Infiltration

Infiltration: The movement of water through the soil surface in to the soil.

Infiltration Capacity (fp) (**mm/hr**) (Potential Infiltration Rate) : The maximum rate at which soil can absorb water through its surface.

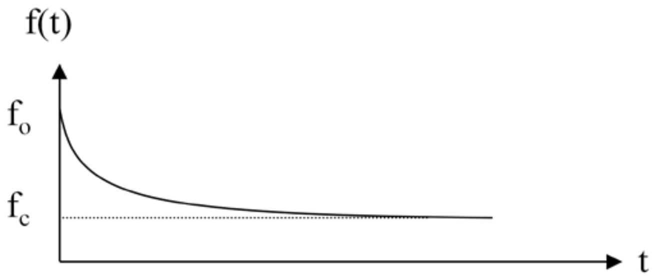
Infiltration Rate, f(t):Rate of water entering the soil surface. If there is no limit on the water supply for infiltration, f(t) = fp. Otherwise,

$0 \le f(t) < fp$.

fo = initial infiltration rate

fc = ultimate infiltration rate

f(t) - fc = excess infiltration rate



Cumulative Infiltration, F(t) : Depth of infiltration from the beginning of rainfall to any time, t.

F(t) = Area under the infiltration curve $= \int_0^t f(t)\, dt$

Experimental Methods

Double Ring Infiltrometer

Purpose:

–measure infiltration capacity

Principle:

–fill rings

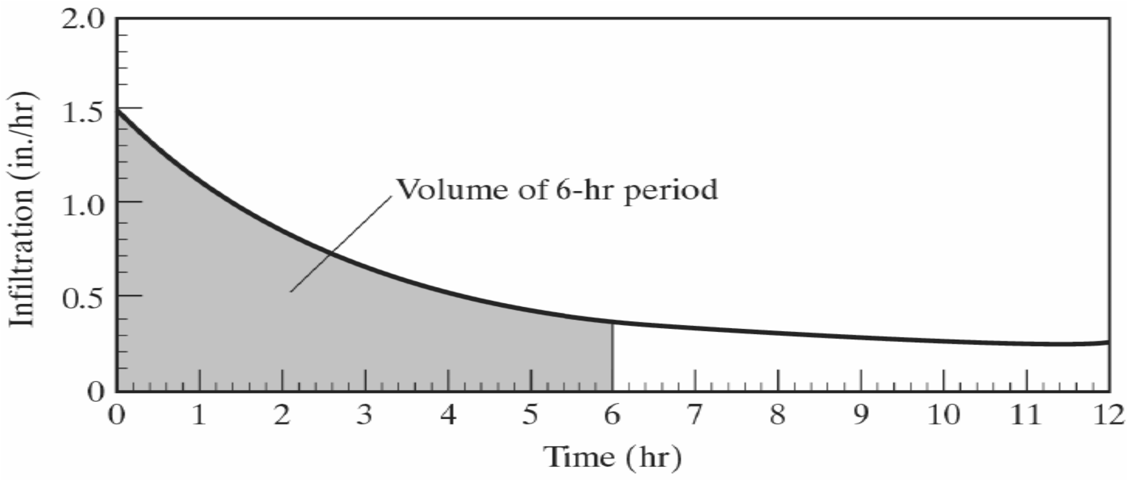
–measure rate of drop in water level of inner ring over time

Infiltration capacity curve

Definition

-maximum infiltration rate [cm/hr or in/hr]

-time dependent to some extent



Infiltration process

Infiltration rates depend on both surface and subsurface conditions:

Surface conditions: Availability of water

Subsurface conditions: Ability of water to infiltrate

Rainfall intensity = I

Actual Infiltration rate = f

Infiltration capacity = fp

Infiltration capacity and infiltration rate

Case 1: Rainfall intensity exceeds infiltration capacity

–Water will pond

–Actual infiltration rate = infiltration capacity

f = fp

–Surface runoff

Case 2: Infiltration capacity exceeds rainfall intensity

–All rain infiltrates no ponding

–Actual infiltration rate = rainfall intensity

f = i

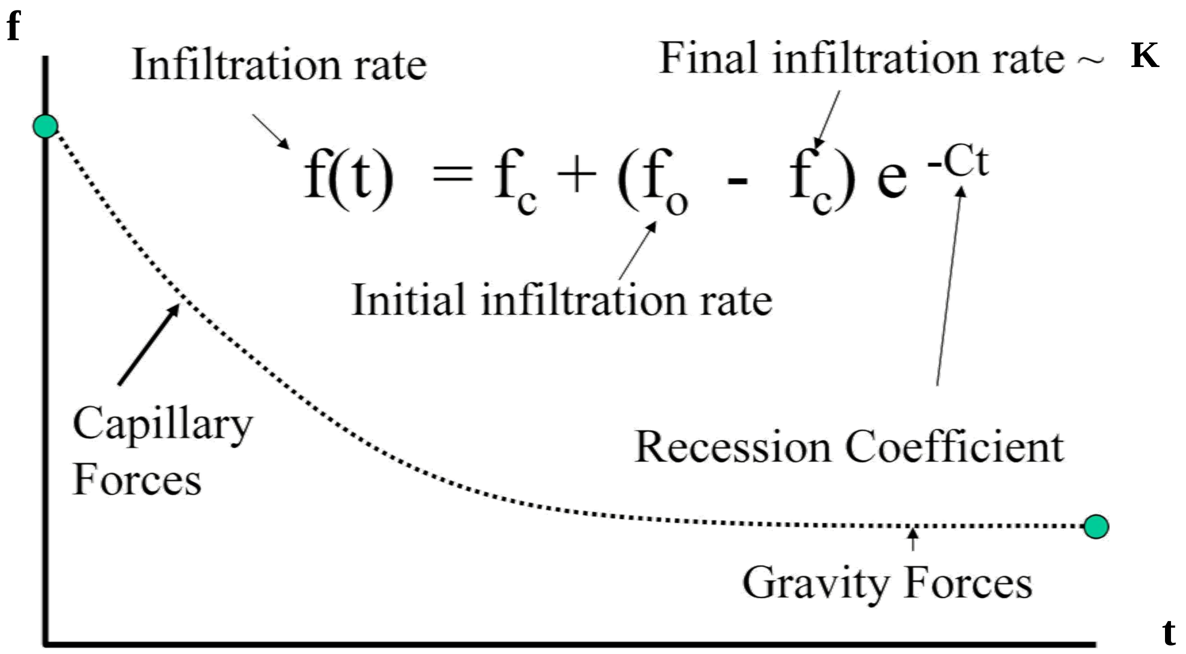
–No surface runoff

Factors Affecting Infiltration

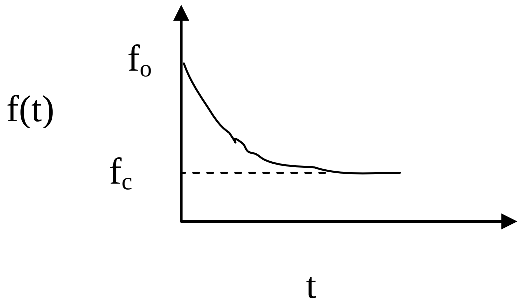
- physical properties of the soil
- soil moisture
- rainfall intensity
- land use
- temperature
- water quality

Infiltration Equations

1- Horton's Equation



$$f(t) = f_c + (f_o - f_c)\, e^{-Ct}$$ **(Horton equ.)**



Where:

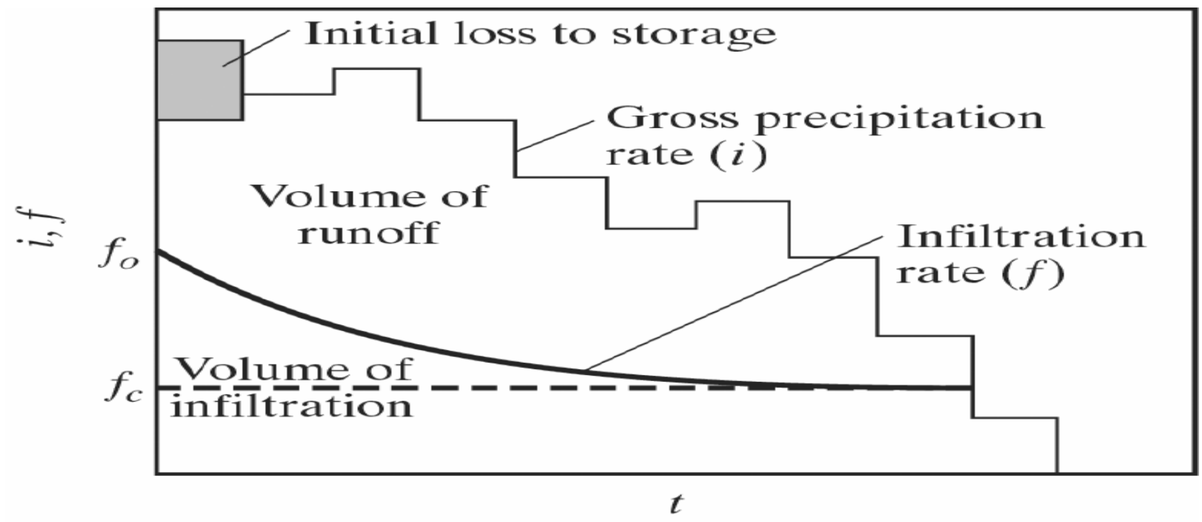
Infiltration rate [in/hr or cm/hr]:

f(t) =Rate of disappearance of water.

f_o= initial infiltration rate at t = 0

f_c= ultimate (final) infiltration rate (constant value)

k = exponential (time) decay constant [hr-1]



Horton's infiltration concept.

Horton's Equation

Advantages:

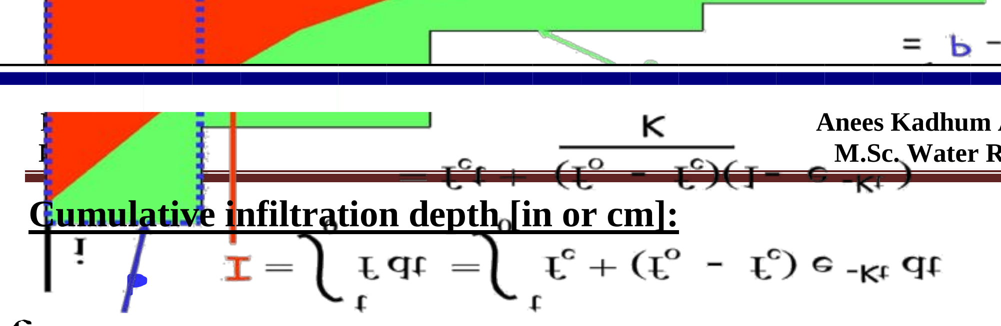
– Simple

– Can be applied graphically

Disadvantages:

– Parameters hard to estimate

– Only valid for i > f



Cumulative infiltration depth [in or cm]:

$$F(t) = \int_0^t f\,dt = \int_0^t f_c + (f_o - f_c)\, e^{-Kt}\, dt$$

$$= f_c\, t + \frac{(f_o - f_c)(1 - e^{-Kt})}{K}$$ (Cumulative infiltration depth) [in or cm]

Example:

A watershed has the following Horton parameters:

fo= 1.5 in/hr

fc= 0.2 in/hr

k = 0.35 hr $^{-1}$

a) Determine infiltration capacity at t=10 min, 30 min, 6 hrs.

b) Total depth of infiltration during a 6-hr period, assuming rainfall intensity exceeds infiltration capacity.

Solution:

Infiltration capacity:

$f(t) = 0.2 + 1.3\, e^{-0.35\, t}$ (in / hr)

t (hr)	f (in /hr)
1/6	1.43
0.5	1.29
6	0.36

Cumulative depth:

$$F(t) = f_c\, t + \frac{(f_o - f_c)(1 - e^{-Kt})}{K}$$

$$= 0.2\, t + 3.71\, (1 - e^{-0.35\, t})$$

F (6) = 4.46 inches

Example: H.W.

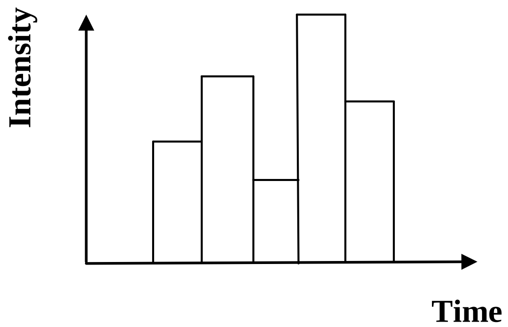
the parameters for Horton's equation are f_c= 1.0 cm/hr, f_o=5.0 cm/hr and k=2 hr^{-1} . Determine the infiltration rate and cumulative infiltration after 0, 0.5, 1.0, 1.5, 2.0 hours if the rainfall rate is 6 cm/hr. Plot as a function of time. What would be the infiltration rate if the rainfall rate were 0.6 in/hr?

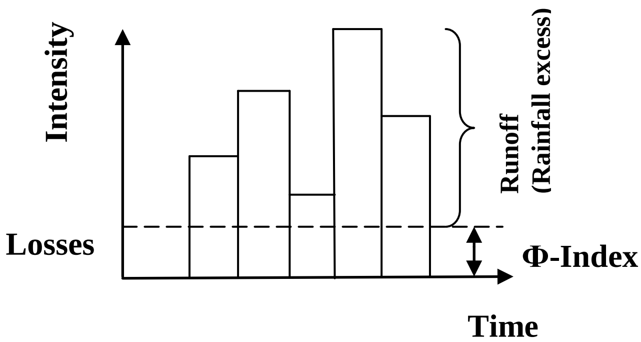
Infiltration indices

1-The Φ-Index:

Φ Index is the average rainfall intensity above which the volume of rainfall equals the volume of runoff **units of [in/hr] or [cm/hr]**

- The area above the dashed line represents measured runoff over the catchment area
- The area below the dashed line is the measured rainfall that did not appear as runoff but represents all the losses including interception, evaporation and infiltration



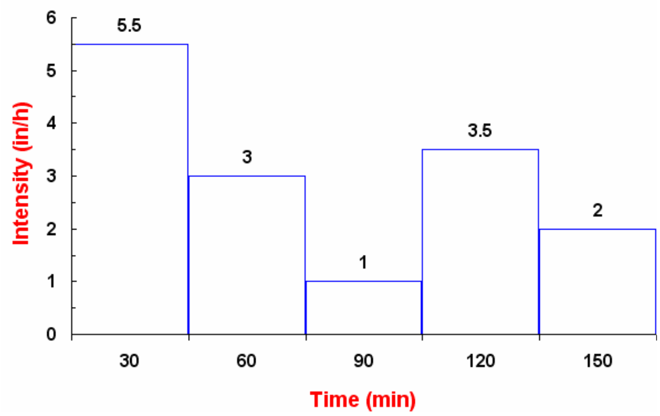


- To determine the Φ Index for a given storm, the amount of bserved runoff is determined and the difference between this quantity and the total gauged rainfall is then calculated
- The volume of loss is then distributed uniformly across the storm pattern
- It should be kept in mind that Φ Index varies as the storm intensity varies with time and thus Φ Index is of limited value and that many

determinations should be made and averaged before the index is used

Example: The rainfall intensities during each 30 min of a 150-min storm over a 500-acre basin are 5.5, 3, 1, 3.5, and 2 in/hr, respectively , The direct runoff from the basin is 105 acre-ft , Determine Φ Index for the basin

Solution:



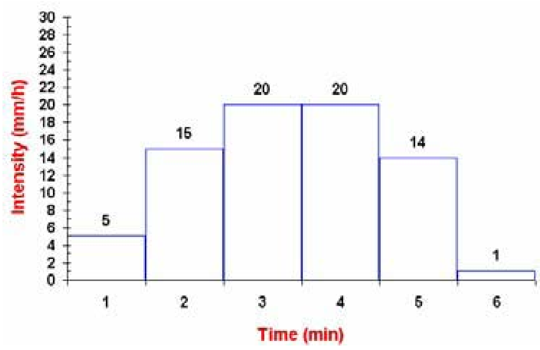
- Find the total rainfall as follows:

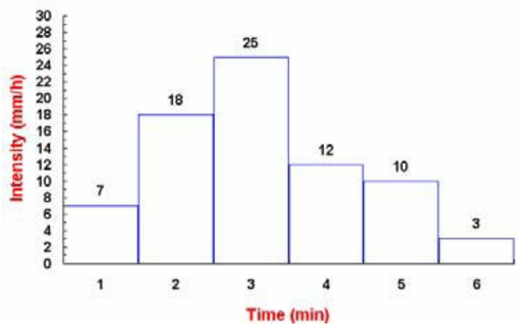
30/60 × (5.5 + 3 + 1 + 3.5 + 2) = 7.5 in or 0.625 ft

- Rainfall volume = 500 × 0.625 = 312.5 acre-ft
- Runoff volume = 105 acre-ft
- Volume under Φ Index = 312.5 – 105 = 207.5 acre-ft
- Infiltration depth (losses depth) = 207.5/500 = 0.415 ft or 5 in
- Φ Index = 5 × (1/150) × (60) = 1.98 in/hr

Example:

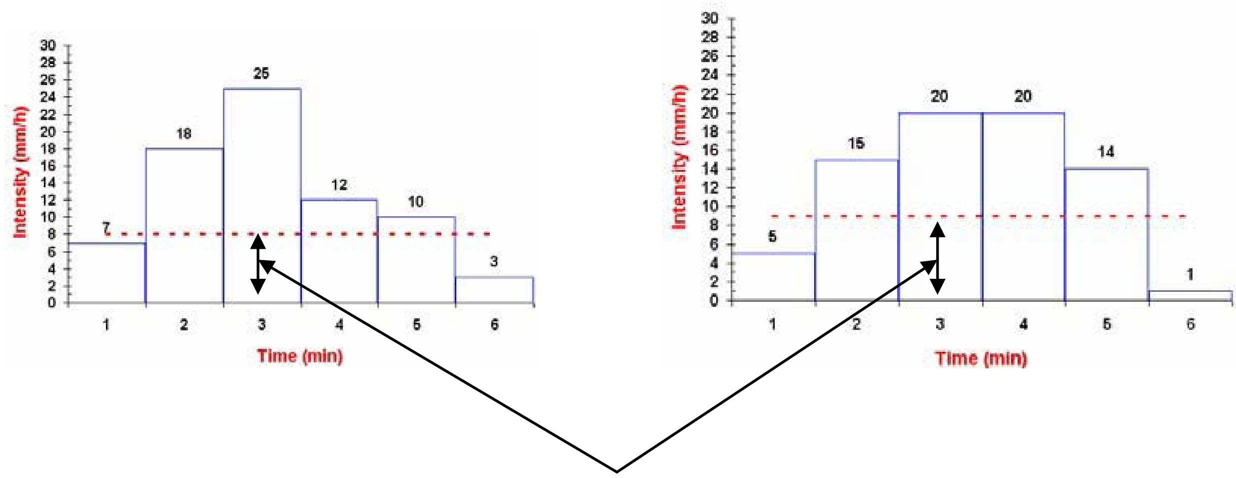
- You have two storm events of 75 mm of a total duration of 6 hours as shown in the figures
- Both produced a total runoff equivalent to 33 mm
- Find out the Φ Index for the two storm events





solution:

Φ= 8 mm/hr **Φ= 9 mm/hr**



Φ-Index

Example:

- Compute the depth of runoff and the infiltration considering the rainfall event summarized in the table
- Assume a Φ Index value of 0.6

Time (hours)	Rainfall (in)
0	
2	1
4	2
6	4
8	1
	8

solution :

- Compute the intensity for each duration
- If the Φ Index is higher than the rainfall intensity then the infiltration equals the rainfall
- If the Φ Index is less than the rainfall intensity then the infiltration equals the Φ Index
- **Net rainfall intensity = the rainfall intensity – Φ Index**

Time (hours)	Rainfall (in)	i (in/hr)	Φ (in/hr)	f (in/hr)	F (in)	ie (in/hr)	Pe (in)
0							
2	1	0.5	0.6	0.5	1.0	0	0
4	2	1.0	0.6	0.6	1.2	0.4	0.8
6	4	2.0	0.6	0.6	1.2	1.4	2.8
8	1	0.5	0.6	0.5	1.0	0	0
	8				**4.4**		**3.6**

Example:

Use the rainfall data below to determine the φ-index for a watershed that is 0.875 mi^2, where the runoff volume is 228.7 ac-ft.

Solution:

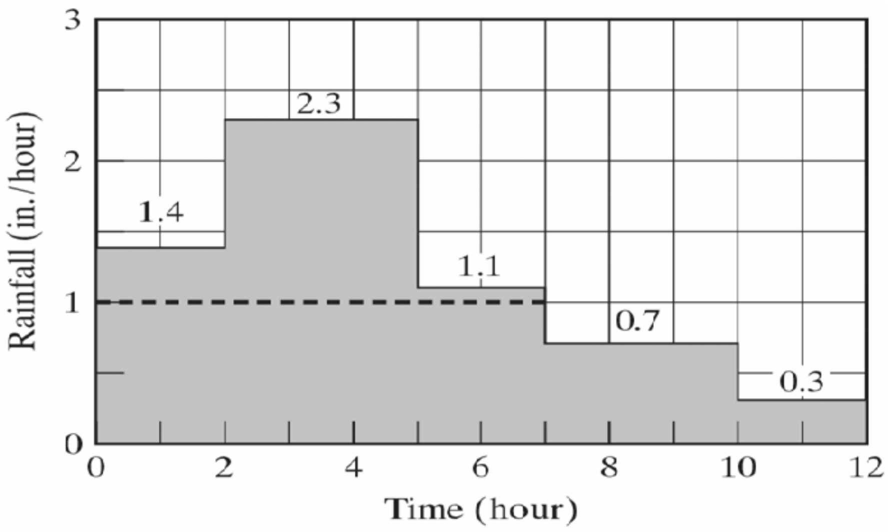


Figure E1.7

Time [hr]	Intensity [in/hr]
0-2	1.4
2-5	2.3
5-7	1.1
7-10	0.7
10-12	0.3

Depth of runoff

A = 0.875 sq mi × 640 acres/sq mi = 560 acres

$$Q = \frac{\text{volume}}{\text{area}} = \frac{228.7\ \text{ac}-\text{ft x } 12\frac{\text{in}}{\text{ft}}}{560\ \text{acr}} = 4.9 \text{ inches}$$

Area above φ-index must equal 4.9 inches.

2(1.4 – φ) + 3 (2.3 – φ) + 2(1.1 – φ) + 3(0.7 – φ) + 2(0.3 – φ) = 4.9

φ = 0.8

2. The w-Index:

W= (P-R)/t

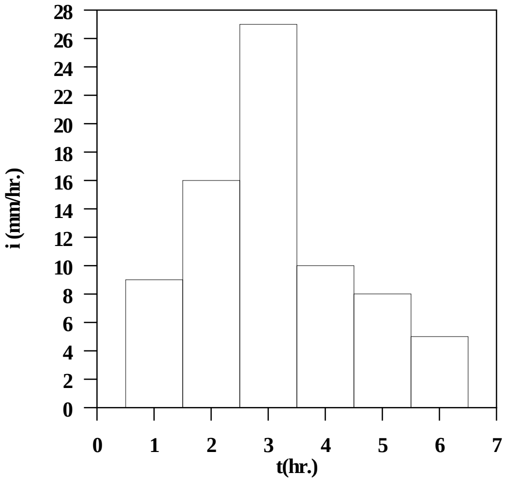
P = total precipitation (cm)

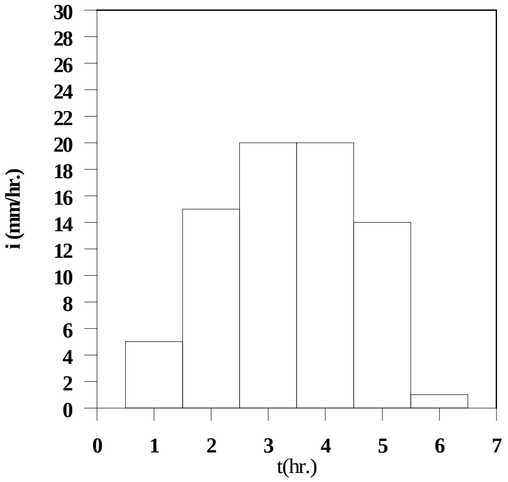
R = total runoff (cm)

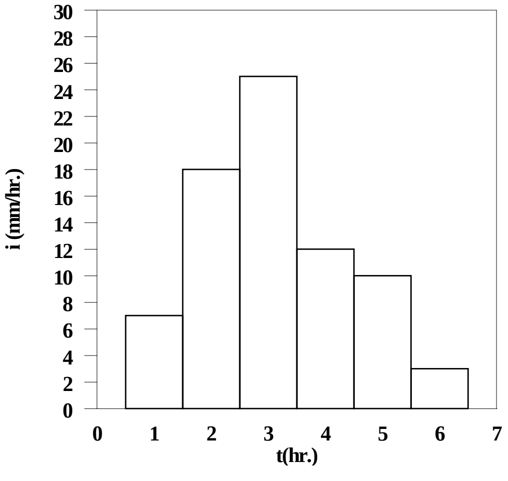
t = duration of rainfall (hour)

W= defined average rate of infiltration (cm)

<u>Example$_1$:</u> Find the Index of a certain catchment has the change of the rainfall intensity which given below. If the **runoff=33mm**, **P=75mm**







Example$_2$: A tabulated below are data for a number of storms happened on a river. Compute the W-index for all storms, what would be the av. Error and av. Percentage error in estimated runoff .If the av. W-index was used to compute the runoff?

Storm no.	Duration,t (hr.)	P (cm)	$R_{ob.}$ (cm)	W-index (cm/hr.)	$R_{comp.}$=P-W*t	Error=$R_{comp.}$-$R_{ob.}$
1	12	2.82	1.32	0.125	1.2	-0.12
2	48	2.98	1.02	0.041	0	-1.02
3	24	4.55	2.46	0.087	1.31	-1.15
4	72	14.22	7.42	0.094	4.5	-2.92
5	18	2.87	0.43	0.136	0.44	0.01
6	24	3.91	0.48	0.143	0.67	0.19
7	36	8.1	1.93	0.171	3.24	1.31
8	12	4.41	1.67	0.228	2.79	1.12
9	30	5.31	1.98	0.111	1.26	-0.72
10	18	6.98	3.15	0.213	4.55	1.4
			∑=21.86	∑=1.35	∑=19.96	∑=-1.9
				(W) ave = 1.35/10 = 0.135		Error=-0.19

For check:

Av. Error= (∑$R_{comp.}$- ∑$R_{ob.}$)/10

= (19.96-21.86)/10

=-0.19 ok.

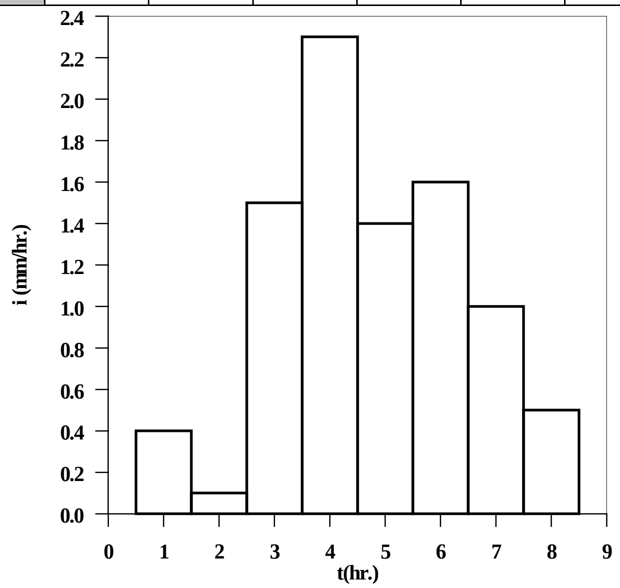
Example$_3$: A rain storm with intensity=**10cm** and direct runoff=**5.8cm** If the distribution of the storm as given in table below.

Find the

Φ-Index for the storm

t(hr.)	1	2	3	4	5	6	7	8
Excess	0.4	0.1	1.5	2.3	1.4	1.6	1	0.5

rainfall/hr.								



Example$_4$: The equation of the **f(t)** curve for a certain catchment is given by:

$$\mathbf{f(t) = 1.2 + 4.2\, e^{-0.33t}}$$

1-Compute the runoff volume for the following rain storm:

2- Compute Φ-Index & W- index and choose the best from them and explain cause that

t(hr.)	1	2	3	4	5	6
Rainfall(mm)	6	8.5	12.8	12.2	6.5	3

t(hr.)	**I_c**
0	5.4
1	4.2
2	3.4
3	2.8
4	2.3
5	2

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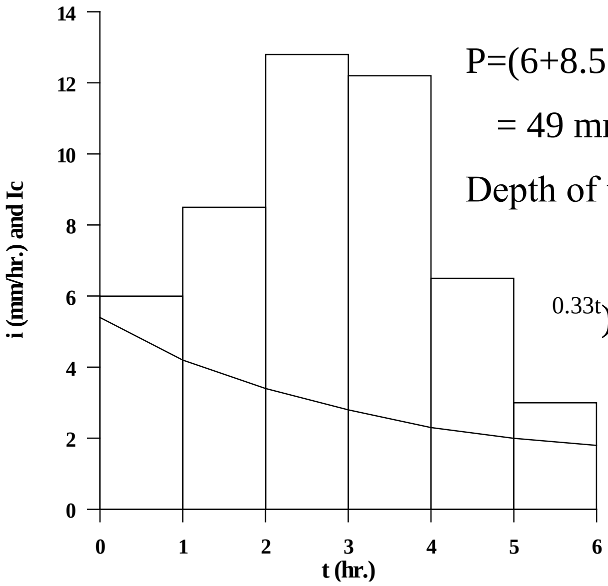
Solution:

6	1.8



P=(6+8.5+12.8+12.2+6.5+3)

= 49 mm

Depth of the infiltration =∫y dt

$=\int(1.2+4.2\,e^{-0.33t})dt$

$= 1.2t-(4.2/0.33)e^{-0.33t}]$

$-(4.2/0.33) *e^{-0.33*0}\ ]$

$=[1.2*6-(4.2/0.33)*e^{-0.33*6}]-[1.2*0$

= 18.19mm

R=P-I

=49-18.19

=30.81mm

W-index=(P-R)/t

=18.19/6

=3.032 mm/hr.

To Find The **Φ-Index:**

R=30.81 mm

30.81=(12.8-12.2)*1+(12.2-8.5)*2+(8.5-6.5)*3+(6.5-6)*4+(6- **Φ)**

30.81=16+6*5-5* Φ

Φ=3.038 mm/hr.

We choose the w-index because it gives larger surface runoff.

Example:

A catchment soil has the following Horton infiltration Parameters:

f_0 = 100 mm/min, f_c = 20 mm/min, and k = 2 min^{-1} the required.

1- Plot the infiltration capacity curve with time for this catchment

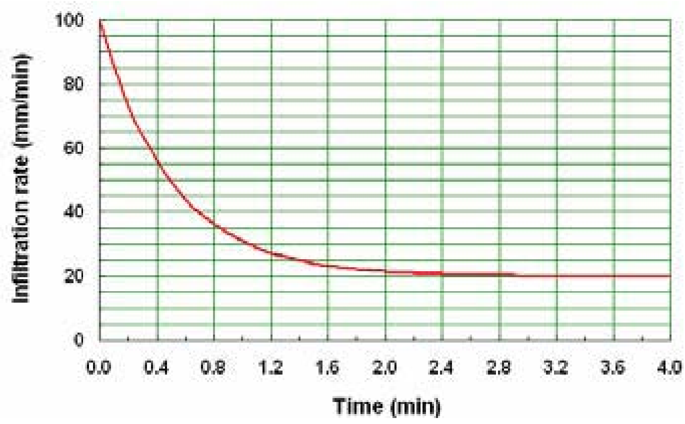
2- Plot the potential cumulative infiltration for this catchment

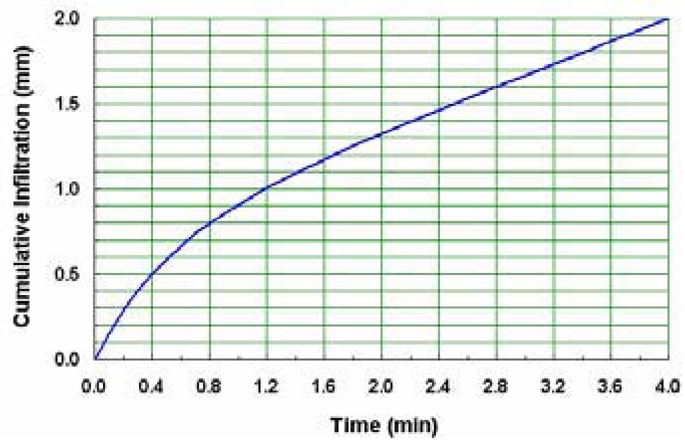
Solution:

$f(t) = f_c + (f_o - f_c)\, e^{-Kt}$ **(Horton equ.)**

$F(t) = f_c\, t + \frac{(f_o - f_c)(1 - e^{-Kt})}{K}$ **(cumulative infiltration rate)**

t (min)	f_p (mm/min)	F (mm)
0.0	100.00	0.00
0.2	73.63	0.29
0.4	55.95	0.50
0.6	44.10	0.67
0.8	36.15	0.80
1.0	30.83	0.91
1.2	27.26	1.01
1.4	24.86	1.09
1.6	23.26	1.17
1.8	22.19	1.25
2.0	21.47	1.32
2.2	20.98	1.39
2.4	20.66	1.46
2.6	20.44	1.53
2.8	20.30	1.60
3.0	20.20	1.67
3.2	20.13	1.73
3.4	20.09	1.80
3.6	20.06	1.87
3.8	20.04	1.93
4.0	20.03	2.00
4.2	20.02	2.07





Example:

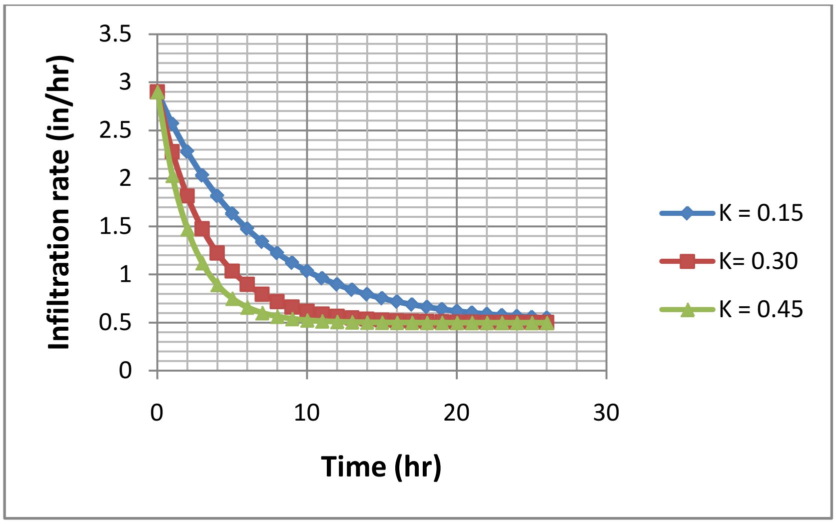
 Find out the sensitivity of the infiltration capacity curve to different decay coefficients (k) assuming that f_0 = 2.9 in/h and f_c = 0.5 in/h

 Assume k values = 0.15, 0.30, and 0.45 hour $^{-1}$

Solution:

$$f(t) = f_c + (f_o - f_c)\, e^{-Kt} \quad \text{(Horton equ.)}$$

t (hr)	f_p(in/hr)	f_p(in/hr)	f_p(in/hr)
	K= 0.15	K= 0.30	K= 0.45
0	2.9	2.9	2.9
1	2.6	2.3	2
2	2.3	1.8	1.5
3	2	1.5	1.1
4	1.8	1.2	0.9
5	1.6	1	0.8
6	1.5	0.9	0.7
7	1.3	0.8	0.6
8	1.2	0.7	0.6
9	1.1	0.7	0.5
10	1	0.6	0.5
11	1	0.6	0.5
12	0.9	0.6	0.5
13	0.8	0.5	0.5
14	0.8	0.5	0.5
15	0.8	0.5	0.5
16	0.7	0.5	0.5
17	0.7	0.5	0.5
18	0.7	0.5	0.5
19	0.6	0.5	0.5
20	0.6	0.5	0.5
21	0.6	0.5	0.5
22	0.6	0.5	0.5
23	0.6	0.5	0.5
24	0.6	0.5	0.5
25	0.6	0.5	0.5
26	0.5	0.5	0.5


3.5
3
2.5
2
1.5
1
0.5
0
Infiltration rate (in/hr)
0
10
20
30
Time (hr)
K = 0.15
K= 0.30
K = 0.45