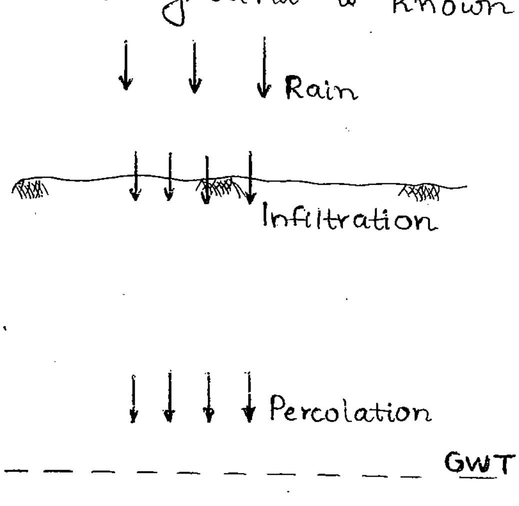
05. INFILTRATION

Infiltration is the method by which water get into surface strata of the Earth to meet soil moisture deficiency.

- After meeting the soil moisture deficiency if any excess water remain in the ground, flow vertically deep into the ground and join ground water table.
- Deep vertical movement of water in the ground is known as '~~Precipitation~~'. 'Percolation'



* Infiltration Capacity: (f_c)

It is the maximum rate at which soil is capable of absorbing water.

* Infiltration Rate: (f_a)

It is the actual rate of infiltration at a given time at a given place under specific conditions.

* Relation among f_a, f_c, i :

$$f_a = f_c \quad \text{when} \quad i \geq f_c$$

$$f_a = i \quad \text{when} \quad i < f_c$$

-23.

1. When $i < f_c$, $f_a < f_c$ or $f_a = i$

2. $f_c = 0.2$ cm/hr.

   $i = 0.5$ cm/hr.

   $i > f_c \Rightarrow f_a = f_c = \underline{\underline{0.2 \text{ cm/hr}}}$

→ Factors affecting Infiltration:

1. Porosity of Soil, (n)

$$f \propto n$$

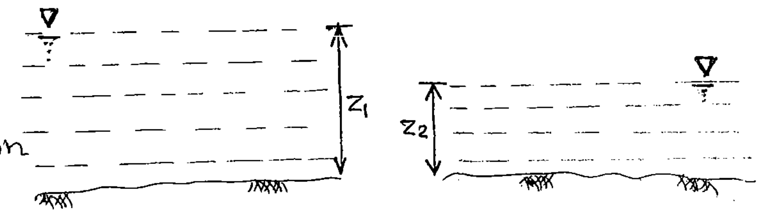
2. Moisture content of Soil, (mc)

$$f \propto \frac{1}{mc}$$

3. Depth of Surface retention, (z)

$$f \propto z$$

more depth ⇒ more infiltration



4. Vegetation

$$f \propto \text{vegetative cover}$$

5. Compaction (due to men, animal, rain etc).

$$f \propto \frac{1}{\text{compaction}}$$

6. Washing of fines

$$f \propto \frac{1}{\text{washing of fines}}$$

7. Entrapment of air.

$$f \propto \frac{1}{\text{entrapment of air}}$$

8. Temperature

As temperature increases, viscosity decreases and resistance to flow decreases and infiltration increases.

$$f \propto \text{temperature.}$$

→ Measurement & Estimation of Infiltration :

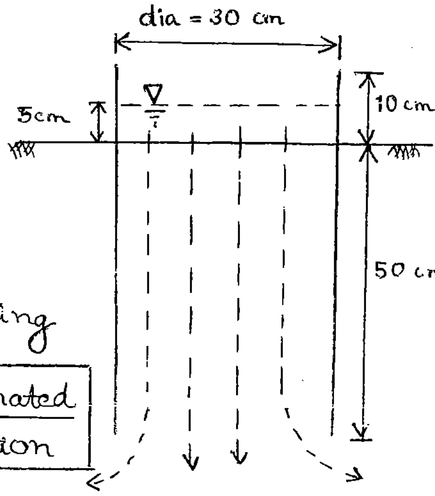
1. Infiltrometer

- For field measurement of infiltration.

(i) Single Ring Infiltrometer.

- Depth of water infiltrated (infiltration)

$$= \frac{\text{vol. of water infiltrated}}{\text{c/s area of infiltrometer.}}$$

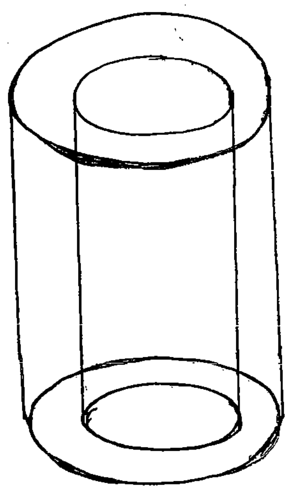


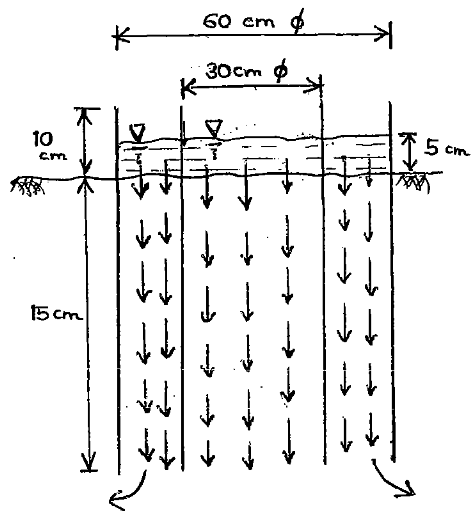
Volume of water infiltrated = volume of water added to ring

$$\text{Infiltration rate} = \frac{\text{depth of water infiltrated}}{\text{duration of infiltration}}$$

- Test is conducted till constant infiltration rate is achieved.
- Single ring infiltrometer always overestimate because of lateral movement of water. To overcome this problem, double ring infiltrometers are used

(ii) Double Ring Infiltrometer





Infiltration

$$= \frac{\text{vol of water added to internal ring}}{\text{c/s area of internal ring}}$$

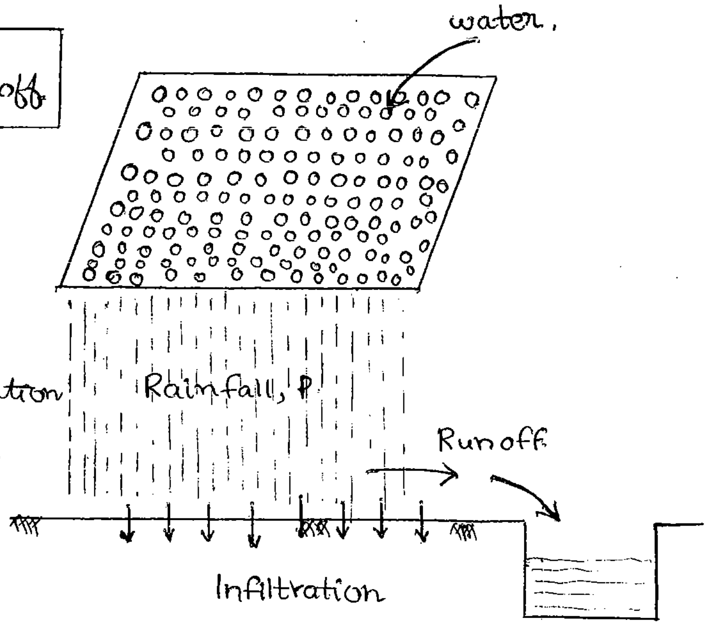
Infiltration rate

$$= \frac{\text{infiltration}}{\text{duration of infiltration}}$$

2. Rainfall Simulator

- laboratory measurement
- test plot of size 2m * 4m

Infiltration = Rainfall − Runoff



⊙ $f_{(infiltrometer)} > f_{(rainfall\ simulator)}$

As depth of retention increases in infiltrometer, rate of infiltration is more in infiltrometer compared to rainfall simulation.

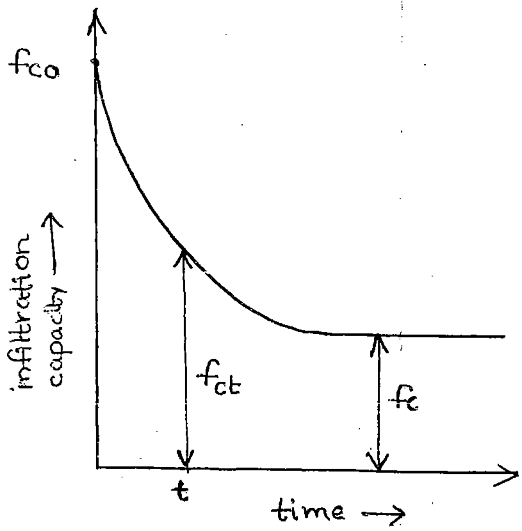
3. Horton's Infiltration Capacity Curve.

- Horton has conducted infiltration studies in his laboratory by simulating $i \geq f_c$ on different soils and concluded the following:

(i) Infiltration capacity is max at the beginning of the storm and it exponentially decreases as storm duration increases

(ii) It attain steady state at some point of time and remain in that state indefinitely.

(iii) I



- The above diagram is obtained by plotting the observations of the test known as 'Horton's Infiltration Capacity Curve'.

$$f_{ct} = f_c + (f_{co} - f_c)\, e^{-kt}$$

Above equation represents the curve, where.

f_{co} → infiltration capacity at time $t=0$

f_c → steady state infiltration capacity.

f_{ct} → infiltration capacity at any time 't'

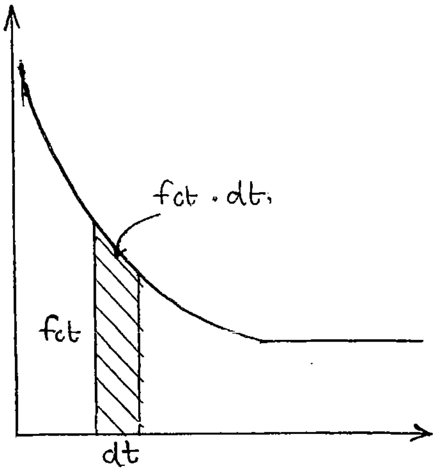
k → infiltration rate constant.

- using the Horton Infiltration Curve, total infiltration in given time 't' as well as infiltration b/w any two periods can be worked out; along with actual rate of infiltration.

- Infiltration in time; 'dt'

  = Area under Horton's Infiltration Capacity Curve in time, 'dt'

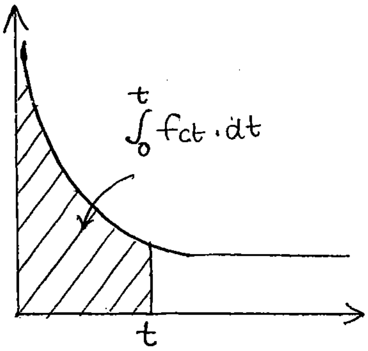
  = $f_{ct} * dt$



⇒ Total infiltration in time t

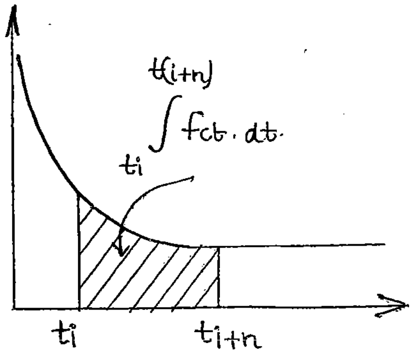
= Area under Hortons IC Curve upto time t.

$= \int_0^t f_{ct} * dt.$



- Infiltration b/w time intervals t_i & t_{i+n} $= \int_{t_i}^{t_{i+n}} f_{ct} . dt.$

  = Area under Horton's IC Curve b/w time intervals t_i & t_{i+n}.



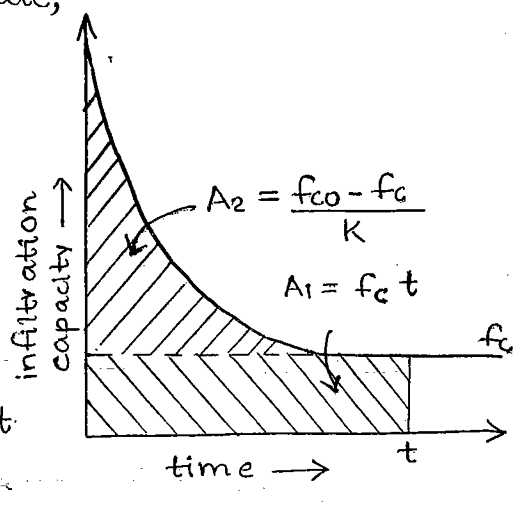
- When soil has attained steady state,

  At any time, 't', $f_{ct} = f_c$

Total infiltration = area under IC Curve

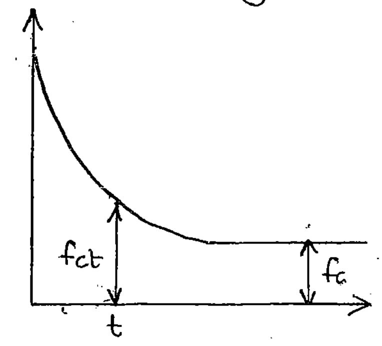
$= A_1 + A_2$

Total infiltration in time 't' $= f_c t + \frac{f_{co} - f_c}{K} = \int_0^t f_{ct} \, dt$



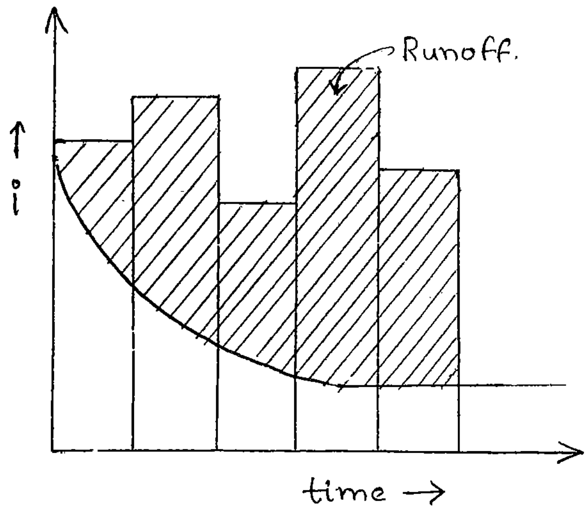
⊙ At any time t, $f_{ct} > f_c$, soil yet to attain steady state

$$\text{Infiltration} = \int_0^t f_{ct} \cdot dt$$



– By superimposing, Horton's IC curve over Rainfall Hyetograph, along with infiltration, runoff can also be estimated.

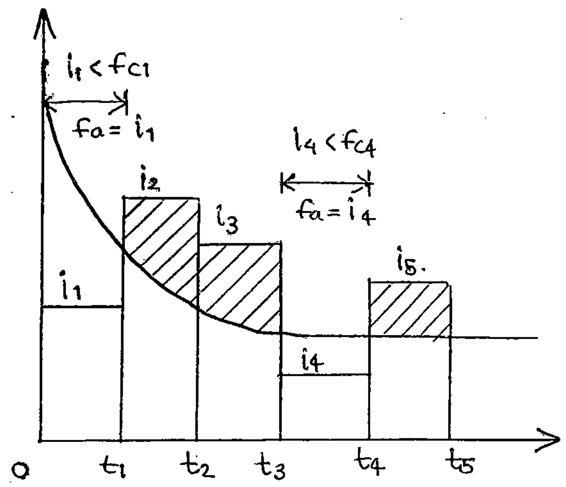
Run off = Area of hyetograph above Horton IC Curve



$$\text{Runoff} = \sum_0^t i_i t_i - \int_0^t f_{ct} \, dt$$

Total rainfall $= i_1(t_1 - 0) + i_2(t_2 - t_1) + i_3(t_3 - t_2) + i_4(t_4 - t_3) + i_5(t_5 - t_4)$.

Total infiltration $= i_1(t_1 - 0) + \int_{t_1}^{t_2} f_{ct}\, dt + i_4(t_4 - t_3) + \int_{t_4}^{t_5} f_{ct}\, dt$.



2-23

03. $f_c = 1.34$, $f_o = 7.62$, $k = 4.182$, $t = 2$ hours.

Infiltration at the end of 2 hours $= f_c \times t + \frac{f_o - f_c}{K} \times$

$= 1.34 \times 2 + \frac{7.62 - 1.34}{4.182}$

$= 4.182$ cm

04. $f_c = 0.5$ cm/hour ; $t = 8$ hours. (27)

$f_0 = 2$ cm/hour ; $K = 4\ (\text{hour})^{-1}$

Total infiltration during 8 hours $= f_c t + \dfrac{f_0 - f_c}{K}$

$= 0.5 \times 8 + \dfrac{2 - 0.5}{4}$

$= \underline{\underline{4.375 \text{ cm}}}$

05. Rainfall in 24 hours = 10 cm.

Pan evaporation in 24 hours = 0.6 cm.

Actual evaporation in 24 hours $= 0.6 \times 0.7 = 0.42$ cm.

Steady state has attained @ 15^{th} hour:

$f_{co} = 1$ cm/hr, $f_c = 0.3$ cm/hr

$K = 5\ (\text{hr})^{-1}$

Total infiltration in 24 hours $= 0.3 \times 24 + \dfrac{1 - 0.3}{5}$

$= 7.34$ cm.

Run off = Rainfall − (infiltration + evaporation).

$= 10 - (7.34 + 0.42) = 2.24$ cm.

Volume of run off $= 2.24 \times 10^{-2} \times 1.8 \times 10^{06}$

$= \underline{\underline{40320 \text{ m}^3}}$

th Dec,
TURDAY

$f_{ct} = 6 + 16\, e^{-2t}$ $\quad (f_{ct} = f_c + (f_{co} - f_c)\, e^{-kt})$.

$f_c = 6$ mm/hr

$f_{co} - f_c = 16$

$\therefore f_{co} = 16 + 6 = 22$ mm/hr

$K = 2\ \text{hr}^{-1}$

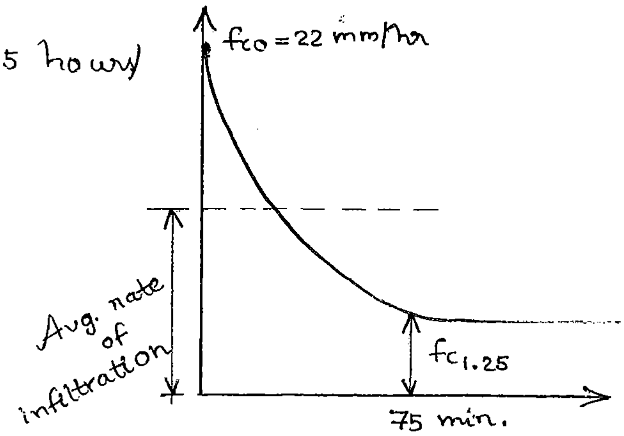
Total infiltration in first 45 min $= \int_0^{0.75} (6 + 16e^{-2t})\, dt$.

$= \underline{\underline{10.715 \text{ mm}}}$

Total Infiltration at 75 min (1.25 hours)

$= 6 + 16e^{-2 * 1.25}$

$= 7.31$ mm/hr.



Total infiltration in 1.25 hours.

$= \int_0^{1.25} f_{ct} \cdot dt = \int_0^{1.25} (6 + 16e^{-2t})\, dt$

$= 14.84$ mm.

∴ Average infiltration rate for first 75 min $= \dfrac{\text{total infiltration}}{\text{time}}$

$= \dfrac{14.844}{1.25} = \underline{\underline{11.875 \text{ mm/hr}}}$

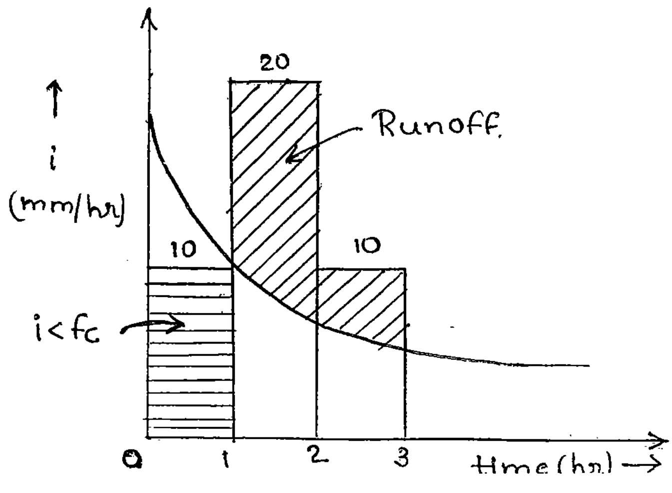
07.

Time	i (mm/hr)	$f_{ct} = 6.8 + 8.7e^{-t}$ (mm/hr)
0	10	15.5
1		10
1–2	20	7.97
2–3	10.	7.23

15.5, 10 } Horton's approach failed $i < f_c \Rightarrow f_a = i$

10, 7.97, 7.23 } Horton's approach is true. $i > f_c \Rightarrow f_a = f_{ci}$

Run off = Effective rain
= Rainfall excess.
= Excess rainfall.
= Net rain.

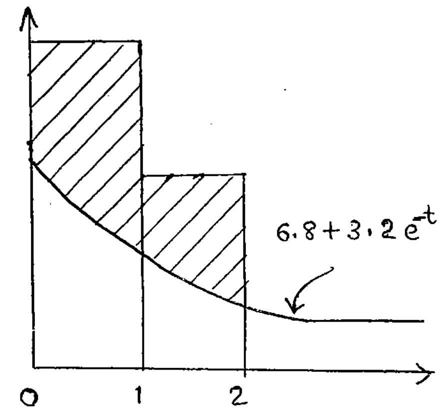


Runoff = area of hyetograph above IC curve $= \sum_{i=1}^{3} i_1 t_1 - \int_1^3 f_{ct}\, dt$

$= 20 \times 1 + 10 \times 1 - \int_1^3 (6.8 + 8.7 e^{-t})\, dt$

$= 30 - 16.367 = \underline{13.633 \text{ mm}}$

(OR)



$f_{ct} = 6.8 + (10 - 6.8)\, e^{-t}$

$= 6.8 + \underline{3.2 e^{-t}}$

Runoff = rainfall − infiltration.

$= 20 \times 1 + 10 \times 1 - \int_0^2 (6.8 + 3.2 e^{-t})\, dt$

$= \underline{13.63}$

Q. Rainfall over a basin in 3 consecutive hours are 4 cm, 5 cm, 3 cm resptly. Estimate the surface runoff from basin assuming negligible surface retention and evaporation losses. Infiltration loss can be estimated using Horton's equation $f = 1.2 + 4.2 e^{-2.5t}$, where f is infiltration in cm/hr, t is time in hour from start of rainfall.

Time t	Rainfall intensity i (cm/hr)
0 – 1	4
1 – 2	5
2 – 3	3

$f_{ct} = 1.2 + 4.2 e^{-2.5t}$

$f_{c0} = 5.4$

$f_{c1} = 1.54$

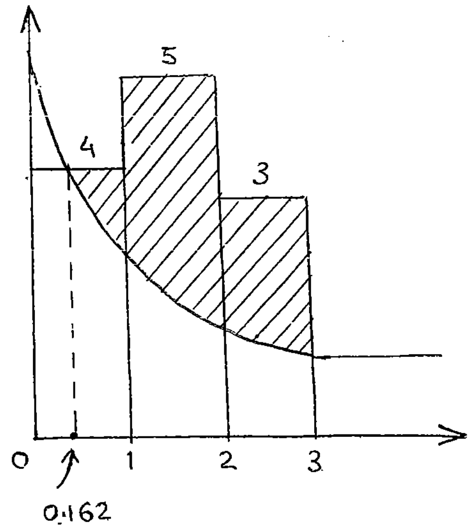
$f_{c2} = 1.23$

$f_{c3} = 1.20$

$f_{ct} = 4 = 1.2 + 4.2e^{-2.5t}$

$e^{-2.5t} = \frac{4-1.2}{4.2}$

$t = \frac{0.415}{2.5} = 0.162$ hr.



Runoff = area of hyetograph above IC curve.

$= \sum_{t=0.162}^{3} i_1 t_1 - \int_{0.162}^{3} f_{ct} \cdot dt$

$= (4 \times 0.838 + 5 \times 1 + 3 \times 1) - \int_{0.162}^{3} (1.2 + 4.2\, e^{-2.5t})\, dt$

$= \underline{6.8627 \text{ cm}}$

08. $f_{co} = 10$ mm/hr, $f_c = 1.2$ mm/hr, $t = 10$ hr.

Total infiltration $= f_c t + \frac{f_{co} - f_c}{K}$

$33 = 1.2 \times 10 + \frac{10 - 1.2}{K}$

$\Rightarrow K = \underline{0.42 \ hr^{-1}}$

* Limitations of Horton's Approach:

1. True only for $i \geq f_c$

2. Applicable only for catchments with homogenous soil conditions.

→ Infiltration Indices :

Infiltration indices represents infiltration at an average rate.

- There are two infiltration indices :

1. ϕ index

ϕ index is the average rate of infiltration during the period of a storm at which there is runoff.

$$\phi \text{ index} = \frac{\text{infiltration during period of effective storm}}{\text{duration of effective storm.}}$$

Let Pe be the magnitude of effective storm.

te be the duration of effective storm.

R be the runoff.

$$\phi \text{ index} = \frac{Pe - R}{te}$$

2. ω index.

ω index is the average rate of infiltration during the entire period of a storm.

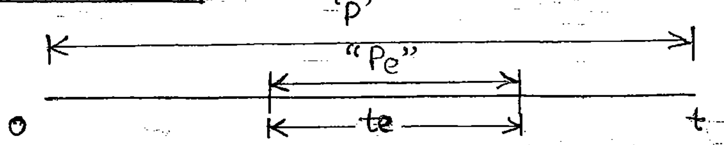
Let P be the total rainfall

t be the duration of total storm.

R be the runoff

$$\omega \text{ index} = \frac{\text{total infiltration during storm}}{\text{duration of storm}}$$

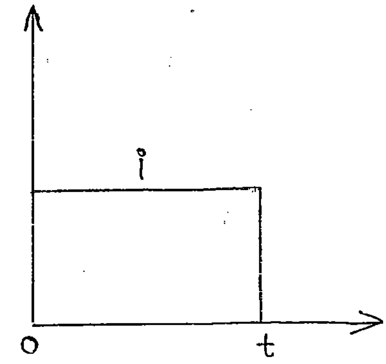
$$\omega \text{ index} = \frac{P - R - \text{losses}}{t}$$



- For uniform rains, $P = P_e$

$t = t_e$.

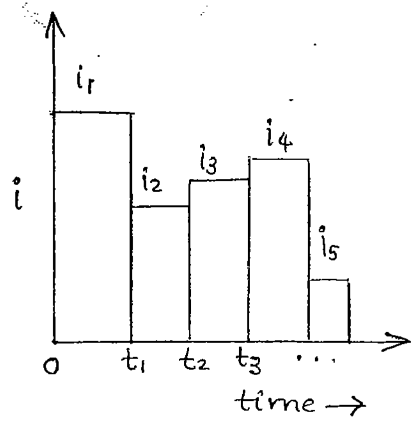
$\Rightarrow \phi$ index $= \omega$ index. (neglecting losses)



- For non-uniform rains, $P > P_e$

$t > t_e$

$\Rightarrow \phi$ index $>$ W index.



- When ϕ index line is super imposed over rainfall hyetograph, then, ϕ index is also defined as 'average rainfall intensity'; anything above which is runoff.

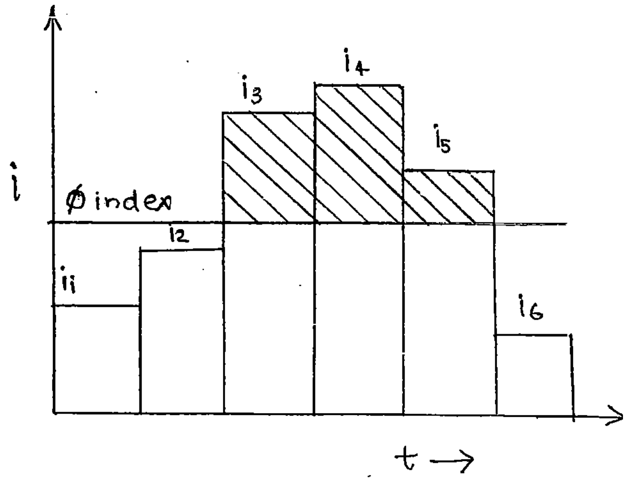
For the given example,

$$P = i_1 t_1 + i_2 t_2 + i_3 t_3 + i_4 t_4 + i_5 t_5 + i_6 t_6.$$

$$P_e = i_3 t_3 + i_4 t_4 + i_5 t_5$$

$$t = t_1 + t_2 + t_3 + t_4 + t_5 + t_6$$

$$t_e = t_3 + t_4 + t_5.$$



- Hyetograph lying above ϕ index is known as Effective Rainfall Hyetograph, 'ERH'

Run off = Area of effective rainfall hyetograph.

$$\boxed{\text{Run off} = \Sigma (i_i - \phi)\, t_i} \quad ; \quad i_i > \phi\text{ index.}$$

9. ϕ index = 0.5 cm/hr   Rainfall @ uniform storm, $P = P_e = 2$ cm.

$P = 2$ cm, $t = 6$ hour.

$$\phi = \frac{P_e - R}{t}$$

$$0.5 = \frac{2-R}{6} \; ; \quad R = -1 \Rightarrow R = 0$$

whenever run off value is −ve, then equate it to zero.

10. Uniform intensity - uniform storm.

$P = P_e$ & $t = t_e = 4$ hour.

$P = P_e = i \times t = 2.8 \times 4 = 11.2$ cm.

Volume of runoff $= 25.2 \times 10^6$ m³.

Catchment area $= 280$ km² $= 280 \times 10^6$ m².

$$\text{Depth of runoff} = \frac{\text{volume of runoff}}{\text{catchment area}} = \frac{25.2 \times 10^6}{282 \times 10^6}$$

$= 0.09$ m $= 9$ cm

Average infiltration rate of ϕ index = w index

$$= \frac{P_e - R}{t_e} = \frac{11.2 - 9}{4}$$

$= 5.5$ mm/hour

11. 4 hour storm.

4 cm = rainfall.

$$\phi \text{ index} = \frac{P-R}{t_e} = \frac{4-2}{4} = 0.5 \text{ cm/hour.}$$

$$0.5 \text{ cm/hr} = \frac{10-R}{8} \Rightarrow R = 6.0 \text{ cm}$$

12. Storm 1

$t_e = 5$ hour

$i = 2$ cm/hour

$R = 4$ cm

Storm 2

$t_e = 8$ hour

$R = 8.4$ cm

$$\phi \text{ index} = \frac{P-R}{t_e} = \frac{5\times2-4}{5} = 1.2 \text{ cm/hr}$$

13. Storm II :

$$\phi \text{ index} = \frac{P-R}{t_e}$$

$$P = 1.2\times8 + 8.4 = 18 \text{ cm}$$

$$i = \frac{18}{8} = 2.25 \text{ cm/hour}$$

14. $P = 7\times1 + 18\times1 + 25\times1 + 17\times1 + 11\times1 + 3\times1$

$= 81$ mm.

$R = 39$ mm.

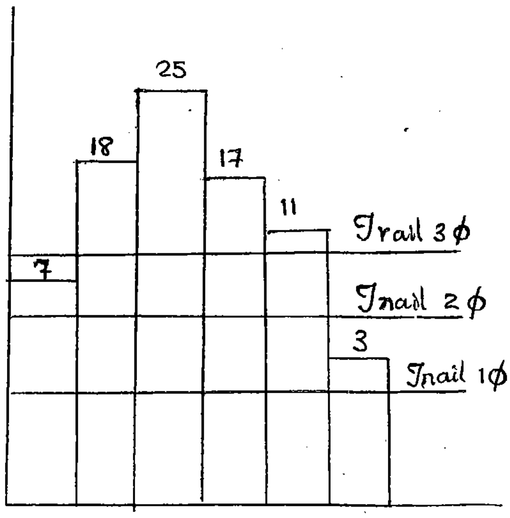
$$\phi \text{ index} = \frac{P-R}{t} = \frac{81-39}{6} = 7 \text{ mm/hr}$$

15. $P = 1.6\times0.5 + 3.6\times0.5 + 5\times0.5 + 2.8\times0.5 + 2.2\times0.5 + 1\times0.5$

$= 8.1$ cm.

$$\phi \text{ index} = \frac{P-R}{t} = \frac{8.1-3.6}{3} = 1.5 \text{ cm/hr}$$

14. Trail 1 : Assuming ϕ index < 3 mm/hr.



Run off $= \Sigma(i_i - \phi)t_i \rightarrow i_i > \phi$

$39 = (7-\phi) + (18-\phi) + (25-\phi) + (17-\phi) + (11-\phi) + (3-\phi)$

$$\phi = \frac{81-39}{6} = 7 \text{ mm/hr}$$ (assumption failed)

Trail 2 : Assuming $3 < \phi < 7$ mm/hr

Run off $= \Sigma (i_i - \phi)\, t_i \rightarrow i_i > \phi$

$39 = (7-\phi) + (18-\phi) + (25-\phi) + (17-\phi) + (11-\phi)$

$\phi = \frac{79-39}{5} = 7.8$ mm/~~failed~~ hr $\Rightarrow$ assumption failed.

Trail 3 : Assuming $7 < \phi$ index < 11 mm/hr.

Run off $= \Sigma (i_i - \phi)\, t_i \longrightarrow i_i > \phi$ index.

$39 = (18-\phi) + (25-\phi) + (17-\phi) + (11-\phi)$.

$\phi = 8$ mm/hr

(OR)

$P = \Sigma P_i t_i = 7\times1 + 18\times1 + 25\times1 + 11\times1 + 3\times1$

$= 81$ mm.

$t = 6$ hour.

W index $= \frac{P-R-\text{losses}}{t} = \frac{81-39}{6} = 7$ mm/hr

To find Pe & te, neglect $i_i \leq$ W index. :

$\therefore$ Pe $= 18\times1 + 25\times1 + 17\times1 + 11\times1 = 71$ mm

te $= 4$ hours

ϕ index $= \frac{71-39}{4} = 8$ mm/hr

15 $P = \Sigma P_i t_i = 1.6\times0.5 + 3.6\times0.5 + 5\times0.5 + 2.8\times0.5 + 2.2\times0.5 + 1\times0.5$

$= 8.1$ cm/hr.

$t = 3$ hour.

W index $= \frac{8.1-3.6}{3} = 1.5$ cm/hour.

ϕ index : to find Pe & te neglect $i \leq$ w index

$P_e = 1.6 \times 0.5 + 3.6 \times 0.5 + 5 \times 0.5 + 2.8 \times 0.5 + 2.2 \times 0.5$

$= 7.6$ cm/hour

$t_e = 3 - 0.5 = 2.5$ hour.

ϕ index $= \frac{7.6 - 3.6}{2.5} = \underline{\underline{1.6 \text{ cm/hr}}}$

16. $P = 1.6 + 5.4 + 4.1 = 11.1$

w index $= \frac{P - R - L}{t} = \frac{11.1 - 4.7 - 0.6}{24} = \underline{\underline{0.242}}$ cm/hr

$i_1 = \frac{1.6}{8} = \underline{\underline{0.2}}$ cm/hr $\quad i_2 = \frac{5.4}{8} = \underline{\underline{0.675}}$ cm/hr

$i_3 = \frac{4.1}{8} = 0.5125$ cm/hr

Neglect i_1 because $i_1 <$ W index.

$P = 0.675 \times 8 + 0.5125 \times 8 = 9.5$ cm

$t = 16$ hours.

ϕ index $= \frac{P - R}{t} = \frac{9.5 - 4.7}{16} = \underline{\underline{0.3}}$ cm/hr

17. W index $= \frac{P - R}{t} = \frac{(0.5 + 2.8 + 1.6) - 3.2}{2 + 2 + 2} = \underline{\underline{0.283}}$ cm/hr

$i_1 = \frac{0.5}{2} = 0.25$ cm/hr

$i_2 = \frac{2.8}{2} = 1.4$ cm/hr

$i_3 = \frac{1.6}{2} = 0.8$ cm/hr.

$P = 1.4 \times 2 + 0.8 \times 2 = 4.4.$

$t_e = 2 + 2 = 4$

ϕ index $= \frac{P - R}{t} = \frac{4.4 - 3.2}{4} = \underline{\underline{0.3 \text{ cm/hr}}}$

18. ϕ index $= 10$ mm/hour.

(31) (32)

Time	Rainfall (mm)	i (mm/hr) = P/t
0-1	9	9
1-2	28	28
2-3	12	12
3-4	7	7

$$\phi \text{ index} = \frac{P - R}{t}$$

$$10 = \frac{28+12-R}{2}$$

$$\Rightarrow R = 20 \text{ mm}$$

19 Total $P = 3 + 8 + 12 + 6 + 2 = 31$ cm

$$w \text{ index} = \frac{P-R}{t} = \frac{31-15}{24 \times 5} = 0.1333 \text{ cm/hr}.$$

$i_1 = \frac{3}{24} = 0.125$ cm/hr. $i_4 = \frac{6}{24} = 0.25$ cm/hr.

$i_2 = \frac{8}{24} = 0.33$ cm/hr. $i_5 = \frac{2}{24} = 0.0833$ cm/hr.

$i_3 = \frac{12}{24} = 0.5$ cm/hr

Neglecting $i_i \leq w$ index,

$$P = 8 + 12 + 6 = 26 \text{ cm}$$

$$\phi \text{ index} = \frac{P-R}{t} = \frac{26-15}{24 \times 5} = 0.153 \text{ cm/hr}$$

$$= 1.53 \text{ mm/hr}.$$