Contents

1. Infiltration

1a. *Hydrologic soil horizons*

are classifications of a soil profile depending on water content ans soil-water pressure observed with depth. These are time-varying horizons that have much spatial variability in accordance to topographic position and soil properties.

Groundwater Zone (phreatic zone) Saturated soil column and positive soil water pressure. At the water table, pressure is equal to atmospheric. Water table designated at depth z'_0. If there is no ground-water flow, the pressure is hydrostatic.

$$p(z) = \gamma_w(z' - z'_o), z' > z'_0 \quad (1)$$

Where p is gage pressure, z' is the distance measured vertically downward. The water talbe is at atmospheric pressure, the level at which water would stand in a well.

Tension-saturated Zone (Capillary fringe) Saturated or nearly saturated soil with negative matric pressure as a result of capillary forces. Water is under tension, pressure remains hydrostatic and the matric head is:

$$\psi = z' - z'_0 \quad (2)$$

ψ_{ae} is equal to the height of the capillary rise in the soil. Ranges from about 10mm for gravel to 1.5m for silt to several meters for clay.

Intermediate Zone Unsaturated zone through which percolation reaches the capillary fringe and recharges the water table. Strong negative matric head. Infiltration waves allow the water content to exceed the field capacity.

Root Zone (or Soil Moisture zone) Layer from which plant roots extract water during transpiration. Water leaves through transpiration, evaporation, gravity drainage

1b. *Infiltration Process*

A water-input event begins at time $t = 0$ and ends at time $t = t_w$. We define:

Infiltration rate $f(t)$ rate at which water enters the soil $[LT^{-1}]$.

Water Input rate $w(t)$ rate at which water arrives at the surface due to rain, snowmelt or irrigation $[LT^{-1}]$.

Infiltration Capacity $f{*}(t)$ maximum rate at which infiltration can occur (changes in time) $[LT^{-1}]$.

Depth of ponding $H(t)$ depth of water standing on the surface. One can have:

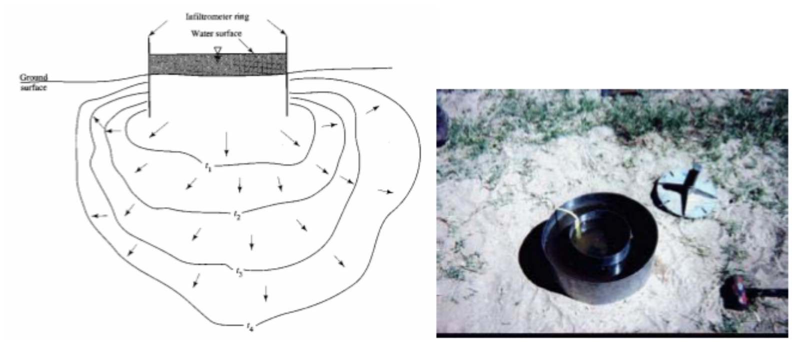
- No ponding $f(t) = w(t)$, or supply controlled situation
- Ponding, water input exceeds infiltration capacity $f(t) = f * (t) \leq w(t)$
- Ponding because the water table has risen to or above the surface. Infiltration is zero $f(t) = 0$

1c. *Measurement*

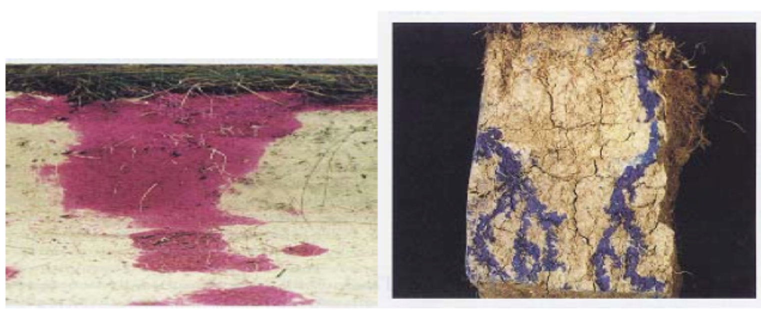
Infiltration measurements at a point can be taken via a single or double ring infiltrometer simulating the ponding of water and infiltration into soil. It can also be measured with dye tracing and visualization experiments in soil profile

Infiltration is by nature a complex phenomenon which is variable in space and time. It is affected by many factors:

- Water input from rainfall, snowmelt, irrigation $w(t)$ and ponding depth $H(t)$.
- Soil saturated hydraulic conductivity and its profile $K_h * (z)$.
- Antecedent soil water content and its profile $\theta(z)$.
- Soil surface topography and roughness (runoff-runon processes).
- Chemical characteristics of soil surface (hydrophobicity).



Infiltration Fronts and Ponding Depth and Double Ring Infiltrometer



Infiltration Dye Tracer Studies through a Water Repellent Soil and a Cracked Dry Clay Top Soil (Hendricks et al).

Figure 1: Courtesy Enrique Vivoni

- Physical and chemical properties of water.
- Soil freeze and thaw conditions.

1d. *Richard's Equation*

We can write the continuity equation using Darcy Flux in terms of the hydraulic conductivity and hydraulic diffusivity:

$$q = -K_h(\theta)\left[1 + \frac{\partial \psi(\theta)}{\partial z}\right] \quad (3)$$

$$= -K_h(\theta) - D_h(\theta)\frac{d\theta}{dz} \quad (4)$$

This equation is exactly the same (physically) as the original Darcy, but it simplifies the following analytical solutions. Remember the original conservation equation:

This equation is exactly the same (physically) as the original Darcy, but it simplifies the following analytical solutions. Remember the original conservation equation:

$$\frac{\partial \theta}{\partial t} = -\frac{\partial q}{\partial z} \quad (5)$$

$$(6)$$

We can now express this in terms of the Darcy Flux, to obtain the **One Dimensional Richards Equation**.

$$\frac{\partial \theta}{\partial t} = -\frac{\partial}{\partial z}\left[-K_h(\theta) - D_h(\theta)\frac{\partial \theta}{\partial z}\right] \quad (7)$$

1e. *The Green-and-Ampt Model*

Numerical solutions of the Richards Equation are computationally intensive and require detailed soil data that are usually unavailable. The Green-and-Ampt model applies Darcy's Law and he principle of conservation of mass, the predictions of this model have been successfully tested against numerical solutions of the Richards Equation.

Consider a block of soil homogeneous to an indefinite depth (porosity and saturated hydraulic condictivity are invariant), no ET, water table, capillary fringe or impermeable layer. Waer content prior to t=0 is $\theta_0 < \phi$. We assume no vertical tension gradient at the beginning so at t=0:

$$q_{z'}(z, 0) = K_h(\theta_0) \tag{8}$$

At $t = 0$, liquid water begins arriving at the surface at a rate w and continues for t_w.

Case 1: Water input rate less than saturated hydraulic conductivity $w < K_h*$

Water enters faster than it is leaving, as θ increases, so does K_h and $q_{z'}$. When the water content reaches θ_w at $q_{z'} = w$ inflow = outflow. This process happens successively in each layer producing a descending front with θ_w above and θ_0 below.
If $w < K_h*$, $f(t) = w$, $0 < t \leq t_w$
$f(t) = 0$, $t \geq t_w$

Case 2: Water-input rate greater than saturated hydraulic conductivity $w > K_h*$

Initially the soil will behave as above, then θ will increase, raising K_h and $q_{z'}$. When there is saturation, $\theta = \phi$ above the front and $\theta = \theta_0$ below. Pressure force decreases as wetting descends approaching $q_{z'} = K_h*$. There is then ponding and water moves as overland flow or runoff. The instant ponding occurs is called *time of ponding (t_p)*. Up to this moment, all the rain that has fallen has infiltrated:

$$\begin{aligned} F(t_p) &= wt_p \quad (9) \\ &= z'_f(t_p)(\phi - \theta_0) \quad (10) \end{aligned}$$

solving for t_p

$$t_p = \frac{z'_f(t_p)(\phi - \theta_0)}{w} \tag{11}$$

to find $z'_f(t_p)$ we use Darcy's Law between the surface and depth $z'_f(t_p)$

$$q'_z(0, t_p) = f(t_p) = w = K_h * -K_h * \frac{\psi_f - 0}{z'_f(t_p)} \tag{12}$$

where $\psi_f$if the effective tension at the wetting front. The tension at the surface is zero because it is saturated, and the hydraulic conductivity is at its saturation value and infiltration is equal to rainfall. Because $\psi_f < 0$

$$z'_f(t_p) = \frac{K_h * |\psi_f|}{w - K_h *} \tag{13}$$

so that

$$t_p = \frac{K_h * |\psi_f|(\phi - \theta_0)}{w(w - K_h *)} \tag{14}$$

After ponding, infiltration continues as:

$$\begin{aligned} f(t) &= a'_z[z'(t)H(t)] && (15) \\ &= K_h * - K_h * \frac{\psi_f + H(t)}{z'_f(t)} = f * (t) && (16) \end{aligned}$$

where $H(t)$ is the depth of ponding. We can assume that $H(t) = 0$ and using $F(t_p) = z'_f(t_p)(\phi - \theta_0)$, yield

$$f(t) = f * (t) = K_h * \left[1 + \frac{|\psi_f|(\phi - \theta_0)}{F(t)}\right] \tag{17}$$

which is the Green-and-Ampt equation for infiltrability as a function of the total infiltration that has occurred.
Since $f(t) = dF(t)/dt$ whe can solve for t for $F(t) > F(t_p)$ to get:

$$t = \frac{F(t) - F(t_p)}{K_h *} + \left[\frac{|\phi_f|(\phi - \theta_0)}{K_h *}\right] ln \left[\frac{F(t_p) + |\psi_f|(\phi - \theta_0)}{F(t) + |\psi_f|(\phi - \theta_0)}\right] \tag{18}$$

To solve this equation we must choose a value of $F(t)$ and solve for t. Note that as time goes on $f(t)$ becomes asymptotic to $K_h *$ as observed in nature.