CHAPTER-5

Canopy Interception

Depression storage

&

Infiltration

Canopy Interception

Part of the precipitation caught by the vegetation & subsequently evaporated (to wet the leaves surfaces).

Factors affecting Canopy Interception

(1) Shape of the leaves

(2) Size of the leaves

(3) No. of leaves / density

(4) Intensity of precipitation

(5) Duration of precipitation (storm characteristics)

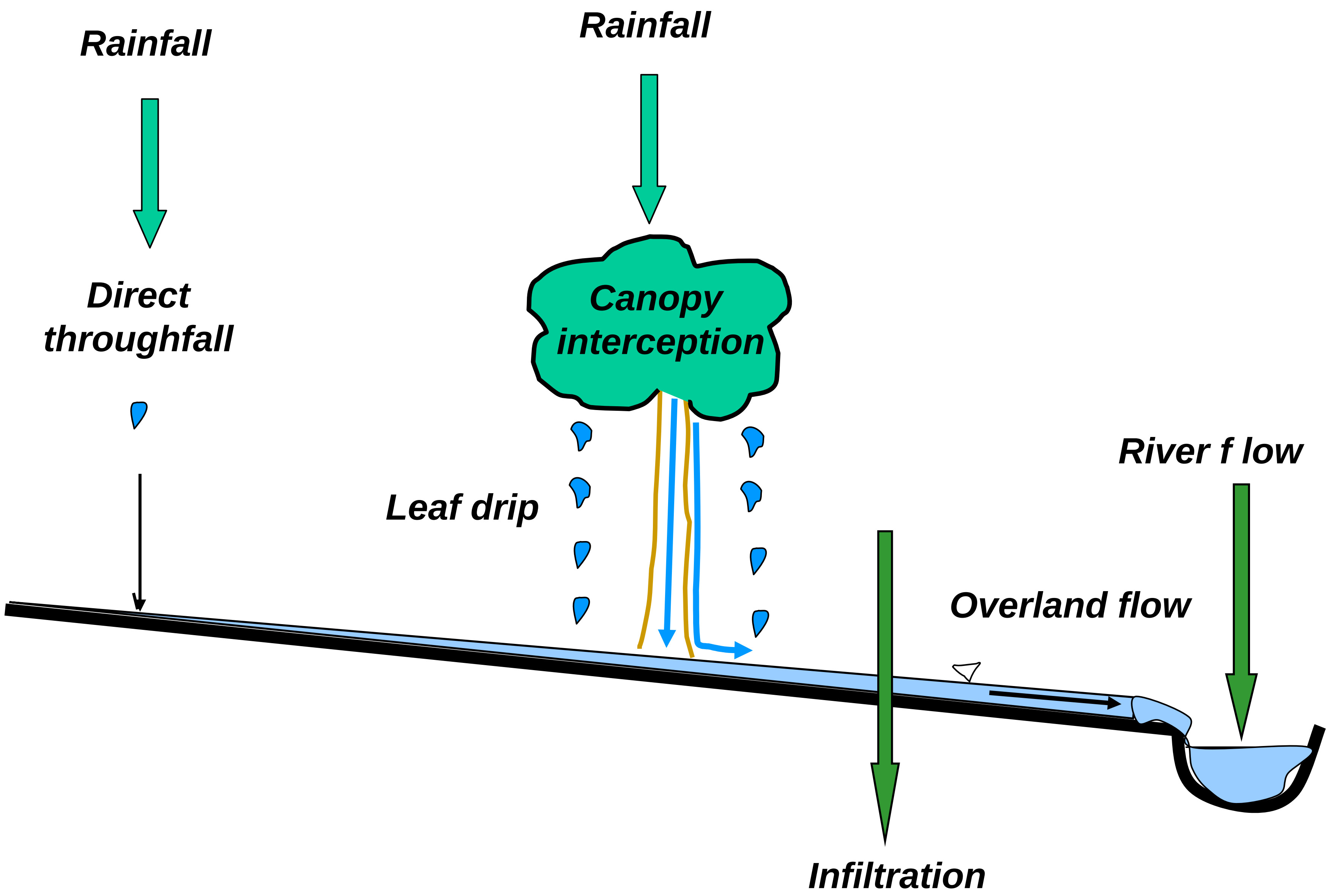
Routes of intercepted water

(1) It may be retained by the vegetation as surface storage & return to the atmosphere by evaporation (interception loss).

(2) It can drip off the plant leaves to join the ground surface (leafdrip).

(3) The rainwater may run along the leaves & branches and down the stem to the ground (stem flow)

Hydrological Processes

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Canopy Interception (condt.)

- Interception loss is = 10-20% (plant growing season)
- Interception loss is > 25% (for forests)
- Interception loss is larger for small rainfall amounts and levels off to a constant value for larger storms.
- Interception loss is insignificant for flood studies.

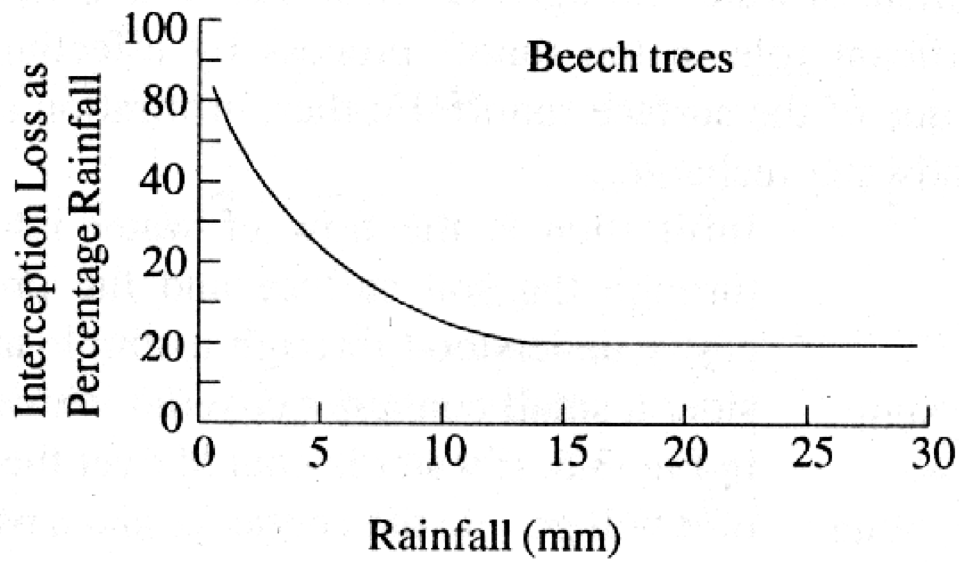


Fig. 3.7 Typical interception loss curve

Canopy Interception Estimation

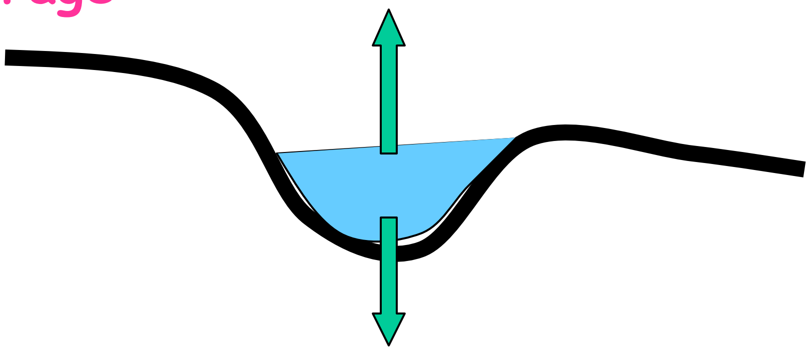
$$I_i = S_i + (LAI)\ E\ T_d$$

Where

- I_i = Interception loss in mm
- S_i = Interception/Canopy storage (0.25 mm – 1.25 mm)
- LAI = Leaf Area Index = Vegetal surface area / its projected area
- E = Evaporation rate (mm/hr)
- T_d = Duration of rainfall

Depression storage

- Precipitation first fill up all depressions before it can flow over the surface.
- The volume of water trapped in these depressions is called depression storage.
- The stored water can be either evaporated or infiltrates in the ground.
- Factors affecting Depression Storage
  - (1) Type of soil
  - (2) Surface conditions
  - (3) Slope of the catchment
  - (4) Precipitation amount



- Depression storage loss during intensive storm is estimated as:
  - (i) Sands 5 mm
  - (ii) Loam 4 mm
  - (iii) Clay 2.5 mm

Infiltration

- Part of the precipitation that seeps into the soil.

Significance

- It plays a significant role in runoff process
- Primary step for groundwater recharge.

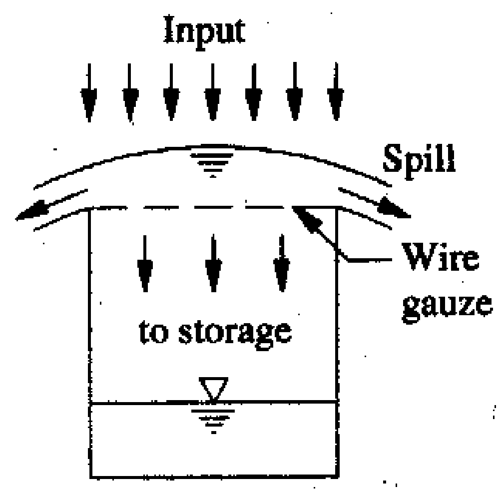


Fig. 3.8 An anology for infiltration

Infiltration Capacity

The maximum rate at which the ground can absorb water.

Field Capacity

The volume of water that ground can hold

Groundwater Recharge by Infiltration

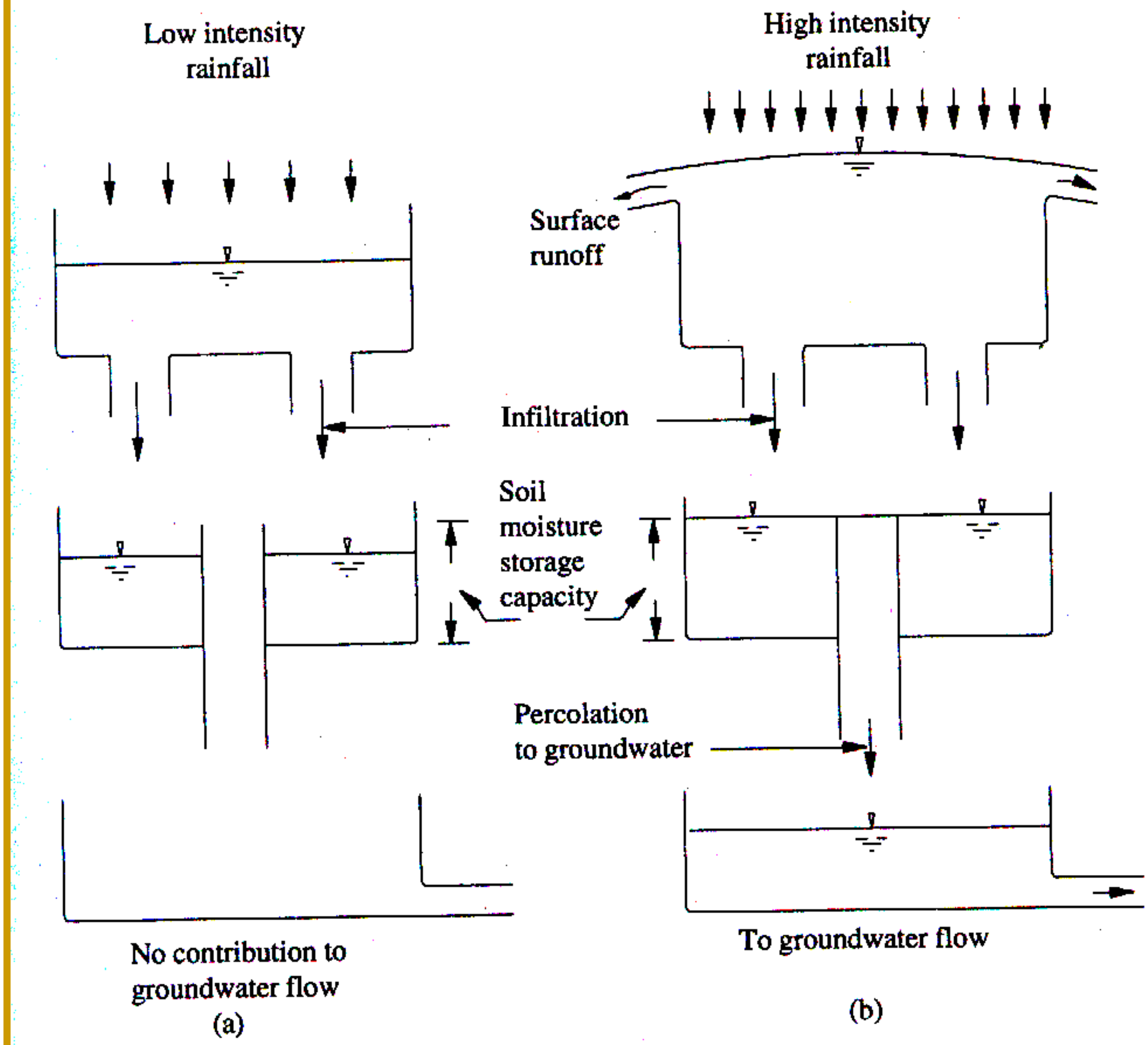


Fig. 3.9 An infiltration model

Infiltration Capacity (f_c)

The maximum rate at which a given soil at a given time can absorb water.

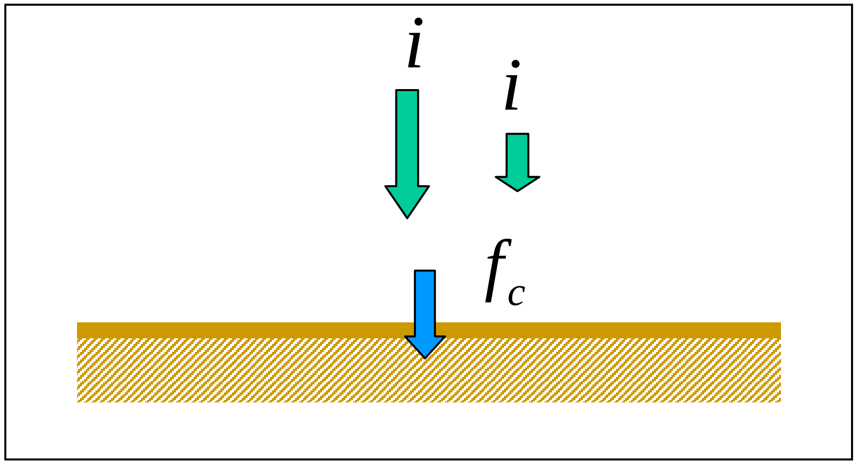
Units (mm/hr)

IF i is the intensity of rainfall then Actual infiltration rate (f)

$$f = f_c \quad when \quad i \geq f_c$$

$$f = i \quad when \quad i < f_c$$

The infiltration capacity of a soil is high at the beginning of a storm & has exponential decay as the time elapses.



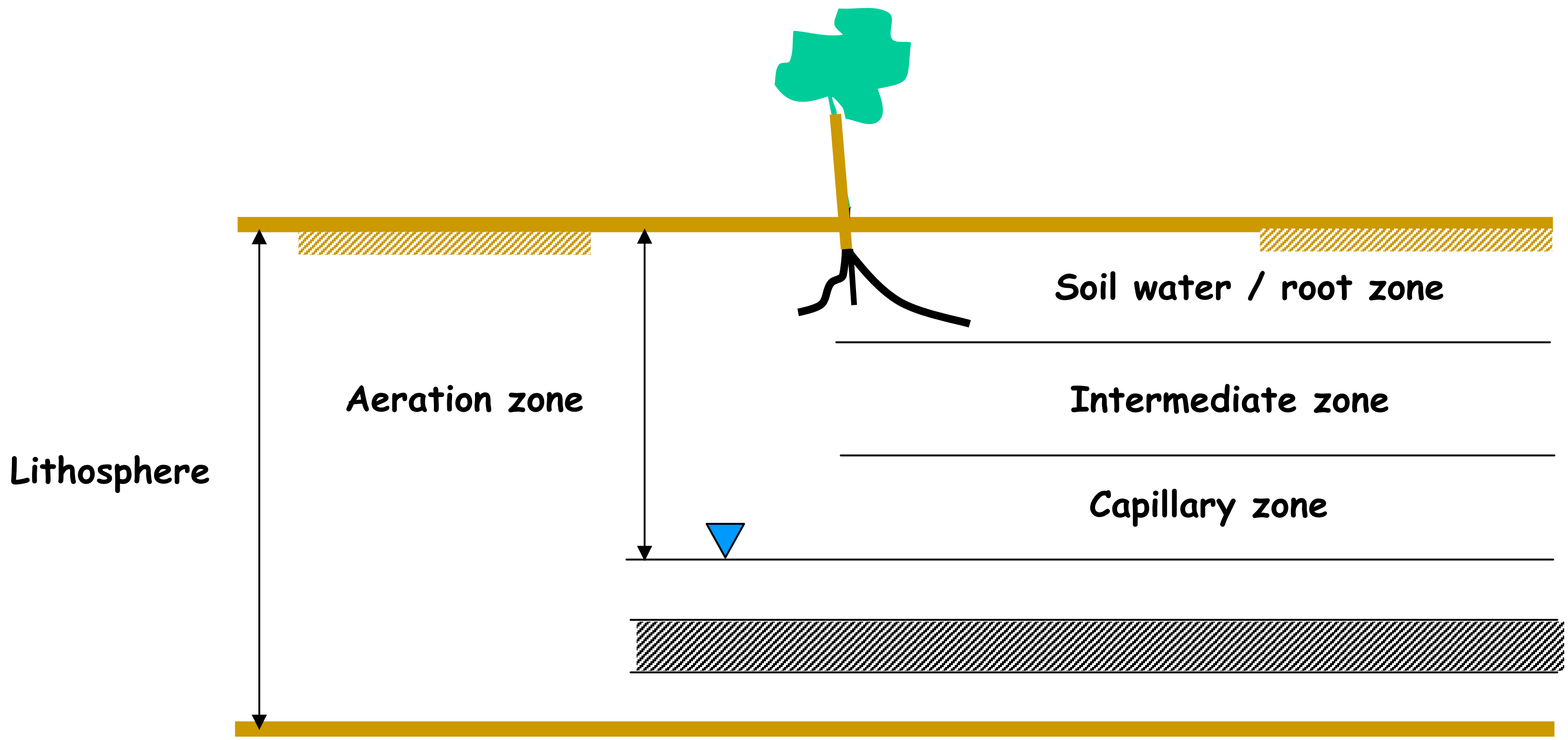
Factors affecting Infiltration

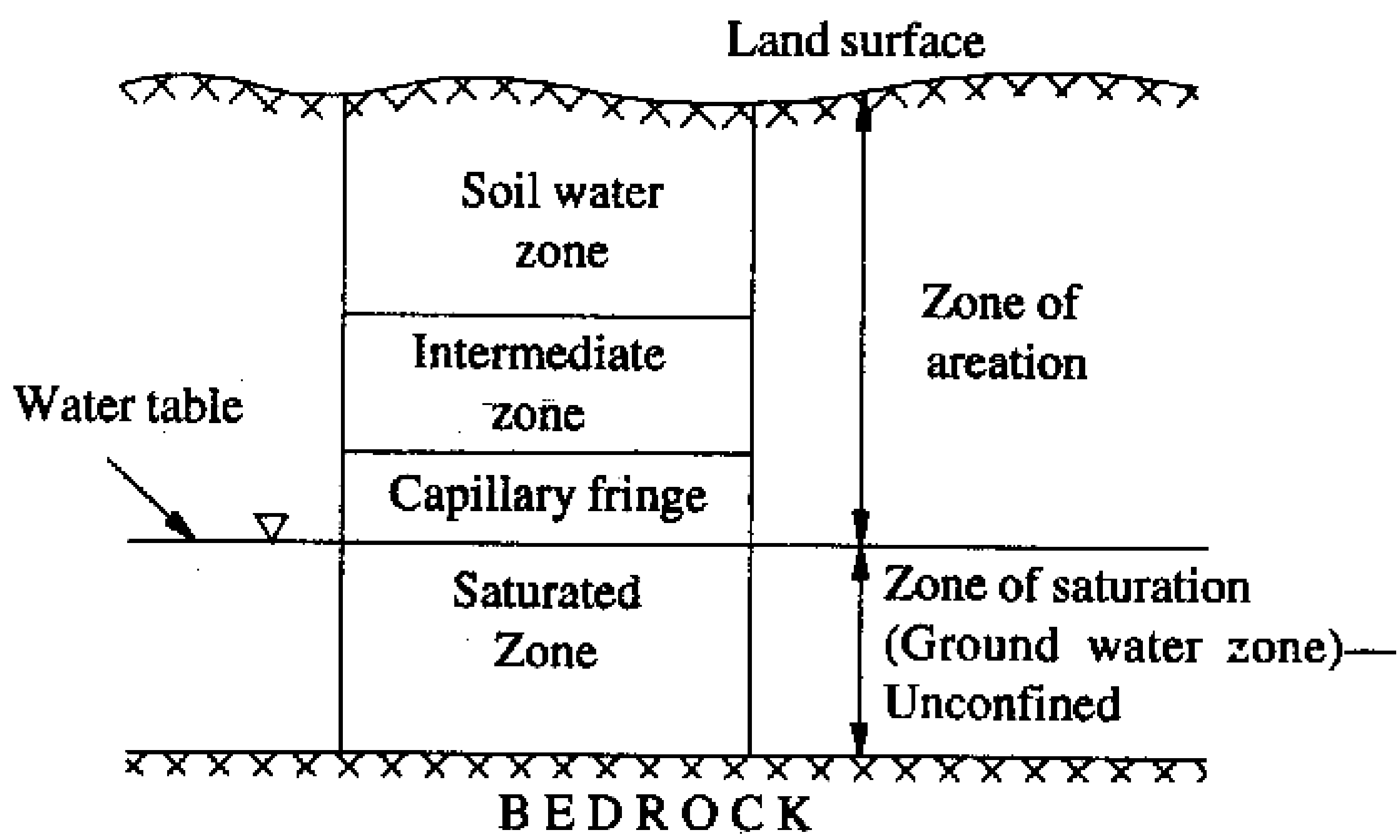
(1) Characteristics of soil (type, K, under-drainage)

(2) Surface conditions (landuse type, clogging of pore spaces)

(3) Fluid characteristics (impurities in suspension, turbidity blocks the fine pores, temperature, viscosity)

Regions of Soil Column on the basis of water content




Land surface
Soil water zone
Intermediate zone
Capillary fringe
Saturated Zone
Zone of areation
Water table
Zone of saturation
(Ground water zone)—
Unconfined
BEDROCK

Regions of Soil Column on the basis of water content

(1) Saturation Zone

W.T. is the upper limit of this zone, voids are filled with water.

(2) Zone of Aeration/Un saturated zone

Voids are partially filled with water and air.

Water in this zone is referred as 'suspended water' or 'vadose water'.

Physical processes are different in these two zones, differentiation is necessary.

Aeration zone can be further divided into three zones

- Soil Water or root zone (gravity water, can drain by gravity)
- Intermediate zone (hydroscopic moisture, water that adhere to the surface of soil particles as a thin film).
- Capillary zone / capillary fringe (water retained by capillary forces)

Sub-Surface Flow

Important sub-surface flow processes are:

- Infiltration
- Sub-surface or unsaturated flow through soil
- Groundwater flow, saturated flow

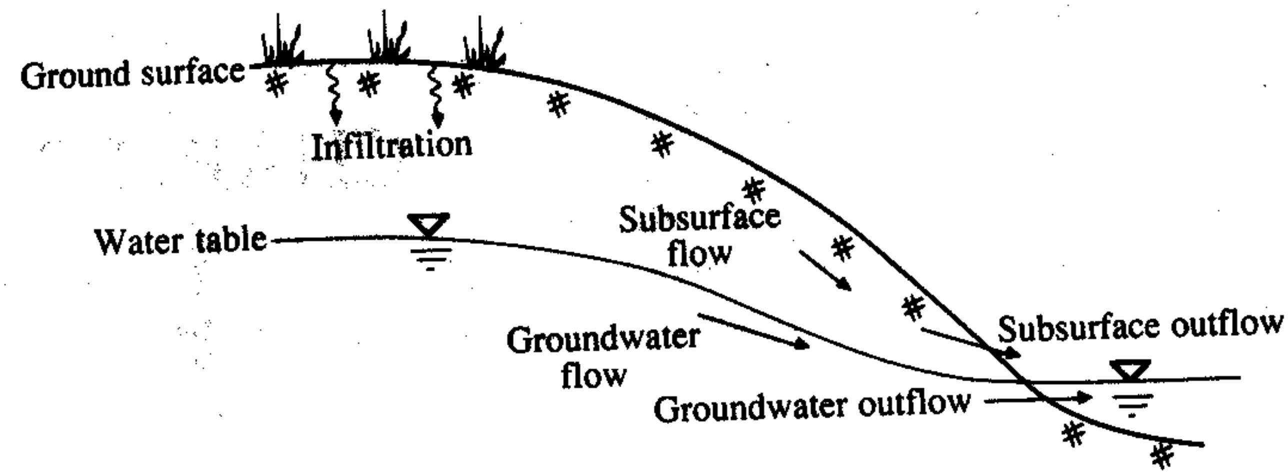


FIGURE 4.1.1
Subsurface water zones and processes.

Main Points

- W.T. is a surface where the water in saturated porous medium is at atmospheric pressure.
- Above W.T. capillary forces can saturate the porous medium for a short distance in the capillary fringe.
- Above it, porous medium is usually unsaturated except in rainfall.
- Sub-surface and groundwater overland flow occur when water emerges to become surface flow in stream or spring.
- Soil moisture is extracted by evapotranspiration as the soil dries out.
- Porosity, $$\eta = \frac{volume\ of\ \ voids}{total\ volume}$$

$$\eta = 0.25 - 0.75$$

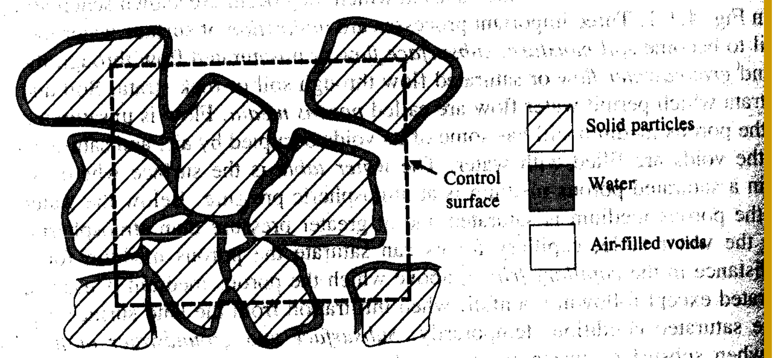


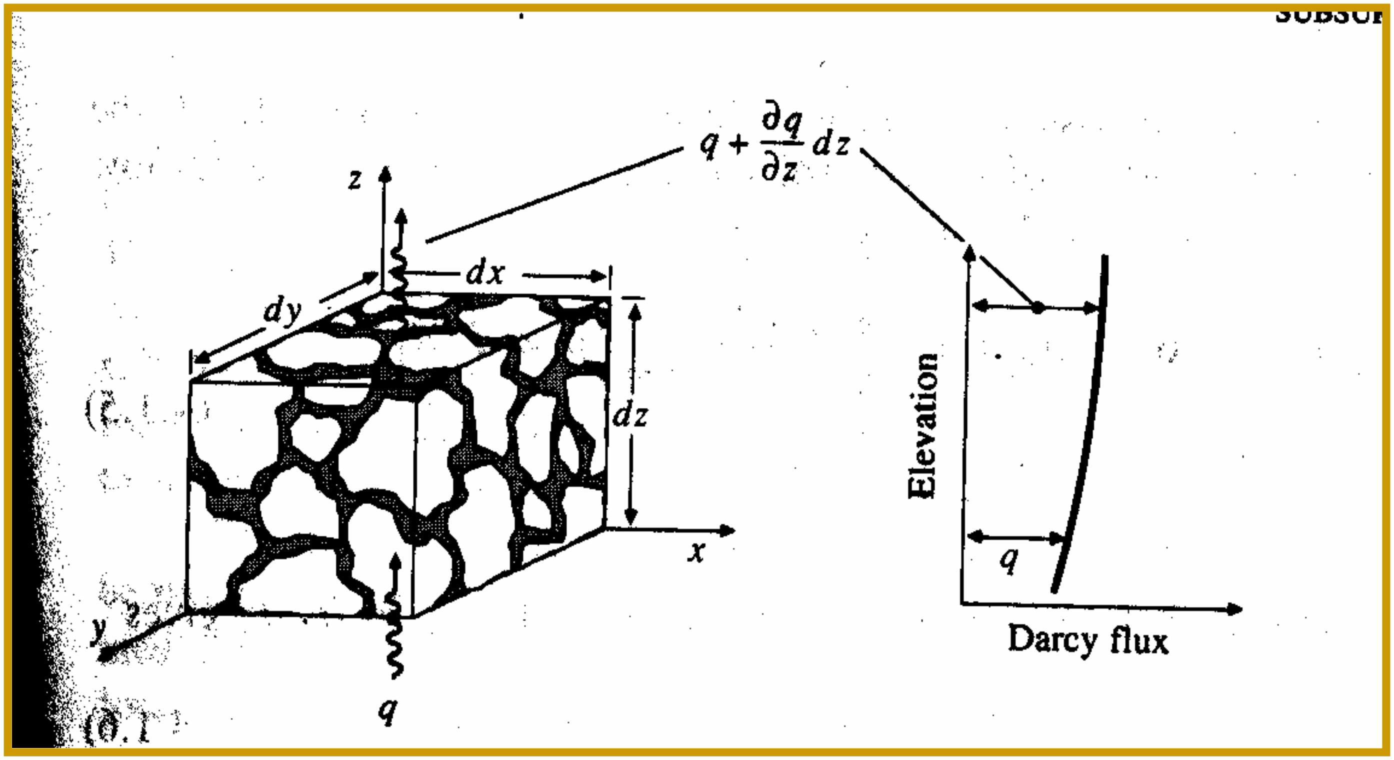
FIGURE 4.1.2
Cross section through an unsaturated porous medium.

- Moisture Content,

$$\theta = \frac{volume\ of\ \ water}{total\ volume}$$

$$\theta = 0 - \eta$$

Continuity & Momentum Equation



$$\frac{\partial \theta}{\partial t} + \frac{\partial q}{\partial z} = 0$$

1-dim. Continuity equation

$$S_f = -\frac{\partial h}{\partial z} = -\left[\frac{\partial (z+\psi)}{\partial z}\right]$$

Momentum equation

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(D\frac{\partial \theta}{\partial z} + K\right)$$

1-dim. Richard's equation for unsat. flow

Moisture Suction Relationship

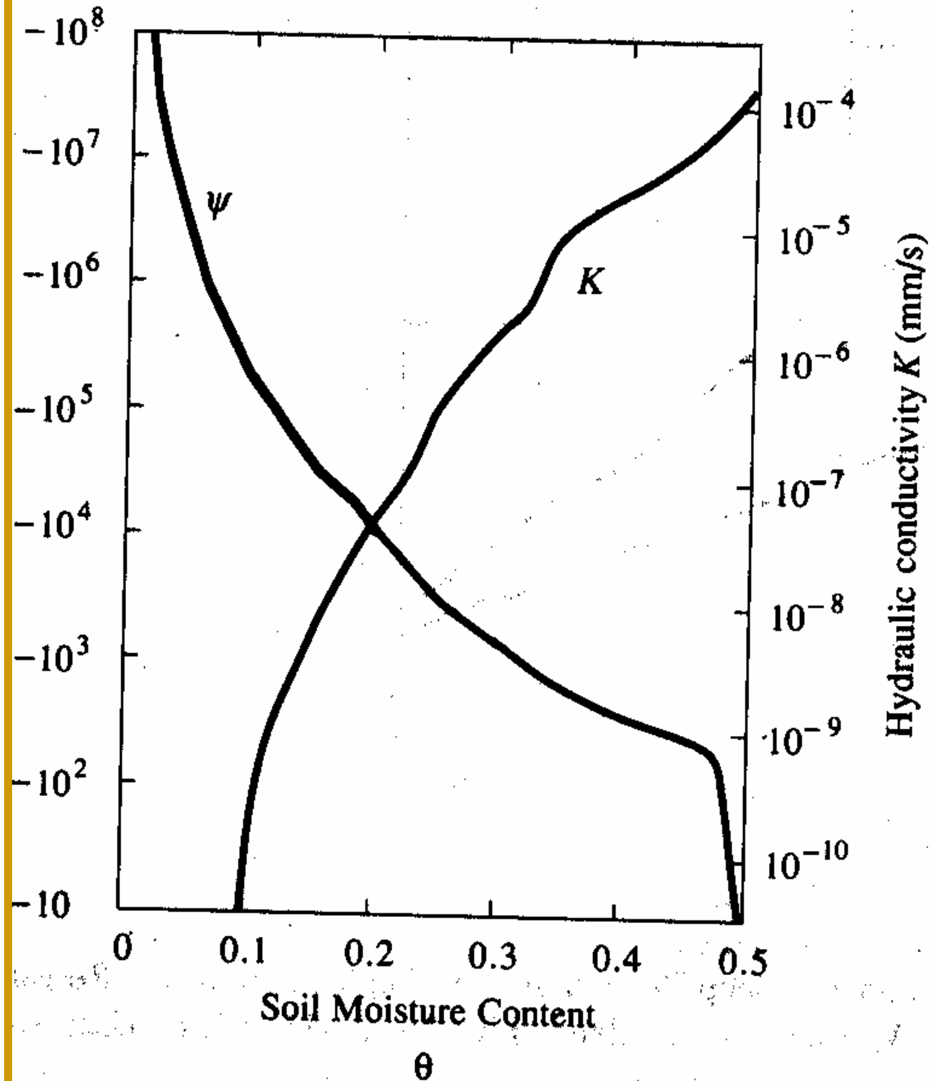


FIGURE 4.1.4
Variation of soil suction head ψ and hydraulic conductivity K with moisture content θ for Yolo light clay. (Reprinted with permission from A. J. Raudkivi, *Hydrology*, Copyright 1979, Pergamon Books Ltd.)

Computation of Soil Moisture Flux

Flow of moisture through the soil can be obtained

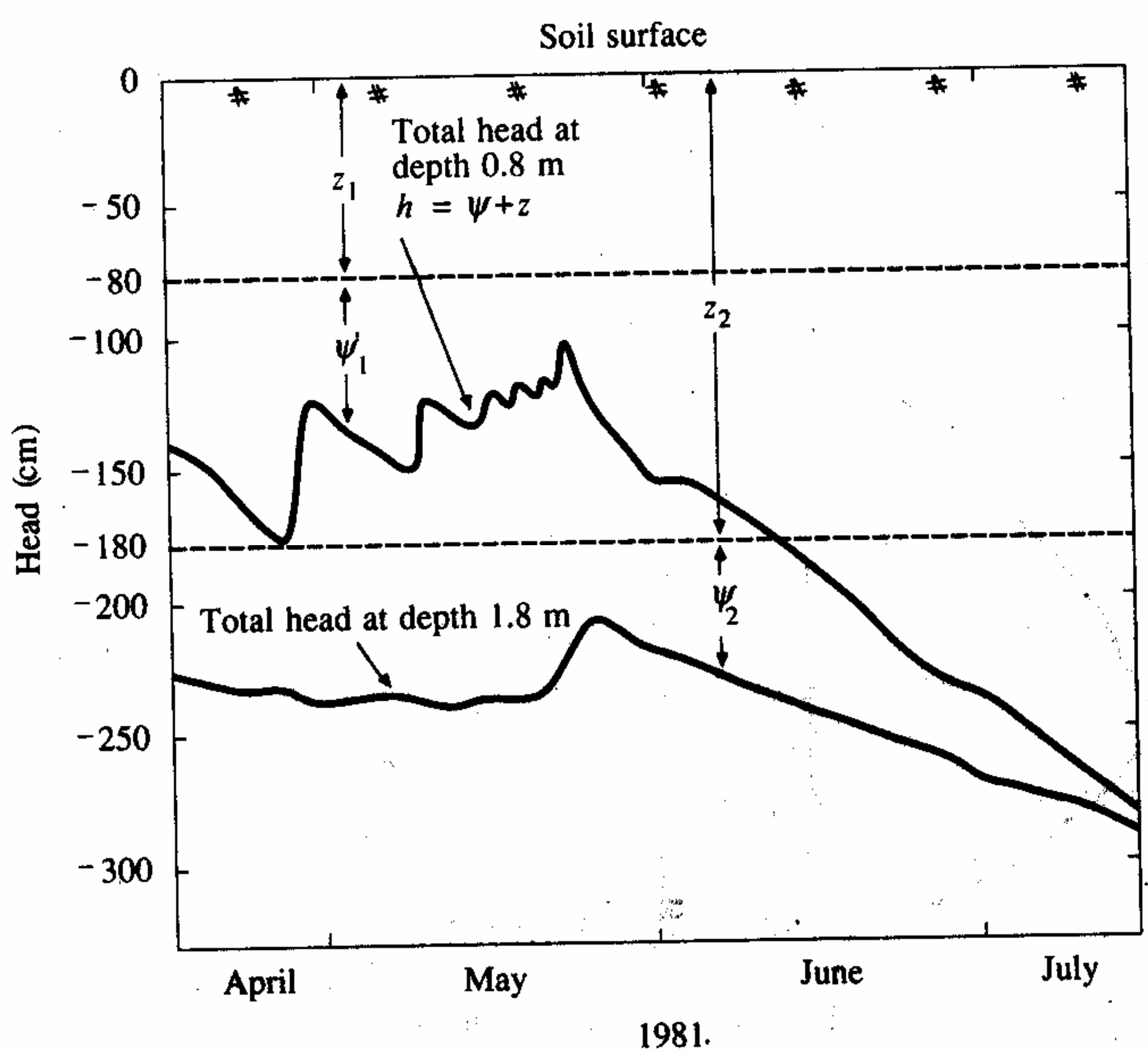
$$\psi = h - z$$

$$\psi_{avg} = \frac{\psi_1 + \psi_2}{2}$$

$$K = C\left(-\psi_{avg}\right)^{-a}$$

$$q = -K\frac{\partial h}{\partial z}$$

$$q_{12} = -K\frac{(h_1 - h_2)}{(z_1 - z_2)}$$



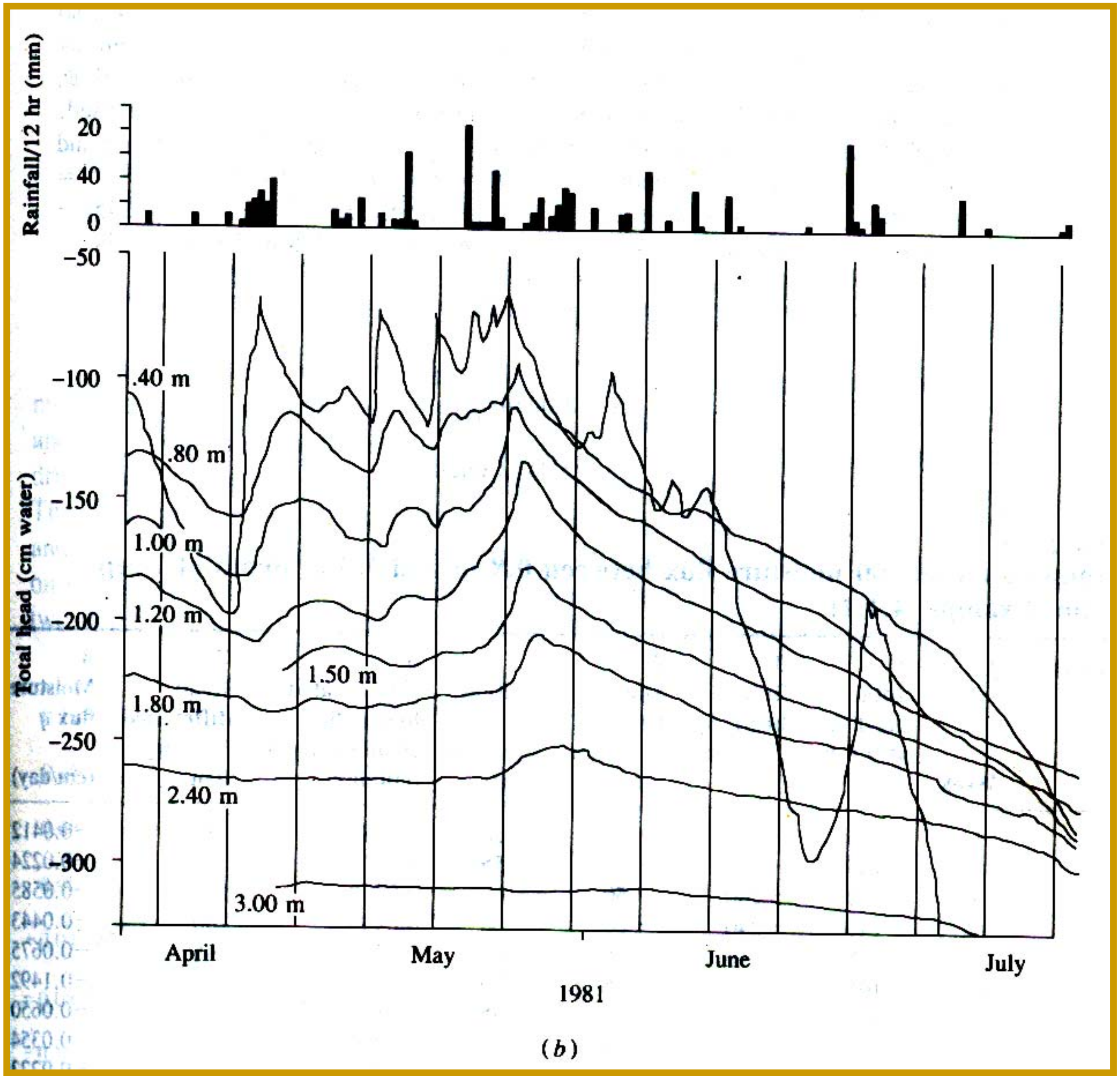
Example 4.1.1

TABLE 4.1.1
Computation of soil moisture flux between 0.8 m and 1.8 m depth at Deep Dean (Example 4.1.1)

Column:	1	2	3	4	5	6	7	8
	Week	Total head h_1 at 0.8 m (cm)	Total head h_2 at 1.8 m (cm)	Suction head ψ_1 at 0.8 m (cm)	Suction ψ_2 at 1.8 m (cm)	Unsaturated hydraulic conductivity K (cm/day)	Head difference $h_1 - h_2$ (cm)	Moisture flux q (cm/day)
	1	−145	−230	−65	−50	0.0484	85	−0.0412
	2	−165	−235	−85	−55	0.0320	70	−0.0224
	3	−130	−240	−50	−60	0.0532	110	−0.0585
	4	−140	−240	−60	−60	0.0443	100	−0.0443
	5	−125	−240	−45	−60	0.0587	115	−0.0675
	6	−105	−230	−25	−50	0.1193	125	−0.1492
	7	−135	−215	−55	−35	0.0812	80	−0.0650
	8	−150	−230	−70	−50	0.0443	80	−0.0354
	9	−165	−240	−85	−60	0.0297	75	−0.0223
	10	−190	−245	−110	−65	0.0200	55	−0.0110
	11	−220	−255	−140	−75	0.0129	35	−0.0045
	12	−230	−265	−150	−85	0.0107	35	−0.0038
	13	−255	−275	−175	−95	0.0080	20	−0.0016
	14	−280	−285	−200	−105	0.0062	5	−0.0003

Example 4.1.1

- ❑ Head at 0.8 m is greater than at 1.8 m.
- ❑ Variation in m.c. reduces at deeper depths
- ❑ High rain causes more infiltration and reduction in suction head and increase in Hydraulic Conductivity.



Example 4.1.1

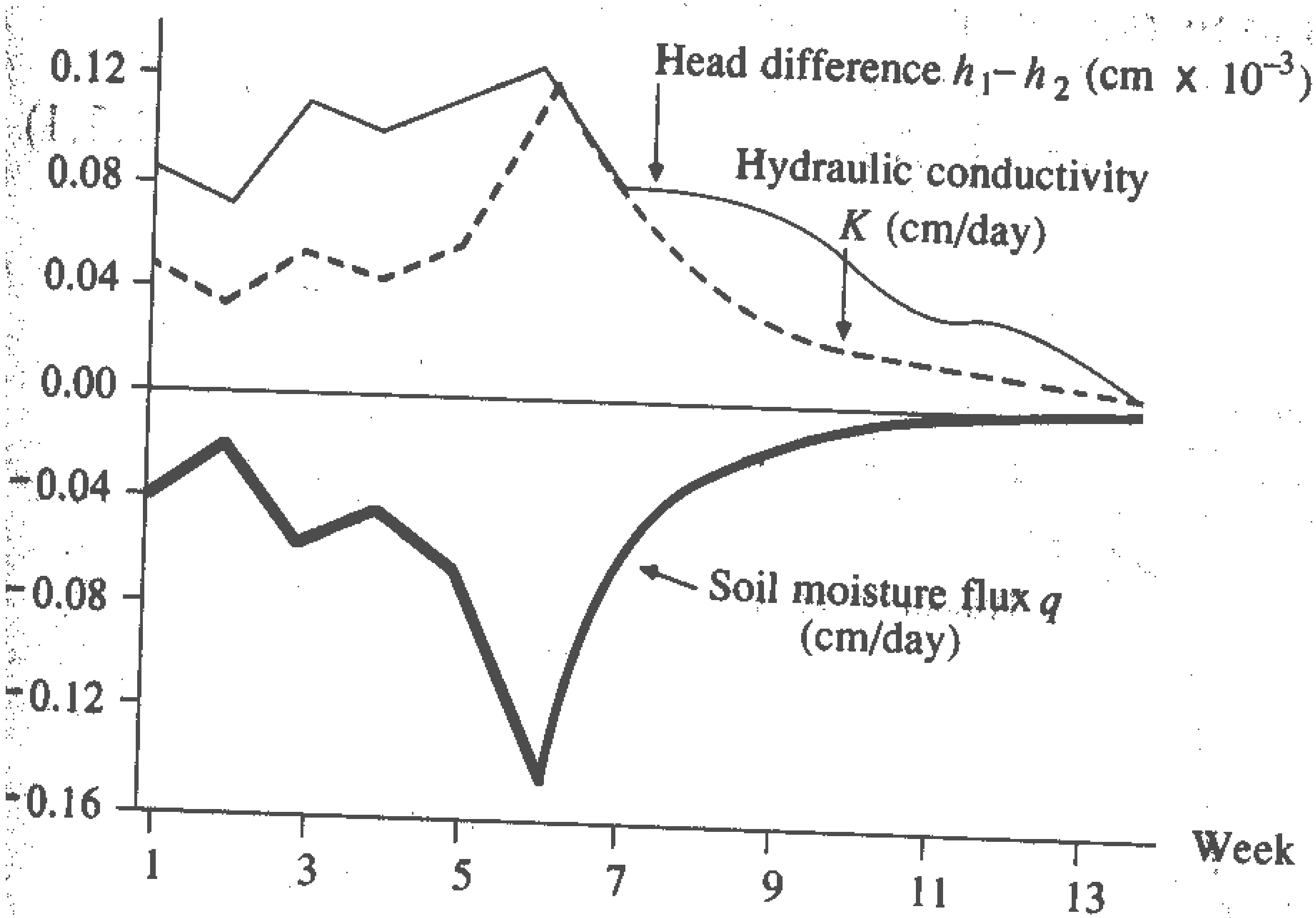


FIGURE 4.1.6
Computation of the soil moisture flux at Deep Dean (Example 4.1.1).

Infiltration

- Process of penetrating water from the ground surface into the soil.
- Infiltration is a very complex process that can be described only approximately with mathematical equations.

Distribution of soil moisture within the soil profile during infiltration.

There are four zones

(1) Saturated Zone

(2) Transmission zone

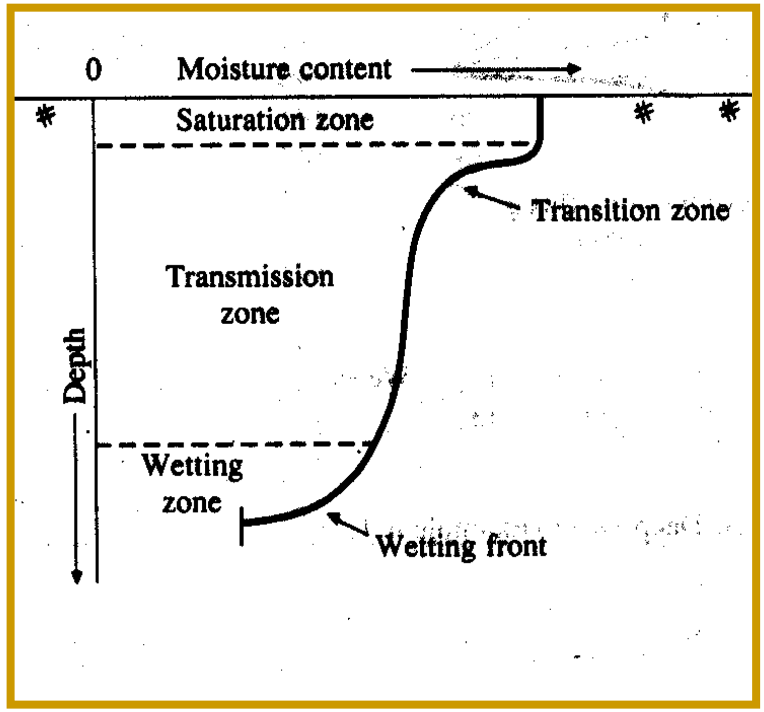
(unsaturated flow fairly uniform m.c.)

(3) Wetting Zone

(m.c. decreases with depth)

(4) Wetting Front

(c.o.m.c. with depth is great)



Infiltration Rate (f)

Rate at which water enters the soil at the surface (mm/hr)

Potential Infiltration Rate

If water is ponded on the surface, the infiltration occurs at the potential infiltration rate.

if rainfall rate < potential infiltration rate, actual infiltration rate will also be less than the potential infiltration rate.

Cumulative Infiltration (F)

Accumulated depth of water infiltrated during a given time period.

It is integral of infiltration rate over that time period.

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

τ is the dummy variable of the time in the integration.

Infiltration Rate f(t)

It is the time derivative of the cumulative infiltration.

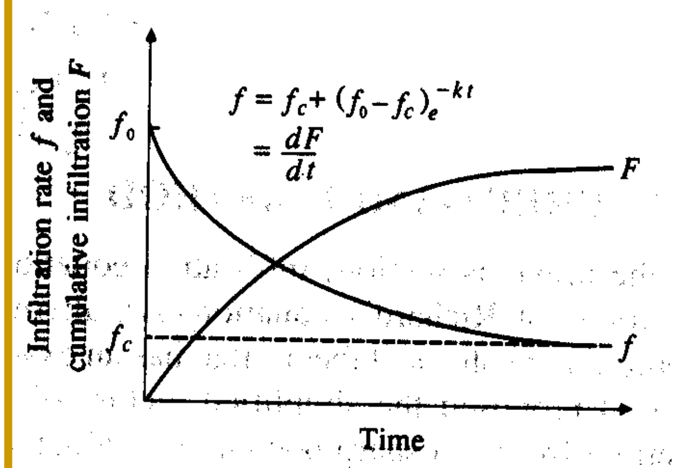
$$f(t) = \frac{d\ F(t)}{dt}$$

Equations for Potential Infiltration Rate

(1) Horton's equation

(2) Philip's equation

(3) Green Ampt equation



(b) Infiltration rate and cumulative infiltration.

(1) Horton's equation

- Derived from Richard's equation
- One of the earliest equations (1933, 1939)
- He observed that infiltration rate begins at some rate f_o and exponentially decreases untill it reaches a constant rate f_c

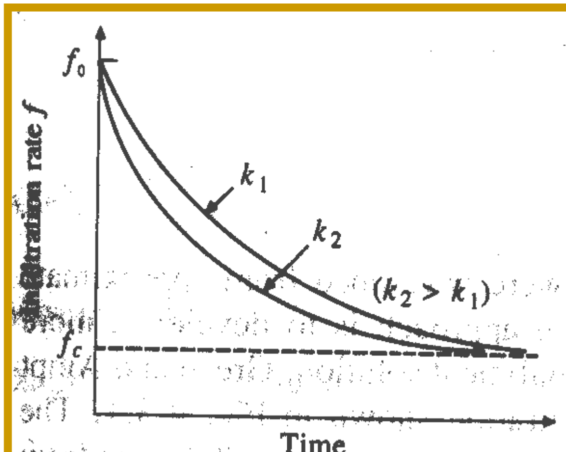
$$f(t) = f_c + (f_0 - f_c)\ e^{-kt}$$

$f(t)$ = Infiltration rate at any time t

k = decay constant [LT^{-1}]

f_0 = Beginning infiltration rate

f_c = Lowest infiltration rate



(a) Variation of the parameter k.

(2) Philip's equation

- Derived from Richard's equation
- Latest than Horton's equation (1957, 1969)
- Cumulative Infiltration rate can be approximated by:

$$F(t) = S\ t^{1/2} + K\ t$$

S = Parameter called Sorptivity [S=f(Sai,K)]

K = Hydraulic conductivity

By differentiating above equation

$$f(t) = \boxed{\frac{1}{2}\ S\ t^{-\frac{1}{2}}} + \boxed{K}$$

Represents gravity head

Represents suction head

$$As\ t \Rightarrow \infty,\quad f(t) \Rightarrow K$$

For horizontal column of soil, Philip's equation reduces to

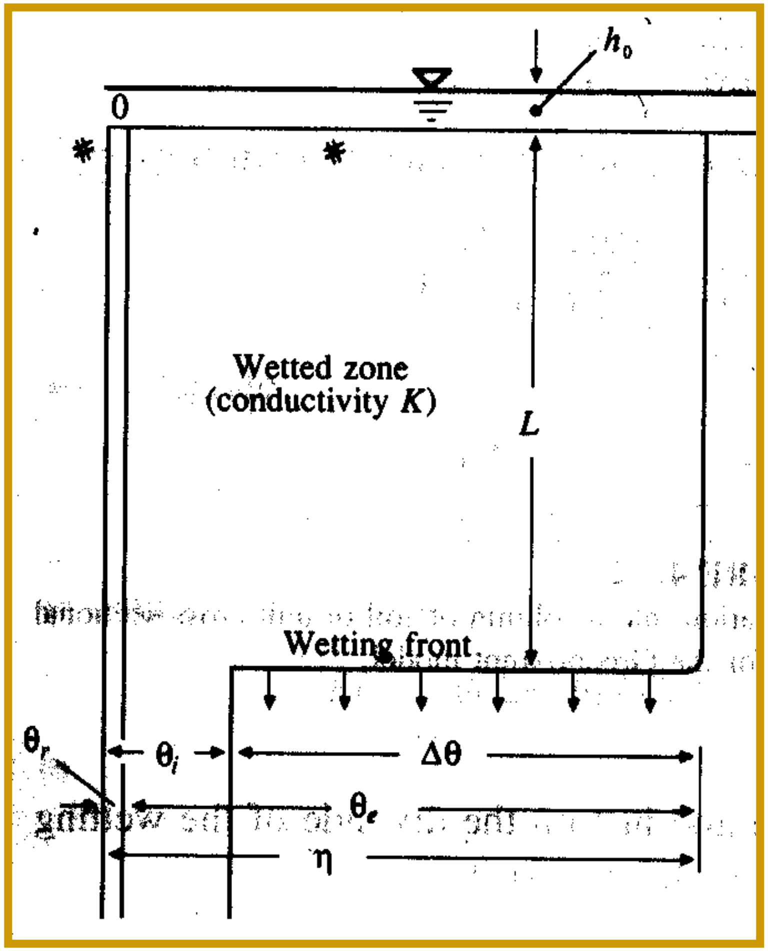
$$F(t) = S\ t^{1/2}$$

(3) Green Ampt equation

- Not Derived from Richard's equation
- Approximate physical theory that has exact analytical solution.
- Green Ampt (1911) has proposed simplified picture of infiltration

$$F(t) = K\,t + \psi\,\Delta\theta\,\ln\left(1 + \frac{F(t)}{\psi\,\Delta\theta}\right)$$

$$f(t) = K\left(\frac{\psi\,\Delta\theta}{F(t)} + 1\right)$$



ψ = Suction head

$$\Delta\theta = \eta - \theta_i$$

When $K,\ t,\ \psi\ \&\ \Delta\theta$ are known

F can be determined by trials

Good trial $F = K\,t$

Green Ampt Parameters

- ❑ Hydraulic conductivity (K)
- ❑ Porosity (η)
- ❑ Wetting front soil suction head (ψ)
- ❑ Effective Saturation (Se)
- ❑ Effective mc (θ_e)

$$S_e = \frac{\theta - \theta_r}{\eta - \theta_r} = \frac{available \quad mositure}{\max.\ possible\ available\ moisture} = \frac{\theta - \theta_r}{\theta_e}$$

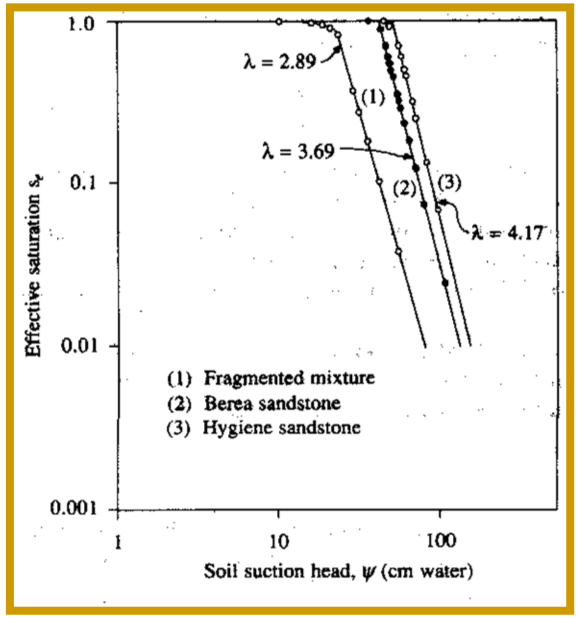
- ❑ Se ranges between 0 - 1.0

$$\Delta\theta = (1 - S_e)\ \theta_e$$

❑ Brooks & Corey (1964) suggested that ψ can be expressed as a logarithmic function of an effective saturation.

$$S_e = \left[\frac{\psi_b}{\psi}\right]^{\lambda}$$

❑ ψ_b and λ are constants obtained by draining a soil in stages.



❑ Effective Hydraulic conductivity for an unsaturated flow is approx. half the corresponding value for saturated flow.

TABLE 4.3.1

Green-Ampt infiltration parameters for various soil classes

Soil class	Porosity η	Effective porosity θ_e	Wetting front soil suction head ψ (cm)	Hydraulic conductivity K (cm/h)
Sand	0.437 (0.374–0.500)	0.417 (0.354–0.480)	4.95 (0.97–25.36)	11.78
Loamy sand	0.437 (0.363–0.506)	0.401 (0.329–0.473)	6.13 (1.35–27.94)	2.99
Sandy loam	0.453 (0.351–0.555)	0.412 (0.283–0.541)	11.01 (2.67–45.47)	1.09
Loam	0.463 (0.375–0.551)	0.434 (0.334–0.534)	8.89 (1.33–59.38)	0.34
Silt loam	0.501 (0.420–0.582)	0.486 (0.394–0.578)	16.68 (2.92–95.39)	0.65
Sandy clay loam	0.398 (0.332–0.464)	0.330 (0.235–0.425)	21.85 (4.42–108.0)	0.15
Clay loam	0.464 (0.409–0.519)	0.309 (0.279–0.501)	20.88 (4.79–91.10)	0.10
Silty clay loam	0.471 (0.418–0.524)	0.432 (0.347–0.517)	27.30 (5.67–131.50)	0.10
Sandy clay	0.430 (0.370–0.490)	0.321 (0.207–0.435)	23.90 (4.08–140.2)	0.06
Silty clay	0.479 (0.425–0.533)	0.423 (0.334–0.512)	29.22 (6.13–139.4)	0.05
Clay	0.475 (0.427–0.523)	0.385 (0.269–0.501)	31.63 (6.39–156.5)	0.03

The numbers in parentheses below each parameter are one standard deviation around the parameter value given. *Source:* Rawls, Brakensiek, and Miller, 1983.

Ponding Time (tp)

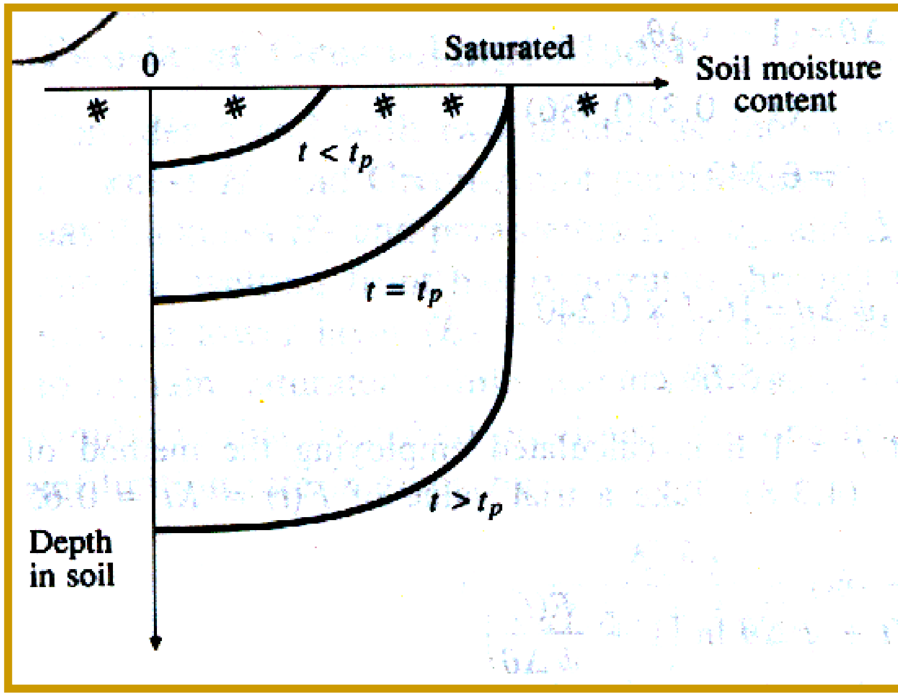
- It is the elapsed time between the time rainfall begins and the time water begins to pond on the soil surface.
- During a rainfall, water will pond on the surface only when rain intensity > infiltration capacity of the soil.

Change in moisture content due to rainfall.

(1) Prior to ponding time (t<tp) the rainfall intensity is less than the potential infiltration rate and soil surface is unsaturated.

(2) Ponding begins when the rainfall intensity exceeds the potential infiltration rate (t=tp), soil is saturated.

(3) As rainfall continues (t>tp), the saturated zone extends deeper into the soil, overland flow occurs.



Soil Moisture Profiles before, during and after Ponding

Ponding Time (tp) Estimation

- Mein & Larsen (1973) presented a method for determining the ponding time using Green Ampt equations
- Principles

(1) Prior to ponding time, all the rainfall is infiltrated.

(2) The potential infiltration rate (f) is a function of the accumulated infiltration F.

(3) Ponding occurs when the potential infiltration rate is less than or equal to the rain intensity.

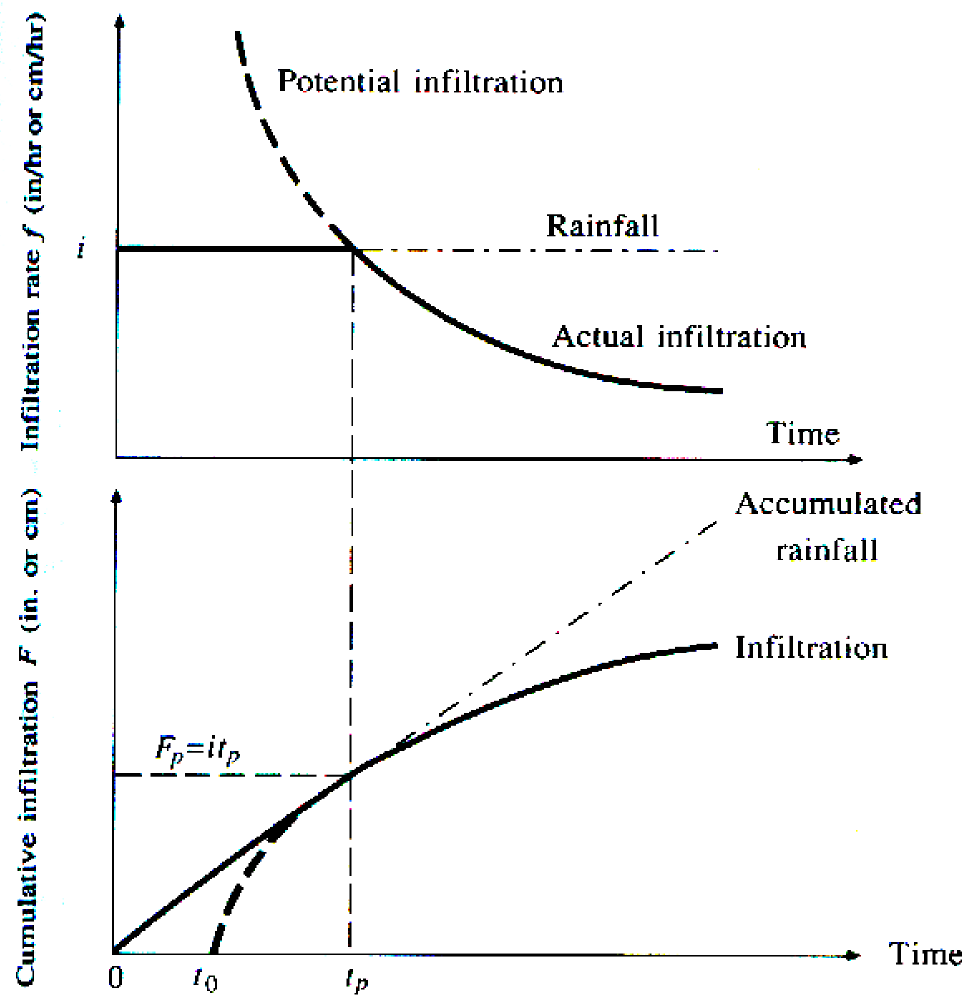


FIGURE 4.4.2
Infiltration rate and cumulative infiltration for ponding under consta

Ponding Time (tp) Estimation

According to Green Ampt equation, f & F are related as:

$$f = K\left(\frac{\psi\ \Delta\theta}{F} + 1\right)$$

$$F = i\ t_P$$

$$i = K\left(\frac{\psi\ \Delta\theta}{F} + 1\right)$$

$$t_P = \frac{K\ \psi\ \Delta\theta}{i(i - K)}$$

Where

F_P = Cumulative infiltration at ponding time

t_P = ponding time

f = infiltration rate (mm/hr)

i = rainfall intensity (mm/hr)

Actual Infiltration Rate after Ponding

- Actual infiltration rate after ponding will reduce as soil will become saturated.
- Depth of infiltration after ponding can be computed as:

$$F - F_P - \psi\ \Delta\theta\ \ln\left[\frac{\psi\ \Delta\theta + F}{\psi\ \Delta\theta + F_P}\right] = K\ \left(t - t_P\right)$$

$$f(t) = K\ \left(\frac{\psi\ \Delta\theta}{F(t)} + 1\right)$$

Summary of Infiltration Equations

TABLE 4.4.1
Equations for calculating ponding time and infiltration after ponding occurs

Equation	Variable calculated	Green-Ampt equation	Horton's equation	Philip's equation
(1)	Potential infiltration rate as a function of time	Solve for F from (2) then use (6).	$f = f_c + (f_0 - f_c)e^{-kt}$	$f = \frac{1}{2}St^{-1/2} + K$
(2)	Potential cumulative infiltration as a function of time	$F - \psi\Delta\theta \ln\left(1 + \frac{F}{\psi\Delta\theta}\right) = Kt$	$F = f_c t + \frac{f_0 - f_c}{k}\left(1 - e^{-kt}\right)$	$F = St^{1/2} + Kt$
(3)	Ponding time under constant rainfall intensity i	$t_p = \frac{K\psi\Delta\theta}{i(i-K)}$ $(i > K)$	$t_p = \frac{1}{ik}\left[f_0 - i + f_c \ln\left(\frac{f_0 - f_c}{i - f_c}\right)\right]$ $(f_c < i < f_0)$	$t_p = \frac{S^2(i - K/2)}{2i(i-K)^2}$ $(i > K)$
(4)	Equivalent time origin for potential infiltration after ponding	$t_0 = t_p - \frac{1}{K}\left[F_p - \psi\Delta\theta \ln\left(1 + \frac{\psi\Delta\theta}{F_p}\right)\right]$	$t_0 = t_p - \frac{1}{k}\ln\left(\frac{f_0 - f_c}{i - f_c}\right)$	$t_0 = t_p - \frac{1}{4K^2}\left(\sqrt{S^2 + 4KF_p} - S\right)^2$
(5)	Cumulative infiltration after ponding	$F - F_p - \psi\Delta\theta \ln\left(\frac{\psi\Delta\theta + F}{\psi\Delta\theta + F_p}\right) = K(t - t_p)$	Substitute $(t - t_0)$ for t in (2).	Substitute $(t - t_0)$ for t in (2).
(6)	Infiltration rate after ponding	$f = K\left(\frac{\psi\Delta\theta}{F} + 1\right)$	Substitute $(t - t_0)$ for t in (1).	Substitute $(t - t_0)$ for t in (1).

Measurement of Infiltration

Infiltrometers can be used to measure infiltration rate.

(1) Flooding type Infiltrometer

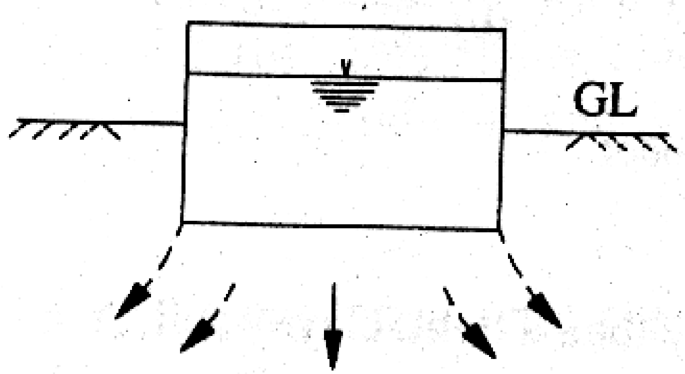
(2) Rainfall Simulator

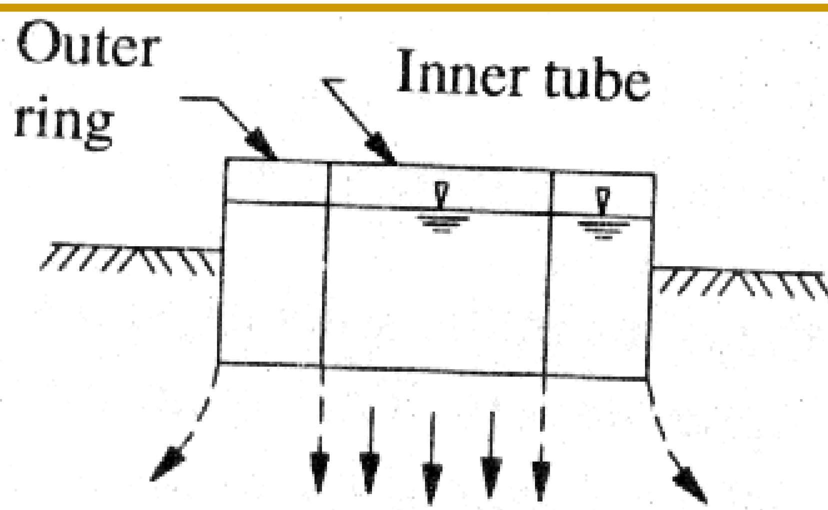
(1) Flooding Type Infiltrometer

- Metal cylinder 30 cm dia, 60 cm long open at both ends.
- The cylinder is driven into the ground to a depth of 50 cm.
- Water is poured into the top part to a depth of 5 cm and a pointer is set to mark the W.L.
- As infiltration proceed, the water is added from a burette to keep the W.L. at the tip of the pointer.
- A plot of the infiltration capacity vs. time is obtained.
- The experiment is continued till a uniform rate of infiltration is obtained (2-3 hrs), time interval may be taken as 10 min
- The soil surface is protected by a perforated disc to prevent formation of turbidity.

Objection: Infiltrated water spread out at the outlet from the tube.

Flooding Type Infiltrometer





3.11 Ring infiltrometer

Flooding Type Ring Infiltrometer

- To overcome this problem a Ring Infiltrometer consisting of two concentric rings is used.
- Two rings are inserted into the ground and water is maintained in both the rings to common fix level.
- The outer ring provides a water jacket
- The measurement of water volume is done on the inner ring only.

Main disadvantages of Flooding type infiltrometer

(1) The raindrop impact is not simulated.

(2) Driving of tube disturbs the soil structure

(3) Scale effects

(2) Rainfall Simulator type Infiltrometer

- Small plot of land (2 m x 4 m) is provided with a series of nozzles.
- Raindrop falling height is approximately 2 m.
- Various rainfall intensities can be provided.
- Arrangement to collect and measure the surface runoff is provided.
- Water budget equation is used

$$P = I + R$$

- Infiltration rate and variation with time are calculated .
- Rainfall simulator type infiltrometer give lower values of infiltration due to turbidity.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