.2 to 0.3 percent and maximum slopes of 2 percent for sandy loams and up to 7 percent for pastured clay soils with water stable aggregates have been recommended by Booher (1974).

Border Ridges

- Ridges:
  - The top width and height of the border ridge must be about the same
  - The height should be sufficient to accommodate the maximum depth of flow
  - A freeboard of about 2.5 cm must be provided
  - The side slope should not be greater than 2.5:1 for cohesive soils and 3:1 for non-cohesive soils
  - The maximum depth of flow can be determined using Manning's equation as:

$$y_{\max} = \left(\frac{Q_{\max} n}{60 S_0^{0.5}} \right)^{3/5} \qquad (15.1)$$

where $y_{\max}$ = maximum flow depth at the border inlet (m)

$Q_{\max}$ = maximum permissible non-erosive inflow rate ($m^3/s/m$)

S_o = slope in fraction

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Border Ridges (Contd.)

- The depth of flow, *d*, at the upstream end of a border can also be obtained as

$$d = K_1 T_L^{\frac{3}{16}} Q^{\frac{9}{16}} n^{\frac{3}{8}} \qquad \text{for } S_o \leq 0.4\% \qquad (15.2)$$

$$d = K_2 Q^{0.6} n^{0.6} S_0^{-0.3} \qquad \text{for } S_o > 0.4\% \qquad (15.3)$$

d is the normal depth of flow at the upstream end of the border (mm, in.);

T_L is the lag time (minutes); *Q* is the stream size (m^3/s/m, ft^3/s/ft);

n is manning's roughness factor; S_o is the slope of the border (m/m, ft./ft.);

K_1 is the unit constant equal to 2454 for *Q* in m^3/s/m and *d* in mm, and equal to 25.4 for *Q* in ft^3/s/ft and *d* in in.;

K_2 is the unit constant equal to 1000 for *Q* in m^3/s/m and *d* in mm, and equal to 9.46 for *Q* in $ft.^3$/s/ft. and *d* in in.

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Number of Borders and Number of Sets

- It can be determined by selecting the unit inflow rate (flow rate per unit width of border) which is in the range of maximum and minimum inflow rates
- The set width that contains an even number of borders of satisfactory width for ease of other farming operations can be computed as:

$$W_b = \frac{Q}{Q_0} \qquad (15.4)$$

where Q = total water supply (m^3/min)

Q_o = unit inflow rate (m^3/min/m)

W = field width (m)

W_b = border set width (m) that contains even number of borders of satisfactory width.

- The integer number of sets (N_b) can be obtained as

$$N_b = \frac{W}{W_b} \qquad (15.5)$$

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Water Delivery

- Water Delivery:
  - Water is delivered from the source of supply to the field either through
    - Open channel
    - A low pressure pipeline
  - For a farm, the delivery system should have sufficient capacity to meet the irrigation demand everywhere in the farm
  - The water delivery system is designed with the knowledge of:
    - Inflow rate
    - Border length
    - Border slope
    - Number of border per set (set width)

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Cutoff time (Inflow time)

- A border irrigation event is defined by the duration within which the desired depth of irrigation occurs at the end of border
- A substantial amount of surface storage remains in the border at the time when inflow is cut off
- This water infiltrates as well as runs off the border during the depletion and recession phases
- The recession time at the end of the border equals the sum of advance time and intake opportunity time
- Knowing the recession time, the time of depletion and cutoff time must be worked out for each chosen inflow rate

Irrigation Stream Size

- Inflow rate and time cutoff are key design variables in border irrigation and they offer maximum flexibility in the design process
- The stream size must be such that water adequately spreads across the width of the border and must reach to the end of the border
- The Soil Conservation Service (USDA, 1974) provided the following guidelines for selecting the maximum non-erosive inflow rate (Q_{max}) and minimum inflow rate (Q_{min}). Q_{max} for non-sod forming crops (alfalfa and small grain) can be obtained as:

$$Q_{max} = 0.01059 S_0^{-0.75} \qquad (15.8)$$

where Q_{max} is in m³/min/m and S_o in m/m.

- For dense sod-forming crops, the value of Q_{max} can be twice that obtained from equation (4).

Irrigation Stream Size (Contd.)

- The value of $Q_{\min}$ can be obtained as:

$$Q_{\min} = \frac{0.000357 L S_0^{0.5}}{n} \qquad (15.9)$$

where $Q_{\min}$ is in m³/min/m and S_o in m/m

- The stream size must be within the range of minimum and maximum inflow rates that results in the maximum application efficiency.

Simplified Border Irrigation Design

- Following Walker and Skogerboe (1987), it is assumed that the surface water profile at the time of cutoff of inflow (T_{CO}) and that at the end of depletion (t_d) which is also the beginning of recession (t_r) are straight lines with end points corresponding to uniform flow conditions, as shown in Figure 15.3.

- Further, the depth at the downstream end (y_L) remains constant and runoff (Q_r) occurs at a constant rate during the depletion phase. During the depletion and recession phases, the sum of infiltration (I) and runoff (Q_r) is equal to the pre-cutoff unit inflow rate (Q_o).

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Simplified Border Irrigation Design

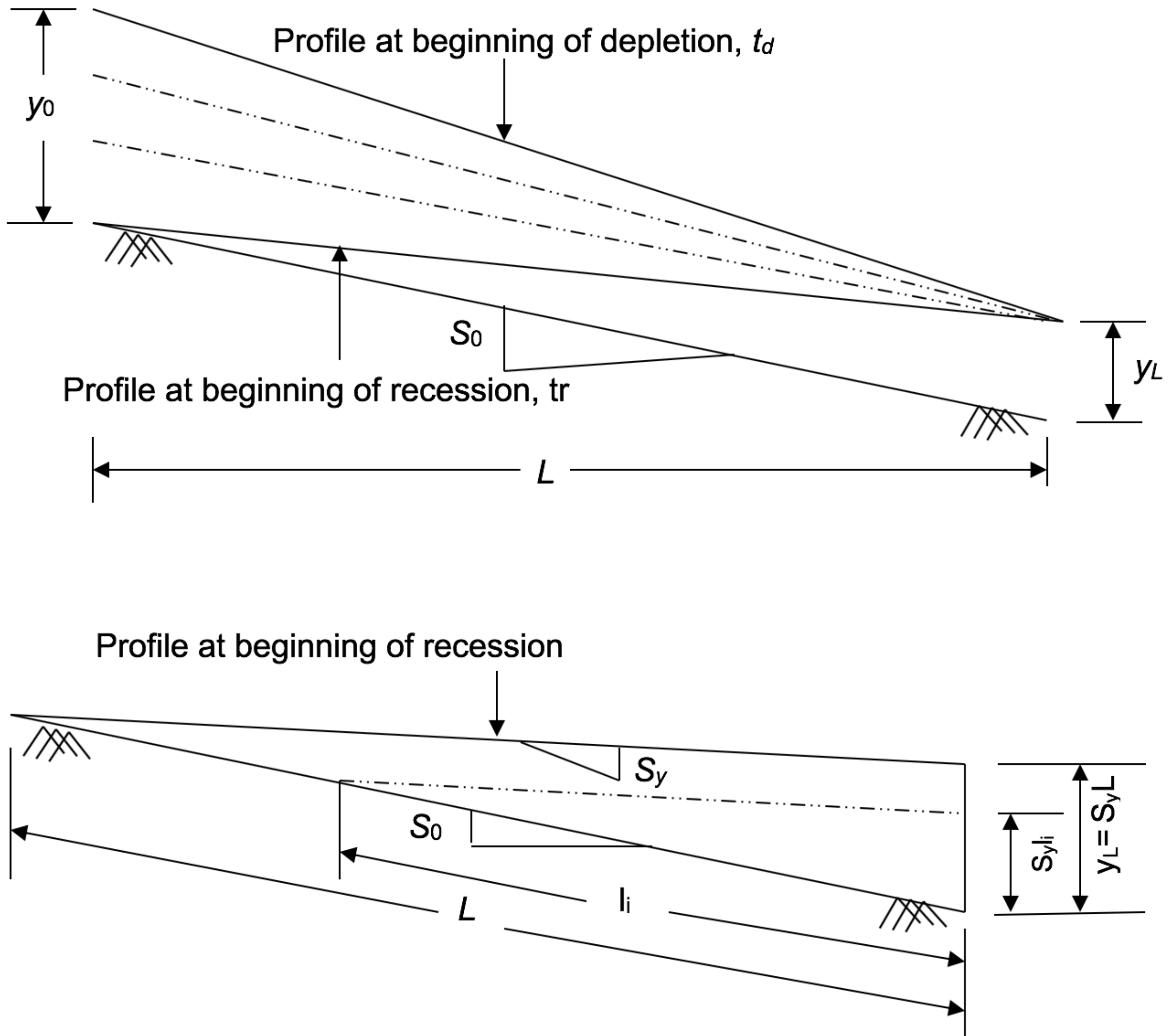

Figure 15.3 Water surface profiles at the beginning of depletion and recession phases

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Simplified Border Irrigation Design (Contd.)

- From Figure 15.3, it is seen that the time required from the cutoff of inflow to the end of depletion phase (i.e. when the upstream depth becomes zero) is equal to the time required to remove the volume of water defined by the triangle of length *L* and height y_o at a constant rate of Q_o through both infiltration and runoff. This can be expressed as:

$$t_d = T_{CO} + \frac{y_0 L}{Q_0} \qquad (15.13)$$

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Simplified Border Irrigation Design (Contd.)

- At the beginning of recession, the depth of flow is assumed to change with distance at a uniform rate over the entire length of border and its slope can be expressed as:

$$S_y = \frac{y_L t_d}{L} \qquad (15.14)$$

- where y_L is a function of Q_r at time t_d which can be determined as:

$$Q_r(t_d) = Q_0 - I \times L = A \frac{R^{\frac{2}{3}} S_0^{\frac{1}{2}}}{n} \qquad (15.15)$$

  - where A is the cross-sectional area per unit width, and R is the hydraulic radius equal to A/WP, WP= the wetted perimeter, and I is the average infiltration rate (m/sec) over the length, L. For borders, $A = y$, and $WP = 1$ and hence, $R = y$ or $S_y L$.

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Simplified Border Irrigation Design (Contd.)

- Therefore, with the use of equation (15.15), equation (15.14) becomes

$$S_y = \frac{1}{L}\left[\frac{(Q_0 - I\times L)\times n}{60\times S_0^{\frac{1}{2}}}\right]^{\frac{3}{5}} \qquad (15.16)$$

  - where *I* can be assumed as the average value of infiltration rate at the upstream end [$I(t_d)$] and that at the downstream end $I(t_d\text{-}t_L)$:

$$I = \frac{ak}{2}\left[t_d^{a-1} + (t_d - t_L)^{a-1}\right] + f_0 \qquad (15.17)$$

  - in which f_o is the steady infiltration rate, and *a* and *k* are parameters of the Kostiakov infiltration equation.

- The recession time can be determined by the equation given by Walker and Skogerboe (1987) as:

$$t_r = t_d + \frac{0.095 n^{0.47565} S_y^{0.20735} L^{0.6829}}{I^{0.52435} S_0^{0.237825}} \qquad (15.18)$$

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Simplified Border Irrigation Design (Contd.)

- Now a **step by step design procedure** for free drained borders can be outlined as follows (Walker and Skogerboe, 1987):

[1] Obtain information on field characteristics, soil, crop, and water supply.

[2] Determine **the maximum (Q_{max}) and minimum (Q_{min}) values of unit inflow rate Q_o** (m^3/min/m) using equations (15.8) and (15.9), respectively. The flow should be limited within the non-erosive velocity with sufficient depth to spread laterally.

[3] Select unit flow rate (Q_o) between Q_{max} and Q_{min} which results in **a set width** comprising an even **number of borders** of satisfactory width and integer number of sets using equations (15.4) and (15.5), respectively.

Simplified Border Irrigation Design (Contd.)

[4] Determine the inflow depth at the inlet $\mathbf{y_o}$ **(m)** using equation (15.1).

[5] Compute the time required (τ_{req}) in minutes to satisfy the irrigation requirement.

[6] Compute the time of advance to the end of border t_L (minutes).

[7] Compute the time of recession (t_r) in minutes from the beginning of irrigation, assuming that the design will meet irrigation requirement at the end of the border:

$$t_r = \tau_{req} + t_L \qquad (15.19)$$

Simplified Border Irrigation Design (Contd.)

[8] Compute the depletion time, t_d (minutes) numerically, say using the Newton-Raphson method, as follows:

- **a**. Assume an initial guess of t_d τ_{req} as $t_d^i = t_r$.
- **b**. Determine the average Infiltration (I) by substituting $t_d = t_d^i$ in equation (15.17).
- **c**. Determine S_y using equation (15.16).
- **d**. Determine a new value of t_d as t_d^{i+1} using equation (15.18) as follows:

$$t_d^{i+1} = t_r - \frac{0.095\, n^{0.47565} S_y^{0.20735} L^{0.6829}}{I^{0.52435} S_0^{0.237825}} \qquad (15.20)$$

- **e.** Compare the initial guess (t_d^i with the new computed value (t_d^{i+1}). If both values are equal, then t_d is the right value and continue with step 9. Otherwise, set $t_d^i = t_d^{i+1}$ and repeat steps b through e.

Simplified Border Irrigation Design (Contd.)

[9] Determine the infiltrated depth at border inlet (Z_o) and compare it with Z_{req} to determine the status of irrigation (complete irrigation: $Z_o >= Z_{req}$; deficit irrigation $Z_o < Z_{req}$):

$$Z_0 = k t_d^a + f_0 t_d \qquad (15.21)$$

[10] If irrigation is complete, then determine *Tco* and *Ea* as follows:

$$T_{CO} = t_d - \frac{y_0 L}{2Q_0} \qquad (15.22)$$

$$E_a = \frac{Q_{req} L}{Q_0 T_{CO}} \qquad (15.23)$$

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Simplified Border Irrigation Design (Contd.)

[11] In the case of deficit irrigation, increase the cutoff time and compute the new t_r value as follows:

a. Calculate the new *Tco* by substituting τ_{req} in place of t_d in equation (15.13).

b. Calculate the average infiltration (*I*) by substituting $t_d = \tau_{req}$ in equation (15.17)

c. Calculate S_y using equation (15.16)

d. Calculate t_r by substituting $t_d = \tau_{req}$ in equation (15.17)

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Simplified Border Irrigation Design (Contd.)

e. Calculate Z_L:

$$Z_L = k(t_r - t_L)^a + f_0(t_r - t_L) \quad (15.24)$$

f. Compute *Ea*

$$E_a = \frac{Z_{req} L}{Q_0 T_{co}} \quad (15.25)$$

[12] Check if the water availability is satisfied and repeat steps 4 to 12 for other unit inflow rates. Choose the design which gives the maximum *Ea* value.

THANK YOU

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