**Infiltration**

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*June 18th, 2011*

1. **Introduction**

A watershed is the topographic area that contributes all the water that passes through a given cross section of a stream, it is also called drainage basin, river basin, or catchment area, depending on scale. The boundary that delimits a watershed is called a divide. A watershed is treated as a unit for hydrologic investigations as its topographic divide typically defines hydrologic boundaries that enable water budgets to be computed. Consequently, one of the main building blocks of a small catchment study is the water balance, which is calculated using the water balance equation for any time period of length t:



Where P is precipitation (rain and snow), is ground-water inflow, also called infiltration, Q is stream or river outflow, ET is evapotranspiration by soil and vegetation, is ground-water outflow, and is the change in all forms of storage (water, snow and ice) over the time period.





Fig. 1 Schematic diagram of a watershed.

As the water balance equation shows, infiltration is one of main components of the hydrologic cycle, it defines how water fluxes at the soil surface enter the soil. Infiltration is measured as an ‘infiltration rate’, the rate at which soil is able to absorb rainfall or irrigation, and thus determines the soil water content, which is a critical factor for vegetation. Besides, it also controls the amount of outflow and ground water level, influencing the general water circulation pattern in the watershed.

Key Reference:

*Dingman, S.L., 2008. Water in Soils: Infiltration and Redistribution in Physical Hydrology, pp243~251.*

**Practice:**

To describe the infiltration process, we need to assess the following variables:

(1) Water-input rate (w(t)) , which is the rate at which water arrives at the surface due to rain, snowmelt, or irrigation [L / T].

(2) Infiltrability (infiltration capacity) (f\*(t)), which is the maximum rate at which infiltration can occur [L / T], this value is not constant, but changes during the infiltration event.

(3) Depth of ponding (H(t)), which is the depth of water standing on the surface [L].

(4) Soil moisture content, which is the quantity of water contained in soil, it is expressed as a ratio, which can range from 0 (completely dry) to the value of soil’s porosity at saturation (θ);

(5) Soil porosity (φ), a measure of the void space in soil, it is a fraction of the volume of voids over the total soil volume, a value between 0-1, or as percentage between 0-100%.

(6) Hydraulic conductivity (K), is a property of soil that describes the ease with which water can move through pore spaces or fractures.

(7) Pressure head (), is used to represent the internal energy of a fluid due to pressure exerted on its container, mathematically expressed as: (where is fluid pressure [M / [L T2]], is the specific weight [M / T2], is the density of fluid [M / L3], and g is the acceleration due to gravity.



Question for Students 1

Note that dimensions are given for each variable, the fundamental dimensions are length, time, mass and electrical charge. Water input rate has the dimensions of length per time; can you think of the units that the weather forecast would present this variable in?

*Answer of Instructors 1*

*Precipitation is reported in mm/hr or inches/hour or mm/day or inches/day (depending on where you live).*

Question for Students 2

Infiltration is driven by gravity and pressure forces on water arriving at the surface. For a constant precipitation rate on a dry soil (when the soil is unsaturated), lasting for a long time, will the infiltration rate change with time? If not, how will it change and why?

*Answer for Instructors 2: Infiltration rate decreases with time. The reason is that the pressure force will decrease; as water will flow from the ground surface downward, the surface will get a higher water concentration than the lower layer. And it is the concentration difference that will cause the pressure force. The increase rate of water content is very fast at surface, but gradually for the subsurface layer. Thus as time goes on, the lower subsurface soil becomes more moist, the pressure force declines, and the infiltration rate will decrease accordingly.*

Question for Students 3

For a very dry soil, and a low precipitation rate, the soil moisture profile goes through three stages 1) unsaturated; 2) partially saturated; and 3) fully saturated. Please describe the relationships between f(t), w(t) and f\*(t) for each case? How about the value of H(t) at each stage?

*Answer for Instructors 3: the infiltration process can be split into 3 stages:*

1. *Unsaturated: as the soil is very dry at first, the infiltrability will be very high, and larger than the water input rate, in this case, all the water will infiltrate to the sub surface layer as soon as it hits the ground, so f(t) = w(t), and there is no water standing on the surface, thus H(t) = 0. In this case, f (t) is dependent on w(t), it did not reach its maximum, thus f(t) <= f\*(t).*
2. *Partially saturated: as the soil becomes more moist, f(t) and f\*(t) will both decrease, and when they become smaller than w(t), there is enough water for infiltration, thus the infiltration rate is constrained by soil porosity, not water input rate. At this point the infiltration rate will get its maximum, thus f(t) = f\*(t). Then the surface layer get saturated, and water will stand on the surface, and H(t) > 0.*
3. *Fully saturated: as water is standing on the surface, the water input rate becomes much larger than infiltration rate, so more and more soil will be saturated from the surface to deeper soil layers. When the saturation from surface contact the ground water level, the whole soil layer will be saturated, and there will be no space left for infiltration, thus f(t) = 0, and all the water will pile up on the surface (H(t) > 0) and flow away along to the local slope.*

Question for Students 3

Infiltration rate can be measured in several ways; one of devices used is called a ring infiltrometer, which directly measures infiltrability over a small area (0.02-1m2). The area is defined by an impermeable boundary, usually a cyclindrical ring extending several centimeters above the surface, and sealed at the surface or extending several centimeters into the soil.



Fig. 2 Ring infiltrometer

The Excel ‘Infiltration.xlsx’ file worksheet ‘Infiltration measurement’ shows the equation used in this field method.

*3A*  Explore average infiltration rate changes with precipitation duration. Calculate f(t) and show infiltration rate for each time interval, make a plot. What does this result in? What would happen if the ring was removed and part of the water was ponded and part of it runs off? (See worksheet for example values).

*Answer for Instructors 3A: The value of f(t) and figure has been created in the instructor’s version, The figure shows that f(t) decreases over time, the soil saturates, and water becomes ponded on the surface, and then runoff dimishes infiltration even further, it is exactly in accordance with the situation of question 1.*

*3B*  Practice 2 calculates the average infiltration rate with increasing water input rate, calculate the value of f(t) and plot a graph of f(t) as a function of P, what did you get? Is there a constant slope? What does that mean and why?

*Answer for Instructors 3B: the calculations of f(t) and the resulting figure are presented in the instructor’s version. The figure shows that f(t) increases with increase of P, however, the slope is not constant, f(t) increases less when precipitation rate rises, the reason is that the intensive precipitation will lead to the condition that f(t) < w(t), and consequently some water will stand on the ground surface.*

Question for Students 4

Hydraulic conductivity is an important parameter in the infiltration process, It depends on the intrinsic permeability of material and on the degree of saturation. Try to think about which factors will influence the hydraulic conductivity of soil (list at least 4) and how they work.

*Answer for Instructors 4*

*Table 1: Factors that may influence the hydraulic conductivity*

|  |  |
| --- | --- |
| *Factors* | *Influences on f(t)* |
| *Grain size* | *The coarser the grain, the higher the f(t).* |
| *Porosity* | *The higher the porosity, the higher the f(t).* |
| *Soil temperature (frost layer)* | *f(t) will be greatly decreased if there is a freezing layer.* |
| *Soil structure (organic matter)* | *High organic matter increases f(t).* |
| *Soil mineral composition (clay minerals)* | *The clay minerals swell when wet and shrink when dry, and thus change the porosity of soil.* |

Question for Students 6

A simple way to calculate infiltration uses ‘Richards equation’. The Excell worksheet named ‘Infiltration Model’ allows you to calculate the vertical flow rate for two different types of soil and with varying pressure heads. Please plot graphs of vertical flow rate changes as a function of K and Ψ. Compare the results, and quantify the role of K and Ψ in the infiltration process (Hint: you can do it by calculating the slope of the trend line, in addition search online to find realistic ranges for K and Ψ)

*Answer for Instructors 6: The graphs have been plotted in the Excell sheet ‘Infiltration Model’, and the slope of each trend line is calculated. One could infer that both K and Ψ have important control on the vertical flow rate. The slope for the relationships are similar, i.e. close to 1. However, K has a much broader range for different soil types, consequently the vertical flow rate is be more affected by K than Ψ.*

*Reference:*

*Hydraulic Conductivity measurement: http://www.connectedwater.gov.au/framework/hydrometric\_k.php*

*Static Pressure and Pressure Head in Fluids: http://www.engineeringtoolbox.com/static-pressure-head-d\_610.html*