IIT KHARAGPUR

NPTEL ONLINE CERTIFICATION COURSES

NPTEL

Irrigation and Drainage

Lecture No: 51 Surface Drainage System Design-1

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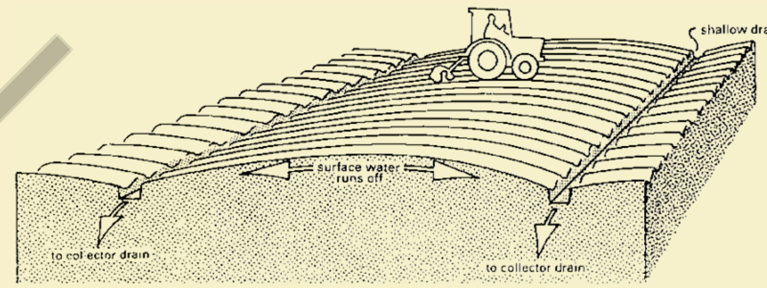
Surface Drainage Design

- ✓ Surface drainage removes excess water accumulated over the land surface in cropped area
- ✓ The sources of excess water
  - o Rainfall local runoff
  - o Incoming water from adjoining higher areas seepage flow
  - o Excess irrigation water



- ✓ The design of surface drainage consists of two stage
  - o **Hydrologic design:** Involves quantification of the excess water to be drained and the rate at which it is to be drained
  - o **Hydraulic design:** The design involves calculating the drainage channel geometry and the drainage network layout

Hydrologic Design

Estimation of Surface Runoff:

a) Rational Method

Widely known and the most commonly used empirical relation to estimate the peak rate of runoff:

$$Q_p = \frac{CIA}{360}$$

Where, Q_p= peak flow (m^3/s) ; C=dimensionless runoff coefficient ; I= rainfall intensity for a given return period. Return period is the average number of years within which a given rainfall event will be expected to occur at least once ; A = area of catchment (ha)

Assumptions of Rational method

- ✓ Uniform rainfall intensity for a duration at-least equal to the time of concentration
- ✓ Uniform rainfall intensity over the entire area of the watershed

Example 51.1

A cultivated area of 40 ha drains to a particular storm water inlet. The runoff coefficient for this drainage area has been estimated to be 0.4. Based on a specified design return period and the time of concentration of the drainage area, the design storm intensity has been determined to be 10 mm/h. What is the peak runoff rate from this area to be used for design of the storm water inlet?

Solution:

$$Q_p = \frac{CIA}{360}$$

$$Q_p = \frac{0.4 \times 10 \times 40}{360}$$

$$Q_p = 0.44 \text{ m}^3/\text{sec}$$

Hydrologic design

Rational Method: Procedure

- ✓ **Area** of catchment- surveying or from maps or aerial photographs.
- ✓ **The runoff coefficient C** is a measure of the rain which becomes runoff.
  - ✓ On a corrugated iron roof, almost all the rain would runoff so C = 1, while in a well drained soil, nine-tenths of the rain may soak in and so C = 0.10.

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Table 3.3
Values of run-off coefficient C

Topography and vegetation	Soil texture: Open sandy loam	Soil texture: Clay and silt loam	Soil texture: Tight clay
Woodland			
Flat 0-5 per cent slope	0·10	0·30	0·40
Rolling 5-10 per cent slope	0·25	0·35	0·50
Hilly 10-30 per cent slope	0·30	0·50	0·60
Pasture			
Flat	0·10	0·30	0·40
Rolling	0·16	0·36	0·55
Hilly	0·22	0·42	0·60
Cultivated			
Flat	0·30	0·50	0·60
Rolling	0·40	0·60	0·70
Hilly	0·52	0·72	0·82
Urban areas	30 per cent of area impervious	50 per cent of area impervious	70 per cent of area impervious
Flat	0·40	0·55	0·65
Rolling	0·50	0·65	0·80

From Schwab, Frevert, Edminster, and Barnes. *Soil and water conservation engineering*, Wiley, New York.

Hydrologic Design

Rainfall intensity (I):

- ✓ According to the desired **return period** for the design of the structure under study
- ✓ The **duration** of the **rainfall intensity** is equal to the **time of concentration** of the runoff, Tc.
- ✓ **Time of Concentration (Tc)** using **Kirpich** equation:
- ✓ It is the time taken for the most remote area of the catchment to contribute water to the outlet.

$$T_c = 0.0195\ L^{0.77} S^{-0.385}$$

Where, Tc is the time of concentration (min); L is the maximum length of flow (m); S is the watershed gradient (m/m)

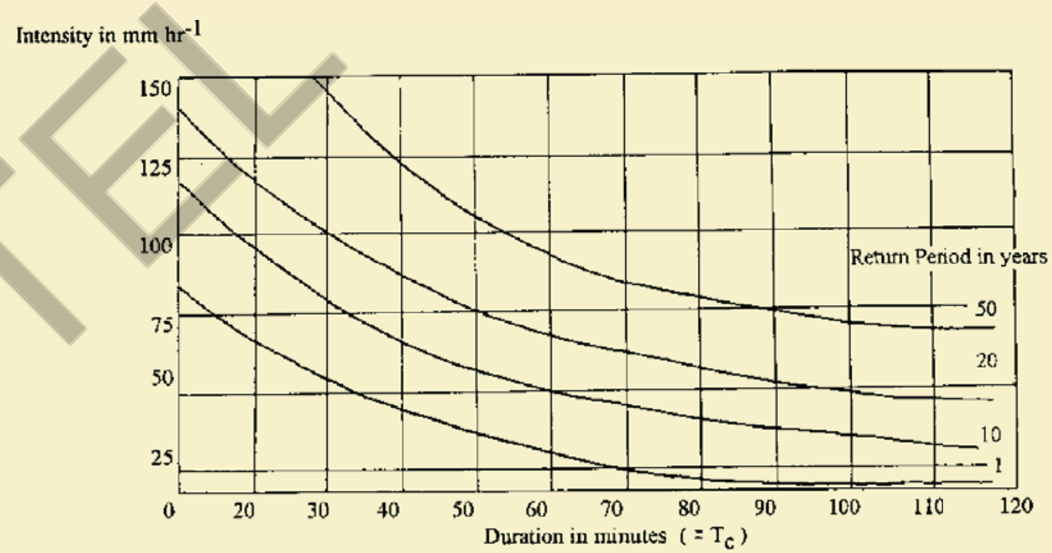
Time of concentration (min)

Maximum length of flow (m)	Time of concentration (minutes)					
	Catchment slope (%)					
	0.05	0.1	0.5	1.0	2.0	5.0
100	13	10	5	4	3	2
300	29	23	12	9	7	5
500	44	33	18	14	11	7
1000	74	57	31	23	18	13
1500	102	78	42	32	25	17
2000	127	97	52	40	31	22
3000	173	133	71	55	42	29
5000	257	196	106	81	62	44

Hydrologic Design

Rainfall intensity (I):

- ✓ With Tc obtained for the catchment, decide on a return period.
- ✓ **The return periods** widely used for different structures:
  - ✓ Field structures, 5-10 yrs
  - ✓ Gully control and Small farm dams, 20 yrs
  - ✓ Large farm dams, 50 yrs
- ✓ With the Duration equal to Tc and assumed return period, get an intensity value from the Intensity-Duration curve derived for the area.



Hydrologic design

Example 51.2

A catchment of **15 ha** is composed of 5 ha of permanent pasture (Soil Group B) and 10 ha of row crop in poor condition (Soil Group C). What peak flow is to be expected from a 1 in 5 year storm? The maximum flow length is 610 m, with a gradient of 2%.

Solution:

From Tc_Table or Tc_equation, T_c = 12 minutes

Values of T_c using Rational Formula

Maximum length of flow (m)	Time of concentration (minutes)					
	Catchment slope (%)					
	0.05	0.1	0.5	1.0	2.0	5.0
100	13	10	5	4	3	2
300	29	23	12	9	7	5
500	44	33	18	14	11	7
1000	74	57	31	23	18	13
1500	102	78	42	32	25	17
2000	127	97	52	40	31	22
3000	173	133	71	55	42	29
5000	257	196	106	81	62	44

Hydrologic design

From Rainfall intensity duration table (hypothetical illustration), Rainfall intensity **73.0** mm h^{-1}

Annual Maximum Series (Hypothetical Example Data.)

m	10 mins		30 mins		60 mins		120 mins		Return Period in years (n+1)/m	
	Maximum Intensities in mm hr^{-1}									
1	85.0		75.0		58.0		20.0		11.0	
2	74.0	**82.8**	63.0	**72.6**	46.0	**56.0**	18.0	**19.6**	6.0	**10.0**
3	70.0	72.0	60.0	**62.0**	43.0	**44.5**	17.0	**17.5**	4.0	**5.0**
4	69.0		58.0		39.0		14.0		3.5	
5	67.0		54.0		37.0		13.0		3.0	
6	66.0		49.0		34.0		10.0		2.7	
7	64.0		47.0		29.0		8.0		2.4	
8	55.0		42.0		28.0		7.0		2.3	
9	53.0		40.0		26.0		6.0		2.1	
10	50.0		37.0		22.0		4.0		2.0	

Coefficient of C values for USA

Runoff coefficient C for permanent pasture (Group B, 5 ha) = 0.14
Runoff coefficient C for poor row crop (Group C, 10 ha) = 0.71

Weighted value of C for whole water shed: **0.52**

Substituting in Rational formula:

$Q_p = 0.0028 \times 0.52 \times 73.0 \times 15 = 1.6\ m^3\ s^{-1}$

Coefficient C for rainfall rates 25, 100 and 200 mm h^{-1}

Cover and Condition	Soil Group A			Soil Group B			Soil Group C			Soil Group D		
	25	100	200	25	100	200	25	100	200	25	100	200
Row crop poor	.56	.58	.59	.63	.65	.66	.69	.71	.62	.71	.73	.74
Row crop good	.40	.48	.53	.47	.56	.62	.51	.61	.68	.54	.64	.72
Small grain poor	.33	.33	.33	.38	.38	.38	.42	.42	.42	.44	.44	.44
Small grain good	.15	.18	.18	.18	.18	.22	.20	.23	.24	.21	.24	.26
Meadow rotation good	.23	.29	.29	.29	.36	.39	.33	.41	.44	.34	.42	.46
Pasture permanent good	.01	.11	.15	.02	.17	.23	.02	.21	.28	.03	.22	.30
Woodland mature good	.01	.05	.07	.02	.10	.15	.03	.13	.19	.03	.14	.21

Soil Groups:

A Lowest runoff potential. Deep sands and permeable loess.

B Moderately low runoff potential. Soils less deep than A, but as a whole above average infiltration after thorough wetting.

C Moderately high runoff potential. Shallow soils and those with clays and colloids. Below average infiltration after wetting.

D Highest runoff potential. Includes mostly clays with high swelling potential and soils with nearly impermeable horizons near the surface.

Source: US SCS National Engineering Handbook, Hydrology. USDA ARS

Hydrologic Design

b) Cook's Method:

- ✓ Developed by the USCS
- ✓ Provides a simpler and more generalized, but similar approach to Rational Method
- ✓ **Catchment size** and **conditions** are accounted

(10+5+5+5 =25)

Values () for Catchment Conditions Cook's method

Conditions	Extreme peaks (100)	High peaks (75)	Normal peaks (50)	Low peaks (25)
Relief	(40) Steep and rugged slopes > 30%	(30) Hilly land slopes 10 - 30%	(20) Rolling slopes 5 - 10%	(10) Flat land slopes 0 - 5%
Soil infiltration	(20) No effective soil with negligible infiltration	(15) Slow to take water clays, low infiltration	(10) Normal deep loam infiltration good	(5) Deep sand takes up water rapidly
Vegetation cover	(20) No effective cover	(15) Poor natural cover < 10% or clean crops	(10) Fair cover grass or wood. Not> 50% clean cultivation	(5) Good to excellent cover 90% grass or wood or equivalent
Surface storage	(20) Negligible ponds or marshes	(15) Low, no ponds, well defined drainage	(10) Normal, lakes, ponds < 20% considerable depression storage	(5) High surface depression storage, drainage not well defined

Hydrologic design

b) Cook's Method:

- ✓ When a total of catchment condition values is made, the peak flow (m^3/s) is estimated using the side table

Peak Flows ($m^3\ s^{-1}$) According to Catchment Condition Total Values and Area Using 10 Year Probability High Intensities for Tropical Storms

Total Value	25	30	35	40	45	50	55	60	65	70	75	80
Area (ha)												
5	0.2	0.3	0.4	0.5	0.7	0.9	1.1	1.3	1.5	1.7	1.9	2.1
10	0.3	0.5	0.7	0.9	1.1	1.4	1.7	2.0	2.4	2.8	3.2	3.7
15	0.5	0.8	1.1	1.4	1.7	2.0	2.4	2.9	3.4	4.0	4.6	5.2
20	0.6	1.0	1.4	1.8	2.2	2.7	3.2	3.8	4.4	5.1	5.8	6.5
30	0.8	1.3	1.8	2.3	2.9	3.6	4.4	5.3	6.3	7.3	8.4	9.5
40	1.1	1.5	2.1	2.8	3.5	4.5	5.5	6.6	7.8	9.1	10.5	12.3
50	1.2	1.8	2.5	3.5	4.6	5.8	7.1	8.5	10.0	15.6	13.3	15.1
100	1.8	3.2	4.7	6.4	8.3	10.4	12.7	15.4	18.2	21.2	24.5	28.0
200	2.8	5.5	8.4	11.7	15.3	19.1	23.3	28.0	33.1	38.5	45.0	52.5
300	4.2	7.0	10.5	14.7	19.6	25.2	31.5	38.5	46.2	54.6	6.7	73.5
400	5.6	10.0	14.4	19.4	25.6	33.6	42.2	51.0	60.0	69.3	79.5	90.0
500	7.0	11.0	17.0	23.5	31.0	40.5	51.0	62.0	73.0	84.0	95.0	106.5

Hydrologic design

c) SCS-CN method

- ✓ The Method is based on the relations between **rainfall amount** and **direct runoff**.
- ✓ These relations are defined by a series of curvilinear graphs which are called "Curves".
- ✓ Each curve represents the relation between rainfall and runoff for a set of hydrological conditions

The equation governing the relations between rainfall and runoff is:

$$Q = (P-0.2S)^2 /(P+ 0.85*S)$$

Where Q = direct surface runoff depth in mm; P = storm rainfall in mm; S = the maximum potential difference between rainfall and runoff in mm, starting at the time the storm begins.

Hydrologic design

c) SCS-CN method

✓ The parameter S is essentially composed of losses from runoff to interception, infiltration, etc.

The US SCS calculates S by:

$$S = \frac{25400}{CN} - 254$$

CN is the "Curve Number", from 0 to 100.

Curve Number 100 assumes total runoff from the rainfall and therefore S = 0 and P = Q.

Hydrologic design

Curve Numbers for Soils and Catchment Condition, Antecedent Soil Moisture Condition II

Land Use	Treatment	Condition	Soil Group A	B	C	D
Fallow Row crops	straight		77	86	91	94
	row	poor	72	81	88	91
	straight	good	67	78	85	89
	row	poor	70	79	84	88
	straight	good	65	75	82	86
	row	poor	66	74	80	82
	contoured	good	62	71	78	81
Small grain	contoured	poor	65	76	84	88
	terraced	good	63	75	83	87
	terraced	poor	63	74	82	85
	straight	good	61	73	81	84
	row	poor	61	72	79	82
	straight	good	59	70	78	81
Close seeded	row	poor	66	77	85	89
legume or	contoured	good	58	72	81	85
rotation	contoured	poor	64	75	83	85
meadow	terraced	goood	55	69	78	83
	terraced	poor	63	73	80	83
	straight	good	51	67	76	80
Pasture	row	poor	68	79	86	89
or	straight	fair	49	69	79	84
Range	row	good	39	61	74	80
	contoured	poor	47	67	81	88
	contoured	fair	25	59	75	83
	terraced	good	6	35	70	79
Permanent	terraced					
meadow		good	30	58	71	78
		poor	45	66	77	83
woods		fair	36	60	73	79
	contoured	good	25	55	70	77
Farmsteads	contoured		59	74	82	86
Roads	contoured		74	84	90	92

Soil group A – Well drained sand or gravel, high infiltration rate

Soil group B – Moderately well drained soil, moderate infiltration rate, with fine to moderately coarse texture

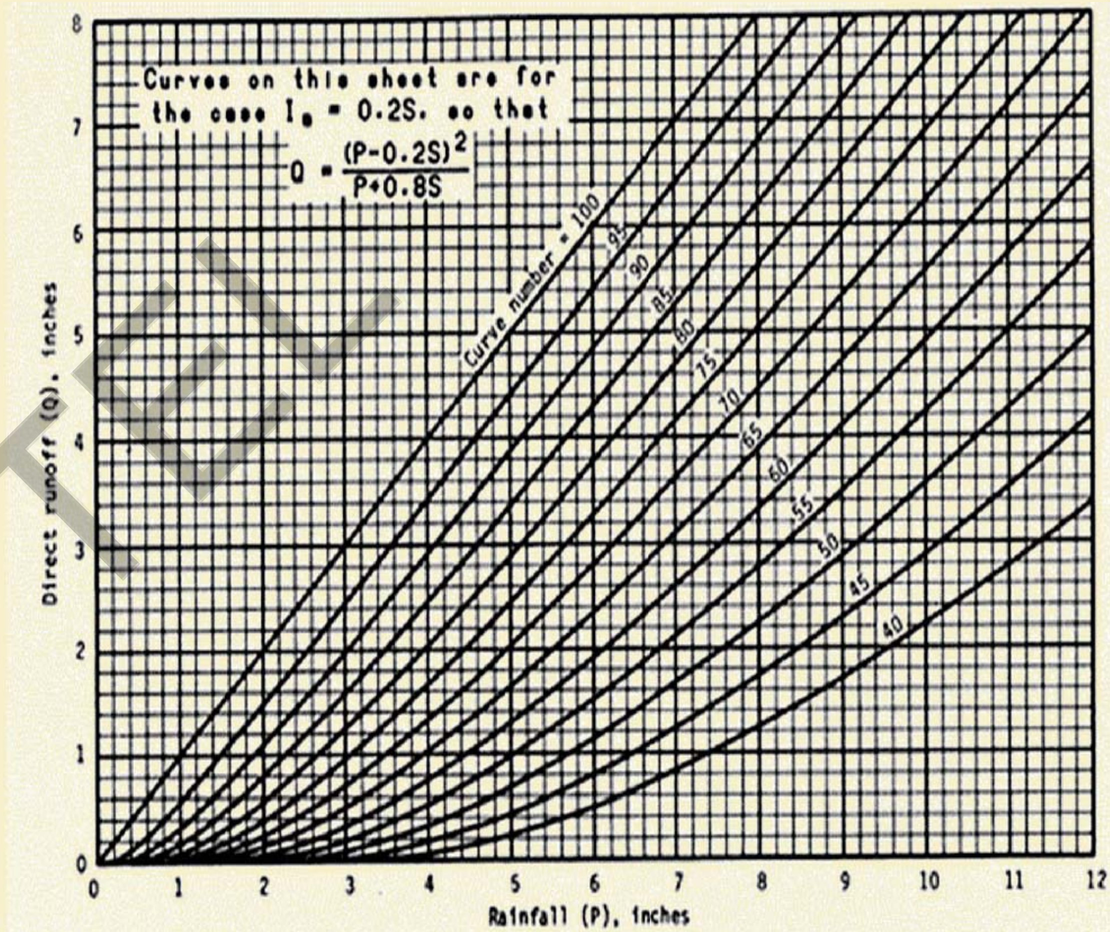
Soil group C – Slow infiltration rate, moderate to fine texture

Soil group D – Very slow infiltration, mainly clay material, relatively impervious

✓**Hydrologic condition –** good/fair/poor (rural land use only)

✓**Antecedent moisture condition (AMC)**

- o**AMC I –** Dry soil
- o**AMC II –** Average soil moisture
- o**AMC III –** Wet soil



Example 51.3:

In a 350 ha watershed the CN value was assessed as 70 for AMC III.

(a) Estimate the value of direct runoff volume for the following 4 days of rainfall. The AMC on July 1st was of category III. Use standard SCS-CN equations.

Date	July 1	July 2	July 3	July 4
Rainfall, mm	50	20	30	18

(b) What would be the runoff volume if the CN_{III} value were 80?

Solution:

Given,

$$CN_{III} = 70$$

$$S = \frac{25400}{70} - 254 = 108.86$$

$$Q = \frac{(P - 0.2S)^2}{P + 0.8\,\mathrm{S}}$$

$$Q = \frac{(P - 0.2 \times 108.86)^2}{P + 0.8 \times 108.86}$$

$$Q = \frac{(P-21.78)^2}{P+87.09}$$ For P> 21.78 mm

Date	P, mm	Q, mm
July 1	50	5.81
July 2	20	0
July 3	30	0.58
July 4	18	0
Total	118	6.39

$Total\ runoff\ volume\ over\ the\ cathment, V_r = 350 \times 10^4 \times \frac{6.39}{1000} = \mathbf{22365\ m^3}$

(b) Given, $CN_{III} = 80$

$$S = \frac{25400}{80} - 254 = 63.5$$

$$Q = \frac{(P - 0.2S\ )^2}{P + 0.8\ S}$$

$$Q = \frac{(P - 0.2 \times 63.5\ )^2}{P + 0.8\ \times 63.5}$$

$$Q = \frac{(P - 12.7)^2}{P + 50.8} \text{ For P> 12.7 mm}$$

Date	P, mm	Q, mm
July 1	50	13.8
July 2	20	0.75
July 3	30	3.7
July 4	18	0.41
Total	118	18.66

$$Total\ runoff\ volume\ over\ the\ cathment, V_r = 350 \times 10^4 \times \frac{18.66}{1000} = \mathbf{65310\ m^3}$$

Thank You!!

Irrigation and Drainage

Lecture No: 52 Surface Drainage System Design-2

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Hydraulic Design

- ✓ Refers to the calculation of geometrical elements of the drainage channel to carry the design runoff
- ✓ The geometrical elements of a channel
  - ✓ bottom width
  - ✓ depth
- ✓ Other essential information (from standard sources/experience)
  - ✓ stable side slope
  - ✓ channel bed slope
  - ✓ channel roughness parameter

Design of Open Ditch

Ditches should be designed to fulfill the following criteria

- ✓ should carry the design discharge
- ✓ should be stable (appropriate side slope)
- ✓ Longitudinal side slope (non-scouring, non stilting velocity)

Design of Open Ditch

The following procedure to be followed for designed of drainage ditch

1. **Estimation of discharge (Lecture #51)**
    1. Rational method
    2. Cook's Method
    3. SCS CN method
2. **Grade:**
    1. Grade should have maximum possible value without exceeding permissible velocity
    2. Grade should not be so low as to allow silting and should be as uniform as possible
    3. Table 1 gives the maximum permissible velocities in non vegetated canals for different soil conditions

Table:1 Maximum permissible velocities in non-vegetable canals

Canal material	Manning's , n	Velocity (m/s)		
		Clear water	Water with colloidal silts	Water with sand, gravel or fragments
Fine sand, colloidal	0.02	0.45	0.75	0.45
Sandy loam, non-colloidal	0.02	0.53	0.75	0.6
Silt loam, non-colloidal	0.02	0.6	0.9	0.6
Alluvial silts, non-colloidal	0.02	0.6	1.05	0.6
Ordinary firm loam	0.02	0.75	1.05	0.68
Stiff clay, very colloidal	0.025	1.13	1.5	0.9
Alluvial silts, colloidal	0.025	1.13	1.5	0.9
Fine gravel	0.025	0.75	1.5	1.13
Coarse gravel, non-colloidal	0.025	1.2	1.8	1.9
Cobbles and shingles	0.035	1.8	1.8	1.5

Design of Open Ditch

3. Cross-section

1. For drainage purpose mostly the trapezoidal section is used (easy to construct and maintain)
2. Cross-section of trapezoidal ditch is shown in Figure 1 and Table 2 gives stable side slopes for open ditches
3. Size of the ditch can be determined using Manning's formula

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

Where, V = the mean velocity of flow (m/s); R = the hydraulic radius (m), = D/4 for pipes flowing full; D = the actual internal diameter of the pipe (m); S = the hydraulic grade; n = roughness coefficient = 0.013 for concrete pipes

Design of Open Ditch

Table:2 Side slopes for open ditches

Soil type	Side slopes	
	Shallow channel (< 120 cm deep)	Deep channel (≥120 cm deep)
Peat and muck	Vertical	0.25:1
Stiff clay	0.5:1	1:1
Clay and slit loam	1:1	1.5:1
Sandy loam	1.5:1	2:1
Loose sand	2:1	3:1

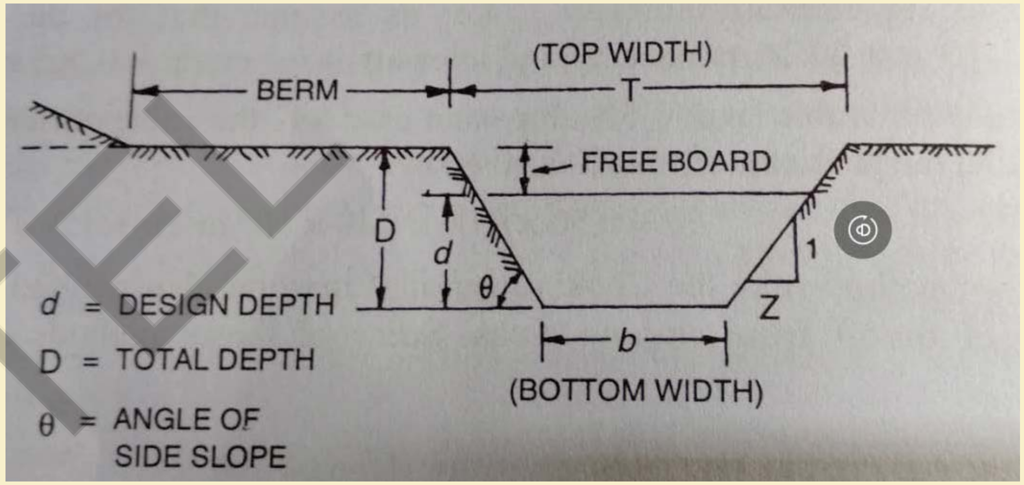


Figure 1 – Cross-section of an open ditch

4. Spoil banks

1. The excavated earth from the open ditch may be placed on one or both sides
2. The berm width should be minimum 3 m
3. Spoil banks should be provided with a flat side slope of 3:1 on the channel and 4:1 on the bund

Example 52.1:

Determine the efficient trapezoidal section of a drainage ditch required to carry a peak runoff of 1.4 m^3/s. the channel is constructed in alluvial silts. The bed slope may be assumed 1/3000 approximately as per exists topographical condition.

Solution:

$$Q = A \times V$$

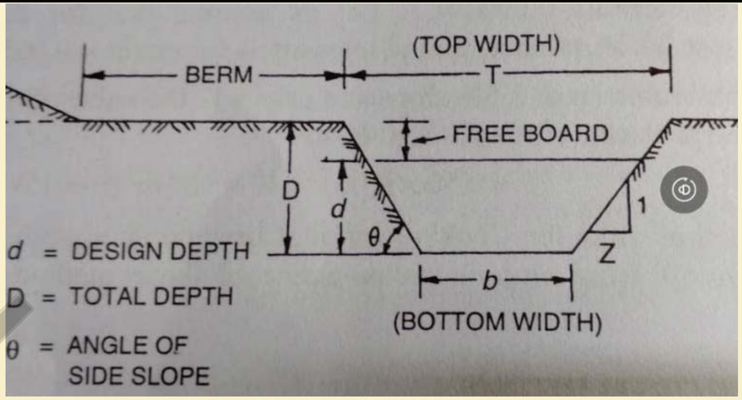
$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

$Q = A \times \frac{1}{n} R^{2/3} S^{1/2}$; $\quad A \times R^{2/3} = \frac{Q \times n}{\sqrt{S}}$

From Table 1, n = 0.020

$$A \times R^{2/3} = \frac{1.4 \times 0.020}{\sqrt{1/3000}} = 1.5336$$

From Table 2 a side slope of 1.5:1 is selected.



If b is the bottom width and d is the depth,

top width = b+3d.

Wetted perimeter, $p = b + 2\sqrt{d^2 + (1.5d)^2}$

$p = b + 2\sqrt{3.25d^2}$; $p = b + 3.606\,d$

$$A = (b + b + 3d) \times \frac{d}{2} = (b + 1.5d) \times d$$

Hydraulic radius, $R = \frac{A}{p}$; $R = \frac{A}{p} = \frac{(b+1.5d)d}{b+3.606\,d}$ *and*

$$A \times R^{2/3} = \frac{1.4 \times 0.020}{\sqrt{1/3000}} = 1.5336 \text{ (from previous slide)}$$

Therefore, $(b + 1.5d)d\left(\frac{(b+1.5d)d}{b+3.606\,d}\right)^{2/3} = 1.5336$

For side slope of 1.5:1, $\tan\theta = 0.667$

$$\theta = 33.69^o, \tan\frac{\theta}{2} = 0.3038$$

For efficient section, $b = 2d\tan\frac{\theta}{2} = 2d \times 0.3028 = 0.6055d$

Substituting this value of b in $(b + 1.5d)d\left(\frac{(b+1.5d)d}{b+3.606\,d}\right)^{2/3} = 1.5336$ *(from previous slide)*

$$2.1055d^2\left(\frac{2.1055d^2}{4.2116\mathrm{d}}\right)^{2/3} = 1.5336$$

$$d^{5/3} = \frac{1.5336}{1.3262} = 1.156329$$

$$d = 1.091\ m$$

$$b = 0.6055;\ \ b = 0.61\ m = 61\ cm$$

Checking the velocity

$$R = \frac{A}{p} = \frac{(0.66+1.5\times1.091)\times1.091}{0.66+3.606\times1.091} = 0.5449 \text{ m}$$

$$V = \frac{1}{n} R^{2/3} S^{1/2} = \frac{1}{0.020}\, 0.5449^{2/3} \frac{1}{3000}^{1/2} = 0.609 \text{ m/s}$$

The velocity is less than the maximum permissible velocity (i.e. 1.05 m/s).

Finally,

Bed width = 61 cm

Depth including free board = 1.30 m (included 20% free board)

Side slope = 1.5:1

Example 52.2:

Find the section dimensions of the drainage channel to carry runoff from a 50 ha watershed with a drainage coefficient of 5 lps/ha. The given parameters are: channel bed slope, S = 0.2%; channel side slope , Z = 1; maximum permissible mean velocity, V = 0.6 m/sec and manning's roughness coefficient, n = 0.025.

Solution:

$$Design\ discharge\ = area\ \times draiange\ coeffficent$$

$$Design\ discharge\ = 50\ \times 5 = 250 \text{ lps} = 0.25 \text{ m}^3\text{/sec}$$

From Manning's equations,

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

$$V = \frac{1}{0.025} R^{2/3} 0.002^{1/2} = 1.79 R^{2/3}$$

$$V = \frac{1}{0.025} R^{2/3} 0.002^{1/2} = 1.79 R^{2/3}$$

Hence, $R^{2/3} = \frac{V}{1.79}$; $R^{2/3} = \frac{0.6}{1.79} = 0.3352$; $R = 0.19407$

From continuity equation $Q = A \times V$

$$A = \frac{Q}{V} = \frac{0.25}{0.6} = 0.4167$$

Also,

$$A = bd + zd^2 = bd + 1 \times d^2$$

$$0.4167 = bd + d^2$$

$$0.4167 = bd + d^2$$

$$b = \frac{(0.4167 - d^2)}{d}$$

$$R = \frac{A}{P} = \frac{bd + zd^2}{b + 2d(Z^2 + 1)^{1/2}}$$

Substituting for b in R and writing R = 0.19407

$$0.19407 = \frac{\frac{(0.4167 - d^2)}{d} d + 1 \times d^2}{\frac{(0.4167 - d^2)}{d} + 2d(1^2 + 1)^{1/2}}$$

$$0.19407 = \frac{\frac{(0.4167 - d^2)}{d} d + d^2}{\frac{(0.4167 - d^2)}{d} + 2.828\, d}$$

$$0.19407 = \frac{0.4167\, d}{0.4167 + 1.828\, d^2}$$

$$d^2 - 1.1746\, d + 0.22796 = 0$$

This equation has two roots 0.9269 m and 0.2477 m.

$$b = \frac{(0.4167 - d^2)}{d} = \frac{0.4167 - 0.9269^2}{0.9269} = -0.477 \text{ m}$$

$$b = \frac{(0.4167 - d^2)}{d} = \frac{0.4167 - 0.2477^2}{0.2477} = 1.434 \text{ m}$$

The first root is not feasible as it substitution in the area relation give negative b.

Hence,

$$\text{b} = 1.43 \text{ m} \;\; and\; d = 0.2477\, m \approx 0.248\, m = 24.8 \text{ cm}$$

$$\text{Then, the } flow\ area(A) = 1.43 \times 0.248 + 1 \times 0.248^2 = 0.416 \text{ m}^2$$

$$The\ flow\ velocity = \left(\frac{0.25}{0.416}\right) = 0.6\ \text{m/sec}$$

Adding a free board of 5% depth to the design depth.

$$The\ construction\ depth\ = 24.8 + 24.8 \times \frac{5}{100} = 26.04\ \text{cm (or say 30 cm)}$$

$$The\ top\ width\ of\ the\ contraction\ = b + 2\,Zd = 1.43 + 2 \times 1 \times 0.3 = 2.03\ \text{m}$$

$$The\ cross\ sectional\ area\ of\ the\ contraction\ = bd + Zd^2 = 1.43 \times 0.3 + 1 \times 0.3^2 = 0.519\ \text{m}^2$$

The volume of earthwork per meter length of the drain for this cross-section is 0.519 m^3

Thank You!!

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Irrigation and Drainage

Lecture No: 53 Non-conventional Drainage

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Non-Conventional Drainage Methods

- ✓ Adopted when the conventional surface drainage or subsurface drainage methods are not suitable due to technical or economic reasons.
  - o Vertical drainage using shallow or deep wells or a shallow multiple well-point system
  - o Biodrainage
  - o Mole drainage

- ✓ The function is to achieve the same goals as those of the conventional drainage methods

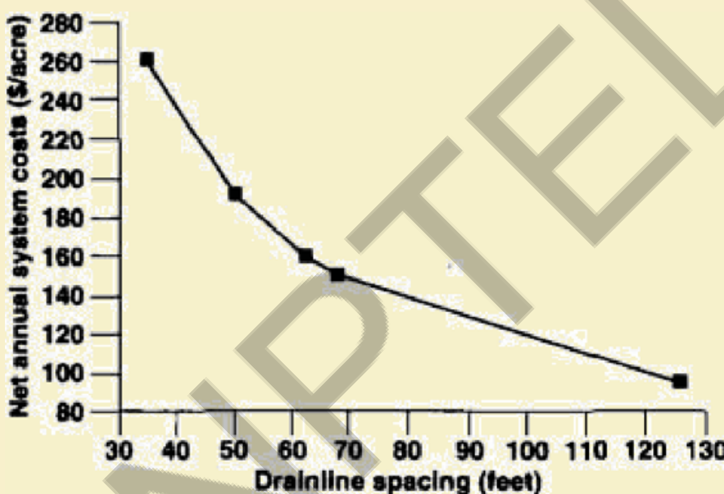
Non-Conventional Drainage Methods

✓ Vertical drainage:

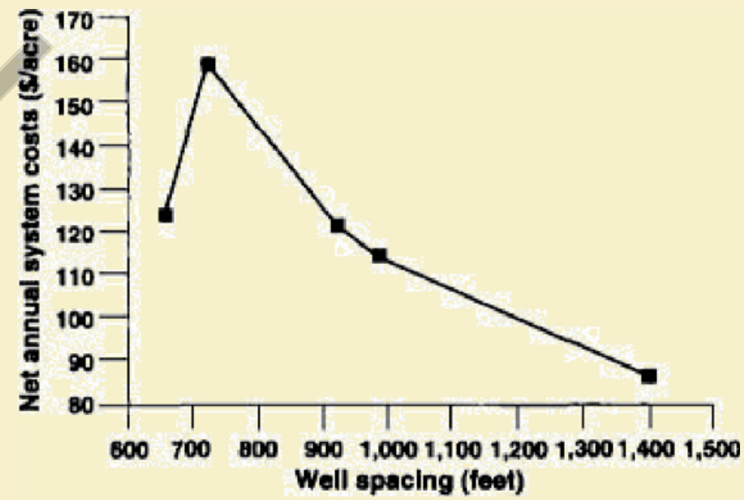
- The drawdown in the case of subsurface drainage system is limited to a maximum depth of 2 m.
- A tubewell dewaters the soil profile from much greater depths (20-30m)

Non-Conventional Drainage Methods

Conventional drainage



Vertical drainage:



Drainage System Costs for clay soil

Vertical drainage systems may be more effective than existing lateral drainage systems.
https://doi.org/10.3733/ca.v049n02p12

Non-Conventional Drainage Methods

✓ Bio-drainage:

- May be defined as “pumping of excess soil water by deep-rooted plants using their bio-energy."
- Plants transpiration is met primarily by withdrawing groundwater
- Rice plants transpire quite heavily but the process is not called biodrainage because rice root system is shallow (30-40 cm deep)

Non-Conventional Drainage Methods

✓ Bio-drainage:

- Medium to deep rooted plants in a shallow water table region may act as small capacity tubewells

- In case of tubewell drainage, the area encompassed by the tubewell network is available for normal crop production but in the case of biodrainage by a cluster of plants, the area within the cluster cannot be used for normal crop production

Non-Conventional Drainage Methods

✓ Bio-drainage:

- Fast growing **Eucalyptus** species known for luxurious water consumption under excess soil moisture condition.
- The eucalyptus trees bio-drained 2022, 2830, 3021 and 2475 mm of water in 1st, 2nd, 3rd and 4th year at a groundwater salinity of 12 dSm^{-1} (Chhabra and Thakur, 1998)

Bio-drainage over Conventional Drainage Systems

- ✓ No operational cost, as the plants use their bio-energy in draining out the excess ground water into atmosphere
- ✓ Increase in worth with age instead of depreciation
- ✓ No need of any drainage outfall and disposal of drainage effluent
- ✓ No environmental problem, as the plants drain out filtered fresh water in to the atmosphere.
- ✓ In- situ solution of the problem of waterlogging and salinity
- ✓ Helps in carbon sequestration and carbon credit
- ✓ Acts as wind break and shelter belts in agroforestry system.

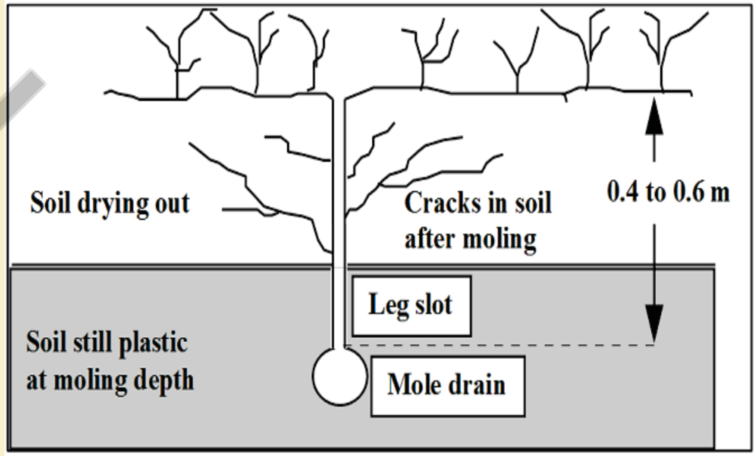
Non-Conventional Drainage Methods

Mole Drainage:

Mole drains are unlined circular soil channels which function like pipe drains in heavy clay subsoils

Why mole drainage?

- ✓ When natural drainage needs improving due to a heavy clay subsoil.
- ✓ Areas affected by salt-waterlogging
- ✓ They do not drain groundwater- only water that enters from above
- ✓ More sophisticated drainage system than open drains.



When to Mole drain?

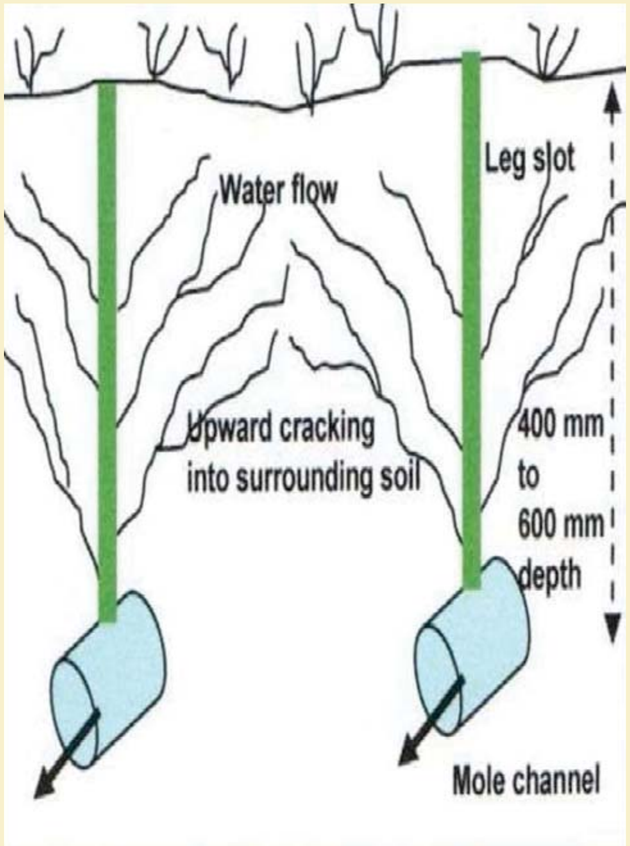
- ✓ The soil in the vicinity of the mole channel needs to be moist enough (20-25%) to form a channel, usually occur in late spring or early summer.
- ✓ The surface soil needs to be dry enough to form cracks at the time of mole draining and allow traction.
- ✓ It is preferable for a drying period with no rain to allow the cracks to dry and the mole channel to harden.

Mole Drainage Factors:

- ✓ Soils should have a minimum of 35% clay and less than 30% sand.
- ✓ Gradients fall between 0.4% and 4% (Good gradient =3%)
- ✓ Generally moles are pulled at 40–60 cm depth
- ✓ A rule of thumb is that the expander to mole draining depth ratio is 1:7 (i.e. a 70 mm diameter expander should have mole depth 490 mm)
- ✓ Spacing between moles should be between 2 to 5 m.
- ✓ Accepted maximum effective length of mole is about 200 m
- ✓ About 1 to 3 m long pipe should be inserted into the mole drain channel to prevent outlet destruction and soil erosion.
- ✓ Low-cost PVC pipe of 1 to 3 m size should be selected for outlet.

Other Factors

- ✓ Good fertilizer management practices such as not applying fertiliser within 4 days of predicted rain should reduce nutrient run-off to a minimum.
- ✓ Open drain outlets should be fenced off from stock and kept clean so the outfall is above the drain water level.
- ✓ Drainage trenches can outfall to dams so that more water can be harvested.
- ✓ Moles should be pulled at 2-3 km/hr to minimize disruption (tearing) of mole channels and increase mole life.



Thank You!!

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Irrigation and Drainage

Lecture No: 54 Economics of Drainage Project

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ECONOMIC EVALUATION OF DRAINAGE PROJECTS

Land drainage Objectives:

- ✓ To bring land into production or
- ✓ To increase the productivity of existing cultivable land
- ✓ To evaluate benefits and costs of any projects/schemes

ECONOMIC EVALUATION OF DRAINAGE PROJECTS

Costs of a drainage project:

- ✓ **Initial or capital investments**: canals, control works, ditches, pipes, pumps, land leveling, land clearing, farm roads, reallocation of existing structures, etc.
- ✓ **Replacement investments**:

  Required in the future when capital goods come to the end of their technical or economic lifetime.

  - Loss of existing property
  - Recurring costs of the maintenance works
  - Recurring costs of the operation and management of a scheme
  - Other associated costs

ECONOMIC EVALUATION OF DRAINAGE PROJECTS

Benefits of land drainage:

- ✓ **Tangible benefits:** enhanced agricultural production, water supply for domestic or industrial use, etc.
- ✓ **Intangible benefits:** improvement in local environment, improved hygiene, better trafficability, etc.

Computation of Costs and Benefits:

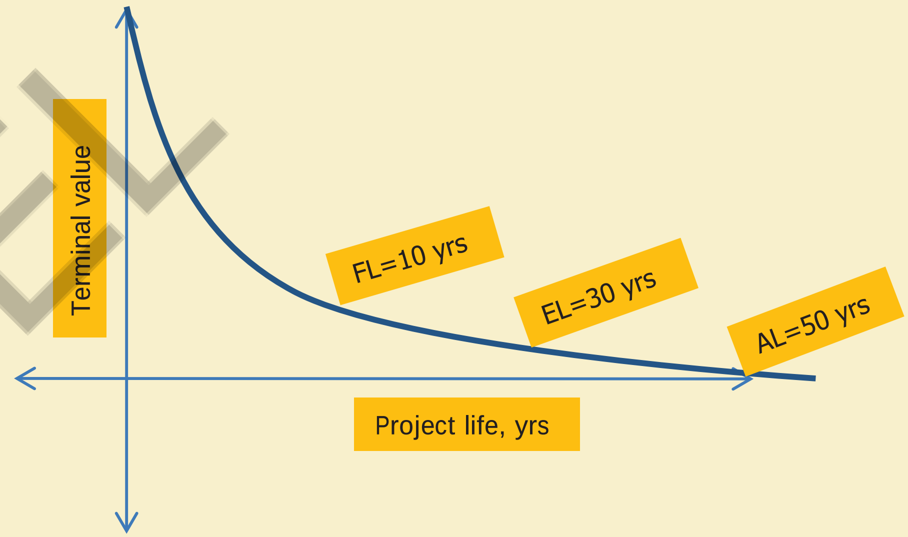
Costs and benefits occur at different times during the project period

- ✓ ***Costs:*** Project construction
- ✓ ***Benefits:*** Project maturity
- ✓ **Discounting** is a device to bring costs and benefits occurring at different points of time on to a common base

ECONOMIC EVALUATION OF DRAINAGE PROJECTS

Time Periods:

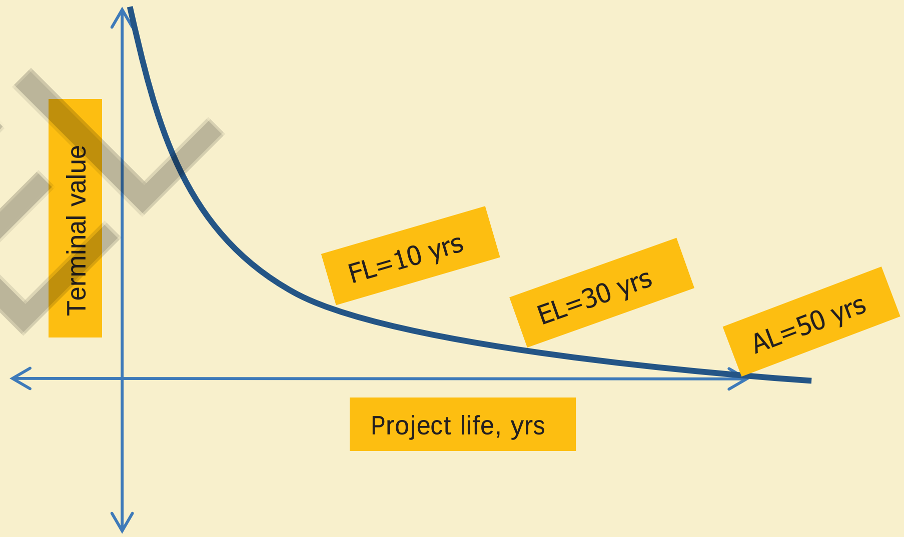
- ✓ **Actual Life (AL):**
  - o Well maintained pipe drainage will have 50-100 yrs of age
- ✓ **Economic Life (EL):**
  - o Corresponding to a notional lifetime at the end of which project will get renewed
  - o At the end of EL, the project cost is zero terminal value.



ECONOMIC EVALUATION OF DRAINAGE PROJECTS

✓ **Financial Life (FL):**

- Often imposed by lending agency
- Repayment period of the loan taken from a lending agency
- 10 yrs (very much shorter than EL and AL)
- Project has terminal value at the end of financial life
- Farmer expects the benefits equal or preferably exceed the cost arising during FL



ECONOMIC EVALUATION OF DRAINAGE PROJECTS

1) Discounting Cashflow Method (DCF)

- ✓ Sum of money observed now is worth more than the same sum of money in 10 yrs.
- ✓ ***Example:***
  - ✓ Present value: Rs. 100; Interest rate: 10%; Value after 1 yr: Rs. 110;
  - ✓ Discounting Factor: 100/110= 0.909

✓ Discounting is the inverse of charging compound interest,

$$DF = \sum_{i=1}^{PL} \frac{1}{(1 + RI)^{i}}$$

Where, DF = discounting factor, PL = life of the drainage project (years), and RI = rate of interest (fraction).

Computation of Costs and Benefits for Economic Analysis

- ✓ What is the present value, if the drainage project expects a benefit of Rs. 10000/ha after 20 yrs, at an interest of 10%.

Exhibit 14B-1

*Present Value of a Single Amount**

n/i	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	12%	14%	16%	18%	20%	25%	30%
1	0.99010	0.98039	0.97087	0.96154	0.95238	0.94340	0.93458	0.92593	0.91743	0.90909	0.89286	0.87719	0.86207	0.84746	0.83333	0.80000	0.76923
2	0.98030	0.96117	0.94260	0.92456	0.90703	0.89000	0.87344	0.85734	0.84168	0.82645	0.79719	0.76947	0.74316	0.71818	0.69444	0.64000	0.59172
3	0.97059	0.94232	0.91514	0.88900	0.86384	0.83962	0.81630	0.79383	0.77218	0.75131	0.71178	0.67497	0.64066	0.60863	0.57870	0.51200	0.45517
4	0.96098	0.92385	0.88849	0.85480	0.82270	0.79209	0.76290	0.73503	0.70843	0.68301	0.63552	0.59208	0.55229	0.51579	0.48225	0.40960	0.35013
5	0.95147	0.90573	0.86261	0.82193	0.78353	0.74726	0.71299	0.68058	0.64993	0.62092	0.56743	0.51937	0.47611	0.43711	0.40188	0.32768	0.26933
6	0.94205	0.88797	0.83748	0.79031	0.74622	0.70496	0.66634	0.63017	0.59627	0.56447	0.50663	0.45559	0.41044	0.37043	0.33490	0.26214	0.20718
7	0.93272	0.87056	0.81309	0.75992	0.71068	0.66506	0.62275	0.58349	0.54703	0.51316	0.45235	0.39964	0.35383	0.31393	0.27908	0.20972	0.15937
8	0.92348	0.85349	0.78941	0.73069	0.67684	0.62741	0.58201	0.54027	0.50187	0.46651	0.40388	0.35056	0.30503	0.26604	0.23257	0.16777	0.12259
9	0.91434	0.83676	0.76642	0.70259	0.64461	0.59190	0.54393	0.50025	0.46043	0.42410	0.36061	0.30751	0.26295	0.22546	0.19381	0.13422	0.09430
10	0.90529	0.82035	0.74409	0.67556	0.61391	0.55839	0.50835	0.46319	0.42241	0.38554	0.32197	0.26974	0.22668	0.19106	0.16151	0.10737	0.07254
11	0.89632	0.80426	0.72242	0.64958	0.58468	0.52679	0.47509	0.42888	0.38753	0.35049	0.28748	0.23662	0.19542	0.16192	0.13459	0.08590	0.05580
12	0.88745	0.78849	0.70138	0.62460	0.55684	0.49697	0.44401	0.39711	0.35553	0.31863	0.25668	0.20756	0.16846	0.13722	0.11216	0.06872	0.04292
13	0.87866	0.77303	0.68095	0.60057	0.53032	0.46884	0.41496	0.36770	0.32618	0.28966	0.22917	0.18207	0.14523	0.11629	0.09346	0.05498	0.03302
14	0.86996	0.75788	0.66112	0.57748	0.50507	0.44230	0.38782	0.34046	0.29925	0.26333	0.20462	0.15971	0.12520	0.09855	0.07789	0.04398	0.02540
15	0.86135	0.74301	0.64186	0.55526	0.48102	0.41727	0.36245	0.31524	0.27454	0.23939	0.18270	0.14010	0.10793	0.08352	0.06491	0.03518	0.01954
16	0.85282	0.72845	0.62317	0.53391	0.45811	0.39365	0.33873	0.29189	0.25187	0.21763	0.16312	0.12289	0.09304	0.07078	0.05409	0.02815	0.01503
17	0.84438	0.71416	0.60502	0.51337	0.43630	0.37136	0.31657	0.27027	0.23107	0.19784	0.14564	0.10780	0.08021	0.05998	0.04507	0.02252	0.01156
18	0.83602	0.70016	0.58739	0.49363	0.41552	0.35034	0.29586	0.25025	0.21199	0.17986	[illegible]	[illegible]	[illegible]	[illegible]	0.03756	0.01801	0.00889
19	0.82774	0.68643	0.57029	0.47464	0.39573	0.33051	0.27651	0.23171	0.19449	0.16351	0.11611	0.08295	0.05961	0.04308	0.03130	0.01441	0.00684
20	0.81954	0.67297	0.55368	0.45639	0.37689	0.31180	0.25842	0.21455	0.17843	0.14864	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00526
21	0.81143	0.65978	0.53755	0.43883	0.35894	0.29416	0.24151	0.19866	0.16370	0.13513	0.09256	0.06383	0.04430	0.03094	0.02174	0.00922	0.00405
22	0.80340	0.64684	0.52189	0.42196	0.34185	0.27751	0.22571	0.18394	0.15018	0.12285	0.08264	0.05599	0.03819	0.02622	0.01811	0.00738	0.00311
23	0.79544	0.63416	0.50669	0.40573	0.32557	0.26180	0.21095	0.17032	0.13778	0.11168	0.07379	0.04911	0.03292	0.02222	0.01509	0.00590	0.00239
24	0.78757	0.62172	0.49193	0.39012	0.31007	0.24698	0.19715	0.15770	0.12640	0.10153	0.06588	0.04308	0.02838	0.01883	0.01258	0.00472	0.00184
25	0.77977	0.60953	0.47761	0.37512	0.29530	0.23300	0.18425	0.14602	0.11597	0.09230	0.05882	0.03779	0.02447	0.01596	0.01048	0.00378	0.00142
26	0.77205	0.59758	0.46369	0.36069	0.28124	0.21981	0.17220	0.13520	0.10639	0.08391	0.05252	0.03315	0.02109	0.01352	0.00874	0.00302	0.00109
27	0.76440	0.58586	0.45019	0.34682	0.26785	0.20737	0.16093	0.12519	0.09761	0.07628	0.04689	0.02908	0.01818	0.01146	0.00728	0.00242	0.00084
28	0.75684	0.57437	0.43708	0.33348	0.25509	0.19563	0.15040	0.11591	0.08955	0.06934	0.04187	0.02551	0.01567	0.00971	0.00607	0.00193	0.00065
29	0.74934	0.56311	0.42435	0.32065	0.24295	0.18456	0.14056	0.10733	0.08215	0.06304	0.03738	0.02237	0.01351	0.00823	0.00506	0.00155	0.00050
30	0.74192	0.55207	0.41199	0.30832	0.23138	0.17411	0.13137	0.09938	0.07537	0.05731	0.03338	0.01963	0.01165	0.00697	0.00421	0.00124	0.00038

Present value =10000x0.149=Rs. 1490

ECONOMIC EVALUATION OF DRAINAGE PROJECTS

2) Computation of Annual Repayment:

The annual repayment on the **initial loan** at a **rate of interest** and over a **repayment period**:

$$F = \frac{IC}{PWF}$$

Here, PWF (present worth factor) is equal to:

$$PWF = \frac{[(1 + RI)^{RP} - 1]}{RI(1 + RI)^{RP}}$$

Where, F = annual repayment (☐); IC = initial investment (☐); RP = repayment period (years)

RI = rate of interest (-)

ECONOMIC EVALUATION OF DRAINAGE PROJECTS

3) Inflation Factor Computation

The future costs and benefits are increased in value to take account of an assumed rate of inflation.

Yearly inflation factor (IF):

$$IF = (1 + IR)^{PL}$$

Where, IF = inflation factor; IR = inflation rate (fraction); PL = Drainage project life (Years)

ECONOMIC EVALUATION OF DRAINAGE PROJECTS

Indices for Economic Evaluation

1) Net Present Value (NPV):

- ✓ NPV is the difference between the present value of benefits and costs
- ✓ It also known as **Net Present Worth** (NPW)
- ✓ Clearly, a positive value of NPV (or NPW) is desirable

$$NPV = \sum_{i=1}^{PL} \frac{(B_i - C_i)}{(1 + RI)^i}$$

Where, B_i = benefits in the i_{th} year; C_i = cost in the i_{th} year

ECONOMIC EVALUATION OF DRAINAGE PROJECTS

2. Benefit-Cost Ratio (B-C Ratio)

- ✓ B-C Ratio is the present value of benefits divided by present value of costs
- ✓ For a project to be economically viable, the B-C ratio should be >1

$$B - C\ ratio = \frac{\sum_{i=1}^{PL}\left[\frac{B_i}{(1+RI)^i}\right]}{\sum_{i=1}^{PL}\left[\frac{C_i}{(1+RI)^i}\right]}$$

ECONOMIC EVALUATION OF DRAINAGE PROJECTS

Example 54.1 (Cost Evaluation of Drainage Project)

- ✓ A farmer in India plans to drain an area of rough grazing land to enable it to be used as arable land
- ✓ **Drainage System:**

Pipe drainage + moling, construction cost = ₹ 52000/ha

Re-moling every seven years = ₹ 2000/ha

Maintenance every 5 years = ₹ 1500/ha

- ✓ **Financing:**

Bank loan over 10 yrs at 10% interest rate

Inflation: 5% over the life of the drainage project

- ✓ **Benefits:** Expected additional profit on arable land = ₹ 9000/ha

ECONOMIC EVALUATION OF DRAINAGE PROJECTS

Calculations (Results are tabulated)

1. The annual repayment on initial loan of ? 52000/ha at 10% interest rate and over a ten year period is ? 8460/ha (col 1)

$$F = \frac{IC}{PWF}; \qquad \text{where } PWF = \frac{\left[(1+RI)^{RP} - 1\right]}{RI(1+RI)^{RP}}$$

Where, F = annual repayment (?); IC = initial investment (?); RP = repayment period (years)

RI = rate of interest (-)

2. The future cost of moling and maintenance (col 3) and benefits (col 4) are increased by standard factor (col 5) to take account of the inflation rate by 5% (col 7 and 8)

year	Costs and Benefits at actual price (₹/ha)			Actual future costs and benefits with 5% inflation (₹/ha)					Percent values of future sums (₹/ha)		
	Initial Loan	Moling maintenance	Benefits	Inflation factor, 5%	Loan	Moling maintenance	Benefits	Benefits-costs	Discount factor, 10%	Benefits-costs	NPV (col 11 summated)
(1)	(2)	(3)	(4)	(From Inflation Table) (5)	(6)	(7) = (3)x(5)	(8) =(4)x(5)	(9) =(8)-(7)-(6)	(From discounting table) (10)	(11) =(9)x(10)	(12)
1	8460		9000	1.05	8460	0	9450	990	0.91	900.9	900.9
2	8460		9000	1.1	8460	0	9900	1440	0.83	1195.2	2096.1
3	8460		9000	1.16	8460	0	10440	1980	0.75	1485	3581.1
4	8460		9000	1.22	8460	0	10980	2520	0.68	1713.6	5294.7
5	8460	1500	9000	1.28	8460	1920	11520	1140	0.62	706.8	6001.5
6	8460		9000	1.34	8460	0	12060	3600	0.56	2016	8017.5
7	8460	2000	9000	1.41	8460	2820	12690	1410	0.51	719.1	8736.6
8	8460		9000	1.48	8460	0	13320	4860	0.47	2284.2	11021
9	8460		9000	1.55	8460	0	13950	5490	0.42	2305.8	13327
10	8460	1500	9000	1.63	8460	2445	14670	3765	0.39	1468.4	14795
11			9000	1.71		0	15390	15390	0.35	5386.5	20181
12			9000	1.8		0	16200	16200	0.32	5184	25365
13			9000	1.89		0	17010	17010	0.29	4932.9	30298
14		2000	9000	2		4000	18000	14000	0.26	3640	33938
15		1500	9000	2.08		3120	18720	15600	0.24	3744	37682
16			9000	2.18		0	19620	19620	0.22	4316.4	41999
17			9000	2.29		0	20610	20610	0.2	4122	46121
18			9000	2.41		0	21690	21690	0.18	3904.2	50025
19			9000	2.53		0	22770	22770	0.16	3643.2	53668
20		1500	9000	2.65		3975	23850	19875	0.15	2981.3	56649
						Terminal value	10400	10400	Discounted terminal value	1560	58190

Inflation factor

FUTURE VALUE OF $1

RATE PER PERIOD

Periods	0.25%	0.50%	0.75%	1.00%	1.50%	2.00%	2.50%	3.00%	4.00%	5.00%	6.00%	7.00%	8.00%	9.00%	10.00%	11.00%	12.00%
1	1.00250	1.00500	1.00750	1.01000	1.01500	1.02000	1.02500	1.03000	1.04000	1.05000	1.06000	1.07000	1.08000	1.09000	1.10000	1.11000	1.12000
2	1.00501	1.01003	1.01506	1.02010	1.03023	1.04040	1.05063	1.06090	1.08160	1.10250	1.12360	1.14490	1.16640	1.18810	1.21000	1.23210	1.25440
3	1.00752	1.01508	1.02267	1.03030	1.04568	1.06121	1.07689	1.09273	1.12486	1.15763	1.19102	1.22504	1.25971	1.29503	1.33100	1.36763	1.40493
4	1.01004	1.02015	1.03034	1.04060	1.06136	1.08243	1.10381	1.12551	1.16986	1.21551	1.26248	1.31080	1.36049	1.41158	1.46410	1.51807	1.57352
5	1.01256	1.02525	1.03807	1.05101	1.07728	1.10408	1.13141	1.15927	1.21665	1.27628	1.33823	1.40255	1.46933	1.53862	1.61051	1.68506	1.76234
6	1.01509	1.03038	1.04585	1.06152	1.09344	1.12616	1.15969	1.19405	1.26532	1.34010	1.41852	1.50073	1.58687	1.67710	1.77156	1.87041	1.97382
7	1.01763	1.03553	1.05370	1.07214	1.10984	1.14869	1.18869	1.22987	1.31593	1.40710	1.50363	1.60578	1.71382	1.82804	1.94872	2.07616	2.21068
8	1.02018	1.04071	1.06160	1.08286	1.12649	1.17166	1.21840	1.26677	1.36857	1.47746	1.59385	1.71819	1.85093	1.99256	2.14359	2.30454	2.47596
9	1.02273	1.04591	1.06956	1.09369	1.14339	1.19509	1.24886	1.30477	1.42331	1.55133	1.68948	1.83846	1.99900	2.17189	2.35795	2.55804	2.77308
10	1.02528	1.05114	1.07758	1.10462	1.16054	1.21899	1.28008	1.34392	1.48024	1.62889	1.79085	1.96715	2.15892	2.36736	2.59374	2.83942	3.10585
11	1.02785	1.05640	1.08566	1.11567	1.17795	1.24337	1.31209	1.38423	1.53945	1.71034	1.89830	2.10485	2.33164	2.58043	2.85312	3.15176	3.47855
12	1.03042	1.06168	1.09381	1.12683	1.19562	1.26824	1.34489	1.42576	1.60103	1.79586	2.01220	2.25219	2.51817	2.81266	3.13843	3.49845	3.89598
13	1.03299	1.06699	1.10201	1.13809	1.21355	1.29361	1.37851	1.46853	1.66507	1.88565	2.13293	2.40985	2.71962	3.06580	3.45227	3.88328	4.36349
14	1.03557	1.07232	1.11028	1.14947	1.23176	1.31948	1.41297	1.51259	1.73168	1.97993	2.26090	2.57853	2.93719	3.34173	3.79750	4.31044	4.88711
15	1.03816	1.07768	1.11860	1.16097	1.25023	1.34587	1.44830	1.55797	1.80094	2.07893	2.39656	2.75903	3.17217	3.64248	4.17725	4.78459	5.47357
16	1.04076	1.08307	1.12699	1.17258	1.26899	1.37279	1.48451	1.60471	1.87298	2.18287	2.54035	2.95216	3.42594	3.97031	4.59497	5.31089	6.13039
17	1.04336	1.08849	1.13544	1.18430	1.28802	1.40024	1.52162	1.65285	1.94790	2.29202	2.69277	3.15882	3.70002	4.32763	5.05447	5.89509	6.86604
18	1.04597	1.09393	1.14396	1.19615	1.30734	1.42825	1.55966	1.70243	2.02582	2.40662	2.85434	3.37993	3.99602	4.71712	5.55992	6.54355	7.68997
19	1.04858	1.09940	1.15254	1.20811	1.32695	1.45681	1.59865	1.75351	2.10685	2.52695	3.02560	3.61653	4.31570	5.14166	6.11591	7.26334	8.61276
20	1.05121	1.10490	1.16118	1.22019	1.34686	1.48595	1.63862	1.80611	2.19112	2.65330	3.20714	3.86968	4.66096	5.60441	6.72750	8.06231	9.64629
21	1.05383	1.11042	1.16989	1.23239	1.36706	1.51567	1.67958	1.86029	2.27877	2.78596	3.39956	4.14056	5.03383	6.10881	7.40025	8.94917	10.80385
22	1.05647	1.11597	1.17867	1.24472	1.38756	1.54598	1.72157	1.91610	2.36992	2.92526	3.60354	4.43040	5.43654	6.65860	8.14027	9.93357	12.10031
23	1.05911	1.12155	1.18751	1.25716	1.40838	1.57690	1.76461	1.97359	2.46472	3.07152	3.81975	4.74053	5.87146	7.25787	8.95430	11.02627	13.55235
24	1.06176	1.12716	1.19641	1.26973	1.42950	1.60844	1.80873	2.03279	2.56330	3.22510	4.04893	5.07237	6.34118	7.91108	9.84973	12.23916	15.17863
25	1.06441	1.13280	1.20539	1.28243	1.45095	1.64061	1.85394	2.09378	2.66584	3.38635	4.29187	5.42743	6.84848	8.62308	10.83471	13.58546	17.00006
30	1.07778	1.16140	1.25127	1.34785	1.56308	1.81136	2.09757	2.42726	3.24340	4.32194	5.74349	7.61226	10.06266	13.26768	17.44940	22.89230	29.95992
35	1.09132	1.19073	1.29890	1.41660	1.68388	1.99989	2.37321	2.81386	3.94609	5.51602	7.68609	10.67658	14.78534	20.41397	28.10244	38.57485	52.79962
40	1.10503	1.22079	1.34835	1.48886	1.81402	2.20804	2.68506	3.26204	4.80102	7.03999	10.28572	14.97446	21.72452	31.40942	45.25926	65.00087	93.05097
50	1.13297	1.28323	1.45296	1.64463	2.10524	2.69159	3.43711	4.38391	7.10668	11.46740	18.42015	29.45703	46.90161	74.35752	117.3909	184.5648	289.0022

ECONOMIC EVALUATION OF DRAINAGE PROJECTS

3) The procedure for evaluating costs/benefits in any one year is explained in relation to year 6.

- ✓ The annual repayment is ₹ 8460.
- ✓ The benefit of ₹ 9000/ha (col4) obtained at the outset has increased in value due to inflation to ₹ 12060 (col8).
- ✓ The excess of benefit over cost of ₹ 3600 (col9) has a present value of 0.56 x 3600 = ₹2016 (col 11).

4) The terminal value of the project at the end of the 20 year period considered is judged to be 20% of its installation cost or 0.2x5200= ₹ 10400

Computation of Costs and Benefits for Economic Analysis

- ✓ What is the present value, if the drainage project expects a benefit of Rs. 10000/ha after 20 yrs, at an interest of 10%.

Exhibit 14B-1

*Present Value of a Single Amount**

n/i	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	12%	14%	16%	18%	20%	25%	30%
1	0.99010	0.98039	0.97087	0.96154	0.95238	0.94340	0.93458	0.92593	0.91743	0.90909	0.89286	0.87719	0.86207	0.84746	0.83333	0.80000	0.76923
2	0.98030	0.96117	0.94260	0.92456	0.90703	0.89000	0.87344	0.85734	0.84168	0.82645	0.79719	0.76947	0.74316	0.71818	0.69444	0.64000	0.59172
3	0.97059	0.94232	0.91514	0.88900	0.86384	0.83962	0.81630	0.79383	0.77218	0.75131	0.71178	0.67497	0.64066	0.60863	0.57870	0.51200	0.45517
4	0.96098	0.92385	0.88849	0.85480	0.82270	0.79209	0.76290	0.73503	0.70843	0.68301	0.63552	0.59208	0.55229	0.51579	0.48225	0.40960	0.35013
5	0.95147	0.90573	0.86261	0.82193	0.78353	0.74726	0.71299	0.68058	0.64993	0.62092	0.56743	0.51937	0.47611	0.43711	0.40188	0.32768	0.26933
6	0.94205	0.88797	0.83748	0.79031	0.74622	0.70496	0.66634	0.63017	0.59627	0.56447	0.50663	0.45559	0.41044	0.37043	0.33490	0.26214	0.20718
7	0.93272	0.87056	0.81309	0.75992	0.71068	0.66506	0.62275	0.58349	0.54703	0.51316	0.45235	0.39964	0.35383	0.31393	0.27908	0.20972	0.15937
8	0.92348	0.85349	0.78941	0.73069	0.67684	0.62741	0.58201	0.54027	0.50187	0.46651	0.40388	0.35056	0.30503	0.26604	0.23257	0.16777	0.12259
9	0.91434	0.83676	0.76642	0.70259	0.64461	0.59190	0.54393	0.50025	0.46043	0.42410	0.36061	0.30751	0.26295	0.22546	0.19381	0.13422	0.09430
10	0.90529	0.82035	0.74409	0.67556	0.61391	0.55839	0.50835	0.46319	0.42241	0.38554	0.32197	0.26974	0.22668	0.19106	0.16151	0.10737	0.07254
11	0.89632	0.80426	0.72242	0.64958	0.58468	0.52679	0.47509	0.42888	0.38753	0.35049	0.28748	0.23662	0.19542	0.16192	0.13459	0.08590	0.05580
12	0.88745	0.78849	0.70138	0.62460	0.55684	0.49697	0.44401	0.39711	0.35553	0.31863	0.25668	0.20756	0.16846	0.13722	0.11216	0.06872	0.04292
13	0.87866	0.77303	0.68095	0.60057	0.53032	0.46884	0.41496	0.36770	0.32618	0.28966	0.22917	0.18207	0.14523	0.11629	0.09346	0.05498	0.03302
14	0.86996	0.75788	0.66112	0.57748	0.50507	0.44230	0.38782	0.34046	0.29925	0.26333	0.20462	0.15971	0.12520	0.09855	0.07789	0.04398	0.02540
15	0.86135	0.74301	0.64186	0.55526	0.48102	0.41727	0.36245	0.31524	0.27454	0.23939	0.18270	0.14010	0.10793	0.08352	0.06491	0.03518	0.01954
16	0.85282	0.72845	0.62317	0.53391	0.45811	0.39365	0.33873	0.29189	0.25187	0.21763	0.16312	0.12289	0.09304	0.07078	0.05409	0.02815	0.01503
17	0.84438	0.71416	0.60502	0.51337	0.43630	0.37136	0.31657	0.27027	0.23107	0.19784	0.14564	0.10780	0.08021	0.05998	0.04507	0.02252	0.01156
18	0.83602	0.70016	0.58739	0.49363	0.41552	0.35034	0.29586	0.25025	0.21199	0.17986	[illegible]	[illegible]	[illegible]	[illegible]	0.03756	0.01801	0.00889
19	0.82774	0.68643	0.57029	0.47464	0.39573	0.33051	0.27651	0.23171	0.19449	0.16351	0.11611	0.08295	0.05961	0.04308	0.03130	0.01441	0.00684
20	0.81954	0.67297	0.55368	0.45639	0.37689	0.31180	0.25842	0.21455	0.17843	0.14864	0.10367	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00526
21	0.81143	0.65978	0.53755	0.43883	0.35894	0.29416	0.24151	0.19866	0.16370	0.13513	0.09256	0.06383	0.04430	0.03094	0.02174	0.00922	0.00405
22	0.80340	0.64684	0.52189	0.42196	0.34185	0.27751	0.22571	0.18394	0.15018	0.12285	0.08264	0.05599	0.03819	0.02622	0.01811	0.00738	0.00311
23	0.79544	0.63416	0.50669	0.40573	0.32557	0.26180	0.21095	0.17032	0.13778	0.11168	0.07379	0.04911	0.03292	0.02222	0.01509	0.00590	0.00239
24	0.78757	0.62172	0.49193	0.39012	0.31007	0.24698	0.19715	0.15770	0.12640	0.10153	0.06588	0.04308	0.02838	0.01883	0.01258	0.00472	0.00184
25	0.77977	0.60953	0.47761	0.37512	0.29530	0.23300	0.18425	0.14602	0.11597	0.09230	0.05882	0.03779	0.02447	0.01596	0.01048	0.00378	0.00142
26	0.77205	0.59758	0.46369	0.36069	0.28124	0.21981	0.17220	0.13520	0.10639	0.08391	0.05252	0.03315	0.02109	0.01352	0.00874	0.00302	0.00109
27	0.76440	0.58586	0.45019	0.34682	0.26785	0.20737	0.16093	0.12519	0.09761	0.07628	0.04689	0.02908	0.01818	0.01146	0.00728	0.00242	0.00084
28	0.75684	0.57437	0.43708	0.33348	0.25509	0.19563	0.15040	0.11591	0.08955	0.06934	0.04187	0.02551	0.01567	0.00971	0.00607	0.00193	0.00065
29	0.74934	0.56311	0.42435	0.32065	0.24295	0.18456	0.14056	0.10733	0.08215	0.06304	0.03738	0.02237	0.01351	0.00823	0.00506	0.00155	0.00050
30	0.74192	0.55207	0.41199	0.30832	0.23138	0.17411	0.13137	0.09938	0.07537	0.05731	0.03338	0.01963	0.01165	0.00697	0.00421	0.00124	0.00038

Present value =10000x0.149=Rs. 1490

Discussion

- ✓ The NPV is ₹ 14810/ha at the end of 10 year financial period and ₹ 56630/ha at the end of the considered 20 year economic life time period (ignoring the terminal value)
- ✓ The present value of all costs (PVC) arising over the first 10 years = (costs in cols 6+ col7)x discounting factor = ₹ 55526.55
- ✓ The present value of the costs after 20 years (similar calculation) = ₹ 57911.6
- ✓ The benefit/cost ratio after 10 years= ((Benefits-Costs)+Costs)/Costs

  = (cum col 11+cum.PVC)/cum.PVC

  = (14794.95 +55526.55)/55526.55 =1.27

Discussion

- ✓ The benefit/cost ratio after 20 years (including terminal value)=

  = (58209.4+57911.6)/57911.6 =2.0

- ✓ From these indicators it appears that the project is financially viable in the short as well as in the long term.

Thank You!!

IIT KHARAGPUR

NPTEL ONLINE CERTIFICATION COURSES

NPTEL

Irrigation and Drainage

Lecture No:55 Tutorial: W11

Dr. DAMODHARA RAO MAILAPALLI

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Example W11.1:

Find the section dimension of a drainage channel to carry runoff from a 50 ha water shed with a drainage coefficient of 5 lps/ha. The given parameters are channel bed slope, S = 0.2%; channel side slope, z=1; maximum permissible mean velocity, V=0.6 m/sec and Manning's roughness coefficient, n=0.025.

Solution:

$Design\ discharge\ = 5 \times 50 = 250\ lps = 0.25$ m³/sec

From Manning's formula $\quad V = \frac{1}{n} R^{2/3} S^{1/2}$

$$0.6 = \frac{1}{0.025} R^{2/3} 0.002^{1/2}; \qquad 0.6 = 1.79\ R^{2/3}$$

$R^{2/3} = \frac{0.6}{1.79};$ $R^{2/3} = 0.3350;$ $R = 0.194$

From continuity equation

$$Q = A \times V; \qquad A = \frac{Q}{V} = \frac{0.25}{0.6}; \qquad A = 0.4167$$

Also, for Trapezoid channel

$$A = bd + zd^2; \qquad 0.4167 = bd + 1 \times d^2; \qquad b = \frac{(0.4167 - d^2)}{d}$$

$$R = \frac{A}{P} = \frac{bd + zd^2}{b + 2d(z^2+1)^{1/2}}$$

Substituting for b in R and writing R = 0.19407

$$R = \frac{\left(\frac{(0.4167-d^2)}{d}\right)d+1\times d^2}{\left(\frac{(0.4167-d^2)}{d}\right)+2.828\ d}; \qquad R = \frac{0.4167\ \mathrm{d}}{(0.4167+1.828\ d^2)}$$

$$d^2 - 1.1746\ d + 0.22796 = 0$$

By solving above equation

$$d = 0.9269\ \mathrm{m\ and}\ 0.2477\ \mathrm{m}$$

Now substituting in equation to find a b value

$$b = \frac{(0.4167-d^2)}{d}; \qquad b = \frac{(0.4167-0.9269^2)}{0.9269}; \qquad b = -0.477\ m$$

The first root is not feasible as it is substitution in the area relation gives negative b.

Hence, $d = \ 0.2477m \ \approx 0.248\, m = 24.8\, cm$

$b = \frac{(0.4167 - d^2)}{d}$; $\qquad b = \frac{(0.4167 - 0.248^2)}{0.248}$; $b = 1.43\, m$

- $The\ flow\ area = 1.43 \times 0.248 + 1 \times 0.248^2 \ = 0.416$ m²
- $flow\ velocity = \frac{0.25}{0.416}$
- $flow\ velocity = 0.6$ m/sec

According to freeboard 5% depth to the design depth, the construction depth = 26 cm (or say 30cm)

$$The\ top\ width\ of\ construction\ = bd + zd^2$$

$$The\ top\ width\ of\ construction\ = 1.43 \times 0.3 + 1 \times 0.3^2$$

$$The\ top\ width\ of\ construction\ = 0.519\ \text{m}^2$$

The volume of earthwork per meter length of the drain for this cross-section is 0.519 m^3

Example W11.2:

Calculate the peak rate of runoff for a 10 year recurrence interval from a drainage basin of 40 ha area. The land is flat (0-5% slope) and consists of cultivated clay soil. The maximum length of flow is 800 m and the difference in elevation between the most remote point and outlet is 7.5 m. Assume rainfall intensity is 6.5 cm/h.

Solution:

$$Average\ slope, S = \frac{H}{L}$$

$$= \frac{7.5}{800}$$

$$= 0.009375$$

$$T_c = 0.0195\ L^{0.77} S^{-0.385}$$

$$T_c = 0.0195 \; L^{0.77} S^{-0.385}$$

$$T_c = 0.0195 \; 800^{0.77} 0.009375^{-0.385}$$

$$= 20.24 \, min$$

From the table for arable land, 0-5% slope and clay soil, the value of runoff coefficient, C is 0.50.

$$Q_p = \frac{CIA}{360}$$

$$Q_p = \frac{0.50 \times 65 \times 40}{360}$$

$$Q_p = 3.61 \text{ m}^3\text{/s}$$

$$\boldsymbol{Q_p = 1.3 \times 10^4} \textbf{ m}^3 \textbf{/h (Ans.)}$$

Table 3.3
Values of run-off coefficient C

Topography and vegetation	Soil texture		
	Open sandy loam	Clay and silt loam	Tight clay
Woodland			
Flat 0-5 per cent slope	0·10	0·30	0·40
Rolling 5-10 per cent slope	0·25	0·35	0·50
Hilly 10-30 per cent slope	0·30	0·50	0·60
Pasture			
Flat	0·10	0·30	0·40
Rolling	0·16	0·36	0·55
Hilly	0·22	0·42	0·60
Cultivated			
Flat	0·30	0·50	0·60
Rolling	0·40	0·60	0·70
Hilly	0·52	0·72	0·82
Urban areas	30 per cent of area impervious	50 per cent of area impervious	70 per cent of area impervious
Flat	0·40	0·55	0·65
Rolling	0·50	0·65	0·80

From Schwab, Frevert, Edminster, and Barnes. *Soil and water conservation engineering*, Wiley, New York.

Example W11.3:

Assuming an Interest rate of 5.5 percent, average cost for irrigation works ₹1,125 per hectare, total drainage cost of ₹875 per hectare, operation and maintenance annual cost ₹23.75 per hectare

Distribution of acreages by economic land class

Class	Hectares	Net direct benefits by land class: (Annual benefit per hectare) in ₹	Total annual benefit [hectares x annual benefit]
1	96	181.25	17,400
2	40	156.50	6,260
2	120	107.75	12930
total			₹36,590

Average annual benefit = ₹36,590/256 = ₹142.93 per hectare

Find an estimate of the economic feasibility over the 100-year life expectancy of the drainage system

Solution:

Present worth (PW of capitalized average annual benefit):

PW = interest factor x annual benefit

$$Pw = \frac{(1+i)^n - 1}{i(1+i)^n} \text{x ₹}142.93 = \text{₹}2586.46 \text{ per hectare}$$

where:

n = number of interest periods in years, and

I = interest rate at which compounding takes place over the period, 12, expressed as a decimal fraction.

Present worth of capitalized annual O&M costs:

$$Pw = \frac{(1+i)^n - 1}{i(1+i)^n} \text{x ₹}23.75 = \text{₹}429.78 \text{ per hectare}$$

cost summary :

Drainage = ₹875 per hectare

Irrigation = ₹1,125 per hectare

O&M = ₹430 per hectare

Total = ₹2,430 per hectare

Benefit-cost (B/C) ratio $=\frac{2586}{2430}=1.06$

Drainage projects having B/C ratios greater than 1 are generally considered feasible

Thank You!!