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Irrigation and Drainage

Lecture No:16 Water Application Methods

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Water Application Methods: Classification

1. Based on energy/pressure required

- ✓ Gravity irrigation
  - ✓ Border, Basin and Furrow irrigations
- ✓ Pressurized irrigation
  - ✓ Drip and Sprinkler irrigations

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Water Application Methods: Classification

2. Based on placement of irrigation water (on, above, or below the soil surface)

- ✓ **Surface irrigation**
  - ✓ **Border, basin, furrow and drip irrigations**
- ✓ **Subsurface irrigation**
- ✓ **Overhead irrigation**
  - ✓ **Sprinkler and hand watering**

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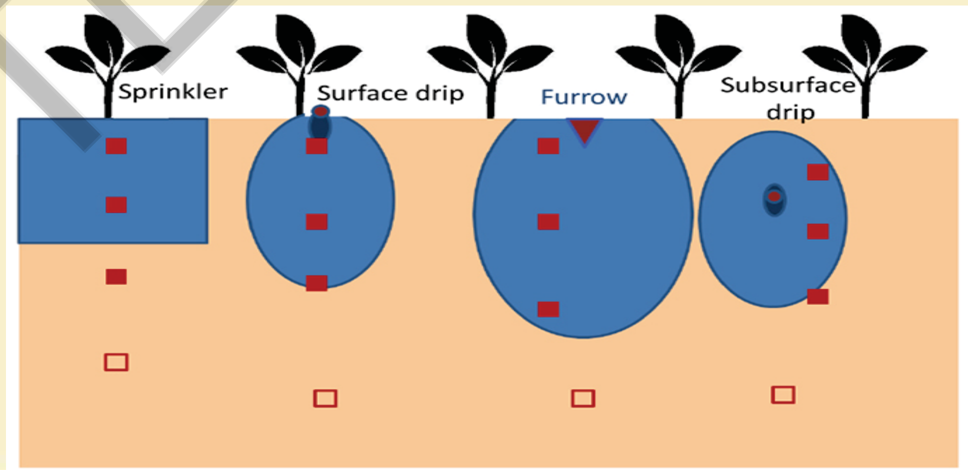
Water Application Methods: Classification

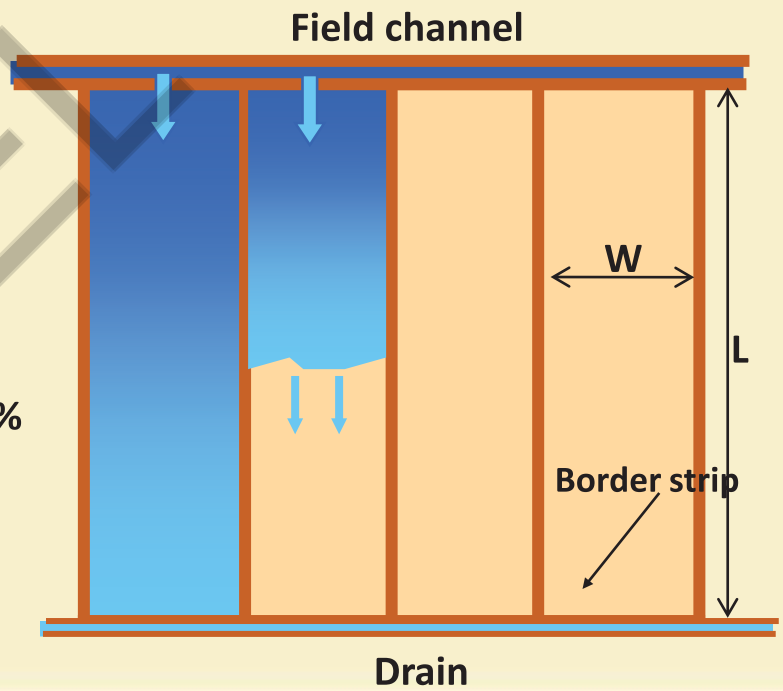
3. Based on wetted area of crop root zone by irrigation

- ✓ Flood irrigation (basin, border and furrow)
- ✓ Drip (or trickle or localized) irrigation
- ✓ Sprinkler irrigation

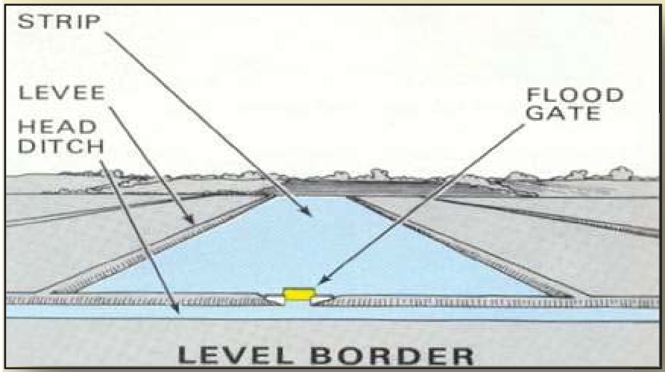


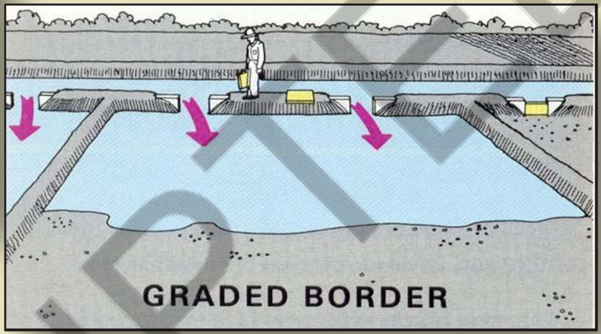
Surface Irrigation Method: Borders

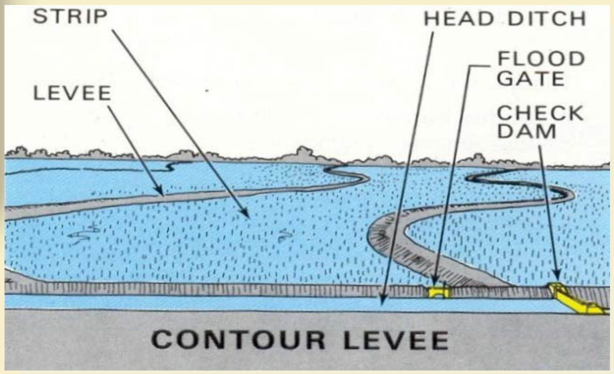
- ✓ Best adapted to grain and forage crops
- ✓ Good for uniform soils with mild slope
- ✓ Not good for crops sensitive to wet soil conditions
- ✓ Typical efficiencies range from 70 to 85%
- ✓ Major investment is that of land grading or leveling
- ✓ Border strip width, W = 3 - 30m; Length, L = 100 – 800m
- ✓ Has zero side slope and uniform longitudinal slope of <1%
- ✓ Strips have no cross slope



Surface Irrigation Method: Borders

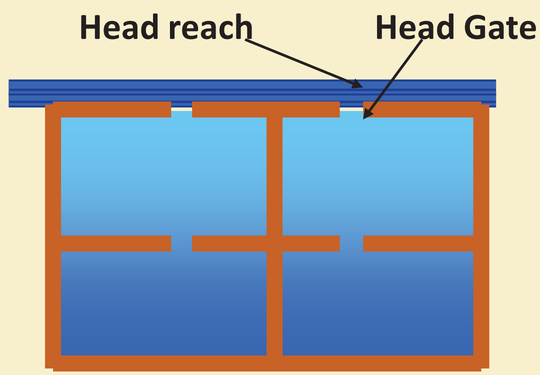


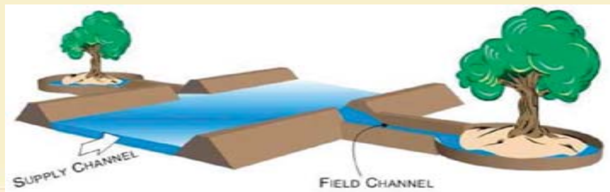




Surface Irrigation Method: Basins

- ✓ Field is divided into small units surrounded by levees or dikes
- ✓ Basin size: 1 to 15 ha; up to 100 to 400 m long
- ✓ Most commonly practiced for rice and orchard tree crops
- ✓ Level basin
  - ✓ Water is held until it infiltrates or is drained away
  - ✓ Minimum runoff loss and High application efficiency is possible
- ✓ Graded basin (contour levee irrigation)
  - ✓ Constructed with two levees parallel and two perpendicular to the field contours
  - ✓ Water enters along the upper contour and flows to the lower





- ✓ Adaptability
  - ✓ Soil Moderate to low infiltration capacity soil

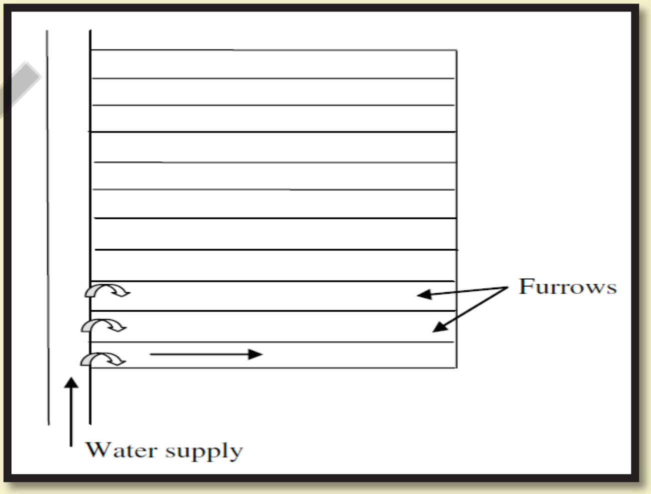
Surface Irrigation Method: Basins

- ✓ Advantages
  - ✓ Water covers the basin rapidly to ensure good uniformity
  - ✓ Best suited for lands/crops where leaching is required to wash out salts from the root zone
  - ✓ Involves the least labour of the surface methods
  - ✓ Design efficiencies can be on the order of 70–85%

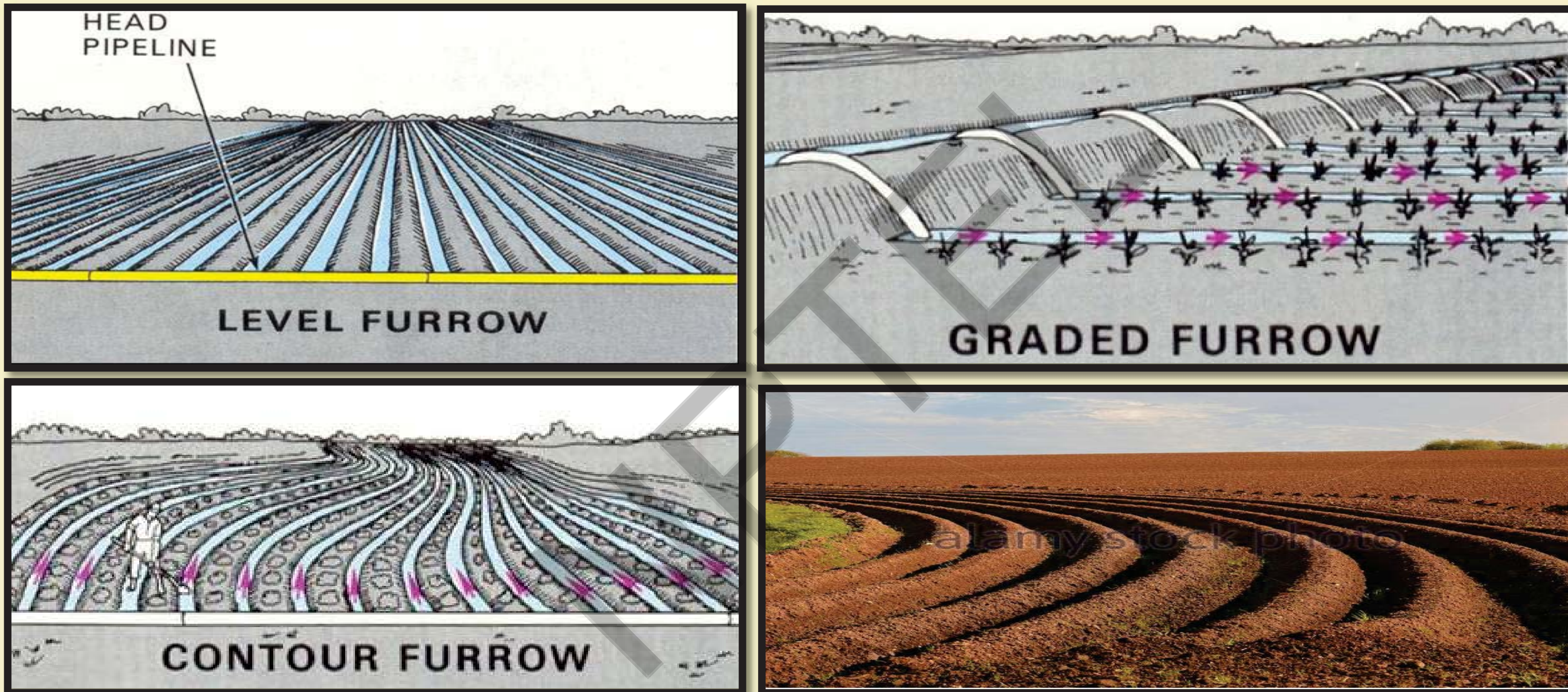
- ✓ Limitations
  - ✓ Levees interfere with movement of farm equipment
  - ✓ Higher amount of water is required compared to sprinkler or drip irrigation
  - ✓ A major cost in basin irrigation is that of land grading or leveling
  - ✓ Impedes surface drainage

Surface Irrigation Method: Furrows

- ✓ Irrigation is accomplished by running water in small channels (furrow)
- ✓ Constructed with or across the field slope
- ✓ Water infiltrates from the bottom and sides of furrows moving laterally and downward to wet the soil and to move soluble salts, fertilizer and herbicides carried with the water
- ✓ Widely spaced row crops such as potato, maize, vegetables, and trees
- ✓ Loam soil with mild slope, 0.5-2%
- ✓ Labour required is generally higher
- ✓ Major initial cost is construction of furrow



Surface Irrigation Method: Furrows



Surface Irrigation Method: Furrows

- ✓ Advantages
  - ✓ Efficiency can be high as 90%
  - ✓ Developed at a relatively low cost after necessary land-forming activities are accomplished
  - ✓ Erosion is minimal
  - ✓ Adaptable to a wide range of land slopes

- ✓ Limitation
  - ✓ Not suitable for high permeable soil where vertical infiltration is much higher than the lateral entry
  - ✓ Higher amount of water is required, compared to sprinkler or drip irrigation
  - ✓ Furrows should be closely arranged

Sprinkler Irrigation

- ✓ Water is delivered through a pressurized pipe network to sprinklers, nozzles, or jets which spray the water into the air, to fall to the soil as an artificial "rain"
- ✓ Light sandy soils are well suited
- ✓ Sprinklers can be used on any topography
- ✓ Sometimes used to germinate seed and establish ground cover for crops like lettuce, alfalfa, and sod
- ✓ Very high efficiency water application
- ✓ High capital investment but has low labor requirements

Sprinkler Irrigation: Types

Sprinkler Irrigation

- ✓ **Advantages**
  - ✓ Readily automatable
  - ✓ Facilitates to chemigation and fertigation
  - ✓ Reduced labor requirements needed for irrigation

- ✓ **Limitations**
  - ✓ Many crops (citrus, for example) are sensitive to foliar damage when sprinkled with saline waters
  - ✓ Initially high installation cost
  - ✓ High maintenance cost

Drip Irrigation

- ✓ Constant steady flow of water is applied directly to the root zone of the plants by means of applicators operated under low pressure
- ✓ Applicators: orifices, emitters, porous tubing, perforated pipe
- ✓ Most efficient irrigation system
- ✓ Most suited to high-density orchards, tree crops, and high-value horticultural crops
- ✓ Not designed for large root systems
- ✓ suited for situations where the water supply is limited
- ✓ Very effective in applying nutrients (fertilizers)/insecticides through the drip system
- ✓ Burying the drip system reduces water loss even further by preventing runoff across the surface

Drip Irrigation

- **Advantages:**
  - Highly efficient system
  - Limited water sources can be used
  - Right amount of water can be applied in the root zone
  - It can be automated and well adapted to chemigation and fertigation
  - Reduces nutrient leaching, labor requirement, and operating cost
  - Nearly uniform distribution of water
  - Lower pressures are required-low energy for pumping
- **Limitations:**
  - High initial cost
  - Technical skill is required to maintain and operate the system
  - The closer the spacing, the higher the system cost per hectare
  - Damage to drip tape may occur
  - Cannot wet the soil volume quickly (to recover from moisture deficit) as other systems
  - Facilitates shallow root zone
  - Needs clean water

Other Forms of Irrigation

- ✓ Hand watering
  - ✓ Nurseries and Fruit trees
- ✓ Capillary irrigation
  - ✓ Wet the root zone by capillary rise
  - ✓ buried pipes or deep surface canals
- ✓ Localized irrigation
  - ✓ Water is applied around each or group of plants
  - ✓ Wets root zone only
- ✓ Subsurface irrigation
  - ✓ Water is applied below the ground surface either by raising the water table within or near the root zone or by using a buried perforated or porous pipe system

Comparison of Irrigation Systems

Site and situation factors	Suitability/preferred factor under the irrigation system: Basin	Border	Furrow	Sprinkler	Drip	Sub-irrigation
Soil	Loam to heavy soil	Loam to heavy soil	Loam to heavy soil	Sandy soil	Sandy soil	Sandy soil
Infiltration rate	Moderate to low	Moderate	Moderate	Moderate to high	Moderate to high	Moderate to high
Topography	Flat/nearly level ground	Flat-to- small slope	Flat-to- small slope	All category (flat to rolling)	Flat	Flat
Crop	Close growing crops, suited to standing water	Close growing crops, not suited to standing water	Widely spaced row crops	Generally short crops	Widely spaced row crops, generally high value crops	Row crops
Water supply/stream size	Large stream	Medium-to- large stream	Medium stream	Small stream	Small stream	Small stream
Water quality	All category	All category	All category	Clean water	Clean water	Clean water
Windy climate	No problem	No problem	No problem	Problem	No problem	No problem
Attainable irrigation efficiency	80–90%	70–85%	65–75%	85–95%	85–95%	85–95%
Capital required/initial investment	Medium cost for establishment of basin	Low cost	Medium cost	High initial cost	High initial cost	High initial cost
Labor requirement	High for establishment, but low for operation	Medium	Medium, low if automated	Medium, low if automated	Low	High for establishment, but low for operation

Ali, M.H. (2011) Practices of Irrigation & On-farm Water Management: Volume 2, Springer publishing house, New York, NY 10013, USA, p:61-62

Comparison of Irrigation Systems

Site and situation factors	Suitability/preferred factor under the irrigation system					
	Basin	Border	Furrow	Sprinkler	Drip	Sub-irrigation
Energy requirement	No energy required (only if groundwater is to be supplied)	No energy required (only if groundwater is to be supplied)	No energy required (only if groundwater is to be supplied)	Energy required	Energy required	No energy required
Skill required	Skill required to establish basin	No skill required	Moderate skill required	High skill required	High skill required	High skill required
Epidemic diseases	No problem	No problem	No problem	Problem	No problem	No problem
Operation and maintenance	Easy; low operation and maintenance cost	Easy; low operation and maintenance cost	Easy; low operation and maintenance cost	Not easy, require skill; high operation and maintenance cost	Not easy, require skill; high operation and maintenance cost	Not easy, require skill; high operation and maintenance cost

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THANK YOU

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Irrigation and Drainage

Lecture No: 17 Surface Irrigation Hydraulics

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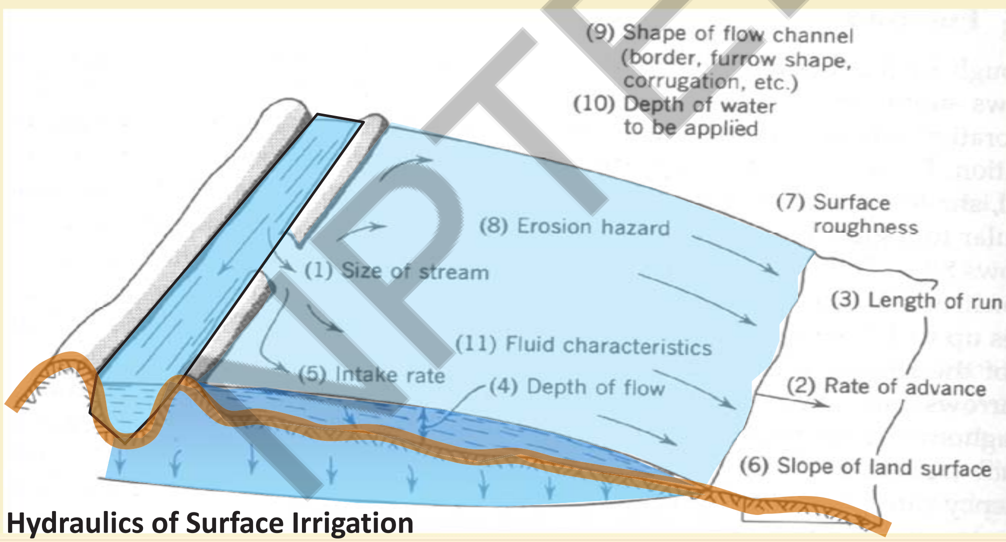
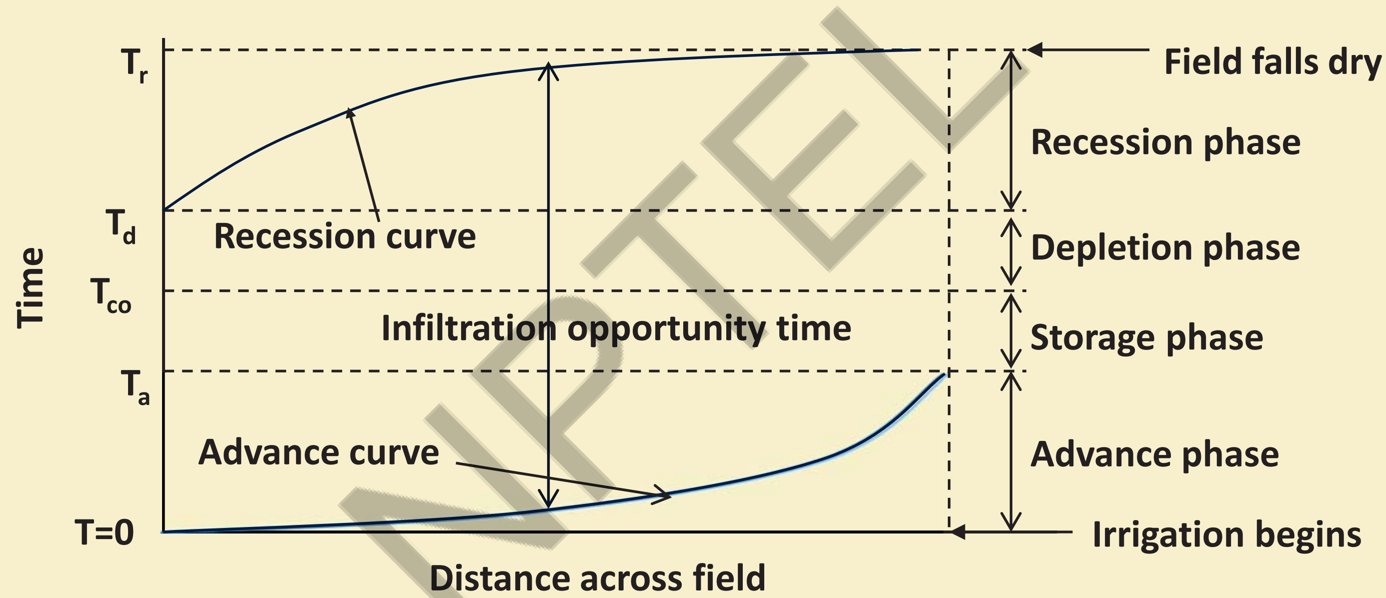
Study of Surface Irrigation

- ✓ **The aim of the surface irrigation system design**
  - ✓ to determine the appropriate **inflow rates** and **cutoff times** so that maximum or desired performance is obtained for a given field condition



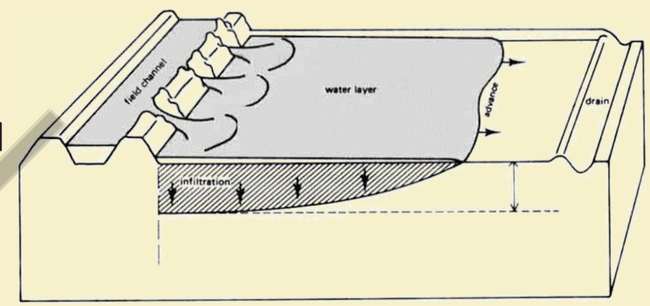
Hydraulics of Surface Irrigation

Hydraulics of Surface Irrigation Event



Typical Surface Irrigation Phases

- ✓ Advance phase
  - ✓ Begins when water is turned into the field
  - ✓ Ends when water reaches the downstream end of the field
- ✓ Storage Phase
  - ✓ Begins when the advance phase ends
  - ✓ The storage phase ends when inflow ends
- ✓ Depletion Phase
  - ✓ Begins when storage phase ends (when inflow ends)
  - ✓ Ends when depth of flow at the headend becomes zero
- ✓ Recession Phase
  - ✓ Begins when depletion phase ends and continues until drying front reaches the end



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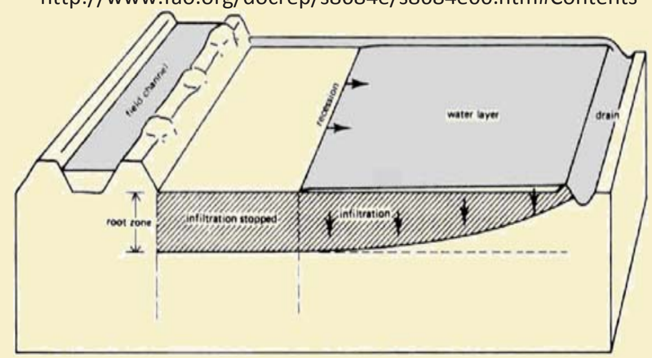
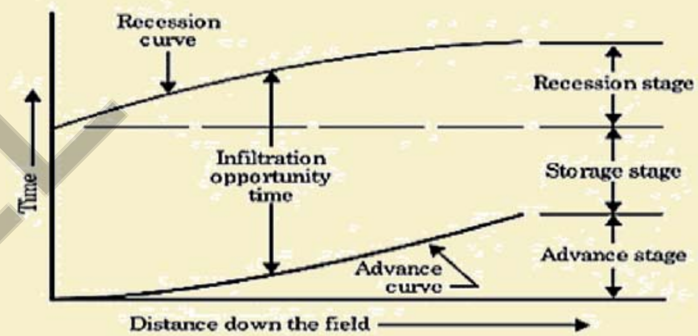


Typical Surface Irrigation Phases

- ✓ **Infiltration opportunity time**
  - ✓ **Time interval between the time it arrives at a point during the advance phase and departs during recession**
  - ✓ **Vertical distance between the advance and recession curves**
  - ✓ **For irrigation uniformity to be high**
    - ✓ **Opportunity time must be same throughout the field**
  - ✓ **This is normally facilitated by "flat" advance curve**



Governing Equations

Saint-Venant Equations

- ✓ **Equations of conservation of mass and momentum,**

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} + I = 0$$

$$\left(\frac{1}{g}\right)\left(\frac{\partial V}{\partial t}\right) + \left(\frac{V}{g}\right)\left(\frac{\partial V}{\partial x}\right) + \left(\frac{\partial y}{\partial x}\right) = S_0 - S_f + \frac{VI}{2gA}$$

Where

y - Depth of flow (m)

t -Time from beginning of irrigation (s)

v - Velocity of flow as f (x, t) (m/s)

x - Distance along the furrow length (m)

I - Infltration rate as f (x, t) (m/s)

g - Acceleration due to gravity (m/s^2)

S_0 - Longitudinal slope of furrow (m/m)

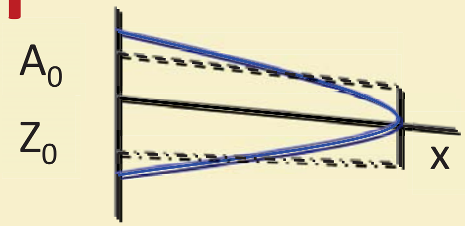
S_f - Slope of energy grade line (friction slope) in m/m

A - Cross-sectional area as f (x, t) (m^2)

Modeling Approach in Surface Irrigation

Model	Governing Principle
Full hydrodynamic	Saint-Venant equations for conservation of mass and momentum
Zero-inertia	Saint Venant Equation that leaves out the acceleration or inertia terms in momentum equation $\frac{dy}{dx} = S_o - S_f$ (momentum eq.)
Kinematic wave	Uniform Flow assumptions: $S_o - S_f = 0$ (momentum eq.)
Volume balance	Numerical solution of temporally and spatially -lumped mass conservation

Volume Balance Model



- **Volume balance equation**

$$\boldsymbol{Q_o t = \sigma_y A_0 x + \int_0^x Z(t - t_s)\, ds} \qquad \textbf{(1)}$$

Where,

Q_o = inflow rate(m^3/min); t = time from the start of inflow (min); A_0 = Wetted area at the head end (m^2); σ_y = Surface profile shape factor (0.77); x = water front advance (m); Z = cumulative infiltration per unit length (m^3/m); t_s=time required to reach water front at a distance of s (m).

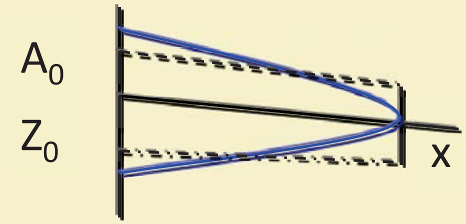
- **Wetted area A_0 is estimated from Manning's equation, after considering, $\boldsymbol{A^2 R^{4/3} = \rho_1 A^{\rho_2}}$**

$$A_0 = \left[\frac{{Q_0}^2 n^2}{3600\rho_1 S_0}\right]^{1/\rho_2} \qquad \textbf{(2)}$$

Where,

n= Manning's roughness coefficient; S_0 = Field slope (S_0>0) and ρ_1, ρ_2 = Furrow shape parameter (Walker and Skogerboe 1987). Since S_0>0, the proposed method is applicable

Volume Balance Model



- ✓ Cumulative infiltration Z is estimated using modified Kostiakov equation

$$Z(\tau) = k\tau^{a} + f_0\tau \qquad \textbf{(3)}$$

Where

K (m²/min^a) and a(-) = fitted parameters; $\tau\ (= t - t_s)$= infiltration opportunity time (min); and f_0 = basic infiltration rate (m²/min)

- ✓ Assumption: the value of f_0 is known prior to the irrigation event
- ✓ Inflow–outflow method can be used to estimate f_0 (Elliott et al. 1983) or soil type (Walker and Skogerboe 1987).

Substitute Eq (3) in Eq (1)

$$Q_0 t = \sigma_y A_0 x + \int_0^x [k(t - t_s)^a + f_0(t - t_s)]\, ds \qquad \textbf{(4)}$$

Volume Balance Model

- ✓ Assuming power function for waterfront advance

$$s = p{t_s}^{b} \tag{5}$$

Where, p and b are the fitted parameters

- ✓ Substitute for t_s in Eq (4)

$$Q_0 t = \sigma_y A_0 x + \int_0^x k\left[t - \left(\frac{s}{p}\right)^{1/b}\right]^a ds + \int_0^x f_0\left[t - \left(\frac{s}{p}\right)^{1/b}\right] ds \tag{6}$$

- ✓ Eq (6) can be written as

$$Q_0 t = \sigma_y A_0 x + k t^a \int_0^x \left[1 - \frac{1}{t}\left(\frac{s}{p}\right)^{1/b}\right]^a ds + f_0 t \int_0^x \left[1 - \frac{1}{t}\left(\frac{s}{p}\right)^{1/b}\right] ds \tag{7}$$

Volume Balance Model

- Considering first three terms of the Binomial expansion of second left side term of (7)

$$Q_0 t = \sigma_y A_0 x + k t^a \int_0^x \left\{1 - \frac{a}{t}\left(\frac{s}{p}\right)^{1/b} + \frac{a(a-1)}{2}\left[\frac{1}{t}\left(\frac{s}{p}\right)^{1/b}\right]^2\right\} ds + f_0 t \int_0^x \left[1 - \frac{1}{t}\left(\frac{s}{p}\right)^{1/b}\right] ds \tag{8}$$

- Integrating and substituting the following,

$$x^{1/b} = \left(p^{1/b}\right) t \text{ and } x^{2/b} = \left(p^{2/b}\right) t^2$$

- Eq.(8) can be reduced to

$$Q_0 t = \sigma_y A_0 x + k t^a x \left(1 - \frac{ab}{b+1} + \frac{a(a-1)b}{2(2+b)}\right) + \frac{f_0 t x}{1+b} \tag{9}$$

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Volume Balance Model

- ✓ Eq. (9) is further reduced to

$$Q_0 t = \sigma_y A_0 x + \sigma_z k t^a x + \frac{f_0 t x}{1+b} \quad (10)$$

$$\sigma_z = 1 - \frac{ab}{1+b} + \frac{ab(a-1)}{2(2+b)}$$

- ✓ Kiefer (1965) approximated σ_z as

$$\sigma_z = \frac{a+b-ab+1}{(1+a)(1+b)} \quad (11)$$

- ✓ Mailapalli et al. (2008) reported that

$$\sigma_z(BA) = 1.0257 \times \sigma_z(KA) \quad (a,b) \in R[0,1] \quad (10)$$

- ✓ BA is the Binomial approximation
- ✓ KA is the Kiefer approximation

Volume Balance Model

Two-point method (Elliott and Walker 1982)

- ✓ Volume balance equation for two advance points (x_1,t_1) and (x_2,t_2), Eq (10) can be written as

$$Q_0 t_1 = \sigma_y A_0 x_1 + \sigma_z k {t_1}^a x_1 + \frac{f_0 t_1 x_1}{1+b} \quad \textbf{(13)}$$

$$Q_0 t_2 = \sigma_y A_0 x_2 + \sigma_z k {t_2}^a x_2 + \frac{f_0 t_2 x_2}{1+b} \quad \textbf{(14)}$$

- ✓ The two unknowns k and a can be estimated from the above two-equations

One-point method (Mailapalli et al. 2008) - Considering two advance points; $t_1 = 0.5 \times t_2$

$$\left(\frac{x_1}{x_2}\right) = \frac{Q_0(0.5t_2)}{(0.5)^a\left[Q_0 t_2 - \sigma_y A_0 x_2 - \frac{f_0 t_2 x_2}{1+b}\right] + \sigma_y A_0 x_2 + \frac{f_0(0.5t_2)x_2}{1+b}} \quad \textbf{(15)}$$

Volume Balance Model

$$b = \frac{log(x_1/x_2)}{log(t_1/t_2)}$$

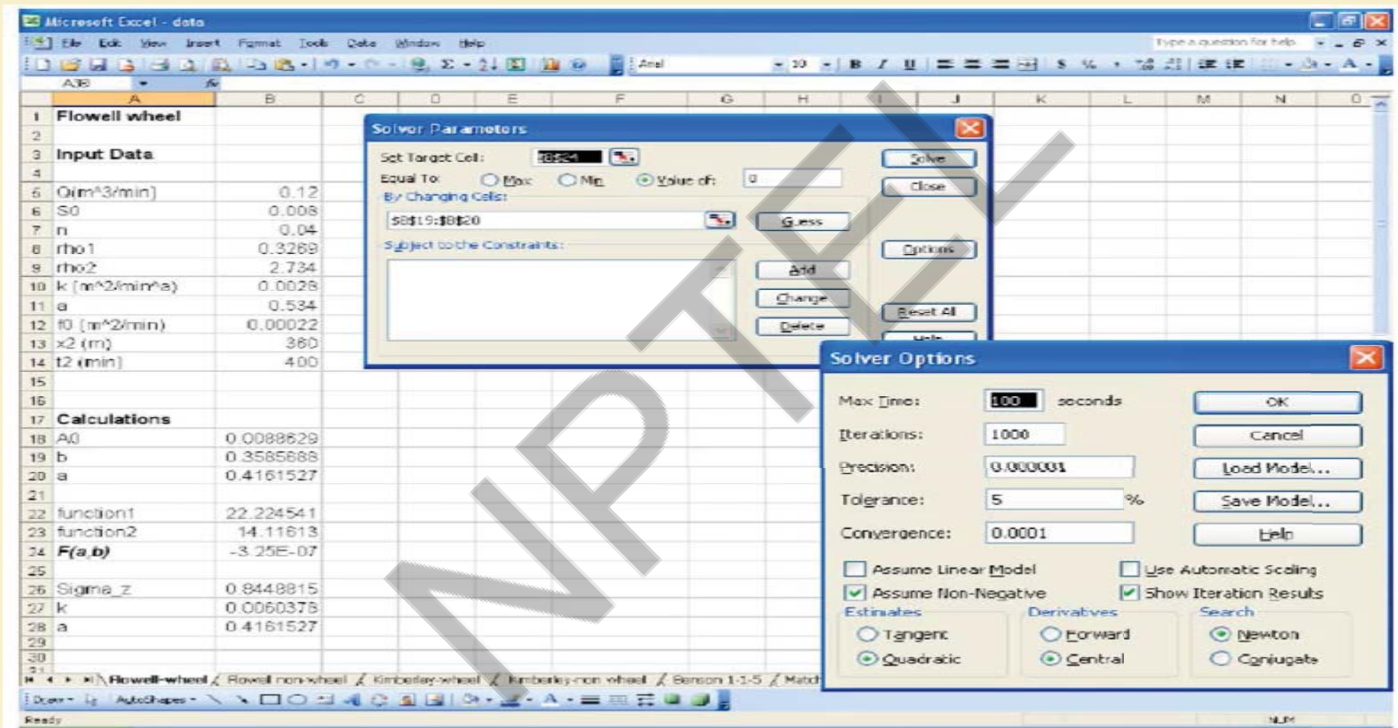
Knowing two advance points, other parameters and a can be estimated from Eq.15 using Newton-Raphson technique

For example, for one-point method (Mailapalli et al. 2008), the following function can be obtained from Eq. (15)

$$f(a,b) = b\log(0.5) - log\left(\frac{Q_0(0.5t_2)}{(0.5)^a\left[Q_0 t_2 - \sigma_y A_0 x_2 - \frac{f_0 t_2 x_2}{1+b}\right] + \sigma_y A_0 x_2 + \frac{f_0(0.5t_2)x_2}{1+b}}\right) = 0 \quad \textbf{(17)}$$

This can be solved using Excel solver tool (Mailapalli et al. 2008)

Volume Balance Model



Furrow Irrigation system

Furrow shape parameters

- ✓ For a typical furrow cross-section, the shape parameters can be determined as follows from pairs of furrow depth and top width measurements :

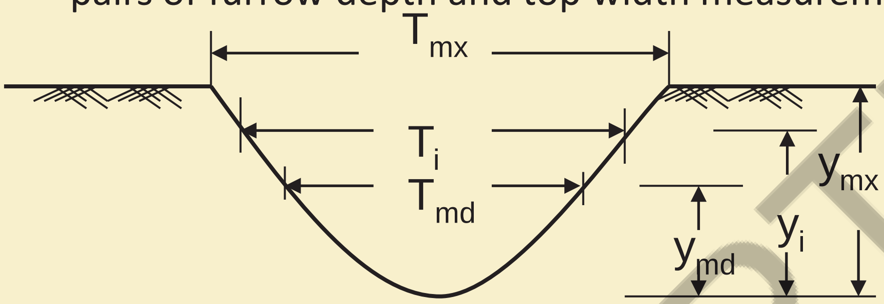


Fig. A schematic of a typical furrow cross-section

$$T = \alpha_1 y^{\alpha_2}$$

$$A = \sigma_1 y^{\sigma_2}$$

$$WP = \gamma_1 y^{\gamma_2}$$

$$A^2 R^{4/3} = \rho_1 A^{\rho_2}$$

Where

$\alpha_1, \alpha_2, \sigma_1, \sigma_2, \gamma_1, \gamma_2$ are fitted parameters; top width of flow (T), flow area (A) and wetted perimeter (WP) to flow depth (y)

Furrow Shape Parameters

$$\alpha_1 = \frac{T_{mx}}{y^{\alpha_2}{}_{mx}}$$

$$\alpha_2 = \frac{\log(T_{mx}/T_{md})}{\log(y_{mx}/y_{md})} \qquad \gamma_1 = \frac{WP|_{y\,mx}}{y^{\gamma_2}{}_{mx}}$$

$$\sigma_1 = \frac{\alpha_1}{\alpha_2 + 1} \qquad \gamma_2 = \frac{\log\,(WP|_{y\,mx}/(WP|_{y\,md})}{\log(y_{mx}/y_{md})}$$

$$\sigma_2 = \alpha_2 + 1$$

$$WP\Big|_{y\,mx} = \sum_{i=0}^{n/2}\{2[(y_i - y_{i-1})^2 + [0.5(T_i - T_{i-1})]^2]^{0.5}\}$$

Where n is the number of depth and top width pairs, and mx, md and i are the max, mid and individual value of depth and top width, σ_1, and σ_2 for borders and basins are 1.0, 0.0, 1.0, and 1.0, respectively.

✓ **The hydraulic section can be computed by combining the above equations:**

$$\boldsymbol{A^2 R^{4/3} = \rho_1 A^{\rho_2}}$$

$$\boldsymbol{\rho_1 = \frac{\sigma_1{}^{10/3}}{\gamma_1{}^{4/3}}}$$

$$\boldsymbol{\rho_2 = \frac{10}{3} - \frac{4\,\gamma_1}{3\sigma_2}}$$

- ✓ Borders and basins, σ_1= 1, σ_2=3.33
- ✓ Border systems ρ_1=1.0 ; ρ_2=1.67.
- ✓ Furrow-irrigated conditions:

ρ_1 - 0.3 to 0.7 ;ρ_2- 1.3 to 1.5.

Estimation of furrow shape parameters

Problem 17.1:

Using the following field measured information, determine the furrow shape factors.

Elevation from furrow bottom (m)	Horizontal width of furrow (m)
0	0
0.01	0.053
0.02	0.092
0.03	0.125
0.04	0.156
0.05	0.185
0.06	0.212
0.07	0.238
0.08	0.263
0.09	0.287
0.1	0.311
0.11	0.334
0.12	0.356
0.13	0.381
0.14	0.405

Solution:

It is assumed that the final stable shape follows a power law, which relates top width of flow (T), flow area (A) and wetted perimeter (WP) to flow depth (y) using the equations discussed earlier.

$$T = \alpha_1 y^{\alpha_2} \qquad A = \sigma_1 y^{\sigma_2} \qquad WP = \gamma_1 y^{\gamma_2}$$

$T_{mx} = 0.405$; $T_{md} = 0.238$; $y_{mx} = 0.14$; $y_{md} = 0.07$

$$\alpha_2 = \frac{\log(T_{mx}/T_{md})}{\log(y_{mx}/y_{md})} = \frac{\log(\frac{0.405}{0.238})}{\log(\frac{0.14}{0.07})} = 0.7670 \qquad \alpha_1 = \frac{T_{mx}}{{y^{\alpha_2}}_{mx}} = \frac{0.405}{0.14^{0.7670}} = 1.8295$$

Estimation of Furrow Shape Parameters

$$\sigma_1 = \frac{\alpha_1}{\alpha_2 + 1} = \frac{1.8295}{0.7670 + 1} = 1.0354$$

$$\sigma_2 = \alpha_2 + 1 = 0.7670 + 1 = 1.7670$$

$$\gamma_2 = \frac{\log\,(WP|_{y\,mx}/(WP|_{y\,md})}{\log(y_{mx}/y_{md})} = \frac{log(\frac{0.4955}{0.2775})}{log(\frac{0.14}{0.07})} = 0.835$$

$$\gamma_1 = \frac{WP|_{y\,mx}}{y^{\gamma_2}{}_{mx}} = \frac{0.4955}{(0.14)^{0.835}} = 2.563$$

$$\rho_1 = \frac{\sigma_1{}^{10/3}}{\gamma_1{}^{4/3}} = \frac{1.0354^{10/3}}{2.563^{4/3}} = 1.36551;$$

$$\rho_2 = \frac{10}{3} - \frac{4\,\gamma_1}{3\sigma_2} = \frac{10}{3} - \frac{4(0.835)}{3(1.767)} = 0.32023$$

THANK YOU

Irrigation and Drainage

Lecture No: 18 Furrow Irrigation Hydraulics

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Flow chart for Calculating Advance Time (t_L)

Input data required Q_0, S_0, n, ρ_1, ρ_2, Z_{req}, a, k, f_0,

↓

$$A_0 = \left(\frac{Q_0 n}{60\rho_1 S_0^{0.5}}\right)^{\frac{1}{\rho_2}}$$

A_0 flow area at field inlet,

↓

Initial guess of 'r' btw 0.3-0.9

r=b in this lecture

↓

Sub surface shape factor,

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

and

$$\sigma_s = \frac{1}{(1+r)}$$

↓

Initial Estimate of

$$t_L = T_1 = \frac{5 \times A_0 \times L}{Q_0}$$

↓

$$T_2 = T_1 - \frac{Q_0 T_1 0.77 A_0 L - \sigma_z k T_1{}^a L - \sigma'_z f_0 T_1 L}{Q_0 - \frac{ak\sigma_z L}{T_1{}^{1-a}} - \sigma'_z f_0 L}$$

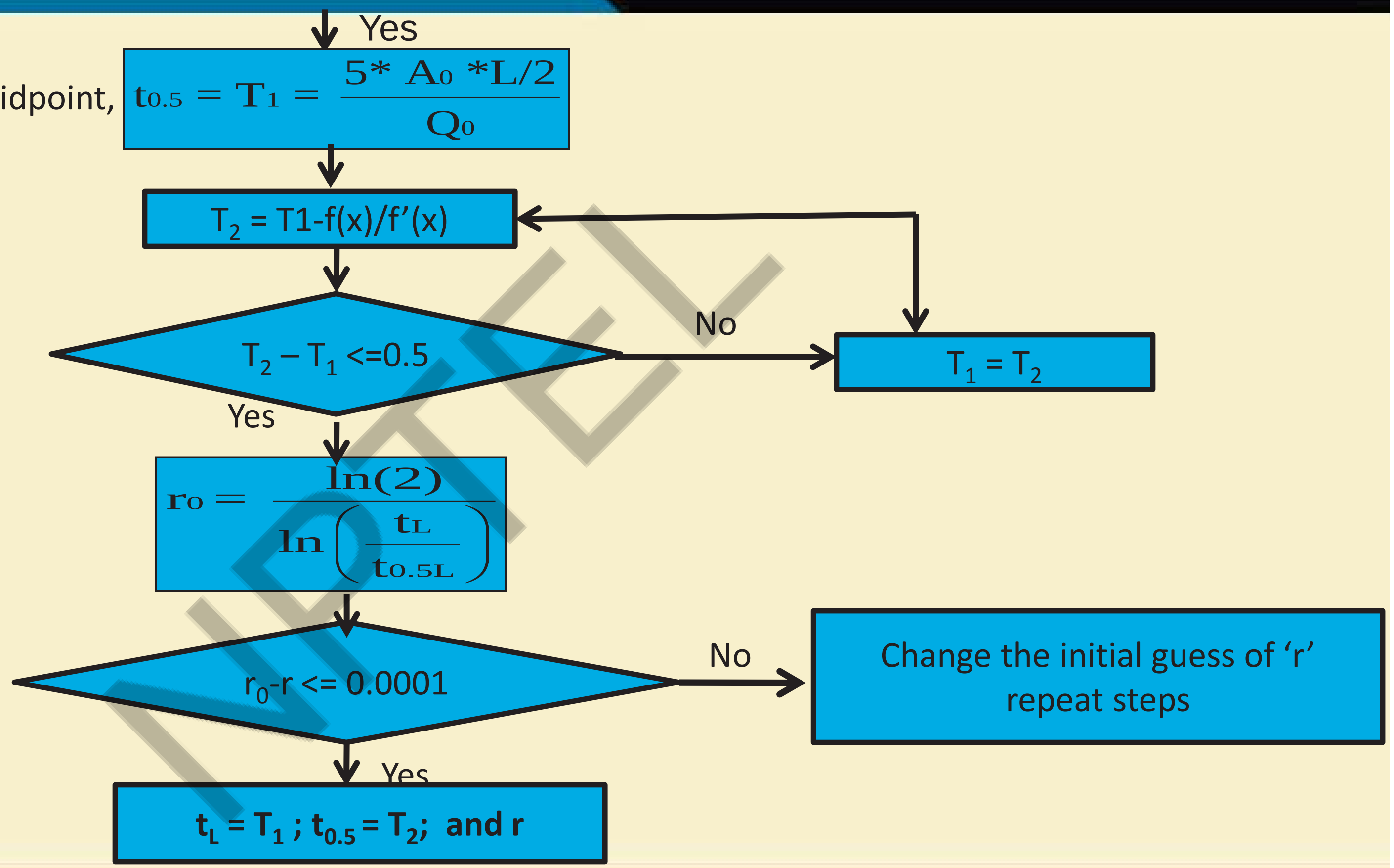
↓

$T2 - T1 <= 0.5$

No → $T1 = T2$ → back to T_2 calculation

Contd....

Time of advance to the field midpoint,



Computation of Intake Opportunity Time

- ✓ Intake opportunity time (τ_{req}) associated with Z_{req} to be known
- ✓ The time can be obtained from modified Kostiakov eq. using the Newton-Raphson procedure
  - ✓ Make an initial estimate of τ_{req} as $\tau^{i}{}_{req}$
  - ✓ Compute a revised estimate as follows

$$\tau^{i+1}{}_{req} = \tau^{i}{}_{req} - \frac{f(\tau_{req})}{f'(\tau_{req})}$$

$$f(\tau_{req}) = Zr_{eq} - k(\tau^{i}{}_{req})^{a} - f_0\tau^{i}{}_{req} \qquad \text{and} \qquad f'(\tau_{req}) = -ak\left(\tau^{i}{}_{req}\right)^{a-1} - f_0$$

  - ✓ Compare $\tau^{i}{}_{req}$ and $\tau^{i+1}{}_{req}$ by taking their absolute difference
    - ✓ If they are equal or are within an acceptable error tolerance (say 0.5 minutes), the desired values is obtained.
    - ✓ If not repeat Steps 2 and 3 until the prescribed termination criteria are met by replacing new value as initial guess

Models for Furrow Irrigation System Design

- ✓ The time of cutoff (t_{co}) by neglecting depletion and recession is given as

$$t_{co} = \tau_{req} + tL$$

- ✓ The value of Qo should be adjusted so that the number of sets is an integer number.

  The procedure is same to calculate τ_{req} and tL as in Basin and Border irrigation system design.

Table : Parameters required for the design of furrow irrigation systems

Sl. No.	Data	Symbol
1	Kostiakov-Lewis's Infiltration Model Parameters	a , k, f_o
2	Field Length	L
3	Field Width	W
4	Furrow Spacing	w
5	Field Slope	S_o
6	Shape Coefficient	ρ_1 and ρ_2
7	Manning's Roughness Coefficient	n
8	Required Application Depth	Z_{req}
9	Water Supply Rate	Q
10	Flow per Unit Width	Q_o
11	Duration	T
12	Number of Furrows	N_f

Design of Free Draining Graded Furrow System

The design procedure is based on the volume-balance principles. Uses two-point method. The design steps are listed below,

1. Collect the following required field data:
   a. **Field characteristics**: L, W, area, S_0 and n.
   b. **Soil characteristics:** texture, water holding capacity, field representative infiltration parameters for the first and later irrigations (k, a and f_o).
   c. **Crop characteristics:** type, design irrigation requirement (Z_{req}), irrigation schedule, sensitive crop stages.
   d. **Water supply:** source, flow rate (Q) and duration.
   e. **Furrow characteristics:** spacing (F_s), shape and geometry (depth and width data for computing furrow shape factors, ρ_1 and ρ_2.

2. **Determine furrow geometry parameters**

   The flow cross-sectional area (A), wetted perimeter (WP) and hydraulics radius (R) affect the surface irrigation performance and are functions of flow depth (Y) and geometry of the section (Explained in the previous slides)

3. **Compute the intake opportunity time (τ_{req})** at the end of the field that exactly satisfies the irrigation requirement (Z_{req})

   - Assume an initial value
   - Use the Newton- Raphson method and compute new value
   - Repeat step b by setting the computed value as the initial guess until the initial guess and the computed value are within a specified tolerance limit

4. **Compute the maximum furrow discharge (Q_{max})** considering the maximum non-erosive velocity for a given soil texture (8 m/min in erosive silt soils to 13 m/min in less erosive clay and sandy soils) using below Eq.

$$Q_{max} = \left(V_{max}^{\rho_2} \frac{n}{60\rho_1 S_0^{0.5}}\right)^{\frac{1}{(\rho_2 - 1)}}$$

5. **Select a furrow discharge (Q_0, m³/min)** near Q_{max} which results in an integer number of furrow sets [N_s]and number of furrows per set [N_{fs}]

$$N_s = \frac{N_f - Q_0}{Q}$$

$$N_{fs} = \frac{N_f}{N_s}$$

Recommended Permissible Velocities*

Material	V (m/s)
Fine sand	0.6
Coarse sand	1.2
Earth	
Sandy silt	0.6
Silt clay	1.1
Clay	1.8
Grass-lined earth (slopes < 5 per cent)	
Bermuda grass	
Sandy silt	1.8
Silt clay	2.4
Kentucky Blue grass	
Sandy silt	1.5
Silt clay	2.1
Poor rock (usually sedimentary)	
Soft snadstone	2.4
Soft shale	1.1
Good rock (usually igneous or hard metamorphic)	6.1

* After U.S. Army Corps of Engineers [1970]

6. **Calculate the cross-sectional flow area** at the field inlet (A_0) using the following Eq. and check the maximum flow velocity and depth of channel:

$$A_0 = \left(\frac{Q_0^2 n^2}{3600\rho_1 S_0}\right)^{\frac{1}{\rho_2}}$$

$$V_{max} = \frac{Q_0}{A_0}$$

If V_{max} is greater than the maximum erosive velocity, or flow area is insufficient, reduce Q_0 and repeat Step 6.

7. Assume an initial value of advance rate exponent (r) equal to 0.5, $r^j = 0.5$.

8. Compute σ_z and σ_z' as follows:

$$\sigma_z = \frac{a + r^j(1-a) + 1}{(1+a)(1+r^j)}$$

$$\sigma_z' = \frac{1}{1 + r^j}$$

9. Compute time $t_{L/2}$- advance time for half the furrow (L/2) distance:

a. $t_{L/2}^{i} = \frac{2.5 A_0 L}{Q_0}$

b. $t_{L/2}^{i+1} = t_{L/2}^{i} - \frac{Q_0\, t_{L/2}^{i} - \sigma_y A_0 (0.5L) - \sigma_z k \left(t_{L/2}^{i}\right)^{a} (0.5L) - \sigma_z' f_0 (t_{L/2}^{i})(0.5L)}{Q_0 - \sigma_z a k \left(t_{L/2}^{i}\right)^{a-1} (0.5L) - \sigma_z' f_0 (0.5L)}$

c. Is $t_{L/2}^{i} = t_{L/2}^{i+1}$ or within the permissible tolerance limit? If this condition is not satisfied then repeat step b by setting $t_{L/2}^{i} = t_{L/2}^{i+1}$. Otherwise, and proceed to step 10.

10. Compute the time t_L necessary for flow to advance L distance:

a. $t_L^{i} = \frac{5 A_0 L}{Q_0}$

b. $t_L^{i+1} = t_L^i - \frac{Q_0\, t_L^i - \sigma_y A_0 (L) - \sigma_z k \left(t_L^i\right)^a (L) - \sigma_z' f_0 (t_L^i)(L)}{Q_0 - \sigma_z a k \left(t_L^i\right)^{a-1} (L) - \sigma_z' f_0 (L)}$

c. Is $t_L^i = t_L^{i+1}$ or within the permissible tolerance limit? If this condition is not satisfied then repeat step b by setting $t_L^i = t_L^{i+1} t_L = t_L^{i+1}$. Otherwise, and proceed to step 11.

- Note that there will be no convergence if the chosen Q_0 is insufficient to complete the advance. In this case either increase Q_0 or decrease furrow (field) length.

11. Compute a revised estimate of advance rate exponent (r^{j+1}) as follows:

$$r^{j+1} = \frac{\ln 2}{\ln\left(\frac{t_L}{t_{L/2}}\right)}$$

12. Compare the initial guess value of r^j with the computed value r^{j+1} Eq. (54). If both values are equal (within the permissible range), continue with step 13, otherwise set $r^j = r^{j+1}$ and repeat steps (8) through (12)

13. **Compute the time of cutoff**, Tco (min) using below Eq. by substituting the values of and t_L as obtained in steps (3) and (10), respectively:

$$T_{co} = \tau_{req} + t_L$$

Note, simultaneous recession is assumed.

14. Compute the application efficiency, E_a

$$E_a = \frac{Z_{req} L}{Q_0 T_{co}}$$

15. Application Efficiency should be maximized considering different values of furrow inflow rate subject to the limitations on erosion velocity, integer number of sets, the availability and the total discharge of water supply, and other farming practices
    - At least, three Q_o values should be tried in order to identify a value that maximizes Ea.
16. The same procedure needs to be repeated considering the representative values of infiltration parameters for later irrigations during the season.
    - It is generally observed that infiltration rate decreases for later irrigations.

Design Problem: Design a furrow irrigation system for a field with the following information:

- Field length, L = 50 m,
- Field width, W = 800 m,
- Longitudinal Slope, S_0 = 0.005,
- n = 0.04,
- soil texture = silt,
- design irrigation requirement = 10 cm,
- furrow spacing, Fs = 0.8 m,
- Furrow shape parameters, ρ_1 = 0.305 and ρ_2 = 2.852,
- Infiltration function parameters: k = 0.0019, a = 0.692 and f_0 = 0.00025,
- available supply rate, Q = 4.5 (m^3/min),
- Supply duration = 24 hrs

Solution:

✓ All the required data including the furrow shape parameters are already given. Thus, design can begin from step 3.

1. Calculate τ_{req} to satisfy the irrigation requirement of 10 cm

   a. Z_{req}= irrigation requirement x F_s = 10 cm x 80 cm = 0.08 m^3/m length

   b. Assume an initial value of τ_{req}^{i} as τ_{req} = 100 min

   c. Compute a new value

$$\tau_{req}^{i+1} = \tau_{req}^{i} - \frac{f(\tau_{req})}{f'(\tau_{req})}$$

$$f(\tau_{req}) = Z_{req} - k(\tau_{req}^{i})^{a} - f_0\tau_{req}^{i}$$

$$f'(\tau_{req}) = -ak(\tau_{req}^{i})^{a-1} - f_0$$

$$\tau_{req}^{i+1} = 100 - \frac{0.08 - 0.0019\,(100)^{0.692} - 0.00025\,(100)}{-0.692(0.0019)(100)^{1-0.692} - 0.00025} = 115.837$$

- Since the new and initial estimates are not close, calculate a new value with 115.837 min as a revised initial guess.

$$\tau_{req}^{i+1} = 115.837 - \frac{0.08 - 0.0019\,(115.837)^{0.692} - 0.00025\,(115.837)}{-0.692(0.0019)(115.837)^{1-0.692} - 0.00025} = 116.044$$

$$\tau_{req} = 116.044 \text{ min}$$

2. Compute maximum furrow discharge (Q_{max})

The maximum non-erosive velocity for silt = 8 m/min

$$Q_{max} = \left(V_{max}^{\rho_2}\frac{n^2}{3600\rho_1 S_0}\right)^{\frac{1}{(\rho_2-2)}}$$

$$Q_{max} = \left(8^{2.852}\frac{0.04^2}{3600\,(0.305)(0.005)}\right)^{\frac{1}{(2.852-2)}} = 0.075 \text{ m}^3/\text{min}$$

3. Select the furrow inflow near Q_{max} which results in integer sets and furrows per set.

$$N_f = \frac{W}{F_s} = \frac{800}{0.8} = 1000 \quad \text{furrows}$$

$$N_s = \frac{N_f Q_0}{Q} = \frac{1000\,(0.075)}{4.5} = 16.66 \quad \text{furrows/set}$$

$$N_{fs} = \frac{N_f}{N_s} = \frac{1000}{16.66} = 60 \text{ sets}$$

- ✓ However, the number of furrows per set is not integer.
- ✓ Therefore, a new value of $Q_0 < Q_{max}$ needs to be selected iteratively such that both the number of furrows and number of set are integer.
- ✓ In this case, the following combination results:

Sets	Number of furrows/set	Furrow inflow rate (Q_0, m^3/min)
10	100	0.0450
8	125	0.0360
5	200	0.0225
4	250	0.0180
2	500	0.0090
1	1000	0.0045

4. Calculate the cross-sectional flow area at the field inlet (A_0)

$$A_0 = \left(\frac{Q_0^2 n^2}{3600 \rho_1 S_0}\right)^{\frac{1}{\rho_2}} = \left(\frac{0.045^2 0.04^2}{3600 \times 0.305 \times 0.005}\right)^{\frac{1}{2.852}} = 0.00654 \text{ m}^2$$

$$V_{max} = \frac{Q_0}{A_0} = \frac{0.045}{0.00654} = 6.88 \text{m/min}$$

V_{max}< Maximum permissible velocity for silt, and thus chosen Q_0 is satisfactory.

5. Assume an initial value of advance rate exponent (r) equal to 0.5, r^j= 0.5.
6. Compute and :

$$\sigma_z = \frac{a + r^j(1-a) + 1}{(1+a)(1+r^j)} = \frac{0.692 + 0.5 \times (1-0.5) + 1}{(1+0.692) \times (1+0.5)} = 0.72734$$

$$\sigma_z' = \frac{1}{1+r^j} = \frac{1}{1+0.5} = 0.6666$$

7. Compute the time necessary for flow to advance half the furrow L/2 distance, $t_{L/2}$:

a. $t^{i}_{L/2} = \frac{2.5A_0L}{Q_0} = \frac{2.5\times0.00654\times50}{0.045} = 18.180$ min

b. $t^{i+1}_{L/2} = t^{i}_{L/2} - \frac{Q_0\, t^{i}_{L/2} - \sigma_y A_0(0.5L) - \sigma_z k\left(t^{i}_{L/2}\right)^{a}(0.5L) - \sigma_z' f_0(t^{i}_{L/2})(0.5L)}{Q_0 - \sigma_z a k\left(t^{i}_{L/2}\right)^{a-1}(0.5L) - \sigma_z' f_0(0.5L)}$

$$t^{i+1}_{L/2} = 18.180 - \frac{0.045\times18.180 - 0.77\times0.00654\times(25) - 0.72734\times0.0019\times18.180^{0.692}\times(25) - 0.6666\times0.00025\times18.180\times(25)}{0.045 - 0.72734\times0.692\times0.0019\times(18.180)^{0.692-1}\times(25) - 0.6666\times0.00025\times25}$$

= 6.6083 min

c. Repeat step b since the initial guess and new value are not within the acceptable limit. After an iteration a new value of **6.0135 min** was obtained, which is close to initial guess.

8. Compute the time necessary for flow to advance L distance, t_L:

a. $t^{i}_{L} = \frac{5A_0L}{Q_0} = \frac{5\times0.00654\times50}{0.045} = 36.361$ min

b. $t_L^{i+1} = t_L^i - \frac{Q_0\, t_L^i - \sigma_y A_0(L) - \sigma_z k\left(t_L^i\right)^a (L) - \sigma_z' f_0\left(t_L^i\right)(L)}{Q_0 - \sigma_z a k\left(t_L^i\right)^{a-1}(L) - \sigma_z' f_0(L)}$

$$t_L^{i+1} = 36.360 - \frac{0.045 \times 36.360 - 0.77 \times 0.00654 \times 50 - 0.72734 \times 0.0019 \times 36.360^{0.692} \times 50 - 0.66666 \times 0.00025 \times 36.360 \times 50}{0.045 - 0.72734 \times 0.692 \times 0.0019 \times 36.360^{0.692-1} \times 50 - 0.66666 \times 0.00025 \times 50}$$

= 24.346 min

c. Repeat step b since the initial guess and new value are not within the acceptable limit. After an iteration a new value of **23.737 min** was obtained, which is close to the initial guess.

9. Compute the revised estimate of advance rate exponent (r^{j+1}) as follows:

$$r^{j+1} = \frac{\ln 2}{\ln\left(\frac{t_L}{t_{L/2}}\right)} = \frac{\ln 2}{\ln\left(\frac{6.013}{23.737}\right)} = 0.5048$$

10. The revised estimate (0.5048) of advance rate exponent (r^{j+1}) is very close to the initial guess (0.50) of (r^j), and hence the value of t_L calculated in step 8 is acceptable.

11. Compute the time of cutoff, Tco (min)

$$T_{co} = \tau_{req} + t_L$$

$$= 116.04 + 23.74 = 139.78 \text{ min}$$

12. Compute the application efficiency, Ea as follows:

$$E_a = \frac{Z_{req} L}{Q_0 T_{co}}$$

$$= \frac{0.08 \times 50}{0.045 \times 139.78} = 63.59\%$$

13. Check thewater availability duration:

- ✓ Duration to complete 10 sets = 139.78 x 10 = 1397.8 min = 23.29 hr
- ✓ Irrigation is completed within the duration of water supply.

14. Repeat steps (4) through 13 for all possible inflow rate and set combination as determined in step 3.

- For the furrow inflow rate of 0.036 m^3/min (8 sets and 125 furrows/set), t_L, Tco and corresponding Ea were obtained as 44.81 min, 160.86 min and 69.07%. It takes around 21.44 hr to complete all 8 sets.

- The furrow inflow rate of 0.0225 m^3/min (5 sets and 200 furrows/set) fails to complete the advance to the end of the furrow.

- The maximum Ea was obtained with a furrow inflow rate of 0.036 m^3/min **(8 sets and 125 furrows/set**) and T_{co} of **160.86 min** and therefore it should be used to irrigate the field.

- It completes irrigation within the water availability time constraints.

THANK YOU

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NPTEL ONLINE CERTIFICATION COURSES

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Irrigation and Drainage

Lecture No: 19 Border Irrigation Design

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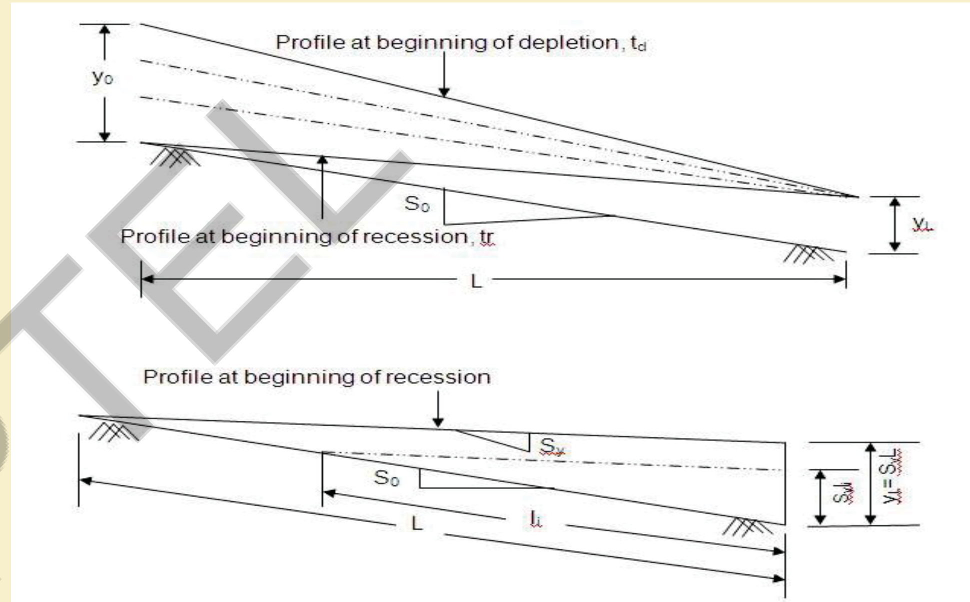
Border Irrigation Design

- ✓ Can be either free drained or diked
- ✓ Design of free drained border is similar to design of free drained furrows,
  - o except that in border design the **depletion and recession phases are significant** and thus cannot be assumed as instantaneous.
- ✓ Design of diked border is similar to the design of basins.



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Border Irrigation Design: Assumptions

- ✓ Surface water profiles at T_{co} as well as t_d, and at the beginning of t_r are straight lines
- ✓ During t_d, the depth y_L and runoff (Q_r) at the downstream end remains constant
- ✓ During both t_d and t_r, sum of infiltration (I) and Q_r remains equal to pre-cutoff unit inflow rate (Q_0)
- ✓ The time required from T_{co} to the end of t_d, is equal to the time required to remove a triangular volume of length L and height Y_0 at constant rate of Q_0 through both infiltration and runoff:
- ✓

$$t_d = T_{co} + \frac{Y_0 L}{2Q_0}$$

- ✓ At the beginning of t_r, it is assumed that the depth changes with distance at uniform rate over a entire length of border, Which can be express as:

$$S_y = \frac{y_{L(}t_{d)}}{L}$$

Where, y_L is the function of Q_r at time t_d and can be evaluated as follows

$$Q_r(t_d) = Q_0 - IL = A\frac{R^{\frac{2}{3}}S_0^{\frac{1}{2}}}{n}$$

For border A = y and WP = 1; therefore R = y or S_yL and I is the average infiltration rate (m/sec) over L.

- ✓ S_y becomes

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

- ✓ *I* can be expressed as a mean of infiltration rate at the upstream end ($I(t_d)$) and at the downstream end $I(t_d - t_L)$:

$$i = \frac{ak}{2}\left[t_d^{1-a} + (t_d - t_l)^{a-1}\right] + f_0$$

- ✓ Walker and Skogerboe (1987) provided an equation for estimating the recession time as follows:

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

A step wise design procedure for free drained borders

1. **Collect** the information related to field characteristics, soil, crop and water supply.
2. **Determine** the maximum (Q_{max}) and minimum (Q_{min}) values of unit inflow rate Q_0 (m^3/min/m) using below Eqs. (to limit the flow within the non-erosive velocity with sufficient depth to spread laterally.

$$Q_{max} = 0.01059 S_0^{-0.75}$$

$$Q_{min} = \frac{0.000357\ LS^{0.5}}{n}$$

3. **Select** unit flow rate (Q_0) between Q_{max} and Q_{min} in such a way that it results in a set width that contains an even number of borders of satisfactory width and integer number of sets using below Eqs.

$$W_b = \frac{Q}{Q_0} \quad \text{and} \quad N_b = \frac{W}{W_b}$$

4. **Compute** the inflow depth at inlet y_0 (m) using below Eq.

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

5. **Compute** τ_{req} (min) to satisfy the irrigation requirement using the same procedure as used in case of furrow design.

6. **Compute the time of advance** to the end of border t_L (min) using the same procedure as used in case of furrow design.

7. **Compute the time of recession** (t_r in minutes since the beginning of irrigation) assuming that the design will meet irrigation requirement at the end of the border.

$$t_r = \tau_{req} + t_L$$

8. **Compute the depletion time,** t_d (min) using the Newton-Raphson method as follows:

   a. Assume initial guess of t_d as $t_d^i = t_r$

   b. Compute av Infiltration (I) by subsisting $t_d = t_d^i$

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

c. Compute S_y

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

d. Compute a new value of t_d as follows:

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

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

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 found and continue with step 9. Otherwise, set and repeat steps b through e.

9. Compute the infiltrated depth at border inlet (Z_0)

$$Z_0 = kt_d^a + f_0 t_d$$

Compare it with Z_{req} to determine the status of irrigation (complete irrigation: $Z_0 \geq Z_{req}$; deficit irrigation $Z_0 < Z_{req}$).

10. Compute T_{co} and E_a, if irrigation is complete, as follows

$$T_{co} = t_d - \frac{Y_0 L}{2Q_0}$$

$$E_a = \frac{Z_{req}\, L}{Q_0\, T_{co}}$$

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

a. Compute new T_{co} by substituting τ_{req} in place of t_d in following Eq.

$$t_d = T_{co} + \frac{Y_0\, L}{Q_0}$$

b. Compute the average Infiltration (I) by substituting $t_d = \tau_{req}$

c. Compute S_y

d. Compute t_r by substituting $t_d = \tau_{req}$

e. Compute Z_L

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

f. Compute E_a,

$$E_a = \frac{Z_{req} L}{Q_0 T_{co}}$$

12. Check the water availability constraint and repeat steps 4 to 12 for other unit inflow rates. Choose the design which gives the maximum E_a value.

Design Problem

Design a border irrigation system for the following conditions:

- ✓ Field length, L = 400 m
- ✓ Field width, W = 600 m,
- ✓ Longitudinal Slope, S_0 = 0.005, n = 0.04,
- ✓ Soil texture = silt,
- ✓ design irrigation requirement = 5 cm,
- ✓ Shape parameters, $\rho_1 = 1$ and $\rho_2 = 3.33$,
- ✓ Infiltration parameters: k = 0.0028, a = 0.356 and f_0 = 0.00017,
- ✓ Available supply rate, Q = 50 (m^3/min),
- ✓ Supply duration = 12 hrs.

Solution:

1. **Determine** the maximum (Q_{max}) and minimum (Q_{min}) limit for unit inflow rate Q_0

$$Q_{max} = 0.01059 S_0^{-0.75} = 0.01059 \times 0.005^{-0.75} = 0.563$$

$$Q_{min} = \frac{0.000357\, LS^{0.5}}{n} = \frac{0.000357 \times 400 \times 0.005^{0.5}}{0.04} = 0.252$$

2. **Select Q_0** within the range of Q_{max} and Q_{min}. Considering the unit flow rate as Q_{max} (0.563 m^3/min/m) results in border width (W_b) of 88.77 m and 6.75 number of borders (N_b).
   - ✓ The flow is adjusted and possible combinations are listed below:

Number of borders (N_b)	Border Width, W_b (m)	Unit inflow rate, Q_0 (m^3/min/m)
6	**100**	**0.5000**
5	120	0.4167
4	150	0.3333
3	200	0.2500

Q_0 = 0.50 m^3/min/m is selected

3. **Compute the inflow depth** at inlet y_0 (m) using the Manning equation as follows:

$$Y_0 = \left(\frac{Q_{max}\, n}{60\, S_0^{0.5}}\right)^{3/5} = \frac{0.04\times0.05}{60\times0.005^{0.0}} = 0.04005 \text{ m}$$

and y_0 value should be less than the ridge (dike) height.

4. **Compute** τ_{req} (min) to satisfy the irrigation requirement using the same procedure as used in the case of furrow design.

$$\tau_{req} = 187.89 \text{ min}$$

5. **Compute the time of advance** to the end of border t_L (min) using the same procedure as used in the case of furrow design.

$$t_L = 34.78 \text{ min}$$

6. **Compute the time of recession** (t_r in minutes since the beginning of irrigation) assuming that the design will meet the irrigation requirement at the end of the border:

$$t_r = \tau_{req} + t_L = 187.89+32.89 = 220.78 \text{ min}$$

7. **Compute the depletion time**, t_d (min) using the Newton-Raphson method as follows:

a) **Assume an initial guess of t_d as $t_d^i = t_r$= 220.78 min**

b) **Compute the average Infiltration (I) by substituting $t_d = t_d^i$**

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

$$I = \frac{0.356 \times 0.0028}{2}\left[220.78^{0.356-1} + (220.78 - 32.89)^{0.356-1}\right] + 0.00017 = 0.000203 \text{ m}^3\text{/min/m}$$

c) **Compute S_y**

$$S_y = \frac{1}{L}\left[\frac{(Q_0 - IL)n}{60 S_0^{1/2}}\right]^{3/5} = \frac{1}{400}\left[\frac{(0.50 - (0.000203 \times 400)) \times 0.04}{60 \times 0.005^{1/2}}\right]^{3/5} = = 0.00009035$$

d) **Compute new value of t_d as t_d^{i+1} using below Eq. as follows:**

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

$$t_d^{i+1} = 220.78 - \frac{0.095 \times 0.04^{0.47565} \times 0.00009035^{0.20735} \times 400^{0.6829}}{0.000203^{0.52435} \times 0.005^{0.237825}} = 166.44 \text{ min}$$

e) The Initial guess ($\boldsymbol{t_d^i}$= 220.78 min) is not close to the new computed value ($\boldsymbol{t_d^{i+1}}$= 166.44 min).Therefore, set $\boldsymbol{t_d^i}$= 166.44 min and repeat steps b through e.

8. **Correct value** of t_d = 167. 5 min

9. **Compute the infiltrated depth** at border inlet (Z_0) and compare it with Z_{req}

$$Z_0 = kt_d^a + f_0 t_d = 0.0028 \times 167.45^{0.356} + 0.00017 \times 167.45 = \mathbf{0.0456\ m}$$

✓ Since the infiltrated depth at the end (Z_0 = 0.0456 m) is less than Z_{req} (0.05 m), it is a case of deficit irrigation and cutoff time must be increased.

10. **In case of deficit irrigation**, increase the cutoff time and compute the new $t_r$value as follows:

a) Compute new T_{co} by substituting τ_{req} in place of t_d in Eq.

$$T_{co} = t_d - \frac{Y_0 L}{2Q_0} = 187.89 - \frac{0.0401 \times 400}{2 \times 0.50} = 171.87 \text{ min}$$

b) Compute the average Infiltration (I) by substituting $t_d = \tau_{req}$

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

$$I = \frac{0.356 \times 0.0028}{2}\left[187.89^{0.356-1} + (187.89 - 32.89)^{0.356-1}\right] + 0.00017 = 0.000206 \text{m}^3/\text{min/m}$$

c) Compute S_y

$$S_y = \frac{1}{L}\left[\frac{(Q_0 - IL)n}{60 S_0^{1/2}}\right]^{3/5} = \frac{1}{400}\left[\frac{(0.50 - (0.000206 \times 400)) \times 0.04}{60 \times 0.005^{1/2}}\right]^{3/5} = 0.000249$$

d) Compute t_r by substituting $t_d = \tau_{req}$

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

$$t_r = 220.78 - \frac{0.095 \times 0.040^{0.47565} \times 0.000249^{0.47565} \times 400^{0.6829}}{0.000206^{0.52435} \times 0.005^{0.237825}} = 254.25 \text{ min}$$

e) Compute Z_L:

$$Z_L = k\,(t_r - t_L)^a + f_0\,(t_r - t_L) = 0.0028 \times (254.25 - 32.89)^{0.356} + 0.00017 \times (254.25 - 32.89)$$
$$= 0.0568 \text{ m}$$

f) Compute Ea

$$E_a = \frac{Z_{req} L}{Q_0 T_{co}}$$

$$E_a = \frac{0.05 \times 400}{0.50 \times 171.87} = 23.27\%$$

13. **Check the water availability** constraint and repeat steps 4 to 12 for other unit inflow rates. Choose the design which gives maximum Ea value.

Number of borders (N_b)	Border Width, W_b (m)	Unit inflow rate, Q_0 (m^3/min/m)	Tco, (min)	Ea, (%)	Irrigation time (hr)
6	100	0.5000*	171.87	23.27	17.19
5	120	0.4167*	170.64	28.19	14.22
4	150	0.3333*	169.05	35.49	11.27
3	200	0.2500	174.10	45.95	8.71
2	300	0.1667**	202.53	59.49	6.75

* flow results initially deficit irrigation

** flow less than Q_{min}

Basin Irrigation Design

- ✓ Tail water is prevented from exiting the field
- ✓ Recession and depletion are accomplished at nearly the same time and nearly uniform over the entire basin
- ✓ Driving force on the flow is solely the hydraulic slope of the water surface
- ✓ **Assumption 1**: During the advance phase, the friction slope can be approximated by the inlet depth of flow (y_0) divided by distance (x) in the direction of flow $S_f = y_o / x$

When Q_o is known, $y_0 = \left(\frac{{Q_0}^2 n^2 x}{3600}\right)^{0.24}$ (1)

- ✓ **Assumption 2:** Immediately upon cessation of inflow, the water surface assumes a horizontal orientation and infiltrates vertically.

Basin Irrigation Systems

- ✓ **Assumption 3:** The irrigation depth to be applied at the downstream end of the basin is equal to required depth of water at the root zone (Z_{req}).

  Time of cutoff, $t_{co} = \frac{Z_{req}L - 0.77 y_0 L}{Q_o} + t_L$ (σ_y= 0.77 also as 0.8 in some cases) (2)

  Application efficiency

  - ✓ The application efficiency is to be maximized

Table. Data required for the design of surface irrigation systems

Sl. No.	Design Variables	Symbol	Sl. No.	Design Variables	Symbol
1	Kostiakov-Lewis's Infiltration Model Parameters	a, k, f_o	6	Basin/Border/Furrow Shape Coefficients	P_1 and P_2
2	Field Length	L	7	Required Depth of Irrigation	Z_{req}
3	Field Width	W_f	8	Soil Erosive Velocity	V_{max}
4	Field Slope	S_o	9	Water Supply Rate	Q
5	Manning's Roughness Coefficient	n	10	Duration of Water Supply	T

Basin Irrigation System Design

The following steps are involved in designing a Basin Irrigation System:

1. Collect information related to field characteristics, soil, crop, and water supply.
2. Determine the maximum allowable non-erosive inflow rate (Q_{max}) using below Eq.

$$Q_{max} = \left[V_{max} \left(\frac{n^2 L}{7200} \right)^{0.24} \right]^{1.857}$$

3. Select unit flow rate (Q_0) near Q_{max} in such a way that it results in integer number of basins and sets.
4. Compute the inflow depth (y_0) at the inlet using Eq. (19) by substituting x = L/2 as follows:

$$y_0 = \left(\frac{{Q_0}^2 n^2 x}{3600} \right)^{0.24}$$

Compare y_0 with the ridge height and make sure that it is lower than ridge height.

Basin Irrigation Systems

5. Compute time of advance to the end of the basin, t_L as follows:
   - ✓ Assume an initial value of advance rate exponent (r) equal to 0.5, $r^j = 0.5$
   - ✓ Compute σ_z and σ'_z by substituting $r = r^j$
   - ✓ Compute the time necessary for flow to advance half the basin L/2 distance, $t_{L/2}$:

(i) $$y_0 = \left(\frac{{Q_0}^2 n^2 L}{7200}\right)^{0.24}$$

(ii) $$t_{L/2}{}^{i} = \frac{5 y_0 L}{2 Q_0}$$

(iii) $$t_{L/2}{}^{i+1} = t_{L/2}{}^{i} - \frac{Q_0 t_{L/2}{}^{i} - 0.8 y_0 (0.5L) - \sigma_z k \left(t_{\frac{L}{2}}{}^{i}\right)^{a} (0.5L) - \sigma'_z f_0 \left(t_{\frac{L}{2}}{}^{i}\right)(0.5L)}{Q_0 - \sigma_z a k \left(t_{\frac{L}{2}}{}^{i}\right)^{a-1} (0.5L) - \sigma'_z f_0 (0.5L)}$$

   - ✓ Check if $t_{L/2}{}^{i} = t_{L/2}{}^{i+1}$ or is within the permissible tolerance limit. If this condition is not satisfied then repeat step (iii) by setting $t_{L/2}{}^{i} = t_{L/2}{}^{i+1}$ Otherwise, proceed to next step.

Basin Irrigation Systems

- ✓ Compute the time necessary for flow to advance L distance, t_L:

(i) $$y_0 = \left(\frac{{Q_0}^2 n^2 L}{3600}\right)^{0.24}$$ (ii) $${t_L}^i = \frac{5 y_0 L}{Q_0}$$

(iii) $${t_L}^{i+1} = {t_L}^i - \frac{Q_0 {t_L}^i - 0.8 y_0 (L) - \sigma_z k \left({t_L}^i\right)^a (L) - \sigma'_z f_0 \left({t_L}^i\right)(L)}{Q_0 - \sigma_z a k \left({t_L}^i\right)^{a-1} (L) - \sigma'_z f_0 (L)}$$

Check if ${t_L}^i = {t_L}^{i+1}$ or is within the permissible tolerance limit. If this condition is not satisfied then repeat step (iii) by setting ${t_L}^i = {t_L}^{i+1}$ Otherwise, proceed to next step

- ✓ Compute a revised estimate of advance rate exponent (r^{j+1}) as follows:

$$r^{j+1} = \frac{ln\ (2)}{ln\left({t_L}/{t_{L/2}}\right)}$$

Basin Irrigation Systems

Compare the initial guess value of rj with the computed value rj+1. If both values are equal (within the permissible range), continue with step 6, otherwise set rj = rj+1 and repeat step (5).

6. Calculate T_{co}, assuming that the irrigation requirement will be satisfied at the end of the basin, If $T_{co} \leq t_L$, set $T_{co} = t_L$.

$$t_{co} = \frac{Z_{req}L - 0.77y_0L}{Q_o} + t_L$$

6. Compute application efficiency.
7. Determine other possible basin configurations and their corresponding unit inflow rate Q_0.
8. Repeat steps 5 though 7 for all configurations and select the design that gives the maximum E_a

THANK YOU

IIT KHARAGPUR

NPTEL ONLINE CERTIFICATION COURSES

NPTEL

Irrigation and Drainage

Lecture No: 20 Tutorial: W4

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Basin Design Problem

Problem W4.1:

Design a basin irrigation system for the following conditions:

Field length, L = 150 m,

Field width, W = 300 m,

n = 0.04,

Soil texture = loam,

Design irrigation requirement = 10 cm,

Infiltration function parameters: k = 0.0028, a = 0.545 and f_0 = 0.00012,

Available supply rate, Q = 10 (m^3/min),

Supply duration = 12 hrs.

Basin Design Problem

Solution:

1. Determine the maximum allowable non-erosive inflow rate (Q_{max}) as follows:

$$Q_{max} = \left[V_{max}\left(\frac{n^2L}{7200}\right)^{0.24}\right]^{1.857} = \left[13\left(\frac{0.04^2 \times 150}{7200}\right)^{0.24}\right]^{1.857} = 1.184m^3/min/m$$

2. Select a unit flow rate (Q_0) near Q_{max} in such a way that it results in an integer number of basins and sets.

- ✓ Since, the available supply rate is fixed, a value of unit flow rate near the maximum would result in a small basin width with a large number of basins.
- ✓ This would increase the labour and other cost. For example, a unit flow rate of 1 $m^3/min/m$ would result in 30 basins of 150 m x 10 m and would require 30 sets to irrigate.
- ✓ It is assumed that the basins would have a 150 m length and a minimum width of 30 m.

This results in a unit inflow rate of 0.333 $m^3/min/m$ with 10 sets.

Basin Design Problem

3. Compute the inflow depth (y_0) at the inlet :

$$y_0 = \left(\frac{{Q_0}^2 n^2 x}{3600}\right)^{0.24} = \left(\frac{(0.333)^2 (0.04)^2 150}{7200}\right)^{0.24} = 0.0497\ m$$

- ✓ Compare y_0 with the ridge height and make sure that it is lower than the ridge height.
- ✓ Considering a freeboard of 5 cm, a ridge height of 10 cm would be sufficient in this case.

4. Compute time of advance to the end of the basin, t_L as follows:
   - ✓ Assume an initial value of advance rate exponent (r) equal to 0.5, $r^j = 0.5$
   - ✓ Compute σ_z and σ'_z by substituting $r = r^j$

   $\sigma_z = 0.76483$, $\sigma'_z = 0.66667$

   - ✓ Compute the time necessary for flow to advance half the furrow L/2 distance, $t_{L/2}$:

$$i. \quad y_0 = \left(\frac{{Q_0}^2 n^2 x}{3600}\right)^{0.24} = \left(\frac{(0.333)^2 (0.04)^2 150}{7200}\right)^{0.24} = 0.0497\ m$$

Basin Design Problem

ii. $t_{L/2}{}^{i} = \frac{2.5 y_0 L}{Q_0} = \frac{2.5(0.0497)\ 150}{0.333} = 55.95\ min$

iii. $t_{L/2}{}^{i+1} = t_{L/2}{}^{i} - \frac{Q_0 t_{\frac{L}{2}}{}^{i} - 0.8 y_0 (0.5L) - \sigma_z k \left(t_{\frac{L}{2}}{}^{i}\right)^{a} (0.5L) - \sigma'_z f_0 \left(t_{\frac{L}{2}}{}^{i}\right)(0.5L)}{Q_0 - \sigma_z a k \left(t_{\frac{L}{2}}{}^{i}\right)^{a-1} (0.5L) - \sigma'_z f_0 (0.5L)}$

$$t_{L/2}^{i+1} = 55.95 - \frac{(0.333)(55.95) - 0.8(0.0497)(75) - (0.76483)(0.0028)(55.95)^{0.545}(75) - 0.66667(0.00012)(55.95)(75)}{0.333 - (0.76483)(0.545)(0.00012)(55.95)^{0.545-1}(75) - 0.66667(0.00012)(75)}$$

= 13.39 min

- ✓ Repeat step iii and after some iterations the value converges to 12.73 min
- ✓ Compute the time necessary for flow to advance L distance, t_L:

$$y_0 = \left(\frac{Q_0^2 n^2 L}{3600}\right)^{0.24} = 0.0587\ m$$

Basin Design Problem

ii. $$t_L^i = \frac{5y_0\ L}{Q_0} = \frac{5(0.0459)\,150}{0.333} = 55.95\,\text{min}$$

iii. $$t_L^{i+1} = 34.94\,\text{min}$$

- ✓ Repeat step iii and after some iterations the value converges to 28.10 min
- ✓ Compute a revised estimate of advance rate exponent (r^{j+1}) as follows:

$$r^{j+1} = \frac{\ln(2)}{\ln\left(t_L / t_{L/2}\right)} = \frac{\ln(2)}{\ln(34.94/12.73)} = 0.87556$$

- ✓ Repeat step 4 since until rj = rj+1. The final value of t_L = 26.99 min

5. Calculate T_{co}, assuming that irrigation requirement will be satisfied at the end of the basin, If $T_{co} \leq t_L$, set $T_{co} = t_L$.

$$Tco = t_L + \frac{(Z_{req} - 0.8y_0)L}{Q_0} = 26.99 + \frac{(0.1 - 0.8(0.0587))150}{0.333} = 50.88$$

Basin Design Problem

6. Compute the application efficiency, Ea,

$$Ea = \frac{Z_{req} L}{Q_0 Tco} = \frac{(0.1)(150)}{(0.333)(50.88)} = 88.52\%$$

Example W4.2:

Furrows of 120 m length with 0.5% slope are made at 90 cm spacing. The maximum nonerosive stream flow rate is applied in a furrow that takes 1.0 hour to reach the lower end. Then this flow rate is reduced to half of its size and, subsequently, continued for another 1.0 hour. The average depth of applied water is ________ cm. (GATE 2018)

Solution:

Given,

Furrow length, L = 120 m

Slope, s = 0.5%

Furrow Spacing, w = 90 cm = 0.9 m

Duration of irrigation for maximum non erosive stream flow, t_1 = 1 h

Duration of irrigation when flow rate is reduced to half of its size, t_2= 1 h

We know for non-erosive flow the maximum flow rate is given as follows

$$q_{m1} = \frac{0.60}{s} = \frac{0.6}{0.5} = 1.2\ l/s$$

When flow rate is reduced to half of maximum flow rate, it is given as follows

$$q_{m2} = \frac{1}{2} q_{m1} = \frac{1}{2} \times 1.2 = 0.6\ l/s$$

And the average depth of water applied is given as:

$$d_1 = \frac{q \times 360 \times t}{w \times L} = \frac{1.2 \times 360 \times 1}{0.9 \times 120} = 4\ cm$$

$$d_2 = \frac{q \times 360 \times t}{w \times L} = \frac{0.6 \times 360 \times 1}{0.9 \times 120} = 2\ cm$$

Net average depth of irrigation $= 4 + 2 = 6\ cm$ (Ans)

Example W4.3:

Graded furrows of 80 m long and 0.75 m spacing are used for irrigating a field with an initial furrow stream of 100 l/min. The initial furrow stream flow reaches the lower end of the field in 40 min. Thereafter, the furrow stream flow is reduced to 30 l/min and the cutback stream flow is continued for 1 hour. the average depth of irrigation over the field in cm will be (Ans. 9.65-9.75) (GATE 2017)

Solution:

Given,

Furrow length, L = 80 m

Furrow Spacing, w = 0.75 m

Initial furrow stream = 100 l/min = 1.667 l/s

Reduced furrow stream = 30 l/min = 0.5 l/s

Duration of irrigation for initial furrow stream, t_1 = 40 min = 0.667 h

Duration of irrigation for reduced furrow stream, t_2 = 1 h

The average depth of water applied is given as:

$$d_1 = \frac{q \times 360 \times t}{w \times L} = \frac{1.667 \times 360 \times 0.667}{0.75 \times 80} = 6.67\ cm$$

$$d_2 = \frac{q \times 360 \times t}{w \times L} = \frac{0.5 \times 360 \times 1}{0.75 \times 80} = 3\ cm$$

Net average depth of irrigation $= 6.67 + 3 = 9.67\ cm$ (Ans)

Example W4.4:

A field is irrigated by constructing 100 m long furrows spaced at 0.75 m apart. The advance time to the end of furrows was 30 min with an inflow rate of 2 L/s. After that the inflow rate was cut back to 0.5 L/s and continued for I hour. The average depth of irrigation is (GATE 2007)

Solution:

Given,

Furrow length, L = 100 m

Furrow Spacing, w = 0.75 m

Initial furrow stream = 2 l/s

Reduced furrow stream = 0.5 l/s

The average depth of water applied is given as:

$$d_1 = \frac{q \times 360 \times t}{w \times L} = \frac{2 \times 360 \times 0.5}{0.75 \times 100} = 4.8\ cm$$

$$d_2 = \frac{q \times 360 \times t}{w \times L} = \frac{0.5 \times 360 \times 1}{0.75 \times 100} = 2.4\ cm$$

Net average depth of irrigation $= 4.8 + 2.4 = 7.2\ cm$(Ans.)

Example W4.5

A border strip of 8 × 250 m is being irrigated by a border stream of 50 lps. The infiltration capacity of the soil is 25 mm h^{-1} (assumed to be constant throughout the period of irrigation). The average depth of the advancing sheet of water over the land is 70 mm. The time required to irrigate the border strip, in minutes, will be ____ (GATE 2012)

Solution:

Given,

Border strip dimension = 8 × 250 m; Area, A = 2000 m^2

Flow rate, Q= 50 l/s $= \; 180 \, m^3/h \; =$

Infiltration capacity of the soil, i = 25 mm/h = 0.025 m/h

The average depth of the advancing sheet of water over the land d = 70 mm =0.070 m

Volume of water at average depth of the advancing sheet,

$$V = 8 \times 250 \times 0.070 = 140\, m^3$$

The time required to irrigate the border strip is given by:

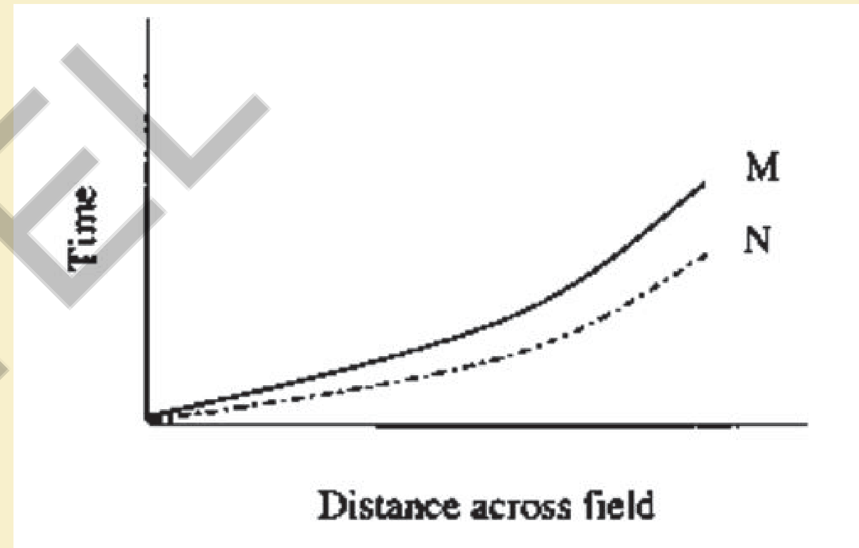
$$t = 2.303 \frac{d}{i} log \frac{Q}{Q - Ai} = 2.303 \frac{0.07}{0.025} log \frac{180}{180 - 2000 \times 0.025}$$

$= 6.4484 \times log \frac{180}{130} = 6.4484 \times 0.14 = 0.91134\, h = 54.68\, min$ (Ans.)

Formula reference from the book Irrigation and Water Power Engineering By Dr. B. C. Punmia, Dr. Pande BrijBasi Lal

Example W4.6:

The following figure shows two advance curve for surface irrigation (GATE 2010)



The advance represented by curve M is slower than N. this could be attributed to_____

1. The inflow rate to the field is lower
2. The intake rate of the soil is lower
3. The field slope is flatter
4. The hydraulic roughness is greater for curve N than for curve M

a) 1,2

b) 1,3

c) 2,4

d) 3,4

THANK YOU

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