SOIL WATER RELATIONSHIP

CHAPTER 4

1. Introduction

Irrigation may be defined as the application of water to soil for the purpose of supplying moisture essential for plant growth.

Root zone (depth of soil penetrated by roots) soil provides the storage reservoir which needs to be periodically recharged.

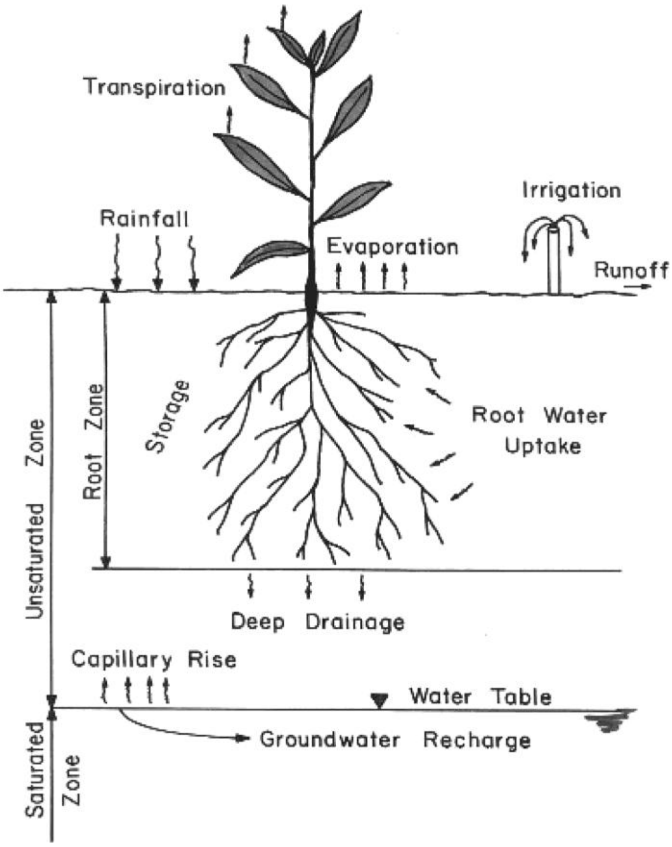


Fig: Schematic diagram of the sub-processes linked to field irrigation system

2. Volume of mass relationships of soil constituents:

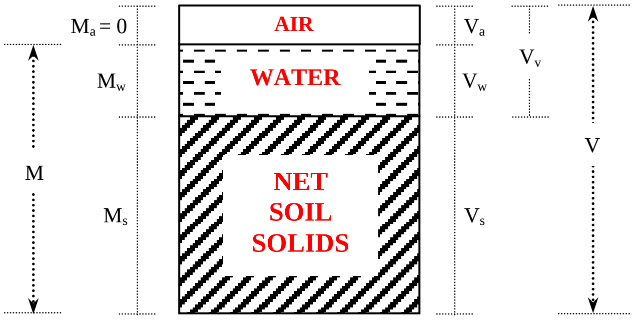


Fig: Schematic diagram of the soil as a three-phase system

Notation:

M_a = Mass of air
M_w = Mass of water
M_s = Mass of solid

V_a = Volume of air
V_w = Volume of water
V_s = Volume of solid

(a) Particle density, ρ_s = Mass of dry soil/Volume of solid = M_s/V_s

(b) Bulk density, ρ_b = Mass of dry soil/Bulk volume of soil = $M_s/(V_a + V_w + V_s)$

(c) Apparent specific gravity, A_s = Bulk density of soil/ Water density = ρ_b/ρ_w

The term bulk density and apparent specific gravity are often used synonymously

(d) Real specific gravity, R_s = Particle density/Water density = ρ_s/ρ_w

(e) Porosity, n = Volume of void/Bulk volume of soil = $(V_a + V_w)/(V_a + V_w + V_s)$

(f) Void ratio, e = Volume of voil/ Volume of solid = $(V_a + V_w)/V_s$

Some relationships exist:

$$\rho_b = \rho_s\times(1 - n/100)$$
$$\rho_b = \rho_b\times(1 + e)$$

(g) Degree of saturation, s = Volume of water/ Total pore volume = $V_w/(V_a + V_w)$

3. Soil Classification:

The most commonly used classification proposed by the United States Department of Agriculture (USDA):

Fraction	Particle diameter (mm)
Gravel	> 2
Sand	0.05 ~ 2
Silt	0.002 ~ 0.02
Clay	< 0.002

4. Soil physical properties influencing irrigation:

- Infiltration capacity of soil
- Water holding capacity of soil
- Soil texture
- Soil structure
- Capillary conductivity
- Soil profile conditions
- Depth to water table etc.

---- are the most important soil properties influencing irrigation

Soil Texture:

- The relative proportion of sand, silt and clay determines the soil texture. Texture can be determined from grain-size distribution using textural classification chart.
- The geometry of voids created in the soil matrix is dependent on the textural classification of soil. The soil texture, therefore, influences considerably the other phases (water and air) contained in the spaces of soil matrix.
- Sandy soils are loose and non-cohesive and have a low water holding capacity. Such soils form relatively simple capillary systems, which ensure good drainage and aeration.
- The clay particles are usually aggregated together into complex granules. Because of their plate-like shape, clay particles have a much greater surface area than cubes or spheres of similar volume. Their extensive surface enables clay particles to hold more water and minerals than sandy soils.

Soil Structure:

- The arrangement of individual soil particles with respect to each other is called soil structure
- The size of aggregates is a valuable criterion of soil structure. Sand-sized aggregates are more favorable for plant growth than very small and very large ones. For instance, a soil made up exclusively of silt-size aggregates cannot be drained by gravity, since the pores are too small.
- Large pores induce aeration and infiltration, medium-sized pores facilitate capillary conductivity, and small pores induce greater water holding capacity.
- Rounded edges of the aggregates result in better pore distribution than angular ones. Regarding the size of aggregates, sand-size and gravel-size are preferred. A massive compact soil restricts aeration and root spread.
- For optimum crop growth, soil structure should be such that the infiltration capacity is large, the percolation capacity is medium and aeration is sufficient, without being excessive.

5. Classes and availability of soil water:

a) **Gravitational water:** Water moves freely in response to gravity.
b) **Capillary water:** Water held by surface tension in the pore spaces.
c) **Hygroscopic water:** Water held tightly to the surface of the grains by adsorption.

Field Capacity (FC):

The water content of the soil when gravitational water has been removed
It represents the upper limit of available soil water range
It is determined two days after an irrigation or thorough wetting. Limitations are: restricting layers, high water table, surface evaporation, consumptive use by crops
Water content corresponding to a soil-moisture of 1/10 atm for sandy soil to 1/3 atm for silty or clay soil

Permanent Wilting Point (PWP):

The moisture content at which plants permanently wilt
Wilting depends on the rate of water use, depth of root zone and water holding capacity of soil
It is the lower end of available moisture range
Water content corresponding to soil-moisture tension of 15 atm
As an approximation, PWP can be estimated from:

$$\text{PWP} = \frac{\text{FC}}{(2 \text{ to } 2.4)}$$

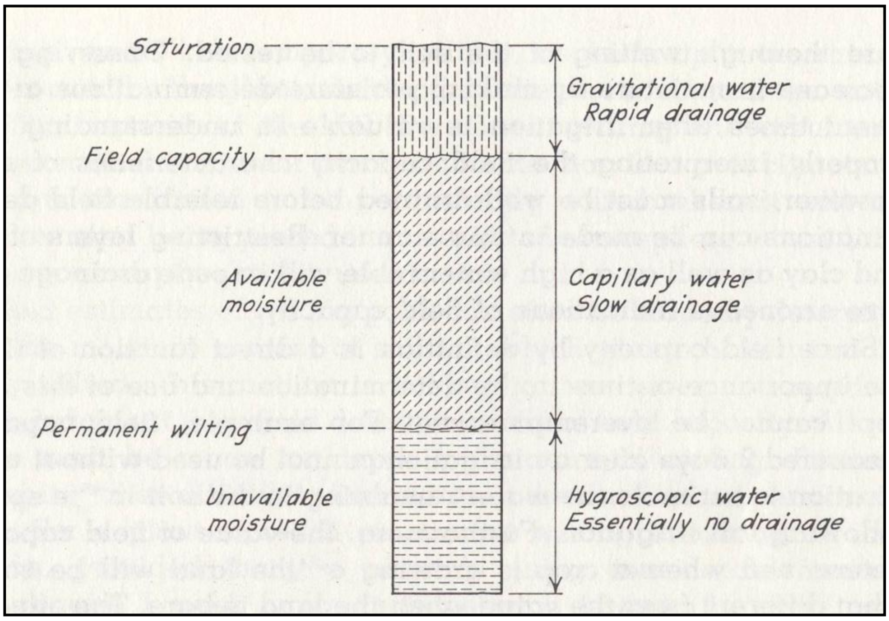


Fig: Classes and soil-water availability to plants and drainage characteristics

Available Water (AW):

- The difference of water content of the soil between field capacity and permanent wilting point
- It represents the moisture which can be stored in the soil for subsequent use by plants
- The moisture near the wilting point is not readily available to the plant. The portion of the available moisture which is most easily extracted by plants is termed as readily available moisture.
- Irrigation water should be supplied as soon as the moisture falls upto optimum level. The optimum level represents the maximum deficiency upto which the soil moisture may be allowed without any fall in crop yields.
- The amount of irrigation should be just enough to bring the moisture content upto its field capacity making allowance for application losses

6. Soil moisture content:

a) Moisture content by mass: $\theta_m = \dfrac{\text{Mass of water}}{\text{Mass of dry soil}} = \dfrac{M_w}{M_s}$

b) Moisture content by volume: $\theta_v = \dfrac{\text{Volume of water}}{\text{Bulk volume of soil}} = \dfrac{V_w}{V_b}$

θ_v is more useful, since it represents the equivalent depth of water per unit depth of soil

$$\theta_v = \frac{d_w}{D_s}$$

$$\Rightarrow d_w = \theta_v \times D_s \text{ --------------------------------- (i)}$$

$$\text{Again, } \theta_v = \frac{V_w}{V_b} = \frac{\dfrac{M_w}{\rho_w}}{\dfrac{M_s}{\rho_b}} = \theta_m \times \frac{\rho_b}{\rho_w} = \theta_m \times A_s$$

$$\therefore\ \theta_v = \theta_m \times A_s \text{ ------------------------------- (ii)}$$

Putting the value of θ_v in equation (i) $\Rightarrow$

$$d_w = \theta_m \times A_s \times D_s$$

7. Soil moisture tension:

In saturated soils, water is held in the soil matrix under negative pressure due to attraction of the soil matrix for water

Instead of referring to this negative pressure the water is said to be subjected to a tension exerted by the soil matrix

The tension with which the water is held in unsaturated soil is termed as soil-moisture tension, soil-moisture suction. It is usually expressed in atmospheres, the average air pressure at sea level. Other pressure units like cm of water or cm or mm of mercury are also often used.

(1 atmosphere = 1023 cm of water = 76 cm Hg)

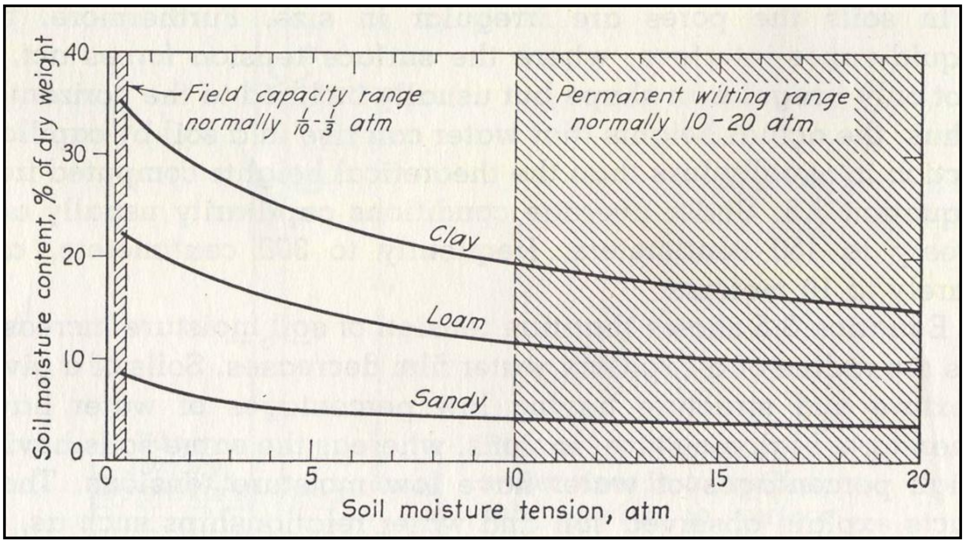


Fig: Typical curves of soil moisture variation with tension

8. Soil moisture characteristics:

Moisture extraction curves, also called moisture characteristics curves, which are plots of moisture content versus moisture tension, show the amount of moisture a given soil holds at various tensions.

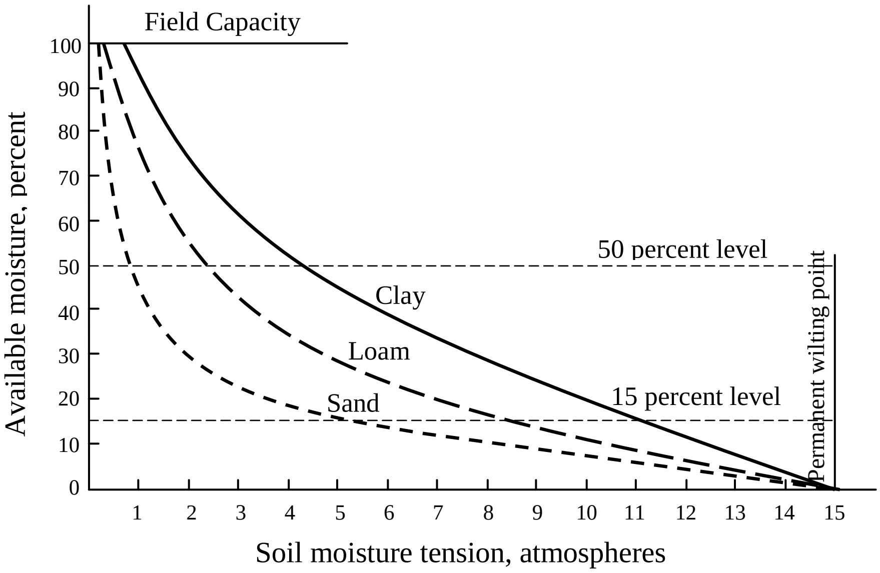


Fig: Typical moisture characteristics curves

A knowledge of the amount of water held by the soil at various tensions is required in order to understand the amount of water that is available to plants, the water that can be taken up by the soil

9. Soil moisture stress:

In many irrigation soils, the soil solution contains an appreciable amount salts. The osmotic pressure developed by the soil solution retards the uptake of water by plants.

Plant growth is a function of the soil moisture stress which is the sum of the soil moisture tension and osmotic pressure of soil solution.

For successful crop production in soils having appreciable salts, the osmotic pressure of the soil solution must be maintained as low as possible by controlled leaching and the soil moisture tension is the root zone is maintained in a range that will provide adequate moisture to the crop.

10. Measurement of soil moisture:

Objective or importance:

- To determine the time and amount of irrigation
- To estimate evapotranpiration/use rate

Methods:

(a) Appearance and feel method:

- Using the soil auger, soil samples throughout the root zone are collected.
- By looking and feeling the sample, soil moisture deficiency is determined using guideline
- Not precise and it requires experience and judgment
- Simple, quick and it requires no equipment except soil auger
- In many applications, greater accuracy is not needed, nor is it justified economically.

(b) Gravimetric method:

- This method is used for primary measurement
- It involves weighting a sample of moist soil, drying to a constant weight at a temperature of $105^o \sim 110^oC$, and re-weighting. Usually 24 hours are required for drying.
- Most accurate and direct method
- Destructive, labor intensive and time consuming; several samples are required to obtain a satisfactory representative indication of moisture content.

(c) Electro-resistance blocks:

- The porous blocks (gypsum) are calibrated against a range of moisture. The blocks containing desired electrical elements are placed in the field of at required depth.
- As the moisture content of the blocks changes, the electrical resistance also changes
- The gypsum blocks are soluble and deteriorate in one to three seasons of use.
- Normally there is considerable variation between blocks and considerable changes occur in the calibration during the season

(d) Tensiometer:

- A porous ceramic cup filled with water is attached to a vacuum gauge or mercury manometer.
- A hole is bored or dug to a desired depth; a handful of loose soil is placed into the hole, and the cup pushed firmly into the soil. The water inside the cup comes into hydraulic contact through the pores in the cup. When initially placed in the soil, water contained in the tensiometer is generally at atmospheric pressure. Soil water, being generally at sub-atmospheric pressure, exercises a suction which draws out a certain amount of water within the tensiometer, thus causing a drop in its hydrostatic pressure. This pressure is indicated by the manometer or vacuum gauge.
- Tensiometer is effective upto a tension of 0.8 bar. At this pressure air enters the closed system through the pores of the cup and makes the unit inoperative.
- Tensiometer readings are useful in deciding when to irrigate, but they do not indicate how much water should be applied. A special moisture-characteristic curve for the particular soil is needed to convert moisture tension measurements into available moisture percentage.
- Tensiometers are less well suited to use in fine-textured soils in which only a small part of the available moisture is held at a tension of less than 1 atmosphere.
- Since the unit operates satisfactorily only upto tensions of 0.8 atm, they are most useful in sandy soil, where this represents a major portion of the available water.
- Because of its narrow range of application the tensiometer is used for moist and resistance blocks for dryer soil conditions. Sometimes a combination of tensiometer and resistance blocks is used.

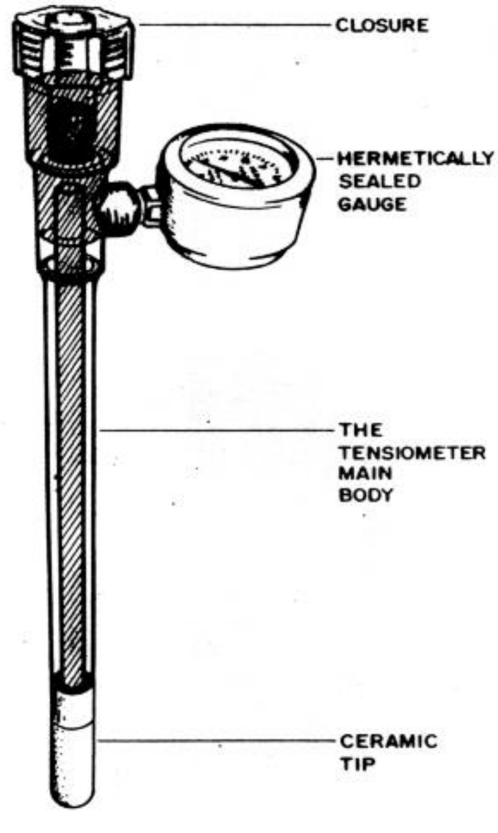


Fig: The essential parts of a tensiometer

(e) Neutron method:

- A hole is dug with an auger, and a metal tube is driven into the hole to retain the soil. The neutron source and counting device are lowered to the desired depth.
- Fast neutrons emitted from the source and slowed down by water in the surrounding soil. The resulting slow neutrons which reach the counting tube are recorded. Fast neutrons are not registered by the counter.
- The greater the water content of the soil, the greater is the number of slow neutrons reaching the counting tube.
- There exists a good correlation between moisture content and the number of slowed down neutron reaching the counter.

$$\theta_v = (a + b) \times \frac{R_s}{R_{st}}$$

Where, a and b are calibration coefficients

R_s = Count rate in the soil

R_{st} = Standard count rate

It measures θ_v directly

It is expensive, can not be used to measure near the surface because of boundary effect and possible radiation hazard, and needs calibration

11. Flow of water through soil:

Energy in fluid is in two forms:

- Kinetic Energy
- Potential Energy consisting of
  a) Energy resulting from pressure difference
  b) Energy resulting from elevation difference

Widely used Bernoulli's Energy Equation, showing energy per unit mass of fluid:

$$H = z + P/\gamma + V^2/2g$$

Since the velocity through soil is very small, the term $V^2/2g$ can be ignored. Thus,

$H = z + P/\gamma$ is called the piezometric head or hydraulic head

Flow of water in soil occurs in the direction of decreasing piezometric head.

Pressure head is due to adsorptive and capillary forces in unsaturated soil; elevation head due to gravitational potential.

Darcy's law relates velocity to head loss:

$$V = k \times (h_L/L)$$

Where,

V = Flow velocity
k = Co-efficient of permeability or hydraulic conductivity
h_L/L = Hydraulic gradient or slope of H.G.L

The hydraulic head h can be measured by piezometer in saturated soil and by tensiometer in unsaturated soil.

The quantity of flow,

$$Q = AV$$
$$= A \times k \times (h_L/L)$$

Where, A = Gross area at right angles to flow direction

Flow of unconfined ground water:

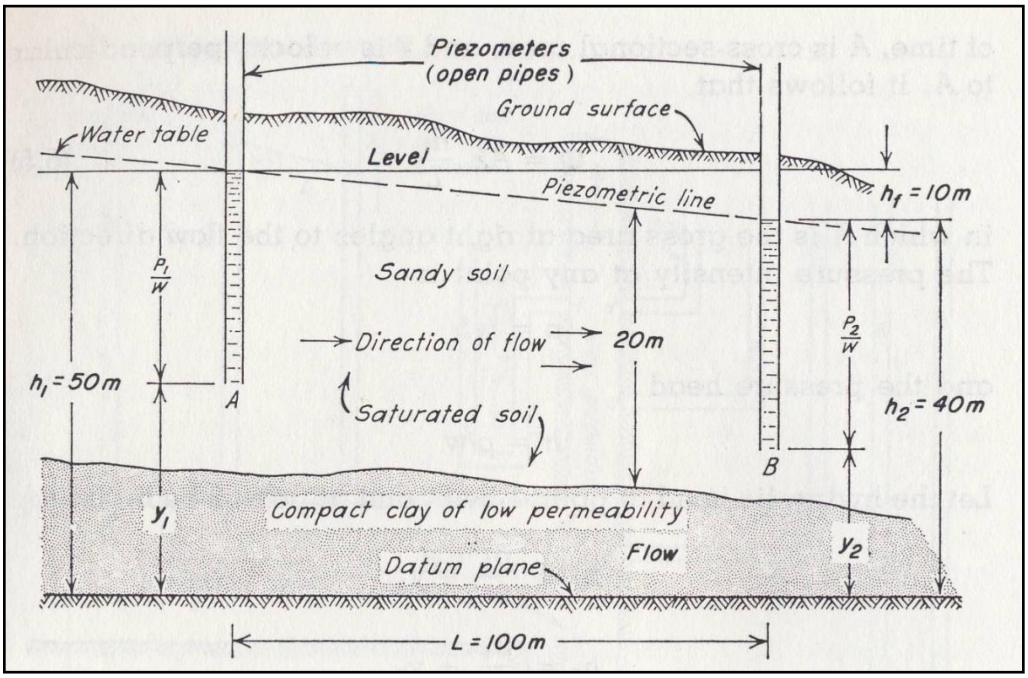


Fig: Flow of unconfined ground water

Flow of confined ground water:

$$\frac{h_L}{L} = \frac{h_a - h_d}{L} = \frac{(6+7)-(4+3)}{16-2}$$

$$= 6/14 = 0.43$$

For unsaturated soil, the hydraulic conductivity decreases many folds as the moisture content decreases. Moreover, it is difficult to measure h because tensiometer becomes inoperative when the tension exceeds 0.8 atm. Furthermore, flow occurs in both liquid and vapor phases.

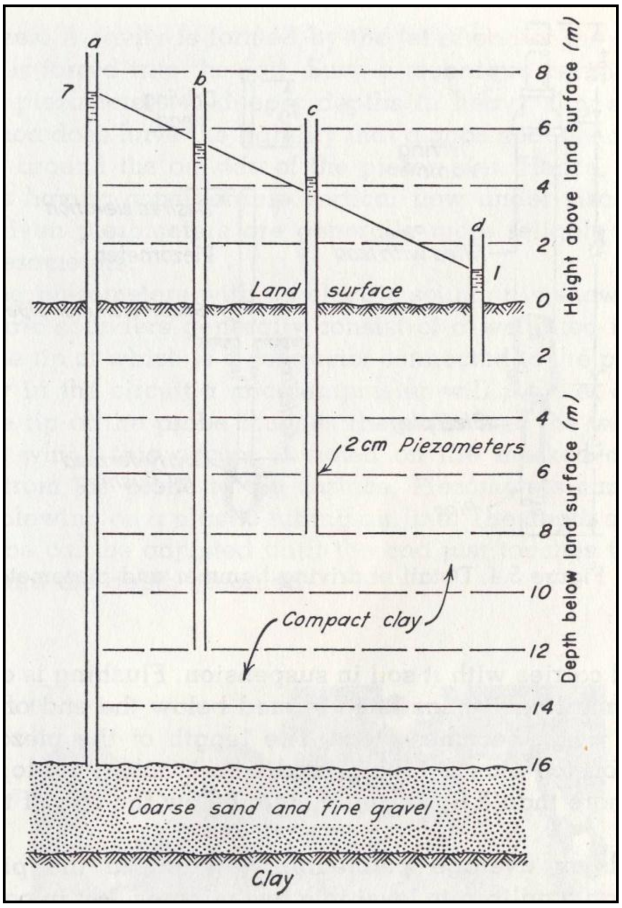


Fig: Flow of confined ground water

12. Infiltration/intake characteristics of soil:

Infiltration is the time rate of entry of water into soil. Whenever the soil surface configuration influences the rate of entry, the term intake is used.

It has great practical importance: design and operation of water application system, intake rate of fine-textured soil is very low.

Factors influencing infiltration are:

- Initial moisture content
- Condition of soil surface
- Hydraulic conductivity of soil profile
- Depth of water on the surface
- Viscosity/temperature of water
- Soil texture

The intake rate plotted against time on a logarithmic scale gives a straight line.

$$I = a \times T^n$$

Where,

I = Intake rate
a = Constant (ordinate at T = 1)
n = slope of the line

When the observation of intake extends over long periods, a better representation of the data can be obtained by: $I = b + aT^n$

Since, n is negative, I decreases with an increase in T. I approaches a constant value b as time increases. This value is called final intake rate.

$$I = k \times \frac{\delta h}{\delta s}$$

Initially I is high because of large difference in tension in addition to gravity, after several hours difference in tension becomes zero and hydraulic gradient equals to unity and I approaches to Ks.

Measuring Intake rate:

25 cm diameter cylinder is driven upto 15 cm below soil surface

Water is applied at surface. The radial flow at bottom of cylinder causes great change in intake rate.

Two concentric cylinders having same water level are used to create buffer ponds

Depth of water for inner cylinder is recorded with time

Table: Tabulation of intake Data Obtained from Test Cylinder

Cylinder No. 3					
Time (hr)			**Intake (mm)**		
Watch	**Difference**	**Cumulative**	**Depth**	**Difference**	**Cumulative**
4:15	1		260	11	
4:16	2	1	249	7	11
4:18	4	3	242	8	18
4:22		7	234		26
Refill	8		271	11	
4:30	18	15	260	14	37
4:48		33	248		61
Refill	14		270	8	
5:02	27	47	252	14	59
5:29	31	74	248	10	73
6:00		105	238		83
Refill	29		280	11	
6:29	28	134	269	9	94
5:57	26	162	260	7	103
7:23	20	188	253	5	110
7:43		208	248		115

Intake rate, $I = aT^n$

Accumulated intake,

$$D = \int I\,dT$$

$$= \frac{a}{n+1} \times T^{n+1}$$

$$= C \times T^N$$

Average Infiltration rate,

$$I_{avg} = \frac{D}{T} = CT^{N-1}$$

Instantaneous Infiltration rate,

$$I_{inst} = \frac{dD}{dT} = CNT^{N-1}$$

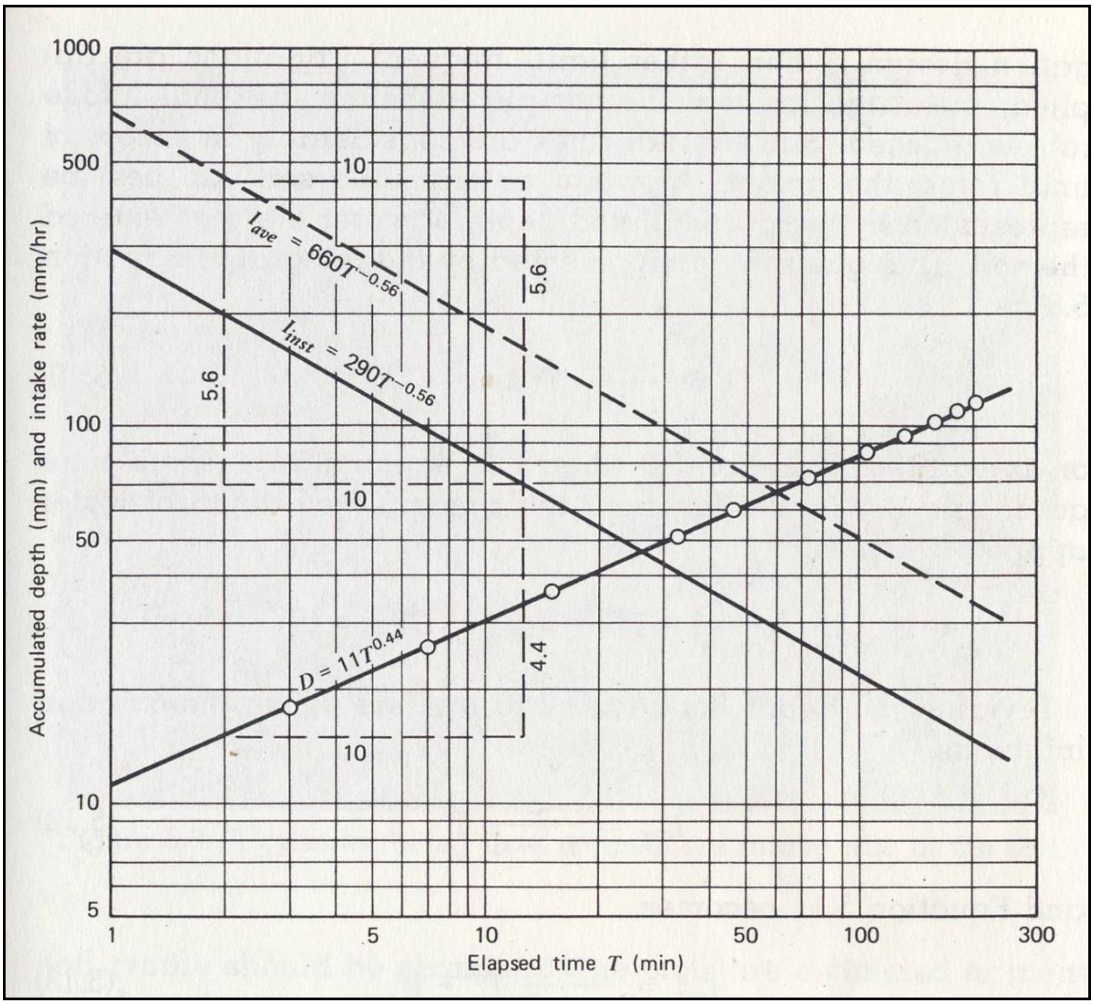


Fig: Typical intake curves

The slope of the line on log-log plot,

$N = 0.44$

Hence, $D = 11 \times T^{0.44}$

$I_{avg} = CT$

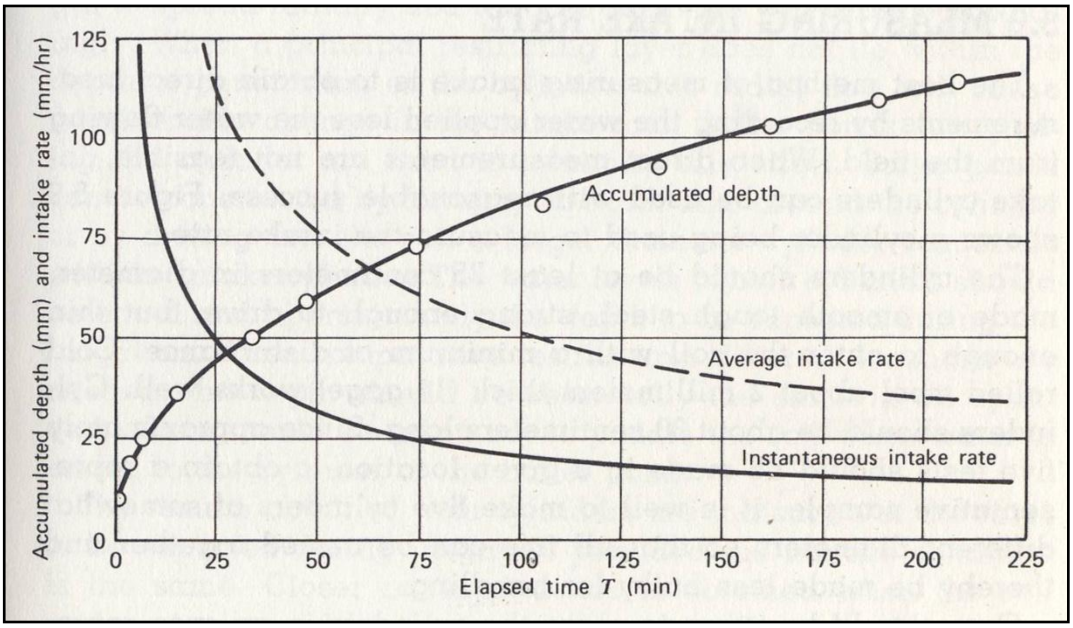
$= (11 \times 60) \times T^{(0.44-1)}$

$= 660 \times T^{-0.56}$

$I_{inst} = CN\ T^{N-1}$

$= (11 \times 60) \times 0.44 \times T^{(0.44-1)}$

$= 290 \times T^{-0.56}$



At T = 1 min, D = 11 mm, so

$$D = CT^N$$

$$\Rightarrow 11 = C\times(1)^N$$

$$\therefore\ C = 11$$