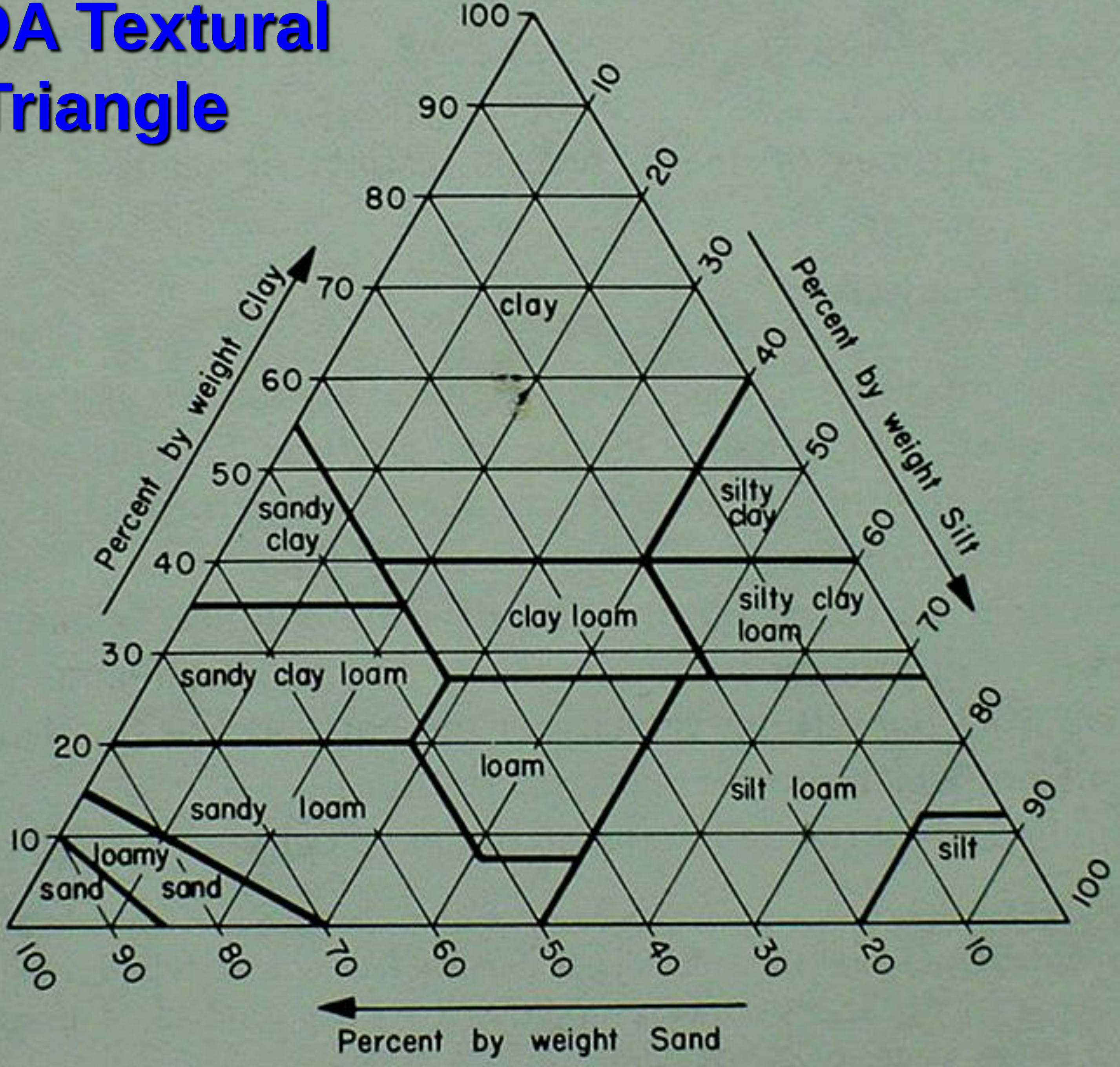
Soil Water Relationships

Soil Properties

- Texture
  - Definition: relative proportions of various sizes of individual soil particles
  - USDA classifications
    - Sand: 0.05 – 2.0 mm
    - Silt: 0.002 - 0.05 mm
    - Clay: <0.002 mm
  - Textural triangle: USDA Textural Classes
  - Coarse vs. Fine, Light vs. Heavy
  - Affects water movement and storage
- Structure
  - Definition: how soil particles are grouped or arranged
  - Affects root penetration and water intake and movement

USDA Textural Triangle



- Bulk Density (ρ_b)

$$\rho_b = \frac{M_s}{V_b}$$

  - ρ_b = soil bulk density, g/cm^3
  - M_s = mass of dry soil, g
  - V_b = volume of soil sample, cm^3
- Typical values: 1.1 - 1.6 g/cm^3

- Particle Density (ρ_p)

$$\rho_p = \frac{M_s}{V_s}$$

  - ρ_P = soil particle density, g/cm^3
  - M_s = mass of dry soil, g
  - V_s = volume of solids, cm^3
- Typical values: 2.6 - 2.7 g/cm^3

- Porosity (ϕ)

$$\phi = \frac{\text{volume of pores}}{\text{volume of soil}}$$

$$\phi = \left(1 - \frac{\rho_b}{\rho_p}\right)100\%$$

- Typical values: 30 - 60%

Water in Soils

- Soil water content

$$\theta_m = \frac{M_w}{M_s}$$

  - Mass water content (θ_m)
  - θ_m = mass water content (fraction)
  - M_w = mass of water evaporated, g (≥24 hours @ 105°C)
  - M_s = mass of dry soil, g

- Volumetric water content (θ_v)

$$\theta_v = \frac{V_w}{V_b}$$

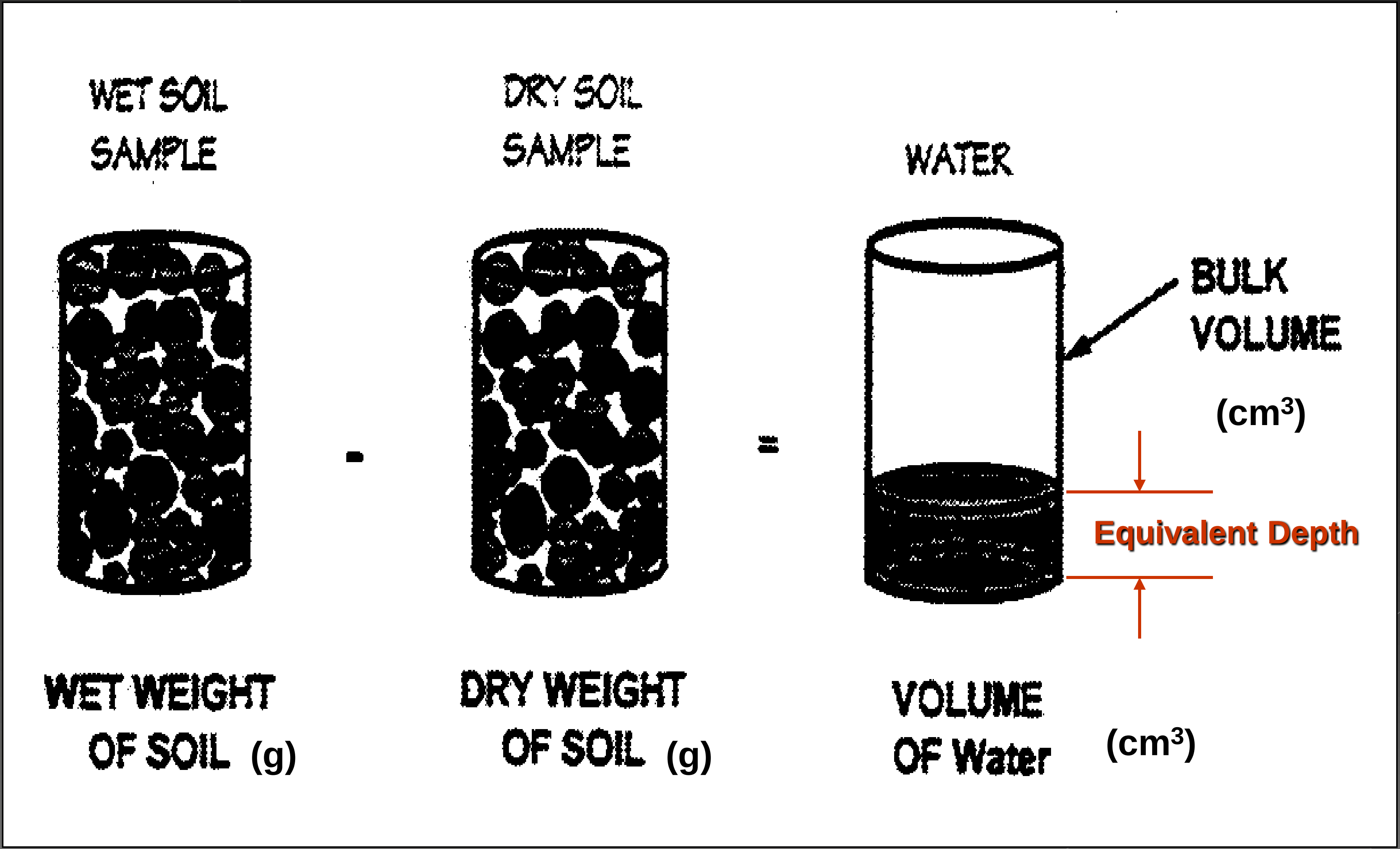
  - θ_V = volumetric water content (fraction)
  - V_w = volume of water
  - V_b = volume of soil sample
  - At saturation, $\theta_V = \phi$
  - θ_V = As θ_m
  - As = apparent soil specific gravity = ρ_b/ρ_w
    (ρ_w = density of water = 1 g/cm^3)
  - As = ρ_b numerically when units of g/cm^3 are used
- Equivalent depth of water (d)
  - d = volume of water per unit land area = (θ_v A L) / A = θ_v L
  - d = equivalent depth of water in a soil layer
  - L = depth (thickness) of the soil layer

Calculating inches from volumetric water content

- $d=\theta_v L$

- $\theta_v=0.25g/cm^3=0.25cm/cm^3$
- $L=60$ cm
- $d=0.25cm/cm^3 X 60=15cm$
- $D=15cm/2.54cm=5.9$inches

Volumetric Water Content & Equivalent Depth



Soil Water Potential

- Description
  - Measure of the energy status of the soil water
  - Important because it reflects how hard plants must work to extract water
  - Units of measure are normally bars or atmospheres
  - Soil water potentials are negative pressures (tension or suction)
  - Water flows from a higher (less negative) potential to a lower (more negative) potential

Soil Water Potential

- Components

$$\psi_t = \psi_g + \psi_m + \psi_o$$

  - ψ_t = total soil water potential
  - ψ_g = gravitational potential (force of gravity pulling on the water)
  - ψ_m = matric potential (force placed on the water by the soil matrix – soil water "tension")
  - ψ_o = osmotic potential (due to the difference in salt concentration across a semi-permeable membrane, such as a plant root)
  - Matric potential, ψ_m, normally has the greatest effect on release of water from soil to plants

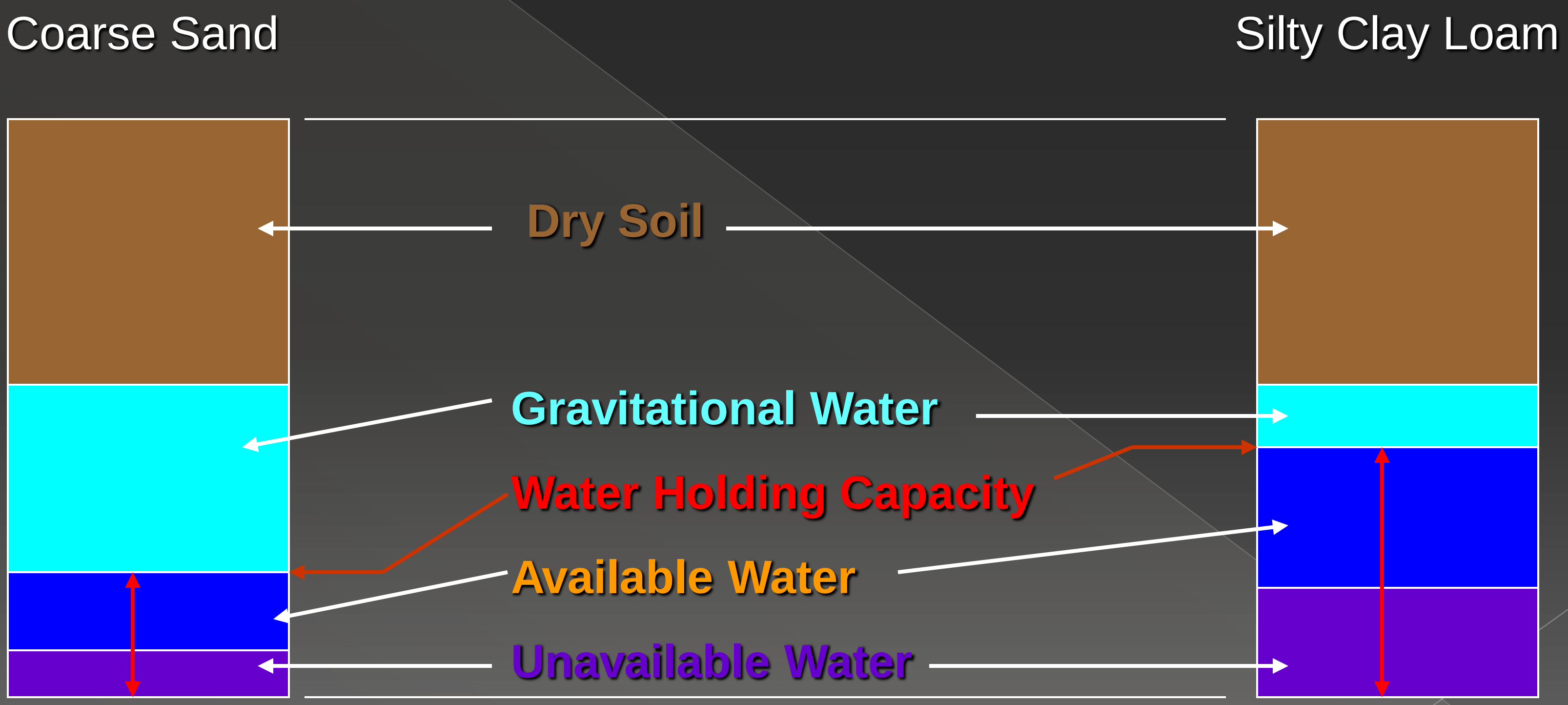
- Field Capacity (FC or θ_{fc})
  - Soil water content where gravity drainage becomes negligible
  - Soil is not saturated but still a very wet condition
  - Traditionally defined as the water content corresponding to a soil water potential of -1/10 to -1/3 bar
- Permanent Wilting Point (WP or θ_{wp})
  - Soil water content beyond which plants cannot recover from water stress (dead)
  - Still some water in the soil but not enough to be of use to plants
  - Traditionally defined as the water content corresponding to -15 bars of SWP

Available Water

- Definition
  - Water held in the soil between field capacity and permanent wilting point
  - "Available" for plant use
- Available Water Capacity (AWC)
  - AWC = $\theta_{fc} - \theta_{wp}$
  - Units: depth of available water per unit depth of soil, "unitless" (in/in, or mm/mm)
  - Measured using field or laboratory methods (described in text)

Water-Holding Capacity of Soil

Effect of Soil Texture



Coarse Sand

Silty Clay Loam

Dry Soil

Gravitational Water

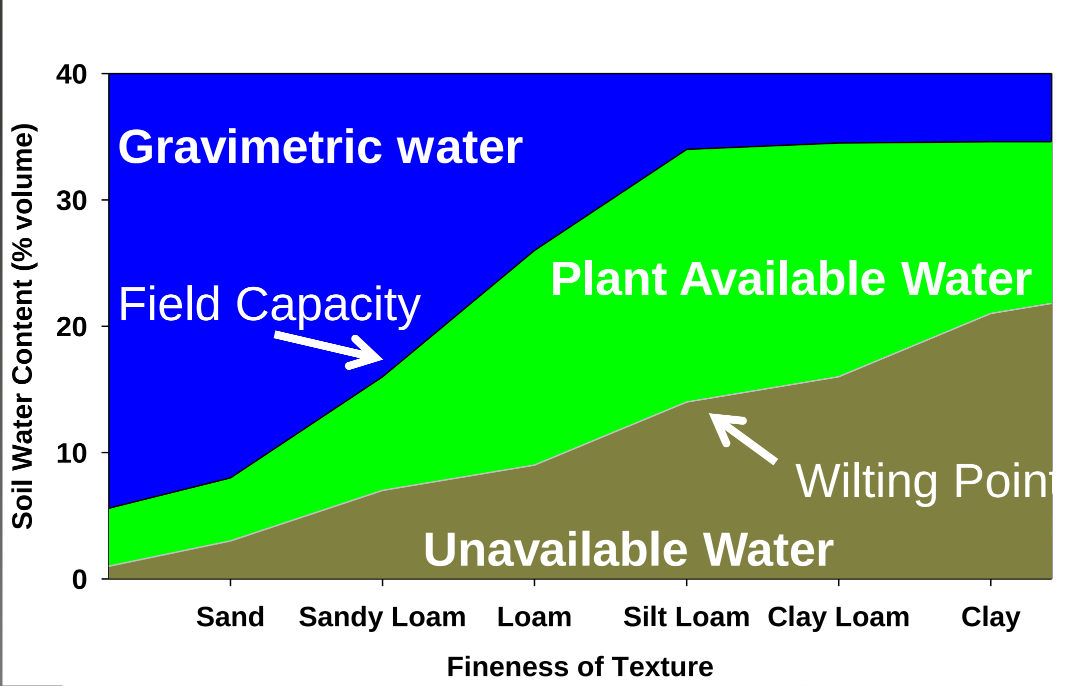
Water Holding Capacity

Available Water

Unavailable Water

Water Holding Capacity

- The maximum amount of water a soil can hold against the pull of gravity that can be extracted by plants
  - Determined primarily by soil texture



Soil Hydraulic Properties and Soil Texture

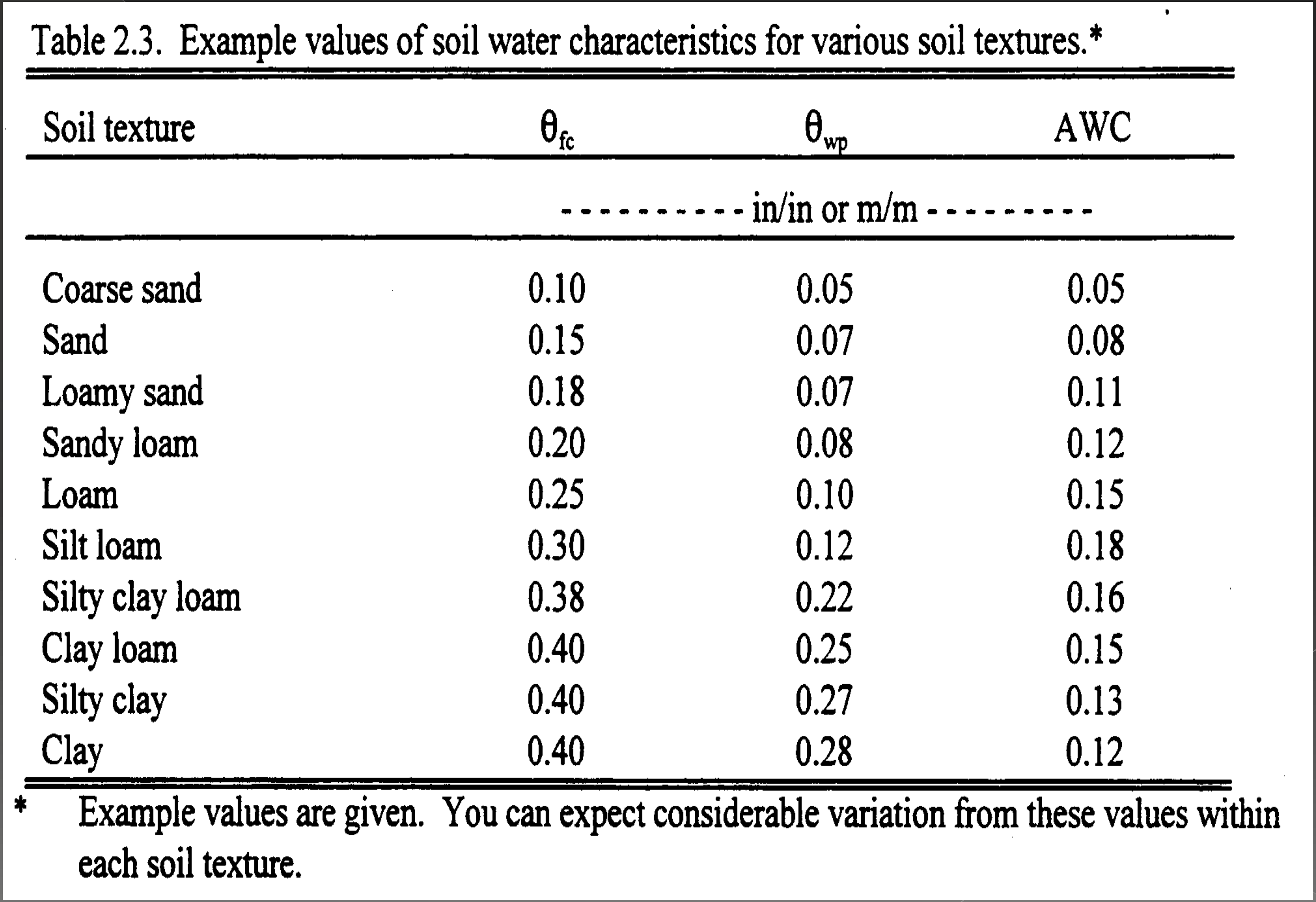


Table 2.3. Example values of soil water characteristics for various soil textures.*

Soil texture	θ_{fc}	θ_{wp}	AWC
	- - - - - - - - - - - in/in or m/m	- - - - - - - - - -	
Coarse sand	0.10	0.05	0.05
Sand	0.15	0.07	0.08
Loamy sand	0.18	0.07	0.11
Sandy loam	0.20	0.08	0.12
Loam	0.25	0.10	0.15
Silt loam	0.30	0.12	0.18
Silty clay loam	0.38	0.22	0.16
Clay loam	0.40	0.25	0.15
Silty clay	0.40	0.27	0.13
Clay	0.40	0.28	0.12

* Example values are given. You can expect considerable variation from these values within each soil texture.

- Fraction available water depleted (f_d)

$$f_d = \left(\frac{\theta_{fc} - \theta_v}{\theta_{fc} - \theta_{wp}} \right)$$

  - (θ_{fc} - θ_v) = soil water deficit (SWD)
  - θ_v = current soil volumetric water content

- Fraction available water remaining (f_r)

$$f_r = \left(\frac{\theta_v - \theta_{wp}}{\theta_{fc} - \theta_{wp}} \right)$$

  - (θ_v - θ_{wp}) = soil water balance (SWB)

- Total Available Water (TAW)

$$TAW = (AWC)*(R_d)$$

- TAW = total available water capacity within the root zone, (inches)
- AWC = available water capacity of the soil, (inches of H_2O/inch of soil)
- R_d = depth of the plant root zone, (inches)
- If different soil layers have different AWC's, need to sum up the layer-by-layer TAW's

$$TAW = (AWC_1)\ (L_1) + (AWC_2)\ (L_2) + \ldots (AWC_N)\ (L_N)$$

- L = thickness of soil layer, (inches)
- $_{1,\ 2,\ N}$: subscripts represent each successive soil layer

Water Infiltration

Def'n.: the entry of water into the soil

Influencing Factors

- Soil texture
- Initial soil water content
- Surface sealing (structure, etc.)
- Soil cracking
- Tillage practices
- Method of application
- Water temperature

Infiltration Rate vs. Time

For Different Soil Textures

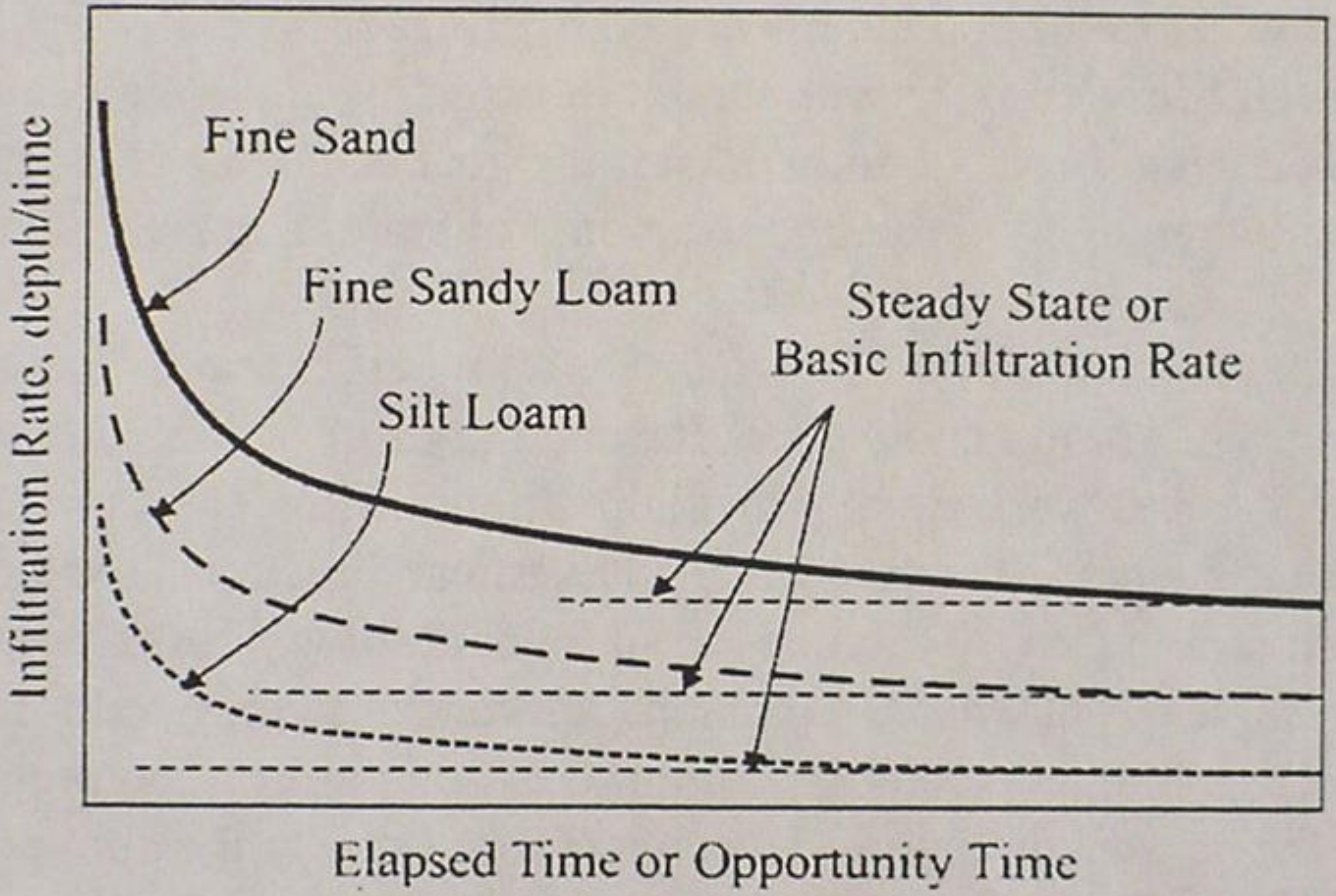
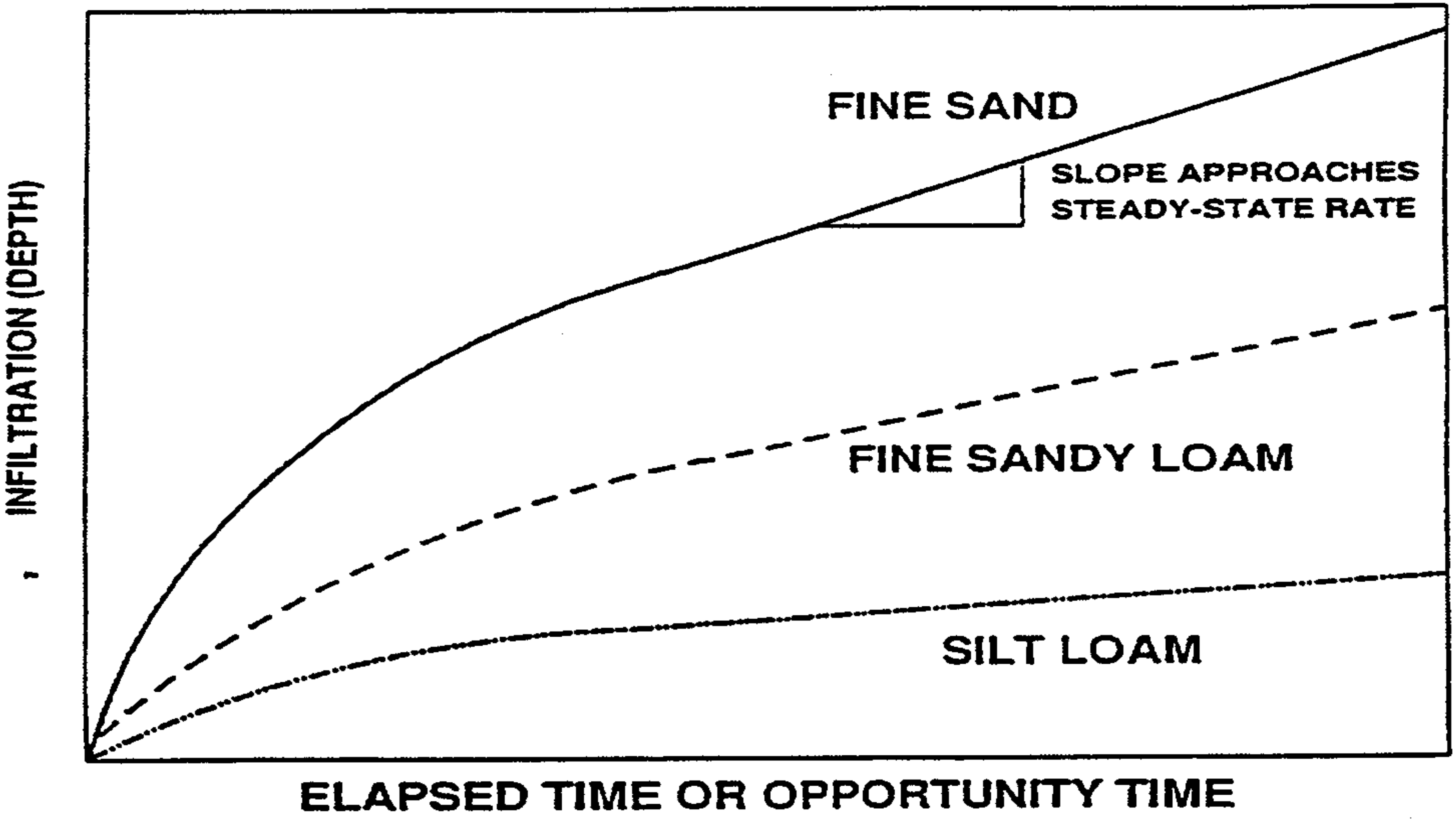


Figure 2.9. Infiltration rate vs. opportunity time.

Cumulative Infiltration Depth vs. Time For Different Soil Textures



Water Infiltration Rates and Soil Texture

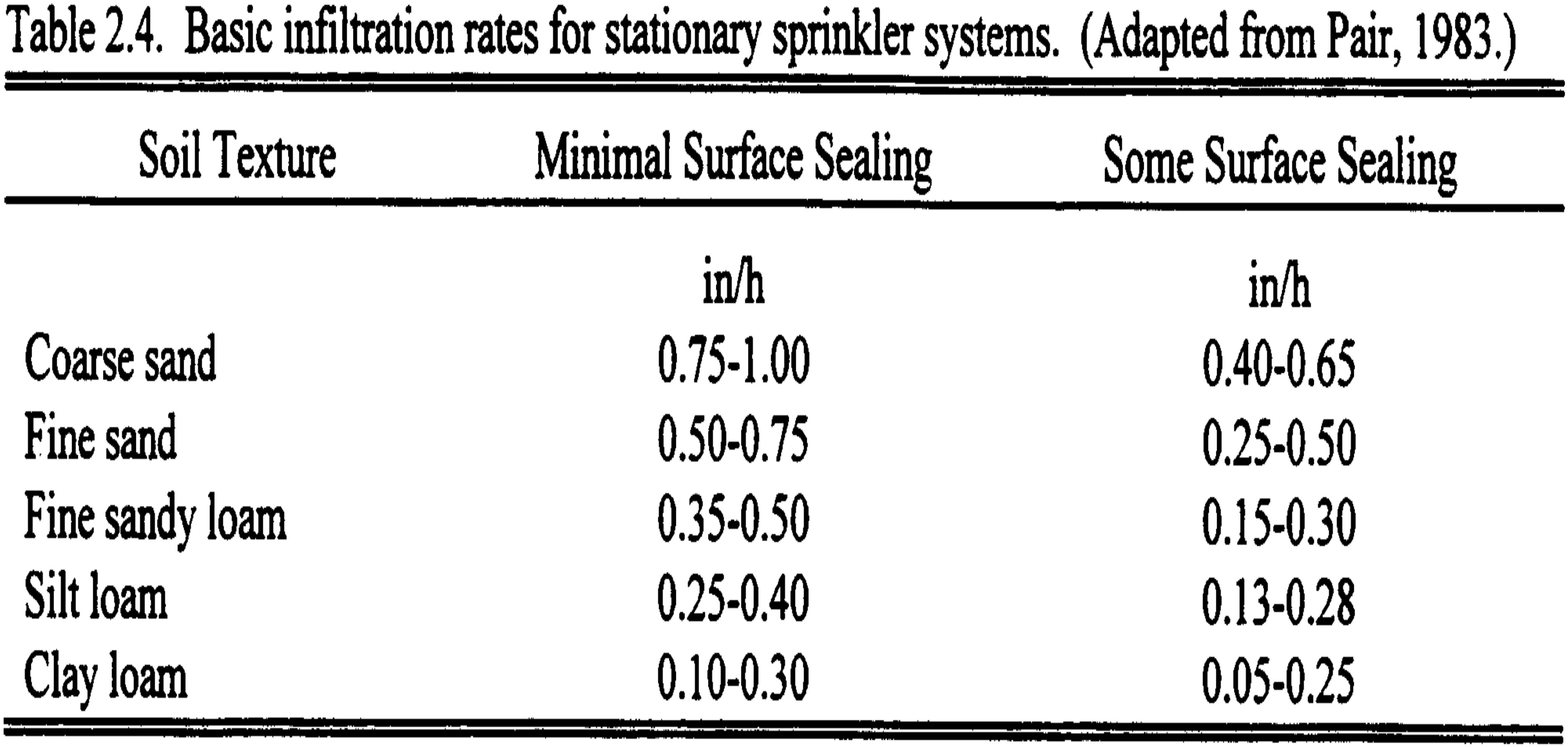
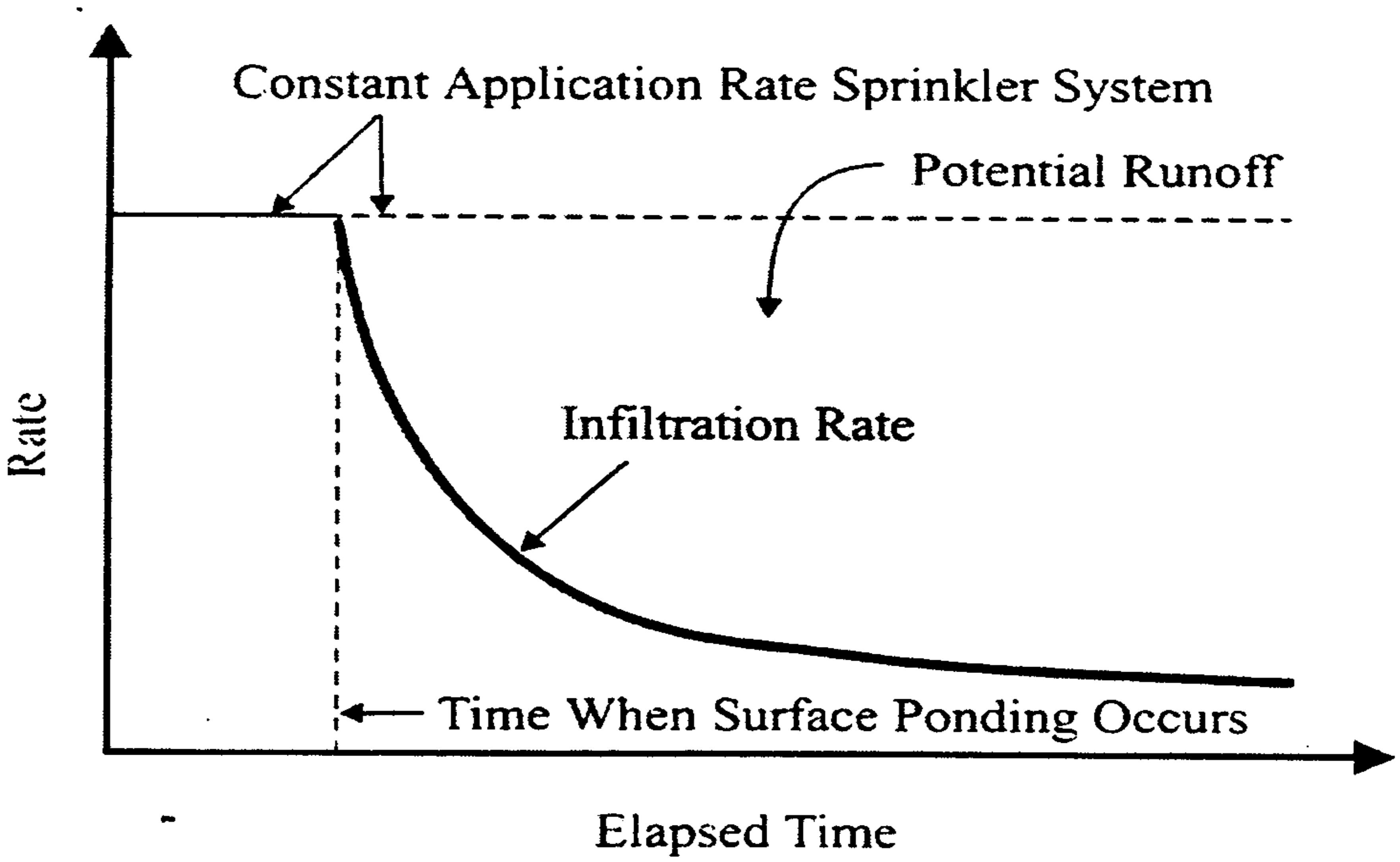


Table 2.4. Basic infiltration rates for stationary sprinkler systems. (Adapted from Pair, 1983.)

Soil Texture	Minimal Surface Sealing	Some Surface Sealing
	in/h	in/h
Coarse sand	0.75-1.00	0.40-0.65
Fine sand	0.50-0.75	0.25-0.50
Fine sandy loam	0.35-0.50	0.15-0.30
Silt loam	0.25-0.40	0.13-0.28
Clay loam	0.10-0.30	0.05-0.25

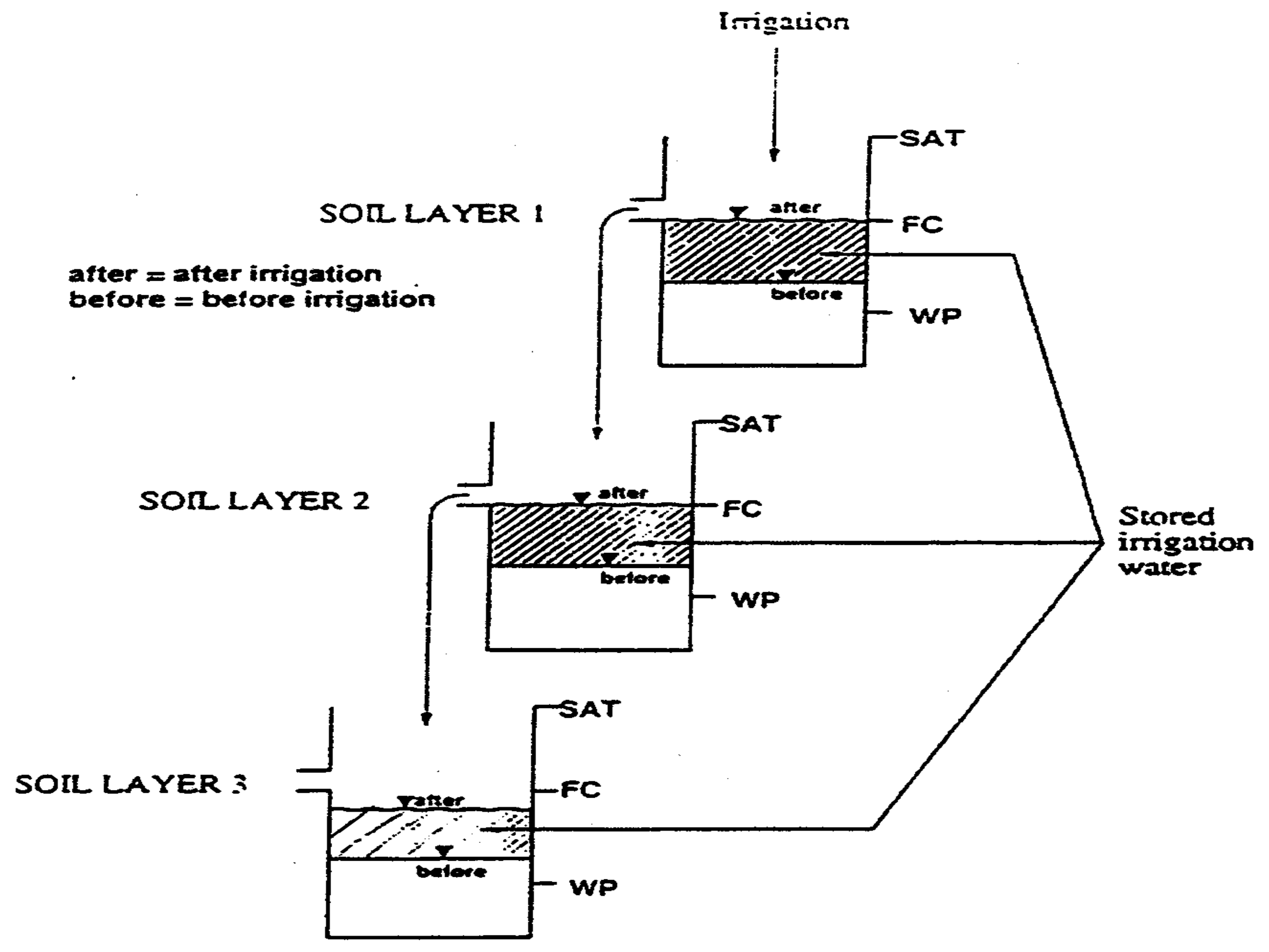
Soil Infiltration Rate vs. Constant Irrigation Application Rate



Depth of Penetration

- Can be viewed as sequentially filling the soil profile in layers
- Deep percolation: water penetrating deeper than the bottom of the root zone
- Leaching: transport of chemicals from the root zone due to deep percolation

Water Storage in Layered Soil Profiles



Example 2.4

Given a soil with the following characteristics, calculate the depth to which 4 in. of infiltrated water would penetrate.

Layer	Depth (in)	θ_{fc}	θ_v
1	0-12	0.34	0.20
2	12-30	0.40	0.33
3	30+	0.30	0.24

Using Equation 2.12:

$SWD_1 = (0.34 - 0.20)$ 12 in. = 1.7 in.
$SWD_2 = (0.40 - 0.33)$ 18 in. = 1.3 in.
3.0 in. (1.7 in. + 1.3 in.) is required to fill the first two layers

The remaining water is: 4.0 in. - 3.0 in. = 1.0 in.

To find the depth penetrated in the third layer (L_3), use the same equation, but solve for L_3 when SWD_3 = 1.0 in.:

$$L_3 = \frac{1.0}{(0.30-0.24)} = 16.7\ in.$$

The depth from the surface penetrated by a 4-inch application is then:
12 in. + 18 in. + 16.7 in. = 46.7 in. (about 4 feet).

Irrigation Water Requirement

Evapotranspiration

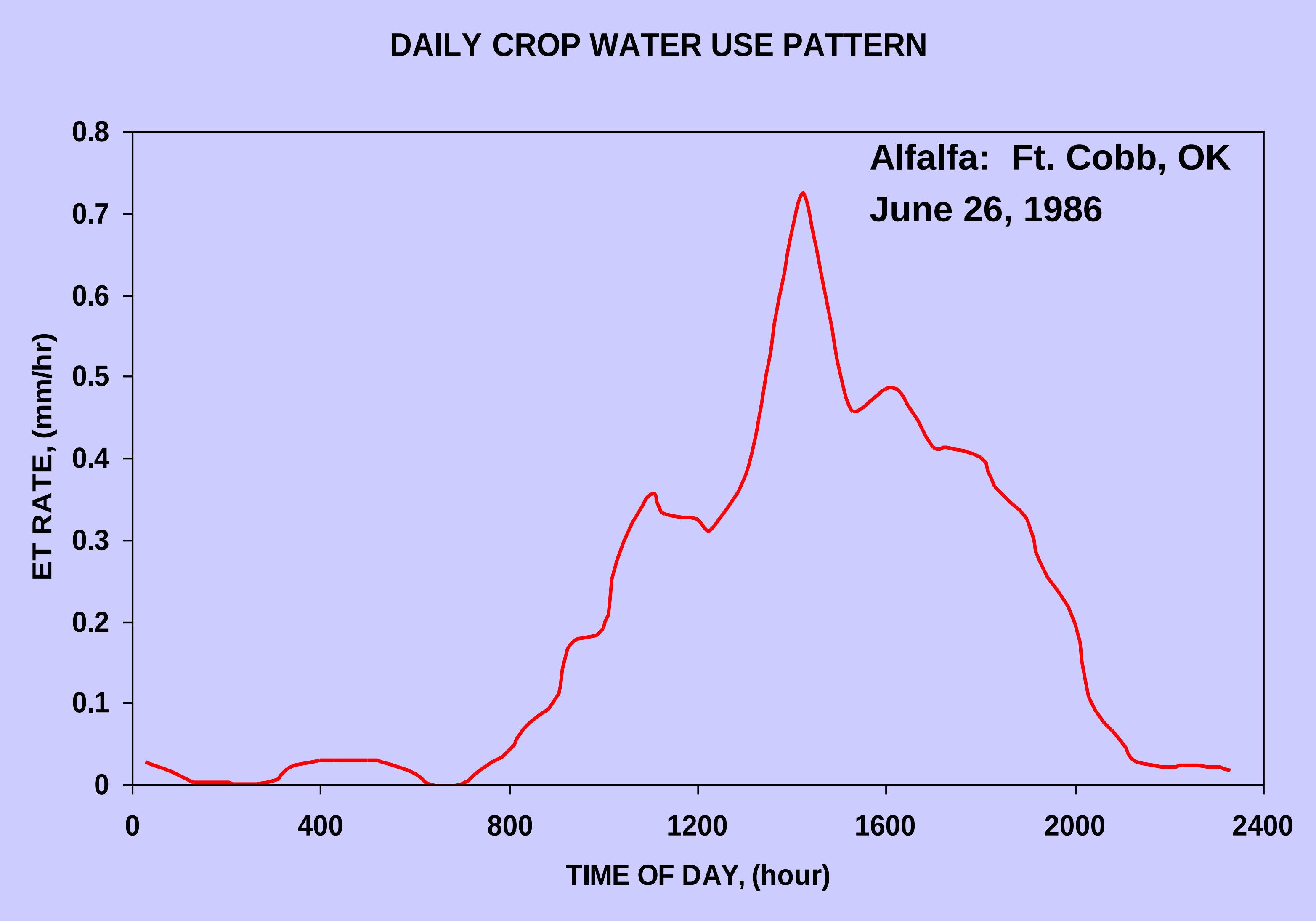
- Terminology
  - Evaporation
    - Process of water movement, in the vapor form, into the atmosphere from soil, water, or plant surfaces
  - Transpiration
    - Evaporation of water from plant stomata into the atmosphere
  - Evapotranspiration
    - Sum of evaporation and transpiration (abbreviated "ET")
  - Consumptive use
    - Sum of ET and the water taken up the plant and retained in the plant tissue (magnitude approximately equal to ET, and often used interchangeably)

Magnitude of ET

- Generally tenths of an inch per day, or tens of inches per growing season
- Varies with type of plant, growth stage, weather, soil water content, etc.
- Transpiration ratio
  - Ratio of the mass of water transpired to the mass of plant dry matter produced (g H_2O/g dry matter)
- Typical values: 250 for sorghum
  500 for wheat
  900 for alfalfa

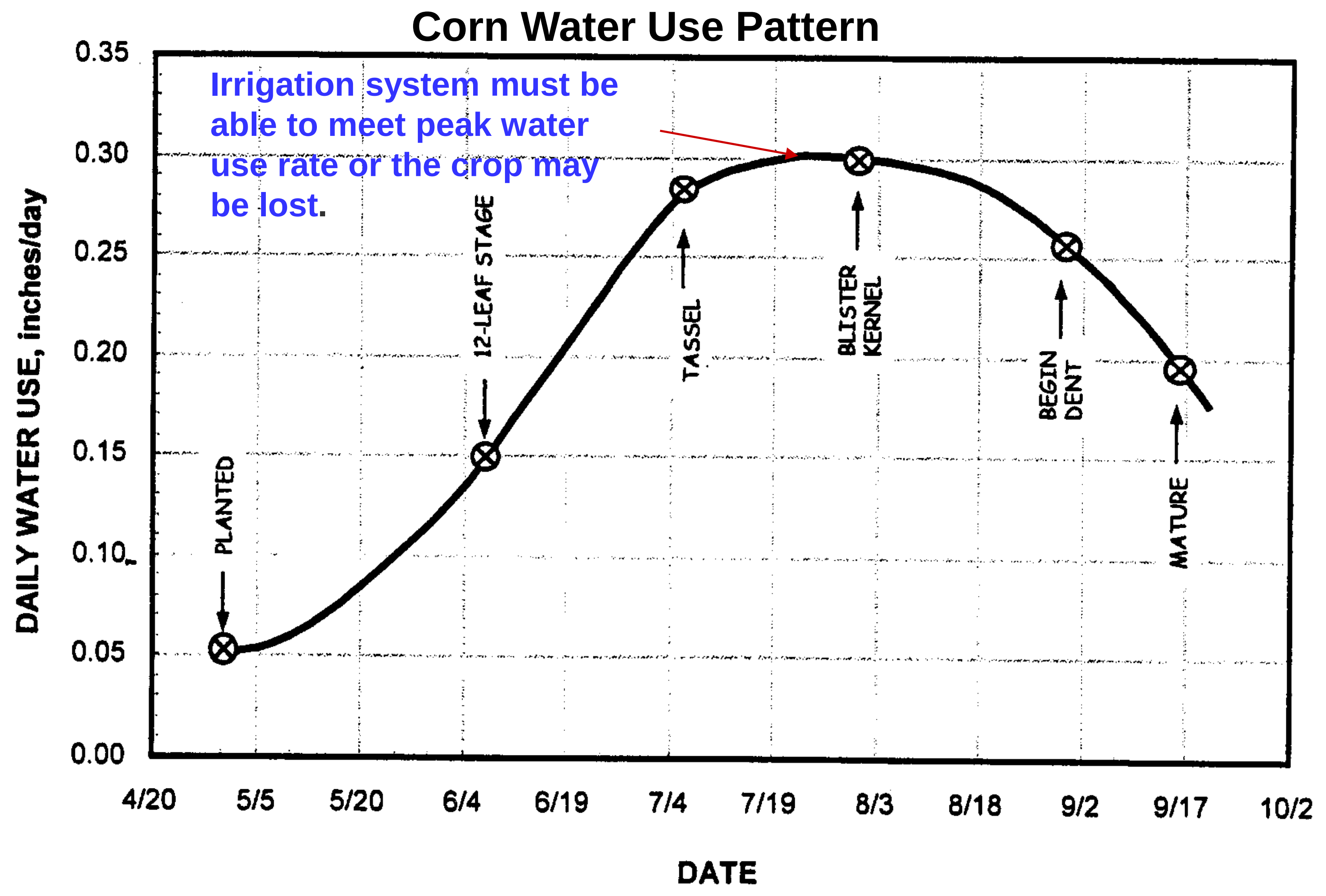
Plant Water Use Patterns

- Daily Water Use: peaks late in afternoon; very little water use at night



Plant Water Use Patterns

- Seasonal Use Pattern: Peak period affects design

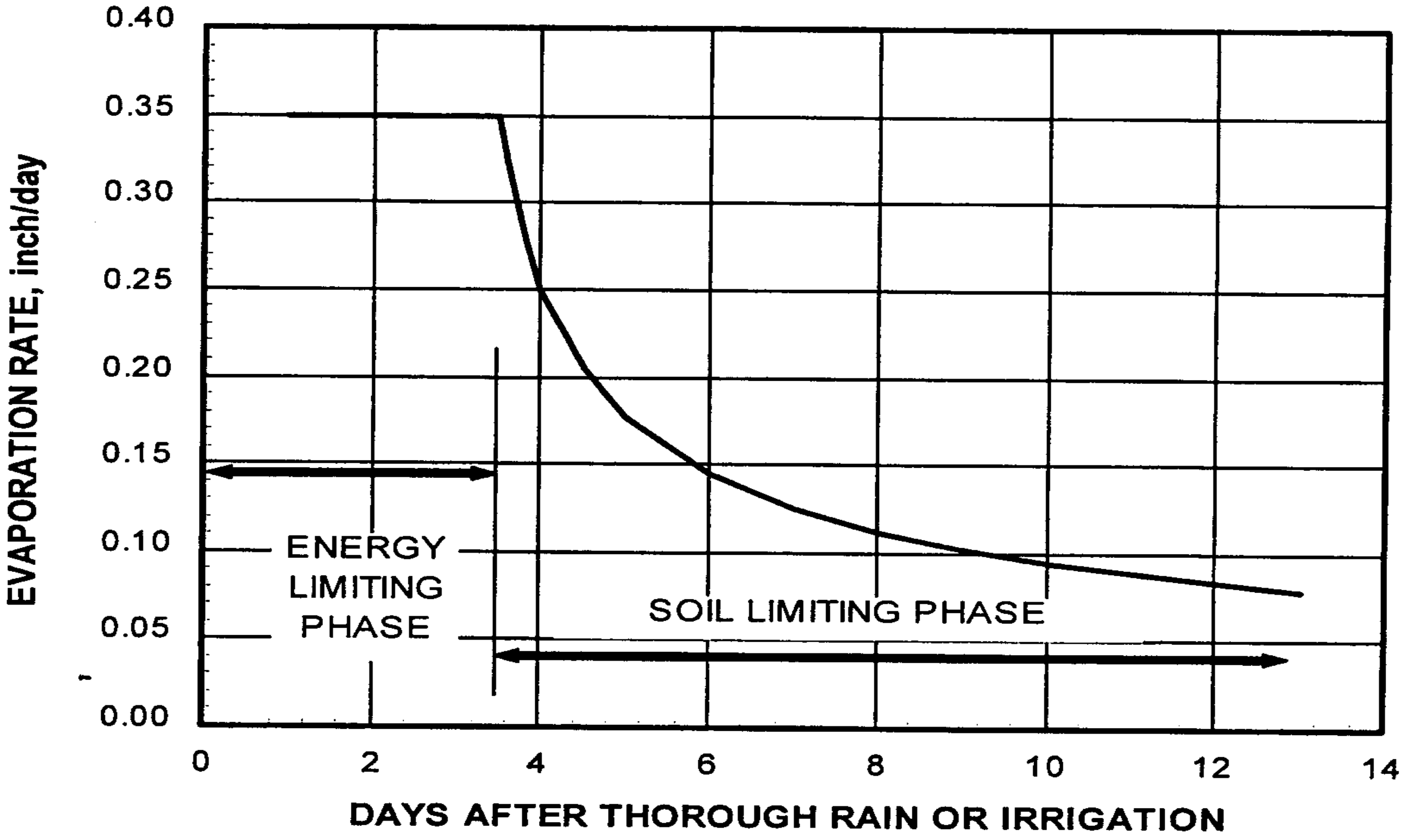


Corn Water Use Pattern

Irrigation system must be able to meet peak water use rate or the crop may be lost.

Evaporation Rate and Time Since Irrigation

Energy or Water Availability as the Limiting Factor in ET Rate



Evapotranspiration Modeling

- Estimation based on:
  - climate
  - crop
  - soil factors

$$ET_c = K_c \, ET_o$$

- ET_c = actual crop evapotranspiration rate
- ET_o = the evapotranspiration rate for a reference crop
- K_c = the crop coefficient

Evapotranspiration Modeling

- Reference Crop ET (ETo)
  - ET rate of actively growing, well-watered, “reference” crop
  - Grass or alfalfa used as the reference crop (alfalfa is higher)
  - A measure of the amount of energy available for ET
  - Many weather-based methods available for estimating ETo
    - (FAO Blaney-Criddle; Jensen-Haise; Modified Penman; Penman-Montieth)
- Crop Coefficient (Kc)
  - Empirical coefficient which incorporates type of crop & stage of growth (Kcb); and soil water status-- a dry soil (Ka) can limit ET; a wet soil surface (Ks) can increase soil evaporation
  - Kc = (Kcb x Ka) + Ks
  - Kc values generally less than 1.0, but not always

Page 87 Lascano et al 2007, text book

ET from Reference Crop

$$Et_o = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{C_n}{T_a + 273} \mu(e_s - e_a)}{\Delta + \gamma(1 + C_d \mu)}$$

- ET0=reference ET (Tall or Short)
- Rn=net radiation (MJ m-2 d-1)
- G=Soil heat flux density (MJ m-2 d-1)
- Ta=daily air temp (°C)
- μ=Daily wind speed (m s-1) at 2 m
- e_s=saturated vapor pressure (kPa)
- e_a=actural vapor pressure (kPa)
- Δ=the slope of the saturation vapor pressure-temperauture curve ((kPa $^oC^{-1}$)
- γ=the psychrometric constant (kPa ^{o}C-1)
- C_n=numeric constant that changes with reference crop
- C_d=denominator constant that changes with reference crop