Infiltration

Infiltration is the process of entry of water into a soil through the soil surface. Once the water enters the soil:

Percolation is the water movement within the soil in the vertical direction and Seepage is in the horizontal direction.

Infiltration rate (f) is the rate at which the water enters into the soil surface. It is expressed as volume per unit area per unit time (L/T). If there is no limit to the availability of water, then the infiltration rate is the same as the infiltration capacity.

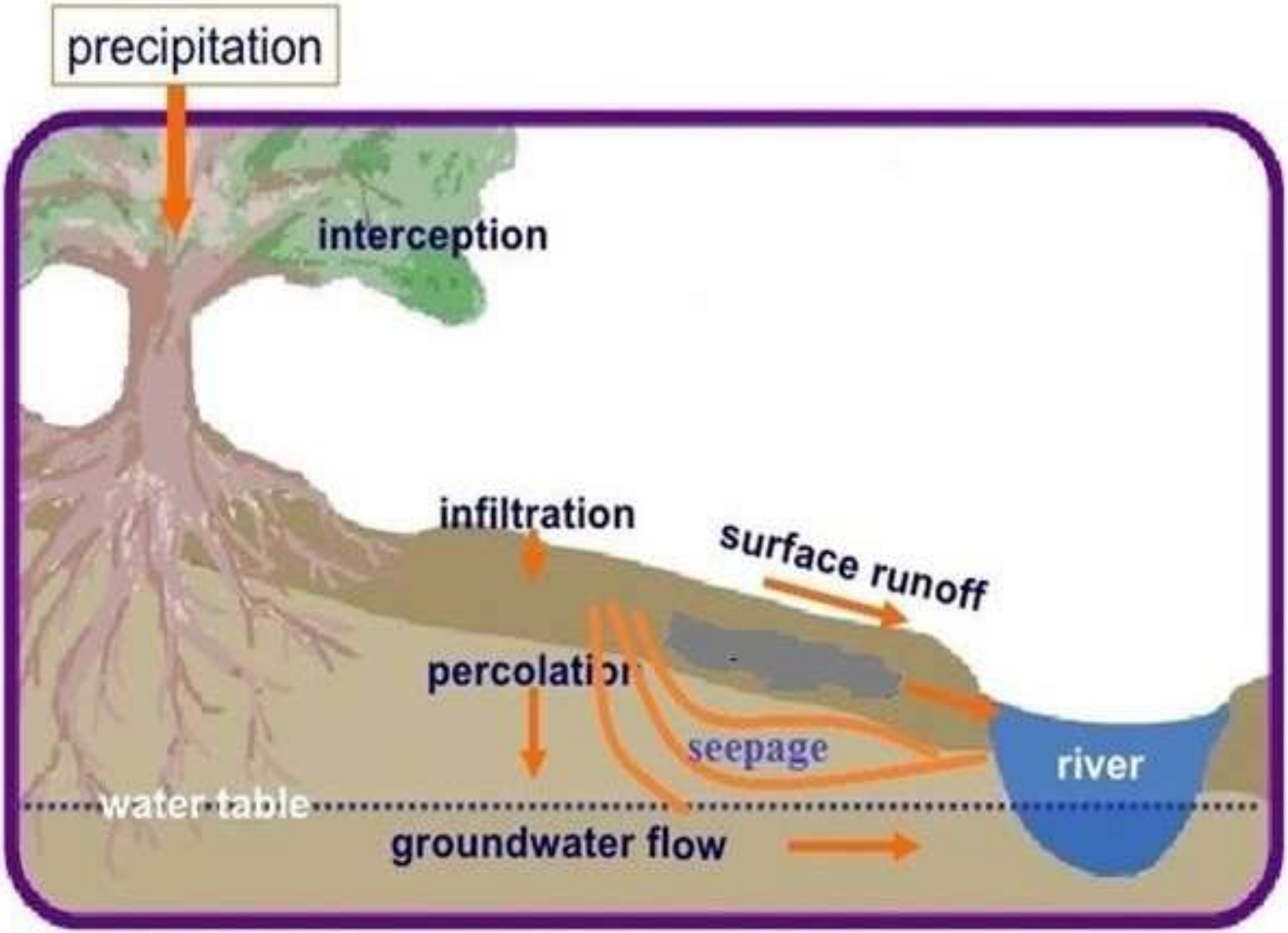
Infiltration Capacity (f_P) or Infiltrability is the maximum rate at which the soil can absorb water through its surface under a particular condition (soil type and moisture content). The value of f_P is at a maximum of f_0 at the beginning of infiltration and approaches a low and constant value of f_C as the soil profile becomes saturated.

Thus, the infiltration rate f can be expressed as:

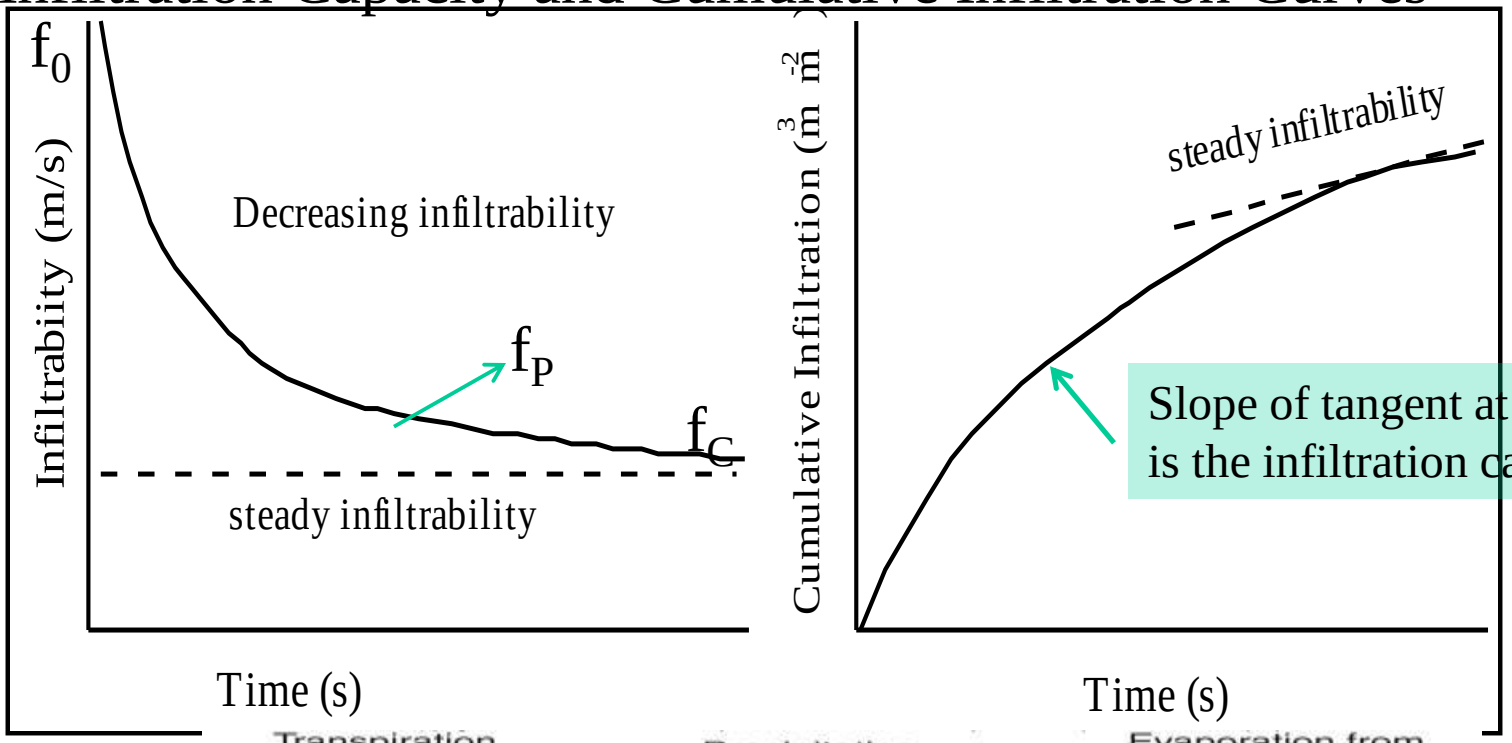
$f = f_P$ when rainfall intensity (supply rate) $i >= f_P$

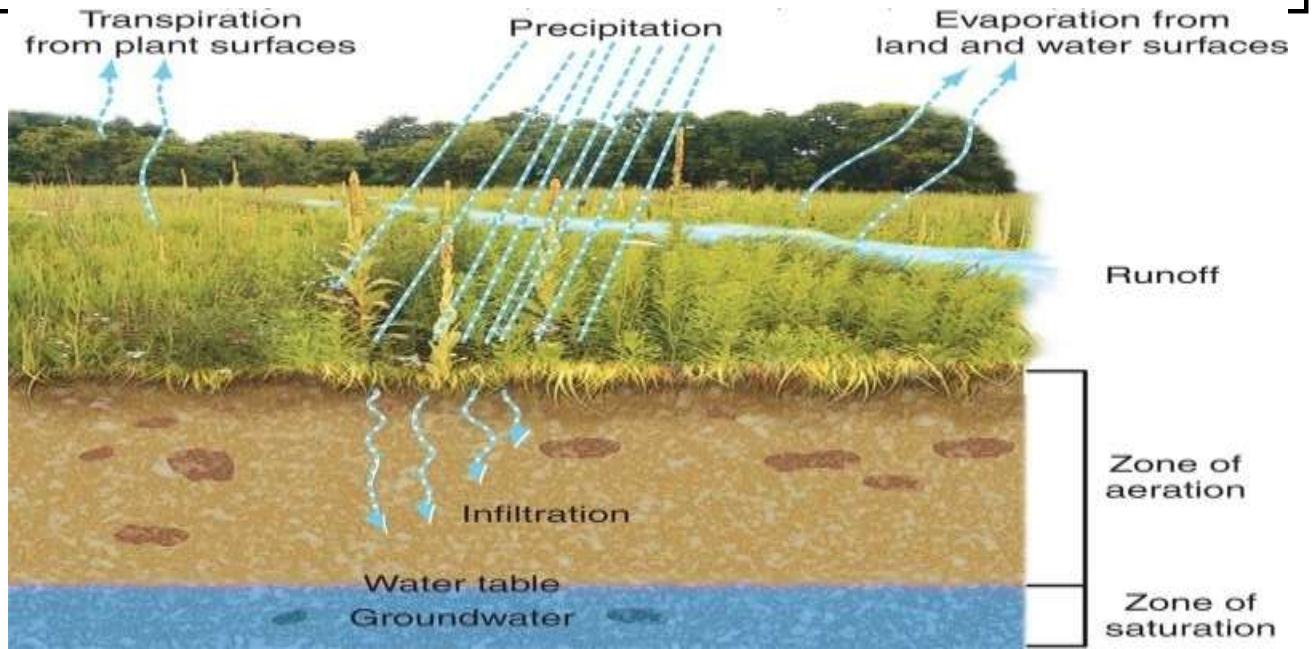
$f = i$ when rainfall intensity $i < f_P$

The infiltration capacity curve has an exponential decay with increase of time.


precipitation
interception
infiltration
surface runoff
percolation
seepage
river
water table
groundwater flow

Infiltration Capacity and Cumulative Infiltration Curves



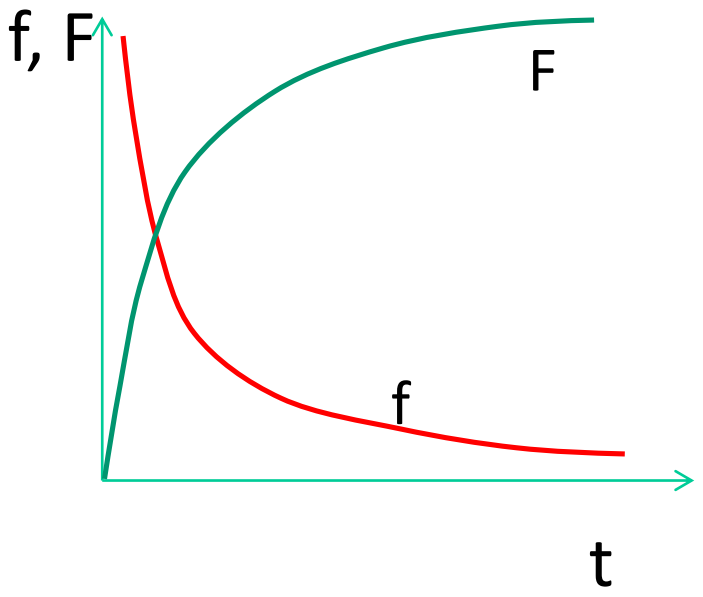


Infiltration

- Infiltration capacity, $f_p(t)$
  - Rate at which water enters the soil at the surface (in/hr or cm/hr)
- Cumulative infiltration, F(t)
  - Accumulated depth of water infiltrating during given time period

$$F(t) = \int_0^t f(\tau) d\tau$$

$$f(t) = \frac{dF(t)}{dt}$$



Infiltration

Infiltration capacity curve or Horton's curve can be expressed as:

$$f_P = f_C + (f_0 - f_C)\, e^{-kt}$$

Where, k is a constant, also known as Horton's constant (dependent upon soil characteristics and vegetation cover and has unit of 1/T) and t is the time from the beginning of infiltration.

The equation is applicable only when $i >= f_P$

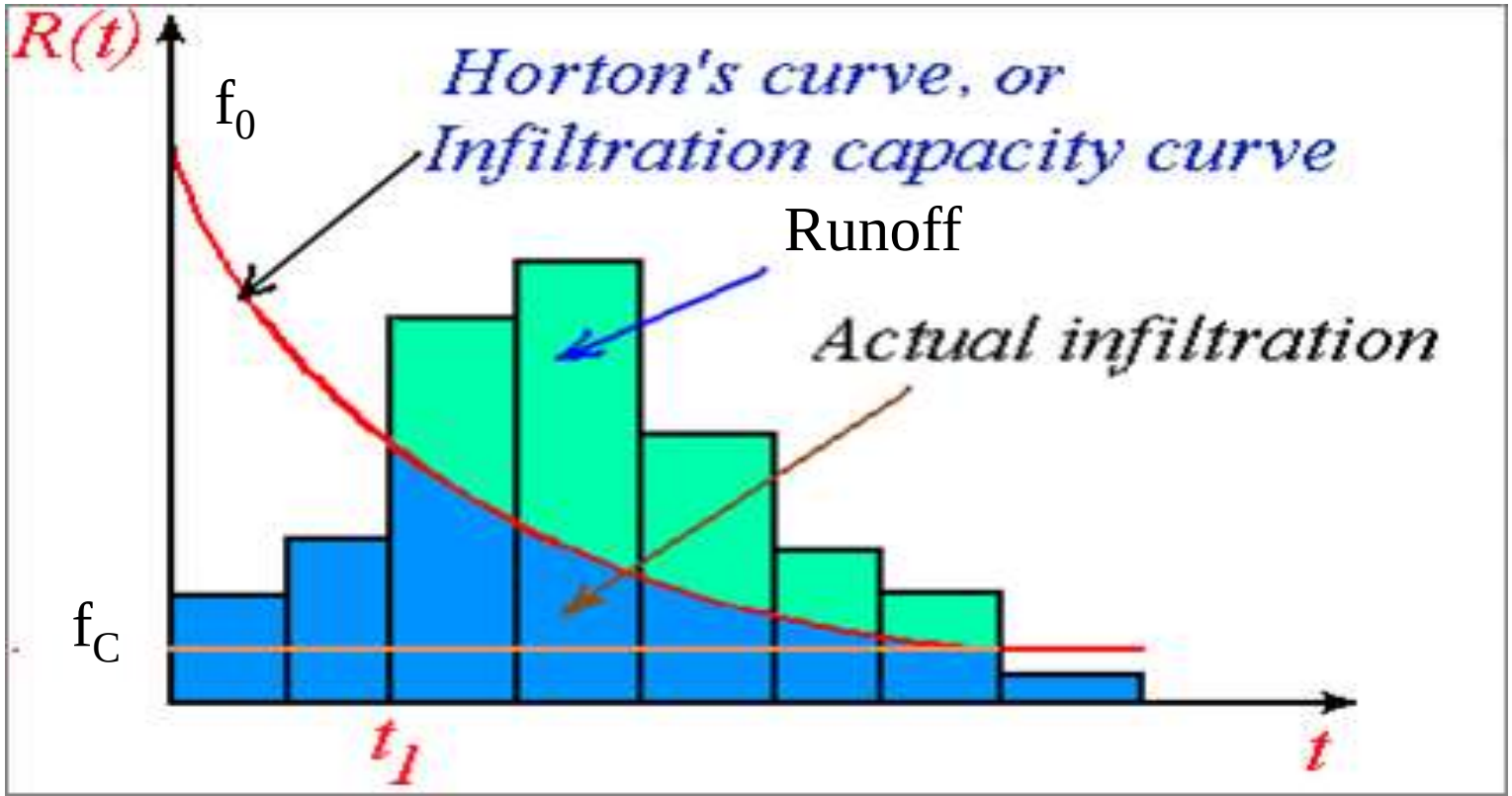
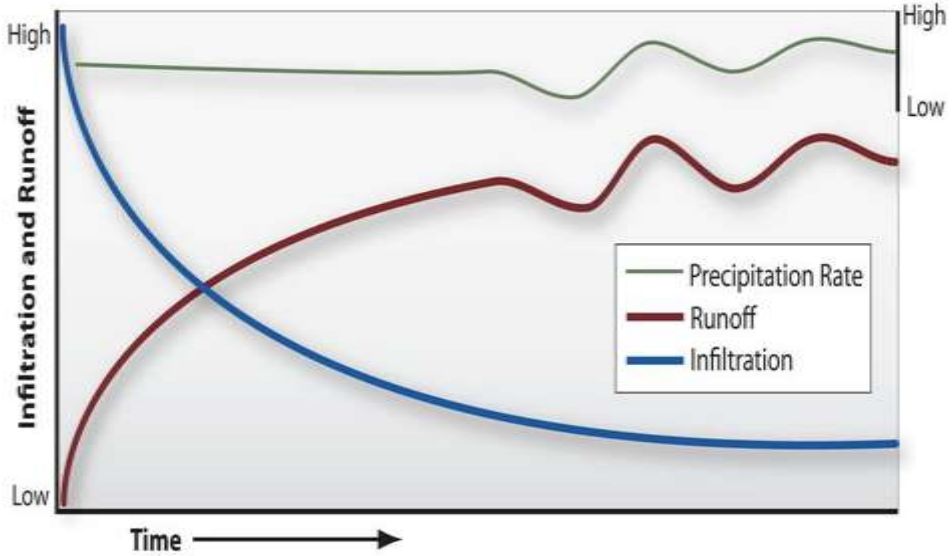
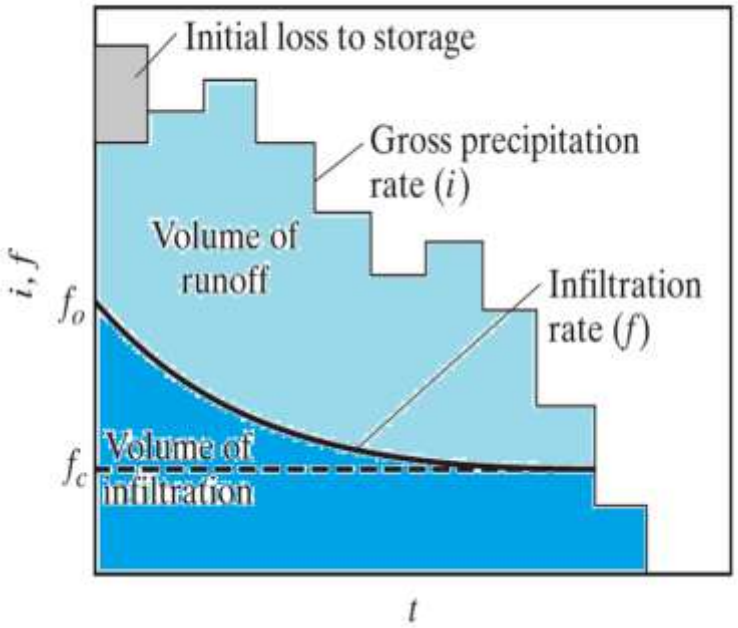


Figure 4.5 - Infiltration and Runoff over time

(chapter 4 - Hydrology)





Infiltration Trends

Infiltration rate decreases over time as dry pore spaces between soil particles fill with water. Rates of infiltration drop and become steady as the soil saturates. After saturation, the infiltration rate is a function of soil hydraulic conductivity.

Runoff Trends

Runoff increases over time because soil pores are filling with water, allowing less of the rainfall to soak into the ground. Once the soil as saturated, runoff varies with the precipitation intensity.

Typical values of infiltration capacities after 1 hour

TABLE 7.1 Typical f_1 Values

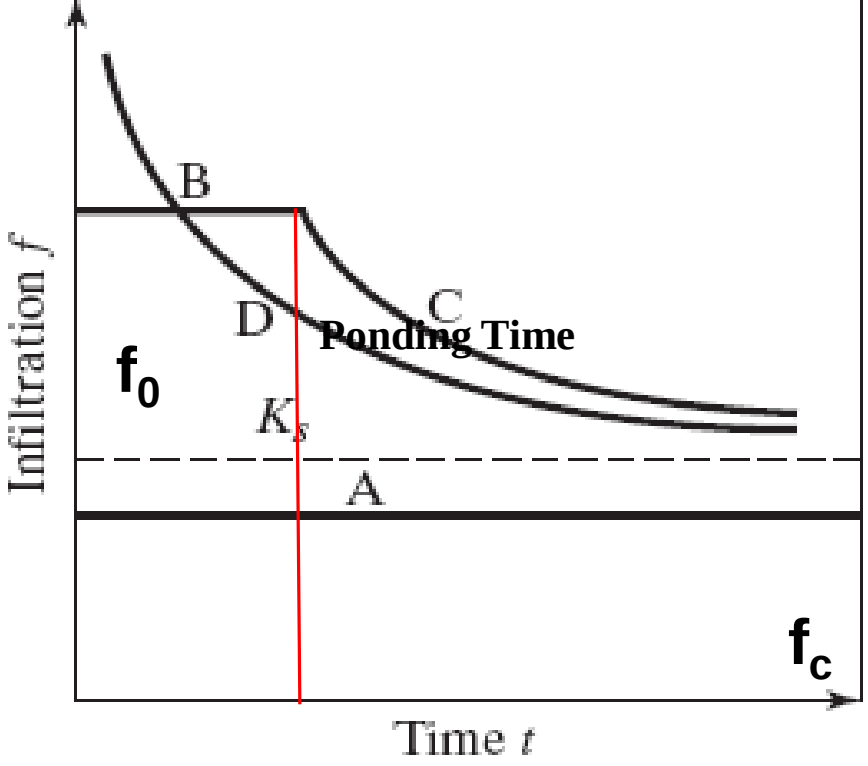
Soil group	f_1 (in./hr)	f_1 (mm/h)
High (sandy soils)	0.50–1.00	12.50–25.00
Intermediate (loams, clay, silt)	0.10–0.50	2.50–12.50
Low (clays, clay loam)	0.01–0.10	0.25–2.50

Source: After ASCE Manual of Engineering Practice, *No. 28.*

i = rainfall intensity

f_0 = maximum infiltration capacity

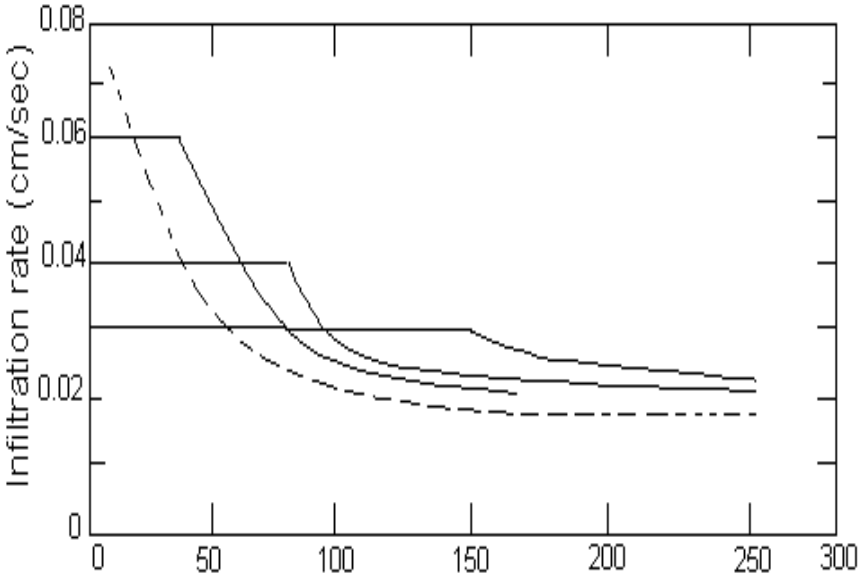
f_c = constant infiltration capacity



Case 1: i < f_c *(line A)*➔ f = i.
Runoff will never occur and all rainfall will infiltrate regardless of the duration

Case 2: f_c < i < f_0 *(line B)*➔ f = i until it reaches ponding time, then line C)

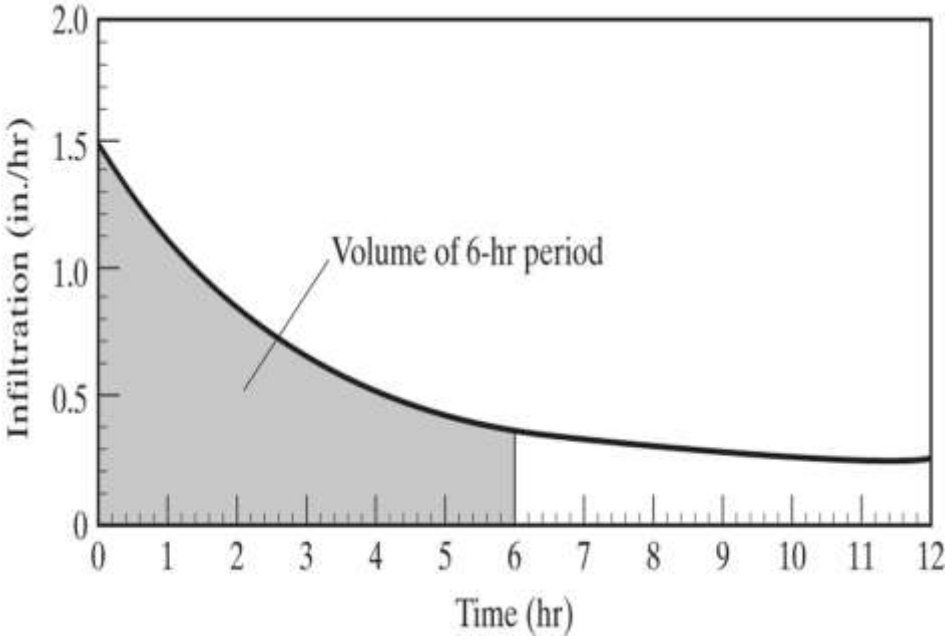
Case 3: i >= f_0 *(curve D)*➔
Runoff can occur.



Infiltration Volume

From Horton's curve:

$f_P = f_C + (f_0 - f_C)\, e^{-Kt}$



The volume of infiltration can be obtained by integrating for time t:

$V = \int [f_C + (f_0 - f_C)\, e^{-Kt}]\, dt$

$V = [f_C\, t - \{(f_0 - f_C) / k\}\, e^{-Kt}]_{0 \text{ to } t}$

$V = [f_C\, t - \{(f_0 - f_C) / k\}\, e^{-Kt} + (f_0 - f_C) / k]$

For large values of t

As $t \longrightarrow \infty$ $\qquad V = [f_C\, t + (f_0 - f_C) / k]$

Note: Even though the equation is for volume, the unit of V is in terms of Length(!).

Example

The maximum and the constant infiltration capacities of a soil are 60 and 10 cm/day and the constant, k is 0.4 hr^{-1}. Estimate the total infiltrated water for the first 10 hours for a watershed.

Solution

The given infiltration capacities are in cm/day: Hence $f_C = 10/24$ and $f_0 = 60/24$ cm/hr

The infiltrated volume = $V = [f_C\, t - \{(f_0 - f_C) / k\}\, e^{-Kt} + (f_0 - f_C) / k]$

$V = [(10/24)(10) - (50/24 \times 0.4)e^{-4}] + (50 / 24 \times 0.4)$

$V = [4.17 - 0.094 + 5.2] = 9.286$ cm

Note:

1. k, t and f must be in similar unit
2. The volume of infiltrated water can be determined if the catchment area is given.
3. The contribution of the exponential term decreases with the increase of time and tends to 0 at large value of t.

Infiltration

Why is infiltration a concern?

The soil can be an excellent temporary storage medium for water, depending on the type and condition of the soil. The stored water is later available to the plants and also helps in replenishing the aquifer.

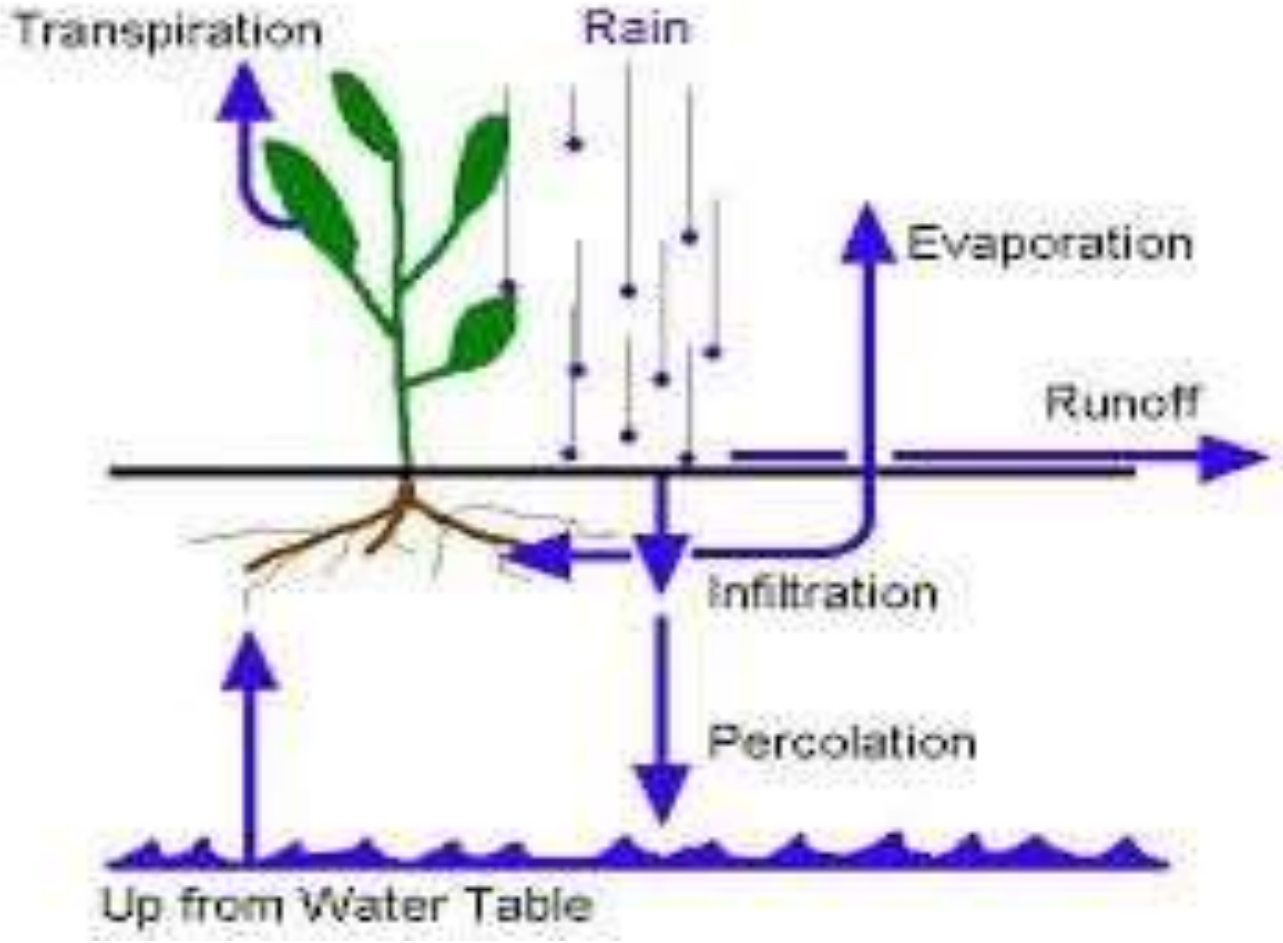
Thus, higher infiltration is always desirable for the better management of the subsurface water as low infiltration means less recharge.

Proper management of the soil can help maximize the infiltration and capture as much water as allowed by a specific soil type.

If water infiltration is restricted or blocked, water does not enter the soil, and it either ponds on the surface or runs off the land. Thus, less water is stored in the soil profile for use by plants and other uses and there is less recharge to the groundwater.

Less infiltration resulting in higher runoff can carry soil particles and surface applied fertilizers and pesticides off the field, all of which are undesirable for a sustainable environment.

These materials can end up in streams and lakes or in other places where they are not wanted and may cause pollution.



More infiltration ⟶ More percolation → More recharge

Less infiltration → More runoff →More flooding → More contamination



Both the porous concrete and asphalt look identical to the current materials. However, their internal structure has added void space between particles – compared to conventional concrete or asphalt.

Infiltration

Factors affecting infiltration

The rate of infiltration is mainly affected by rainfall pattern, soil characteristics including ease of entry, storage capacity, and transmission rate through the soil.

The factors affecting the infiltration capacity are: soil type, moisture content, vegetative cover, organic matter and compaction.

Soil type: porosity and the pore size distribution are the main factors affecting infiltration. Thus uniform sand would have a much higher porosity and infiltration than non-uniform clay.

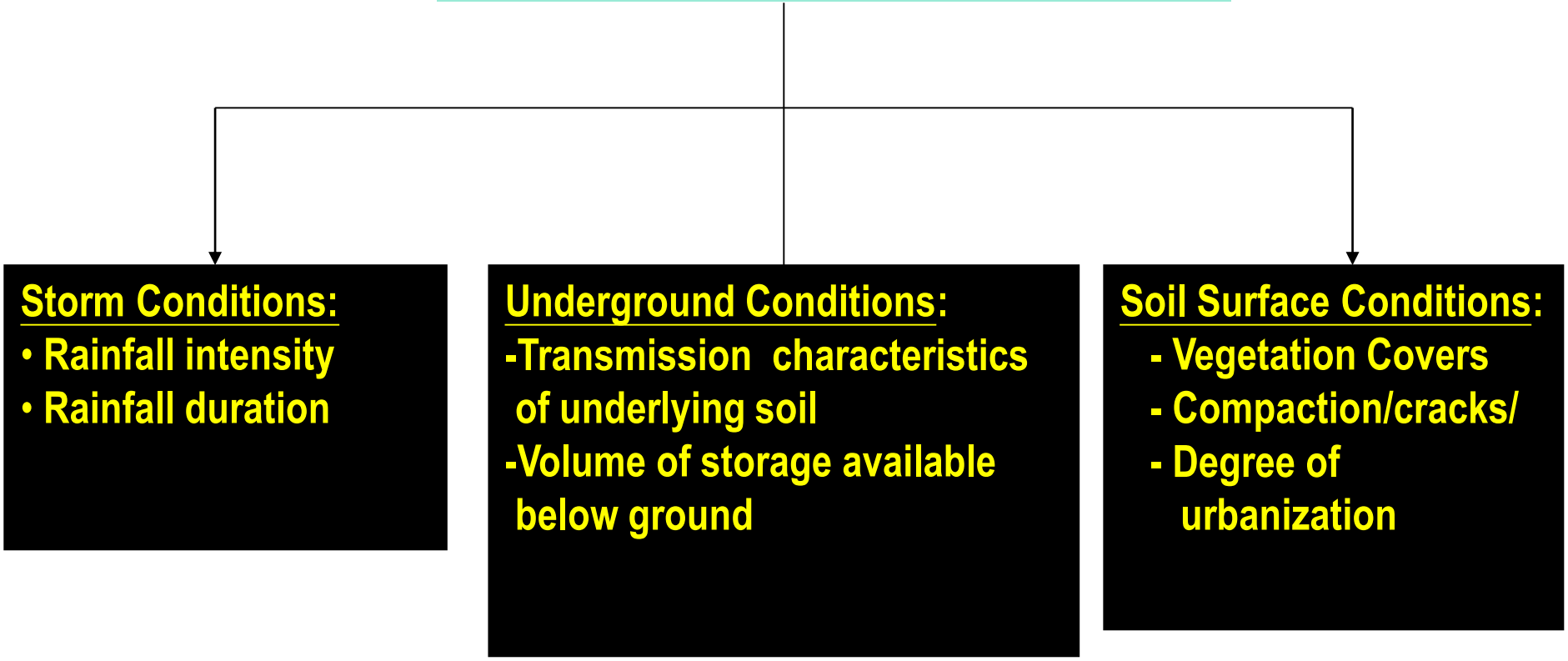
Moisture content: the infiltration rate decreases as the soil gets wetter. This happens due to decrease of capillary force with the increase of soil moisture.

Vegetation cover: vegetation cover increases the infiltration due to root openings, by increasing the retention time and by protecting the soil surface from sealing by rain drops. (no sealing and compaction)

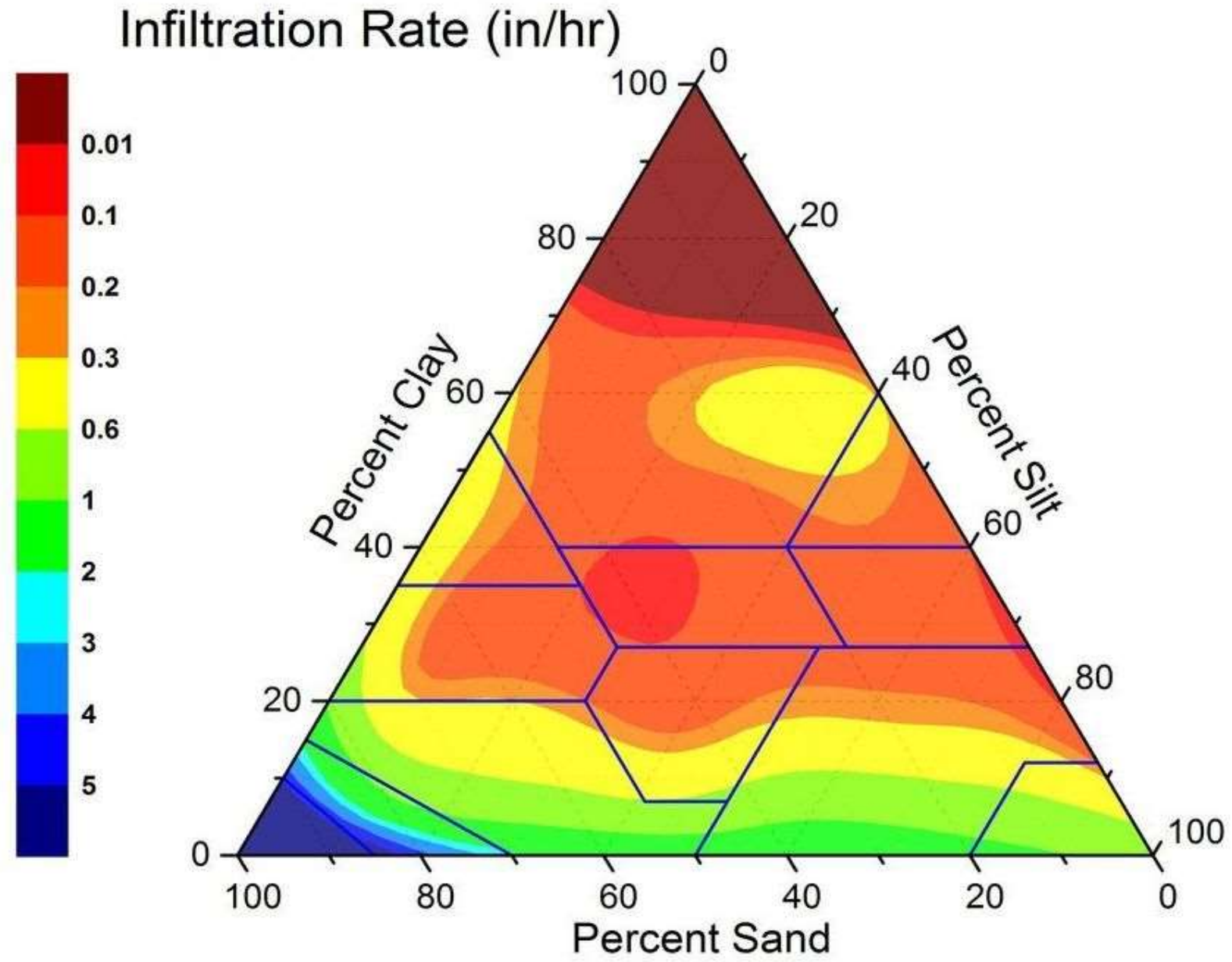
Organic matter: an increased amount of organic matter (mostly plant material) generally assists the process of infiltration by increasing the soil porosity.

Compaction: a compacted soil or an impervious layer close to the surface restricts the entry of water into the soil and tends to result in decrease of infiltration.

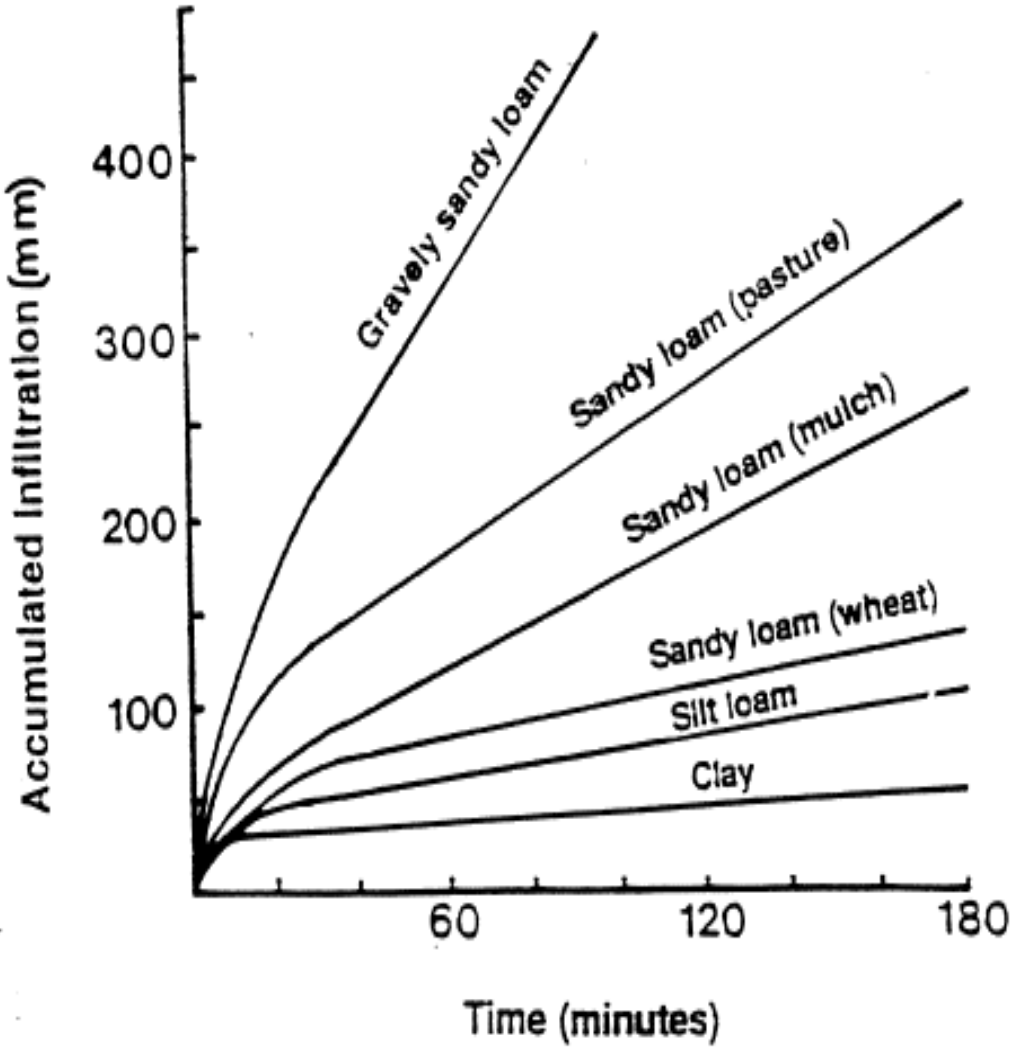
Factors affecting infiltration



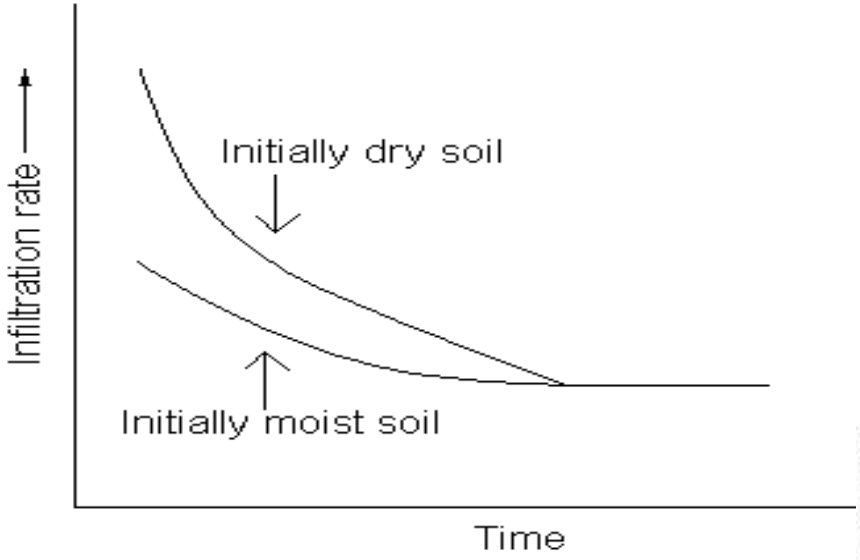
Soil Texture and Infiltration

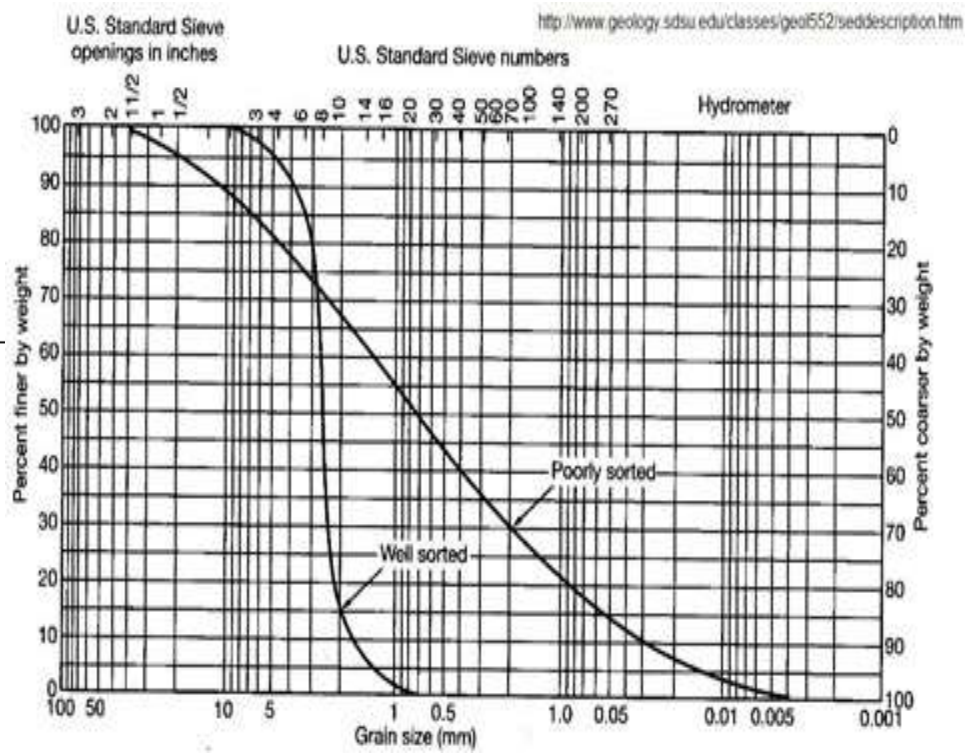


Soil texture	Infiltration rate (mm/hr.)
Gravelly loamy sand	30
Sandy loam	20-30
Loamy sand	15-20
Sandy clay loam	10-15
Silty clay loam	7.5-10
Clay loam	5-10
Clay	1-5

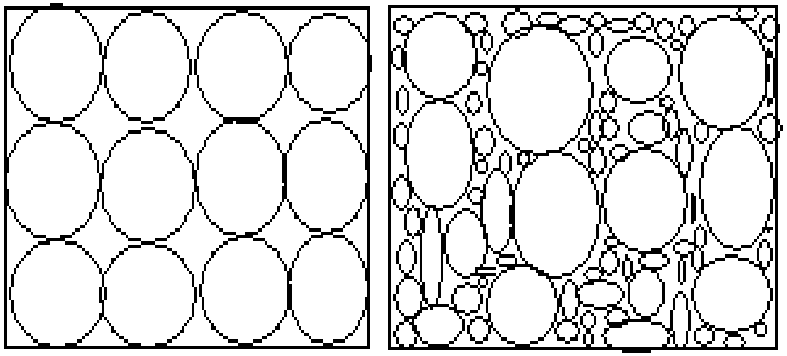


Effect of soil and vegetation on infiltration rate





Uniform = higher porosity or pore space



Non-uniform = lower porosity because the smaller particles fill in the pore space

Effect of soil and vegetal cover on infiltration

Infiltration decreases in bare soil due to:

- Surface sealing during rainfall
- Compaction of surface by raindrop impact
- Washing in of fines into surface pores



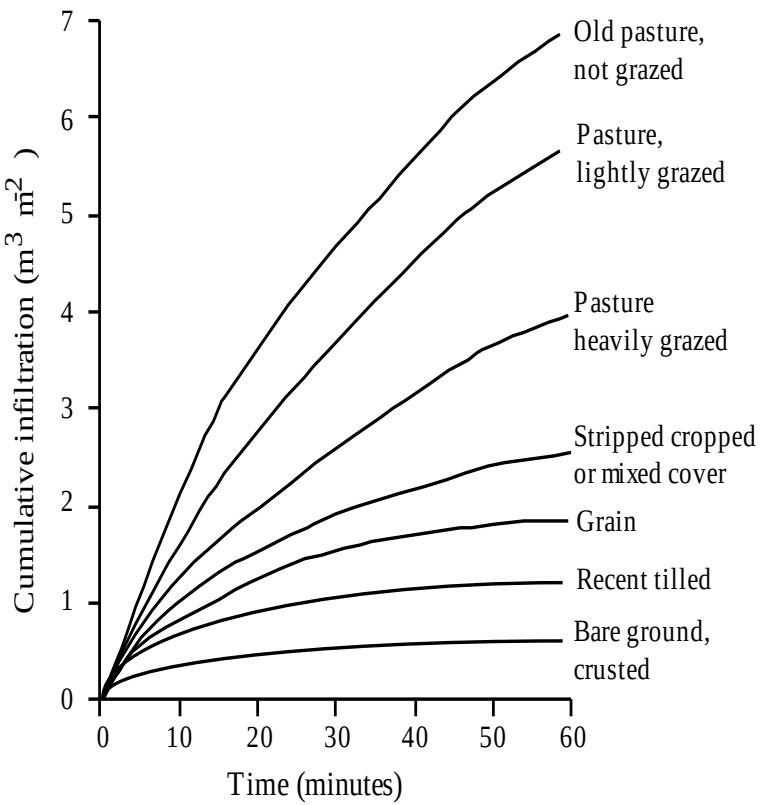
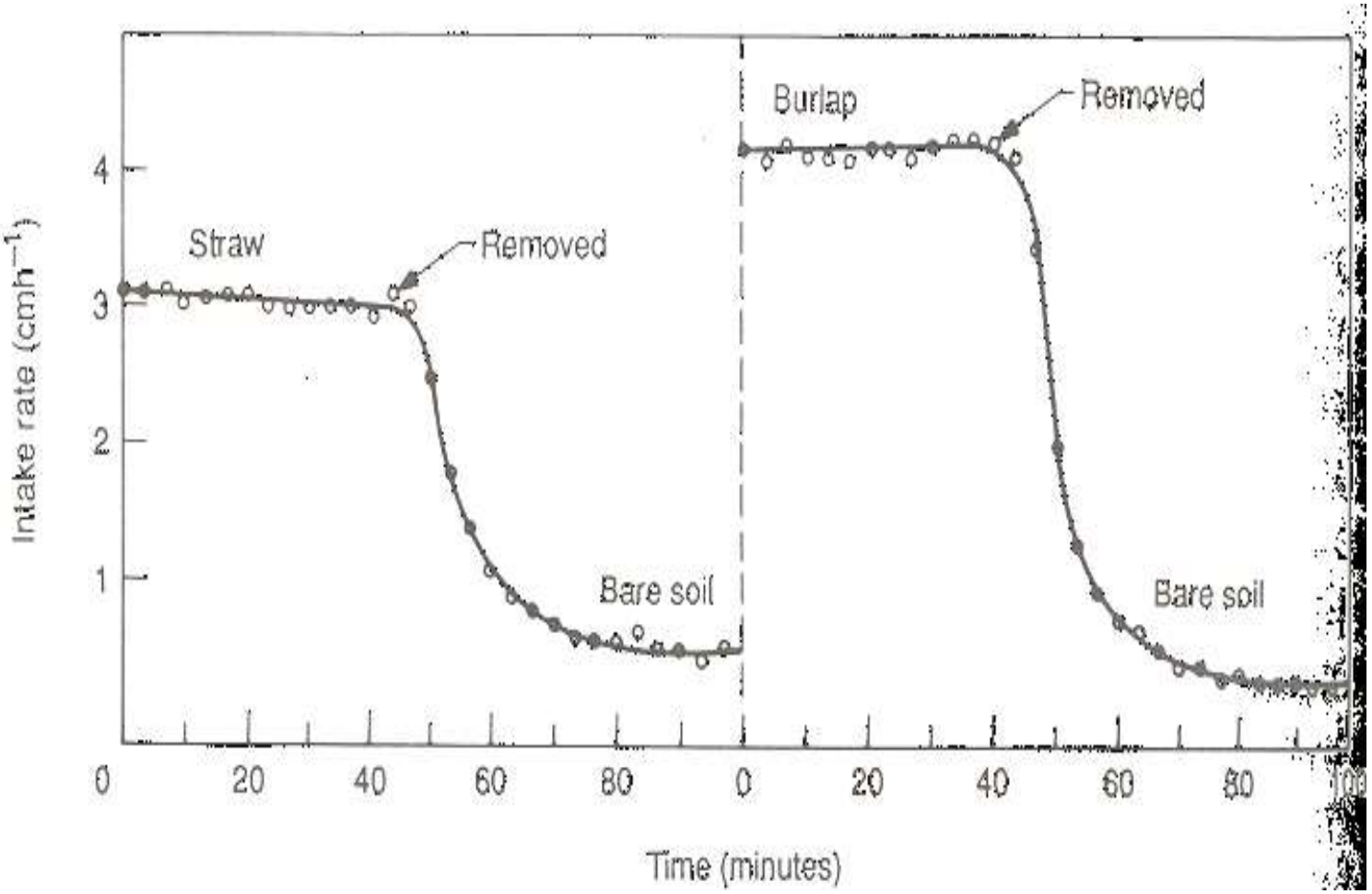


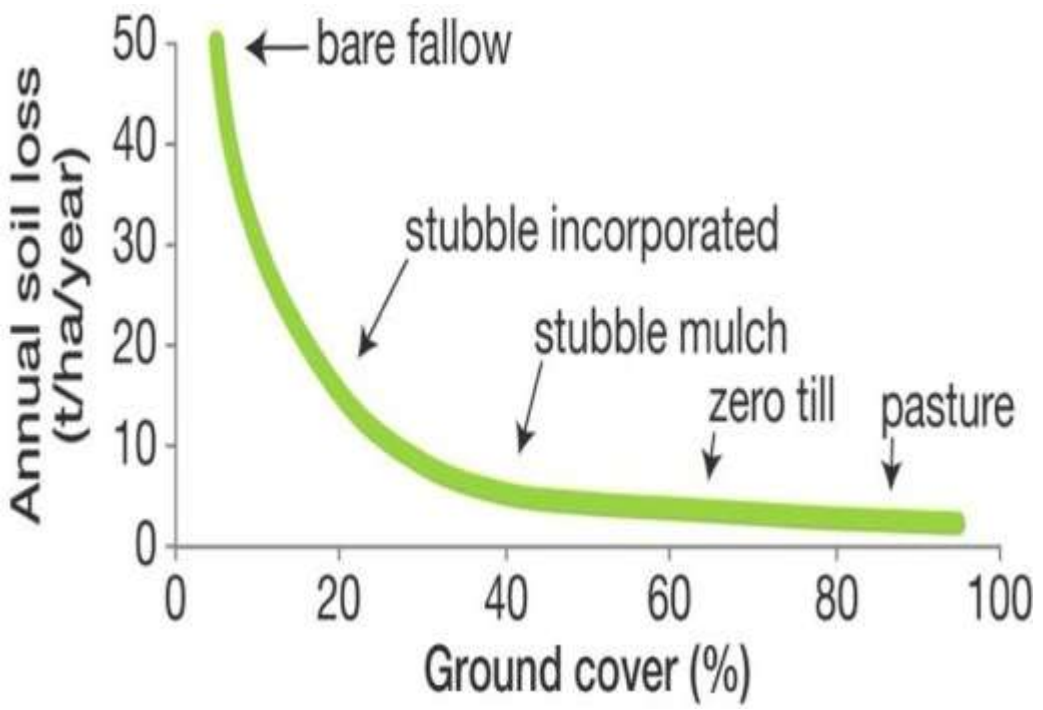
Figure 9.2. Cumulative infiltration curves for different land uses for a silt loam soil *(adapted from Holtan and Kirkpatrick 1950)*



Infiltration in bare soil



A bare soil leads to the formation of a surface crust under the impact of raindrops or other factors, which breakdown the soil structure and move soil fines into the surface or near-surface pores. Once formed, a crust impedes infiltration.



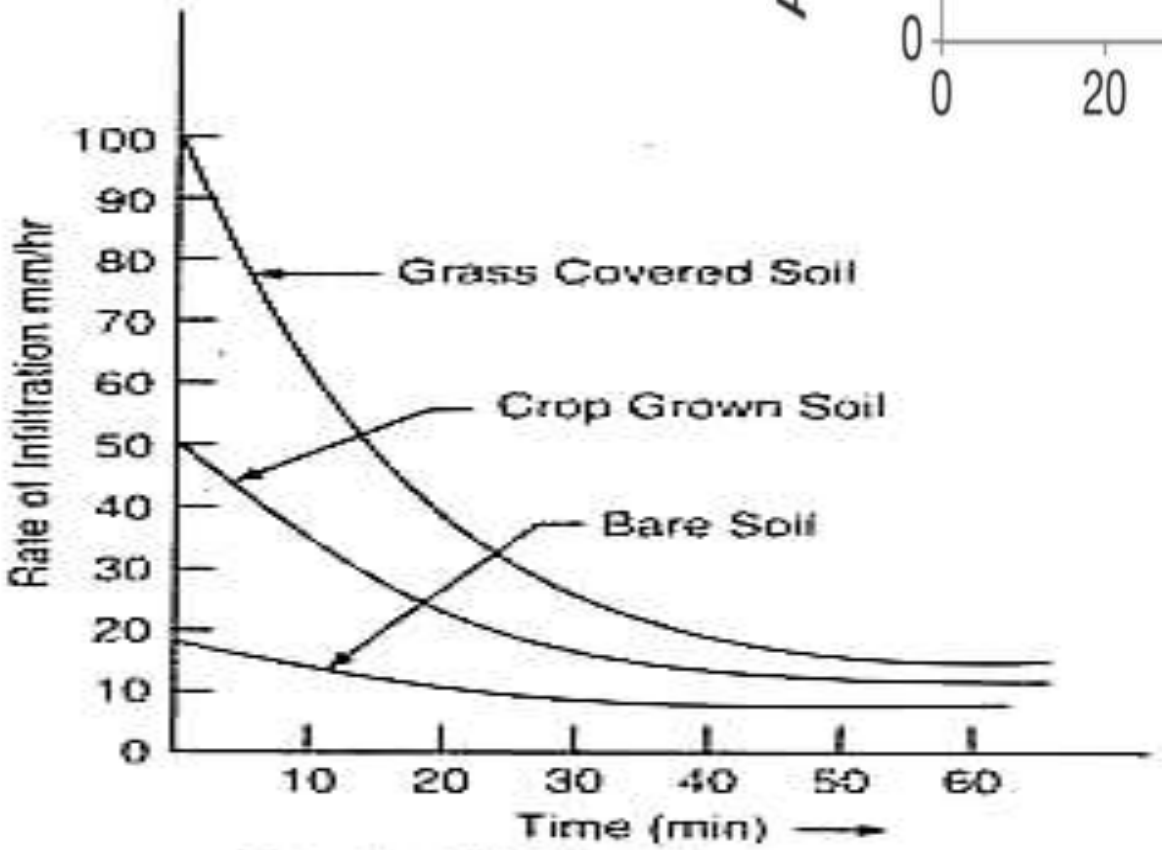


Fig. 3.1. Infiltration curves

Infiltration

Measurement of infiltration: (Point measurement)

Infiltration at a point (location, site or soil is generally measured by Infiltrometer (single ring or double ring).

Infiltrometers enclose an area and pond water to a specified depth. The infiltration rate is calculated from the drop in water level per unit time or the amount of water required to maintain the specified depth or head of water per unit time.

One or two concentric rings of stainless steel are commonly employed. The advantage of two rings is that the larger ring forms a buffer compartment around the inner to account for lateral flow.

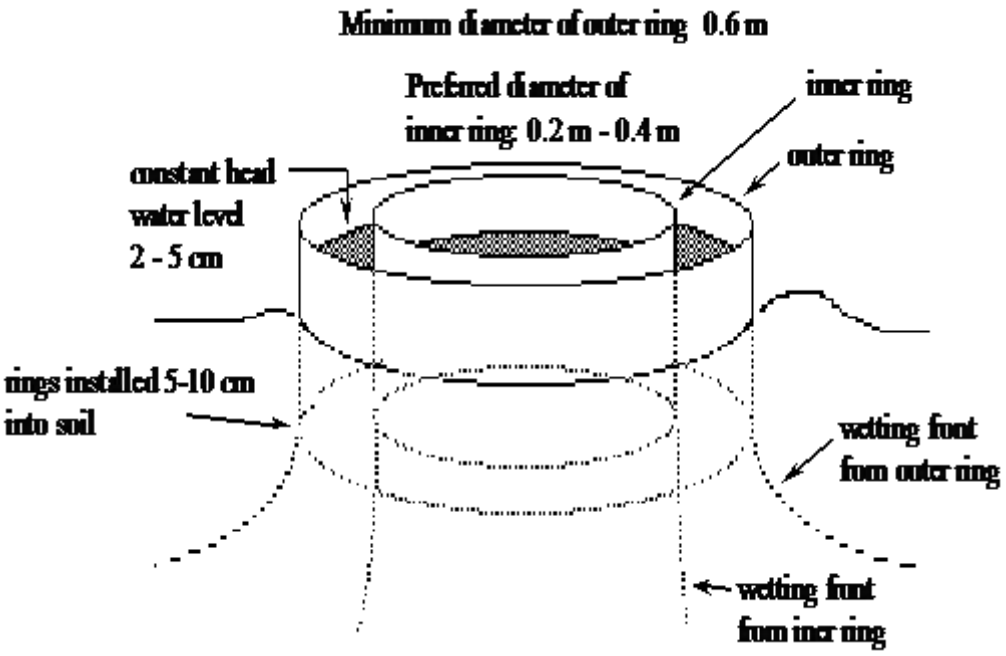
The rings are jacked or hammered into the ground 5 to 10 cm. Care is taken to minimize disturbance of the soil surface and the soil structure during installation.

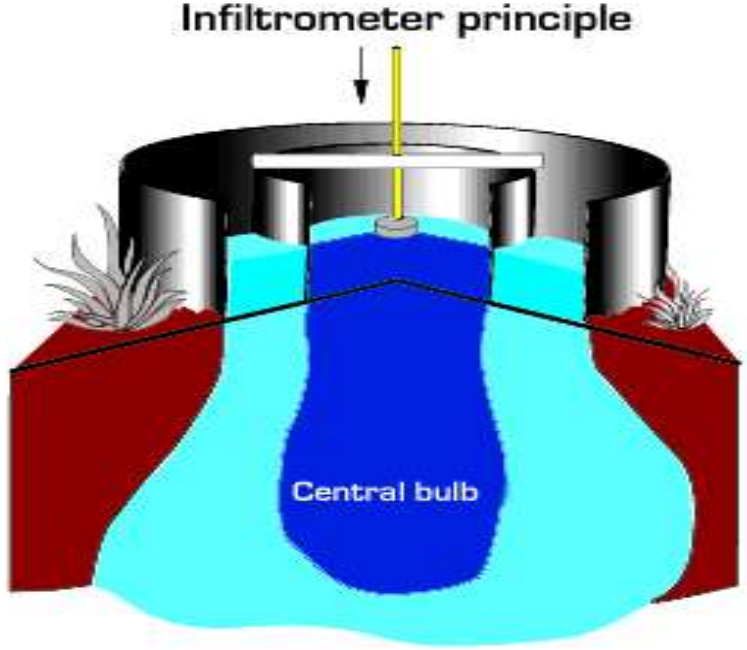
A specific and constant head of water (less than 5 cm of depth) is maintained in both rings, while the rate of water usuage from the inner ring is measured.

The length of time required to achieve steady infiltration rate (f_C) ranges from 2 to 6 hours depending upon soil type, texture, and antecedent soil moisture conditions.






Minimum diameter of outer ring 0.6 m
Prefered diameter of inner ring: 0.2 m - 0.4 m
inner ring
outer ring
constant head water level 2 - 5 cm
rings installed 5-10 cm into soil
wetting front from outer ring
wetting front from inner ring

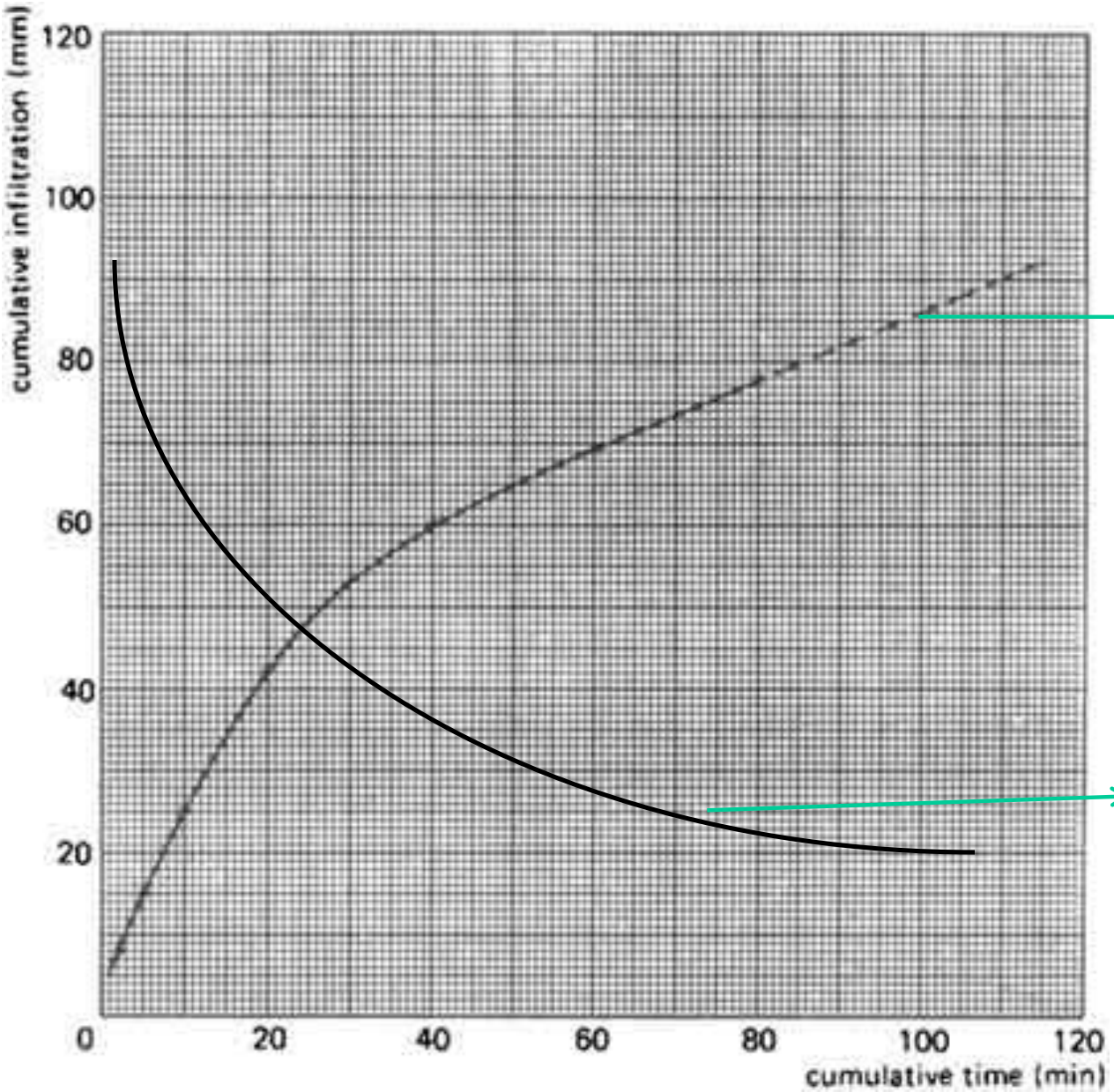

Infiltrometer principle
Central bulb

Data Sheet of an Infiltration Experiment

Site location: EXAMPLE Soil type: Loam Test date: 5 DEC 1987

1 Reading on the clock hr min sec	2 Time difference min	3 Cumulative time min	4 Water level readings before filling mm	4 Water level readings after filling mm	5 Infiltration mm	6 Infiltration rate mm/min	7 Infiltration rate mm/hour	8 Cumulative infiltration mm
14 05 0	start = 0	start = 0		100				start = 0
14 07 0	2	(0+2) 2	92	100	(100-92) 8	(8/2) 4.00	240	(0+8) 8
14 10 0	3	(2+3) 5	93	99	(100-93) 7	(7/3) 2.33	140	(8+7) 15
14 15 0	5	(5+5) 10	89	101	(99-89) 10	(10/5) 2.00	120	(15+10) 25
14 25 0	10	(10+10) 20	84	100	(101-84) 17	(17/10) 1.70	102	(25+17) 42
14 35 0	10	(20+10) 30	89	102	(100-89) 11	(11/10) 1.10	66	(42+11) 53
14 45 0	10	(30+10) 40	95	101	(102-95) 7	(7/10) 0.70	42	(53+7) 60
15 05 0	20	(40+20) 60	92	100	(101-92) 9	(9/20) 0.45	27 *	(60+9) 69
15 25 0	20	(60+20) 80	91		(100-91) 9	(9/20) 0.45	27 *	(69+9) 78

Plots of Infiltration Capacity and Cumulative Infiltration Curves



col. 8 vs. col. 3

col. 6 vs. col. 3

Infiltration

Determination of k (Horton's constant)

The infiltration capacity equation is: $f_P = f_C + (f_0 - f_C)\, e^{-kt}$

or $f_P - f_C = (f_0 - f_C)\, e^{-kt}$

Taking log both sides: $\log (f_P - f_C) = \log (f_0 - f_C) - kt \log e$

Or $kt \log e = C_1 - \log (f_P - f_C)$ or $t = C - \log (f_P - f_C) / (k \log e)$

where $C_1 = \log(f_0 - f_C)$ and $C = \log(f_0 - f_C) / k \log e$

This is the equation of a straight line ($y = mx + C$)

where $y = t$ and $x = \log (f_P - f_C)$ and $m = 1/k\log e$

Hence a plot of t and $\log (f_P - f_C)$ in normal paper or t and $(f_P - f_C)$ in semi-log paper ($f_P - f_C$ in log scale) would result in a straight line from where Horton's k (the slope of the line) can be determined.

The unit of k is generally expressed as 1/hr.

Assignment

Determine the infiltration capacity (Horton's) equation from the data sheet of infiltration experiment.

Horton's Equation

$$f = f_c + (f_0 - f_c)e^{-Kt}$$

