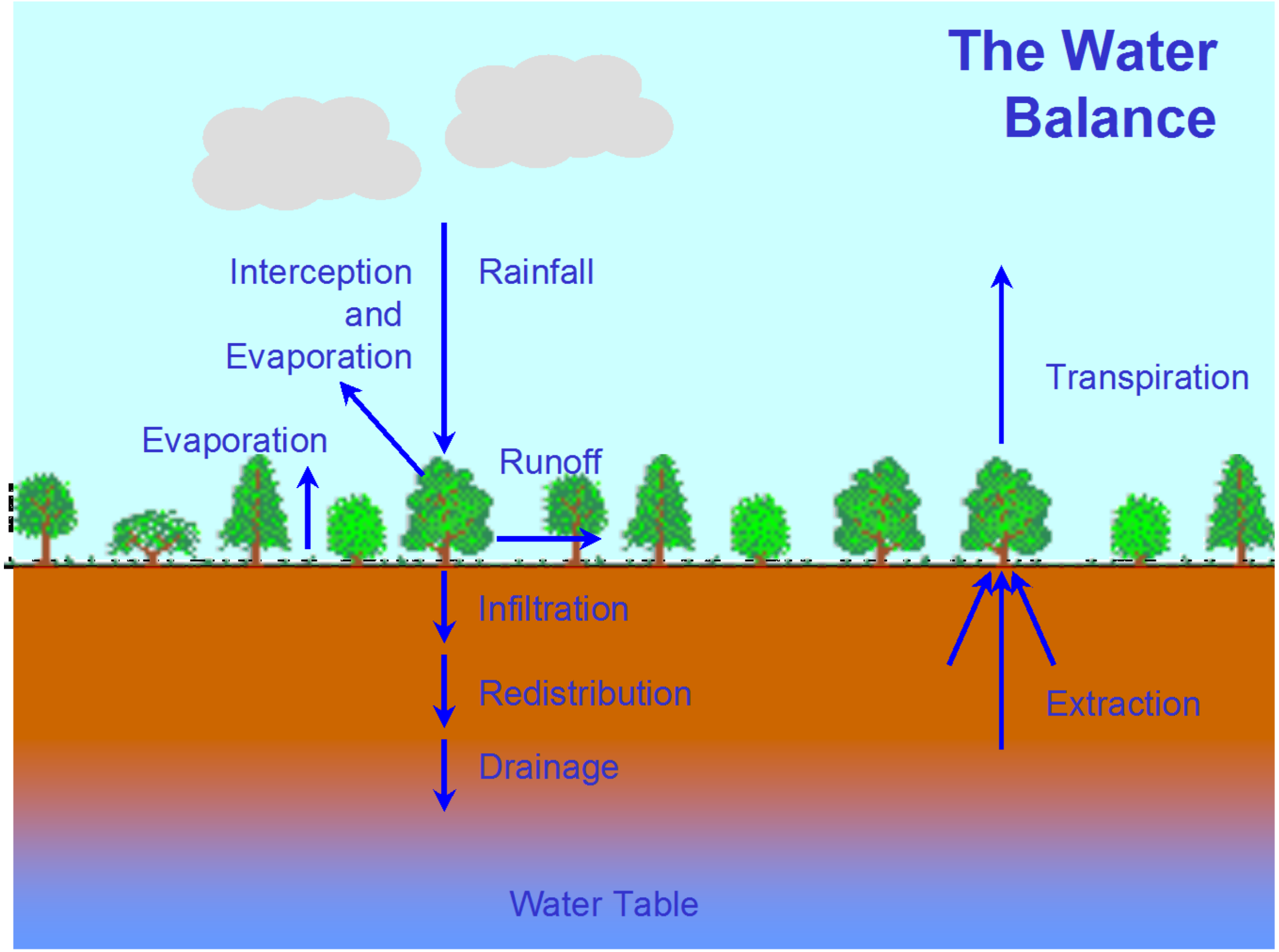
Modelling Soil Water and Solute Dynamics

Assoc. Prof. Dr. Ahmad M. Manschadi

Water & Nitrogen

- The two limiting factors for crop growth that are most responsive to management practices are the supply of **water** and **nitrogen**.



Soil Water Balance

- Basis of a soil water balance is the simple statement of the conservation of water in soil

- change in soil water content

  = water in – water out

  = precipitation + irrigation + runon

  - runoff – drainage – transpiration – evaporation

- This can be applied over any block of soil and any time scale

Soil Water Balance

- Simulation of the soil water balance (as in APSIM SoilWat) is based on the different components of the water balance

The subroutine structure in SoilWat2

Note that transpiration is estimated by the crop modules

SoilWat

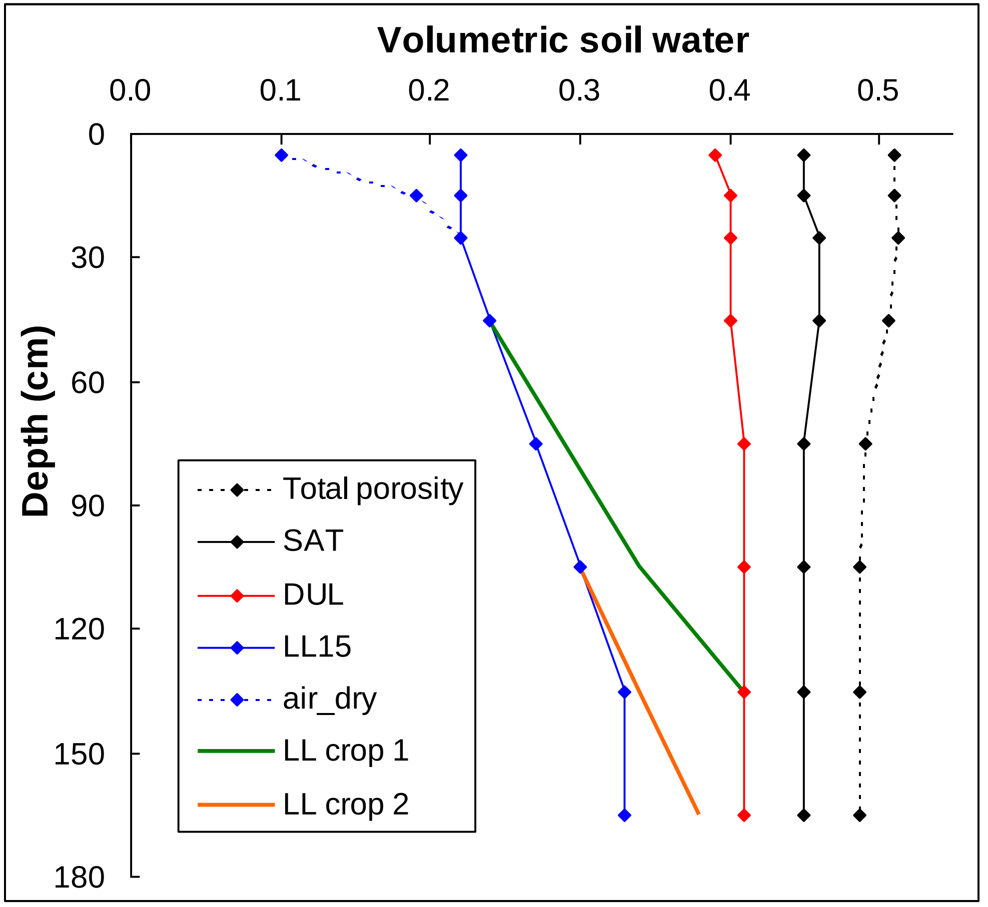
- Runoff
- Drainage
- Solute Flux
- Potential Evapotranspiration
- Soil Evaporation
- Unsaturated Flow
- Solute Flow

Soil Water Balance

- Characterizing soil water properties

Specified in terms of:

- **SAT (saturation)**
- **DUL (drained upper limit)**
- **LL15 (lower limit; biological activity ceases)**
- **LLcrop (not a true soil property)**
- **Air Dry**



Soil Water - Runoff

- Precipitation has to be partitioned into what infiltrates into the top soil layer and what runs off
- Runoff is calculated using the USDA Soil Conservation Service (SCS) procedure known as **curve number technique**
  - Based on total precipitation for the day – no allowance for number of storms or rainfall intensity
  - Curve numbers have been derived from experimental data and depend on:

    - soil type

    - land use (row crops, contoured, terraced)

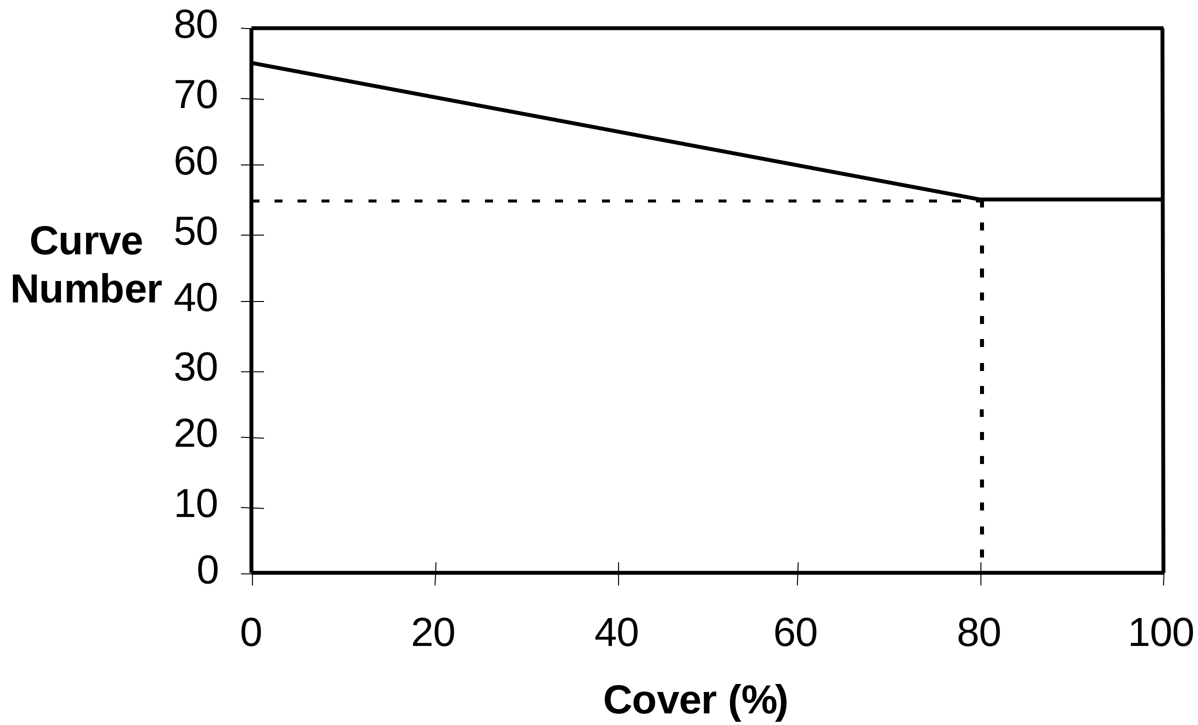
    - antecedent rainfall condition

Soil Water - Runoff

- **Surface residues** affect movement of water during runoff events. Curve number is adjusted according to amount of crop and residue cover

Effect of cover on runoff curve number where bare soil curve number is 75 and total reduction in curve number is 20

at 80% cover.



Soil Water - Evaporation

- Soil evaporation occurs in **two stages** –
- **In 1st stage**, the soil is sufficiently wet for water to be transported to the surface to keep up with potential atmospheric evapotranspiration (based on Priestly and Taylor approach)
- **In 2nd stage**, transport of water to the surface can't meet potential.
- In SoilWat2 this behaviour is described by two parameters:

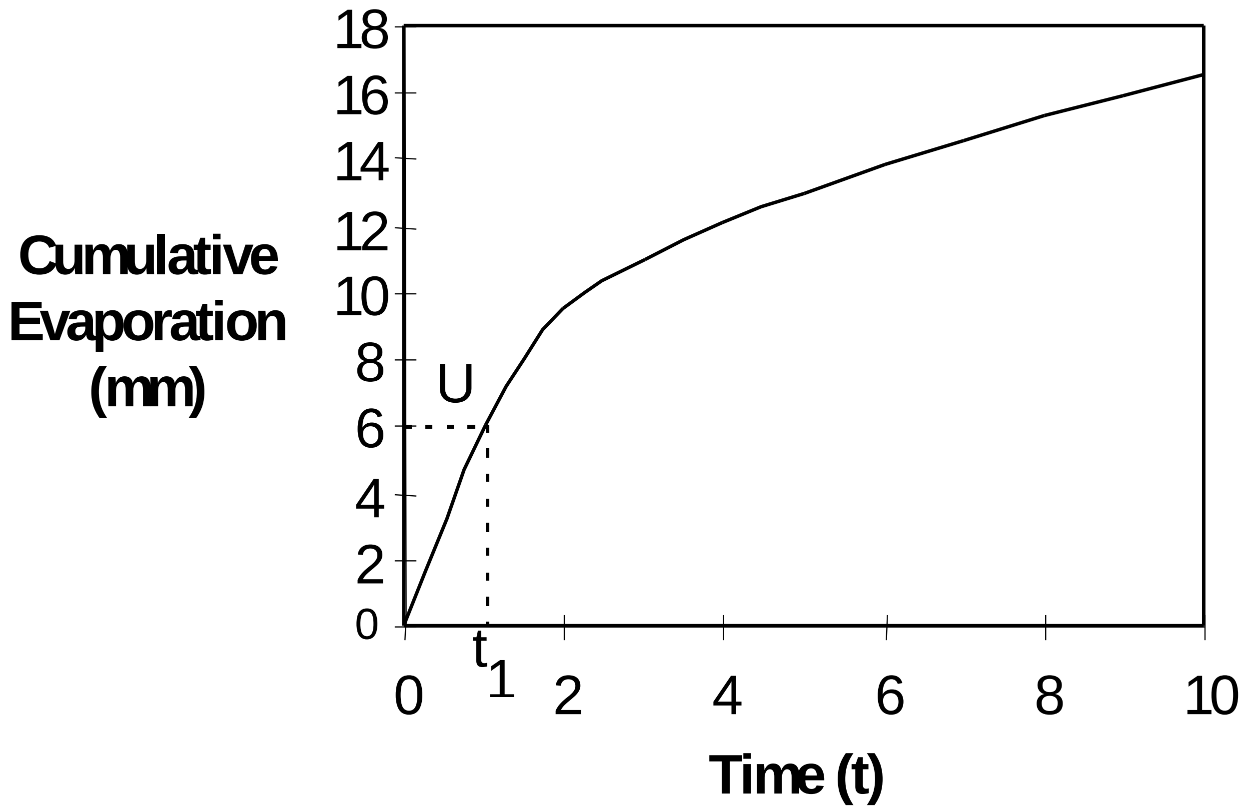
  U – the cumulative evaporation (mm) before actual evaporation falls below potential

  CONA – 2nd stage evaporation is described as square root of time (days) since 2nd stage commenced and CONA is the coefficient

- Water lost by evaporation is only removed from the surface layer which can be dried out to the Air Dry moisture content

Soil Water - Evaporation

- Cumulative soil evaporation through time for **U = 6 mm** and **CONA = 3.5**



- The evaporation loss is linear against time until cumulative loss exceeds U, beyond which it is calculated as **CONA * (t –t$_1$)$^{1/2}$**.

Soil Water - Saturated Water Flow

- **Cascading water balance model**
- When soil water content in any layer exceeds DUL, a fraction (SWCON) of the excess drains to the next layer

  FLUX = SWCON x (SW_dep – DUL_dep)

- **SWCON** is the fraction of the water that drains. It can be set to have different values in each layer.
- Typically in clay soils SWCON has low values (0.2) while in a free draining sand a higher value would be used (0.7)
- Any water in excess of SAT automatically cascades to the next layer

Soil Water - Unsaturated Water Flow

- When water content is below DUL, movement of water depends on water content gradient between adjacent layers and the soil's diffusivity.

FLOW = DIFFUSIVITY x SOIL WATER GRADIENT

- **Unsaturated flow** can move water either up or down in the profile (saturated flux is only downwards).
- But it can't move water out of the bottom layer. In SoilWat2 drainage from the deepest layer can only occur when this layer wets up above DUL.

Soil Water – Solute Movement

- **Solutes are moved together with water** for both saturated and unsaturated flow.
- **Nitrate-N** is a mobile ion whereas **ammonium-N** is considered to be immobile. Other solutes that are to be redistributed as mobile must be specified in the SoilWat2 INI file (eg **chloride**, **TDS**)
- SoilWat2 uses a **simple "mixing" algorithm** to calculate the redistribution of solutes between layers. All water and solute entering a layer is completely mixed with water and solute already present to derive an average concentration.
- The water that leaves the layer is at a concentration that is proportional to this average concentration.

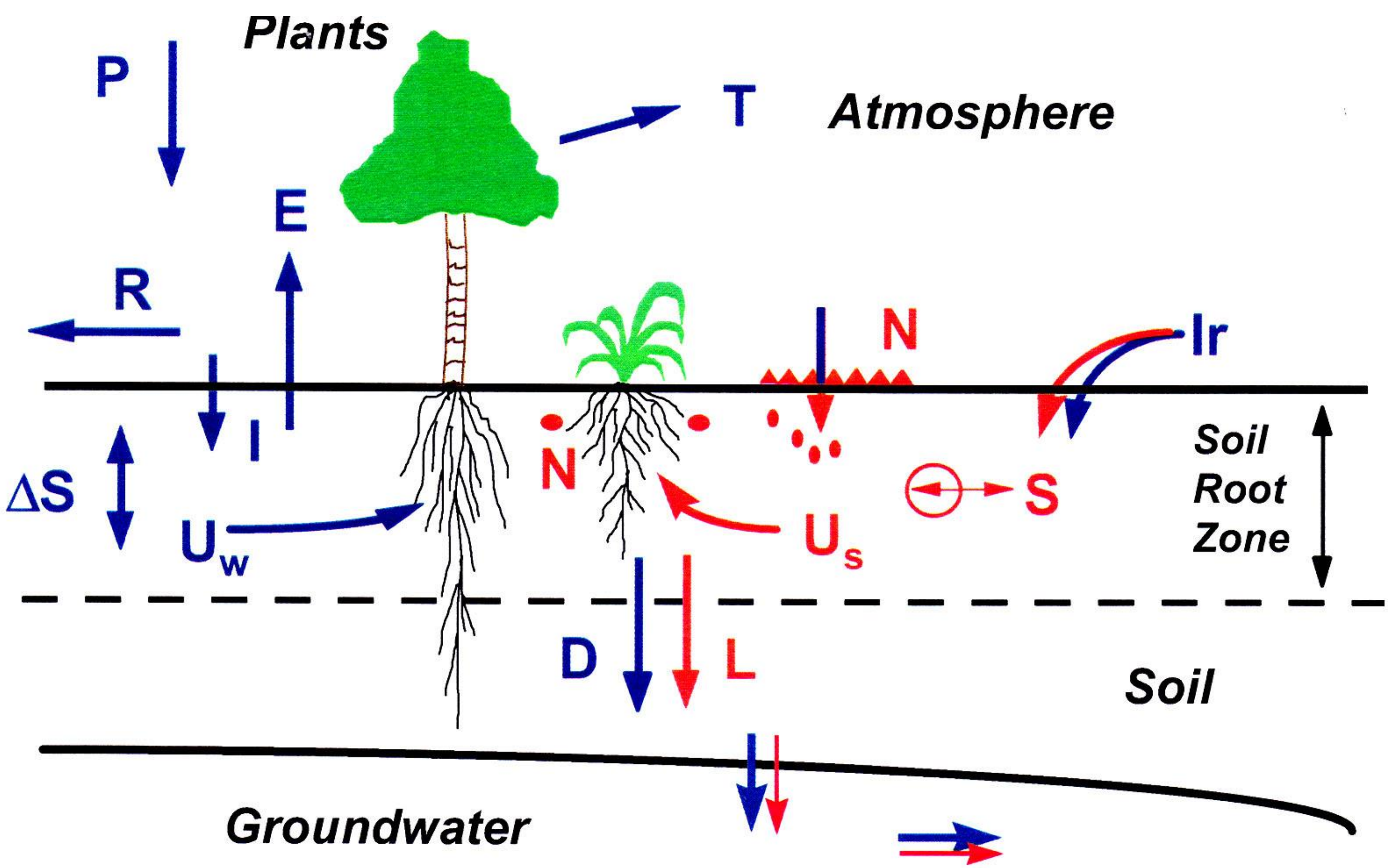
Soil Water

- There are other approaches!
- Soil physicists describe soil water behaviour in terms of **soil water potential** and the movement of water in terms of **differential equations (Richards' Equation)**…… which can be solved simultaneously.

- An APSIM module (**SWIMSOIL**) is available and provides an efficient numerical solution of Richards' Equation.
- It's main users would be those interested in surface soil condition and solute movement (e.g simulating soil/groundwater salinity).
- Not generally used for agronomic applications

SWIM Module – Soil Water Infiltration and Movement

- Developed by CSIRO Division of Land & Water
- Based on a numerical soluation of the Richards´ equation and the advection-dispersion equation
- Components of soil water and solute balances (SWIM ver 2.1; Verburg et al. 1996)



SWIM Module

- SWIM simulates
  - One-dimensional layered soil profile (vertically inhomogenous but horizontally uniform
  - Saturated/unsaturated conditions
  - Surface ponding (high rainfall intensities)
  - Surface runoff (remove excess water)

Water Movement in Soil

- Water flows down a hydraulic gradient at a rate proportional to the gradient (Darcy‵s law):

$$q = -K \frac{dH}{dx}$$

q = water flux density (cm³ water/cm² soil/h)
K = hydraulic conductivity (cm water/h)
H = hydraulic head (cm water)
x = soil depth (cm)

- Combinig Darcy‵ equation with the continuity equation to conserve mass of water

$$\frac{\partial \theta}{\partial t} = -\frac{\partial q}{\partial x} + S$$

θ = volumetric water content (cm^3/cm^3)
t = time (h)
S = source/sink strength (cm^3 water/cm^3 soil/h)

- **Richards‵ equation**

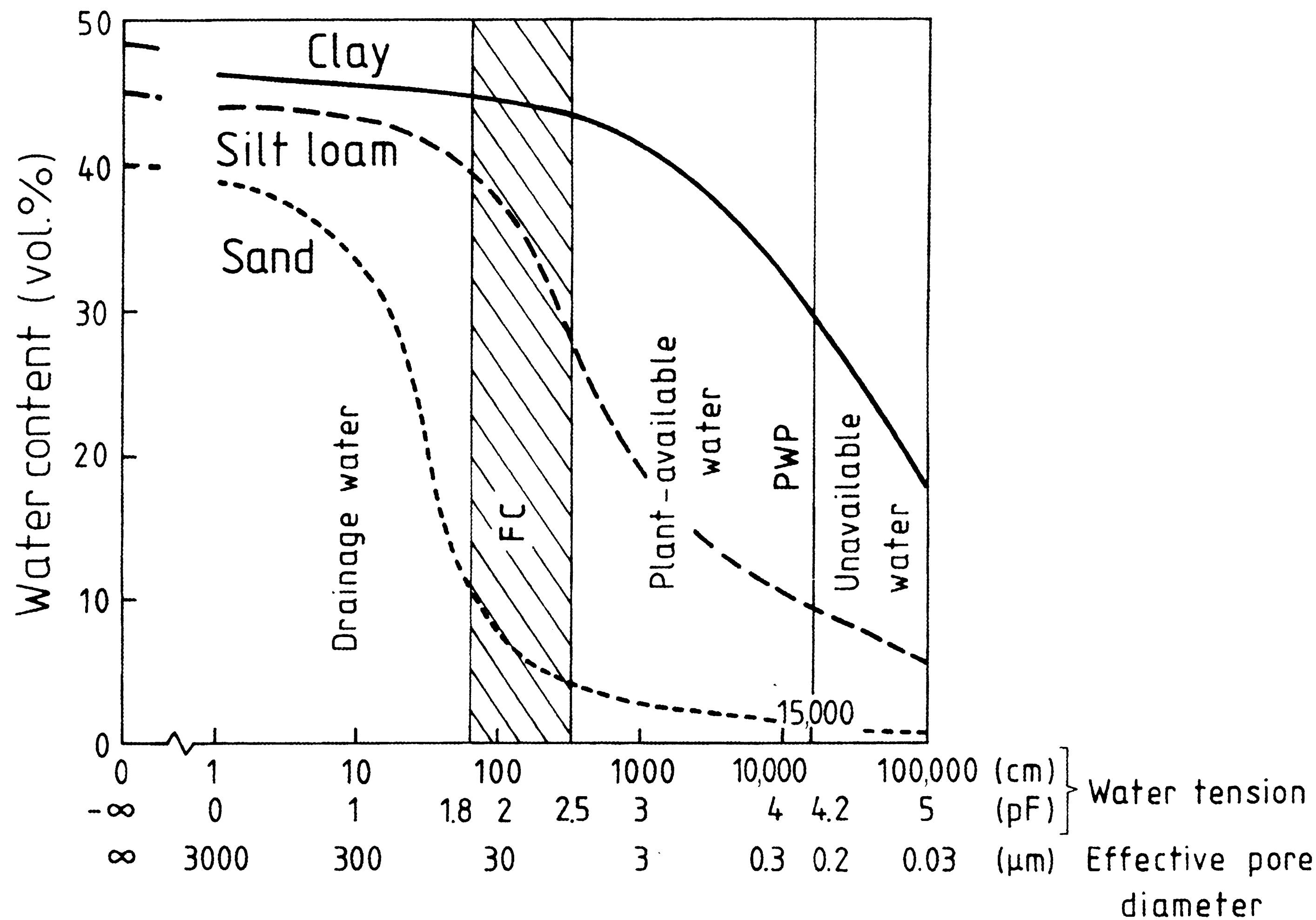
$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}\left(K \frac{\partial H}{\partial x} \right) + S$$

- Hydraulic head (*H*) is the sum of gravitational potential (*z*) and the matric potential (*ψ*)

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x} K \left(\frac{\partial \psi}{\partial x} + \frac{dz}{dx} \right) + S$$

- *θ* and *ψ* are related by the water retention curve.
- *K* is related to *θ* by the hydraulic conductivity function.

- Water retention curve



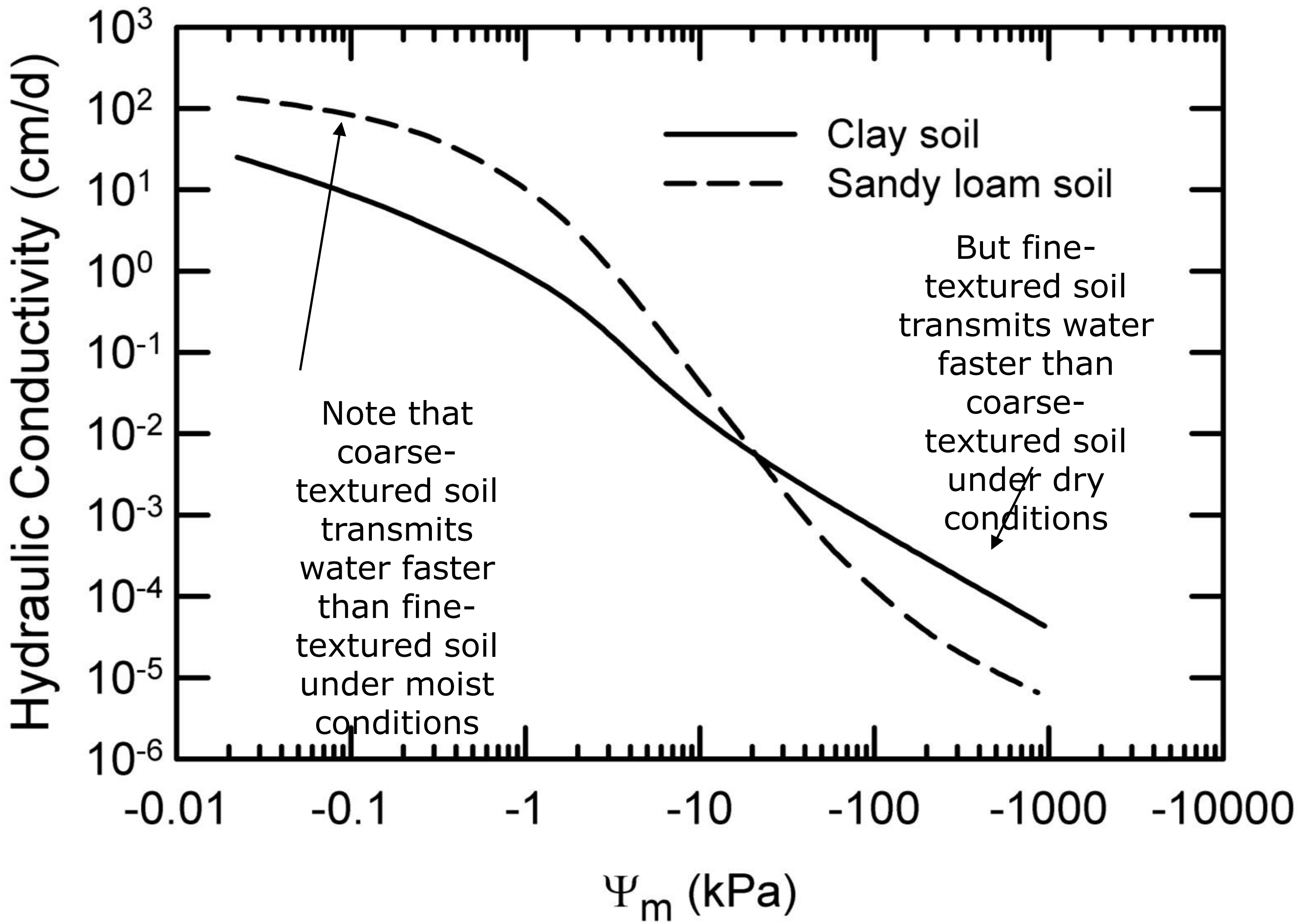
Units of Soil Matric Potential

bars	kPa (=J/kg)	MPa	cm of H_2O
-0.01	-1	-0.001	-10
-0.1	-10	-0.01	-102
-0.33	-33	-0.033	-337
-1	-100	-0.1	-1020
-10	-1000	-1	-10,204
-15	-1500	-1.5	-15,306

~FC

~PWP

Hydraulic Conductivity Function



Hydraulic Conductivity & Soil Water Potential

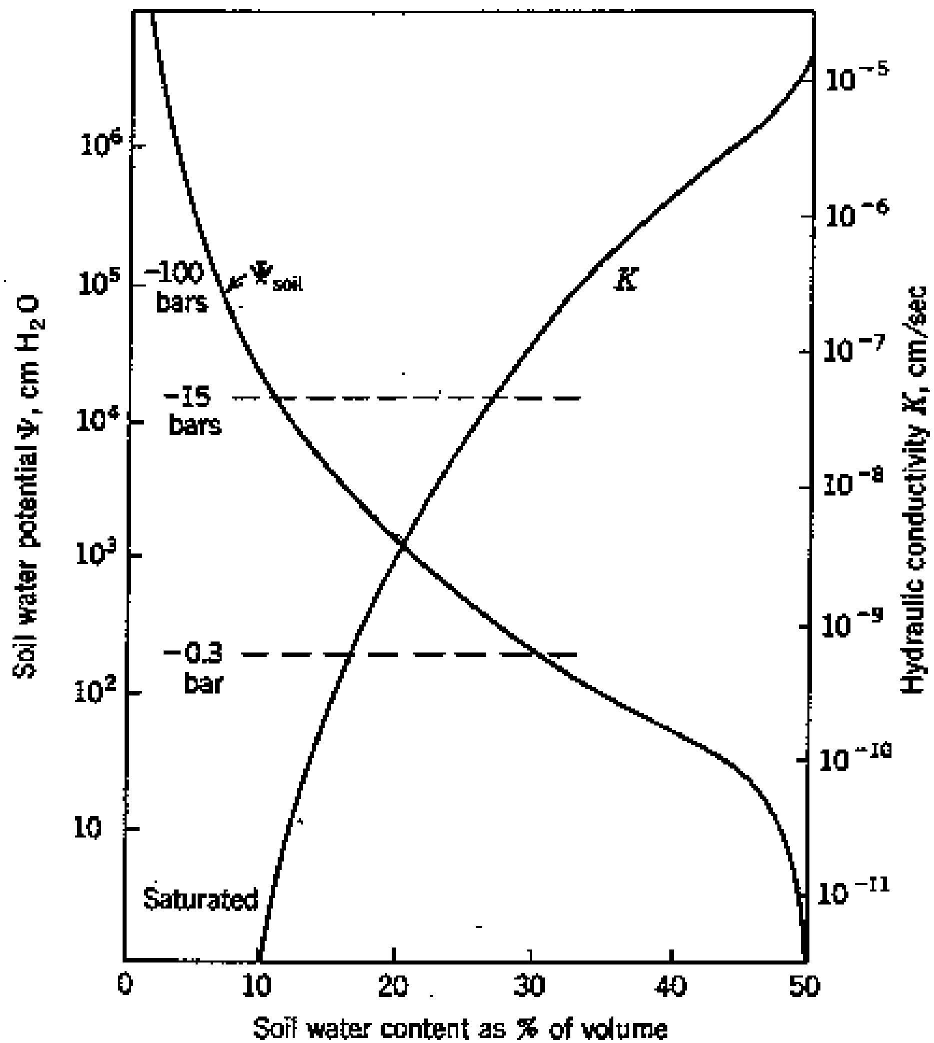


FIG. 2.12 **Decrease in hydraulic conductivity *K* and soil water potential Ψ_{soil} with decrease in soil water content. (*After Philip*, 1957*b*.)**

- The soil profile is represented by a series of nodes
- Water retention curve:
  - Instead of relating θ and ψ directly, SWIM uses a normalised parameter S, effective saturation

$$S = \frac{(\theta - \theta r)}{(\theta s - \theta r)}$$

***S* = effective saturation (cm^3/cm^3)**
***θr* = residual vol. water content (cm^3/cm^3)**
***θs* = saturated vol. water content (cm^3/cm^3)**

- Campbell equation (CropSyst):

$$S(\Psi) = (\Psi \,/\, \Psi_e)^{-1/b}$$

Ψ_e = air entry potential (cm)

SWIMSOIL Parameters

- User-defined water retention and hydraulic conductivity functions
- **HYPROPS** generates a hydraulic property table
- This table is used by SWIMSOIL
  - $\text{Log}_{10} |\Psi|$
  - Volumetric water content θ
  - Slope of θ vs. $\text{Log}_{10} |\Psi|$
  - Log_{10} K
  - Slope of Log_{10} K vs. $\text{Log}_{10} |\Psi|$

Solute Transport

- The Advection-Dispersion Equation
  - At macroscopic level: solute transport is a function of vol. Soil water content, solute concentration in solution, adsorbed concentration
  - At microscopic level: differencess in pore water velocities lead to unequal solute movement in the direction of flow
  - Solute transport goverened by ADVECTIVE and DISPERSIVE
  - **Advection (convection):** movement of a solute with flowing water; depends on water flux
  - **Dispersion:** quantifies the effects of mechanical dispersion and diffusion
  - **Diffusion:** movement of solute molecules from higher to lower concentrations (little or no water flow); diffusion coefficient, tortuosity (ratio of actual to shortest path length for diffusion)

Solute Transport

- Solute transport parameters in SWIM
  - **Solute_name**: TDS, Cl, NO3, NH4 etc.
  - **slupf**: factor for solute uptake (TDS=0)
  - **slos**: osmotic pressure per unit solute concentration (TDS=1.14); multiplied by solute concentration to calculate osmotic potential
  - **d0**: diffusion coefficient in water (TDS=0.21)
  - **disp**: used for calculating dispersion (TDS=1)
  - **a** & **athc**: used for calculating tortuosity
  - **ground_water_conc**: solute concentration in GW (ppm)
  - **Default_tds_conc**: irrigation solute concentration (ppm)

Plant Water Uptake

- Based on Campbell (1985) method: soil-plant-atmosphere continuum is a resistance network
  - Soil matric potential, xylem potential
  - Soil resistance of layer: a functionn of *K*, RLD, water uptake rate
  - Root resistance: resistance per unit length of root & root length density of each soil layer

- Required input parameters
  - **min_xylem_potential** (cm)
  - **root_radius** (mm)
  - **root_conductance**