PENETRABILITY

The ability of a soil or other substance to be penetrated. It is measured by means of a penetrometer, an instrument which determins the consistency or hardness of the soil by measuring the depth or the rate of penetration of a rod or needle driven by a known force.

PEPTIZATION

The process by which a colloid is converted from gel to sol. In pedological terms colloidal particles of clay in soil, are dispersed from an aggregated to a dispersed state. As a dispersion in soil water, clay is capable of being transported within a profile.

PERCOLATION

Percolation is the downward movement of soil moisture through the vadose zone that is located between the root zone and the capillary fringe of the permanent groundwater table (Hill, 1979). Percolation is also called internal drainage (Hillel, 1980). The rate of percolation is highest shortly after rain has infiltrated the soil surface (see *Infiltration*). This rate generally decreases with time until the next infiltration event. Given any particular rainstorm event, the percolation rate is higher for an initially wet soil than for a dry soil. As capillary forces act to maintain moisture between pores (see *Capillary pressure*), any percolating moisture is primarily controlled by gravitational forces and under steady-state conditions the rate of percolation P is the vertical hydraulic conductivity $k(\theta)$ given by

$$P = k(\theta) \tag{1}$$

Equation (1) is derived from Darcy's Law assuming that the suction gradient is negligible (see *Water movement*).

The speed and the residence time of percolating moisture in the vadose zone is of concern in many branches of soil science and hydrology e.g., groundwater hydrology, contaminant transport and irrigation scheduling. In these disciplines, a precise estimate of the percolation rate is required. However, the percolation rate is difficult to measure as it is highly dependent on the medium through which the moisture moves and to a lesser extent the characteristics of the water itself (Hill, 1979). Density, viscosity and surface tension of water affect the percolation rate. Viscosity effects are related to soil temperature and the concentration of solutes. However, pore size distribution is the predominant mechanism affecting percolation rates (see *Soil pores*). The soil is not uniform but comprises a mixture of organic material, entrapped gases and grains and particles of varying sizes. Preferential percolation is the rapid and non-uniform transport of soil moisture through the vadose zone. This form of percolation often occurs through macropores and sub-surface channels, which result from either biological activity (biopores, e.g., roots, worm holes, etc), geological forces (e.g., subsurface erosion, cracks and fractures) or agrotechnical practices (e.g., plowing, bores and wells). Soils are also often layered and each layer possesses characteristically differing hydraulic conductivities and consequently different percolation rates.

Preferential percolation was recognized as early as last century. Lawes, Gilbert and Warington (1882), theorized that moisture could be separated into two parts: "direct" and "general" drainage. Direct drainage or preferential percolation may be initiated when moisture is transported through near surface cracks and deeper down channels following a precipitation or irrigation event. On the other hand, general drainage or matrix flow occurs whenever the percolating moisture in the soil matrix is transported by a hydraulic gradient resulting from pore-scale diffusion and gravity-maintained convection. General or matrix percolation obeys Darcy's Law. Preferential percolation exceeds transport velocities predicted by Darcy's Law. The relative importance of the two forms of percolation (preferential and matrix) is dependent on the soil type and rainfall intensity. For example, well-structured soils consisting of clay and loam mixes, typically experience low permeability rates. In such soils, typically less than 1% of the pore volume consists of cracks and subsurface channels. However, often during precipitation, water infiltrating from the soil surface, flow through these channels in preference to the surrounding soil matrix, whose small pores are penetrated comparatively slowly. Even though these channels consist of a relatively small percentage of the total pore volume, they may be responsible for the bulk of moisture and solute transport after an infiltration event. Further, preferential flow in these soils can be initiated well below soil-water saturation.

Even in homogeneous, sandy soils, percolation rates may be highly spatially variable. Parlange and Hill (1972) were first to document, preferential flow in homogeneous sand at low infiltration rates. This phenomenon has also been widely observed and documented by many others (see Steenhuis et al., 1996, for excellent reviews). This research has shown that moisture may be transported through a soil in a number of paths called soil-water fingers. A poorly conducting layer of top soil at the surface, for example, produces a wetting front instability that leads to finger formation. The number of fingers, their size and rate can be predicted. Gravity is the main driving force. Figure P8a–d, reproduced from Glass et al. (1989) illustrate the development of fingers in a homogeneous sandy soil.

The existence of preferential flow paths in soils have important implications for agricultural land management, storage of industrial chemicals and waste disposal (see *Fertilizers; Leaching*), For example, the chemical composition of percolating moisture in direct drainage paths often reflects the concentration of surface water rather than the concentration of moisture in the surrounding matrix. If the concentration of chemicals in the surface water is high, for instance, as a result of applying fertilizers or pesticides in irrigation water or prior to a precipitation event, then the concentration of chemicals in the direct drainage paths is likely to be higher than the equilibrium concentration in the soil matrix. Figures P9a and P9b, from Andreini and Steenhuis (1990), illustrate moisture transport through an undisturbed soil core from an experimental farm in northern New York state. These figures illustrate that structured soils, regardless of farm management practices engender preferential percolation.

Experimental determination of percolation rates is difficult due to the inability to properly characterize the soil's pore structure (Germann and DiPetro, 1996). Recently, computer-based

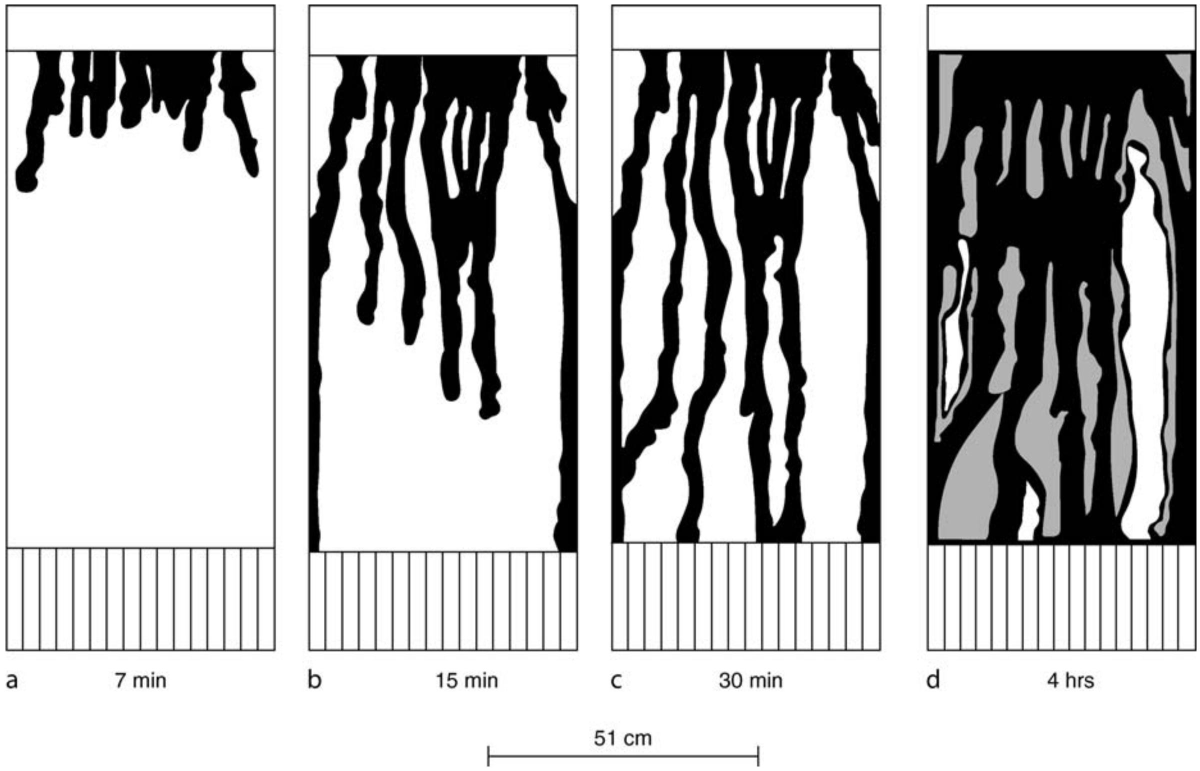


Figure P8 Development of the finger core area-fringe area in time. Core areas grow from the textural interface downward to the bottom of the chamber within the first 30 min (a, b, c). Finger fringe areas are formed as wetting fronts leave the fingers and move laterally into the dry sand on either side of the finger core areas (d) (reproduced from Glass et al., 1989).

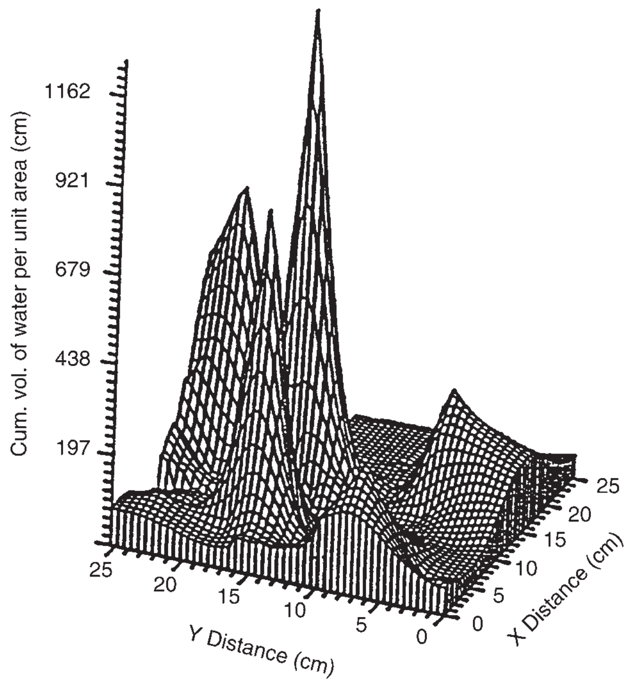
imaging techniques have been useful in describing the macroporous nature of soils and providing estimates of percolation rates in undisturbed soil cores (e.g., see Posadas, et al., 1996), however, these techniques cannot be used on a field scale. Agricultural tile lines seem to offer the best strategy for sampling preferential percolation on a field scale (Steenhuis, et al., 1990). On a smaller scale, multi-segment percolation systems like the one described in Boll, Steenhuis and Selker (1992) may be used to provide an estimate of the average percolation rate and its variability. These systems usually consist of a grid of individual fiberglass wick sampling units and are installed in the field at a certain depth below the soil surface. Moisture and solutes flow through the wicks into bottles, which are periodically collected for analysis. The fiberglass wicks provide a suction (see *Capillary pressure*) close to that of the unsaturated soil. They act as hanging water columns and sample unsaturated flow without the need to apply external suction.

In sanitary engineering the determination of a single, average percolation rate is used in designing wastewater treatment facilities, such as septic systems, rapid and slow infiltration basins and field applications of wastes. Procedures known as the standard percolation test determine the required size of a soil adsorption system for in situ sewage disposal. This method involves auguring holes with diameters ranging from 150 to 300 mm and at depths from 0.6 m to 1.0 m. After the test hole and surrounding soil has been pre-soaked for a certain time (usually 24 hours), the percolator rate is determined by measuring the drop in elevation of the head of water in the hole. The units are either expressed as the time the head drops a certain distance or the distance the head drops in a certain time. The flow of water from the percolation test is not strictly confined to downward drainage; even though this is the usual situation. The test also includes lateral flow and possible upward movement by capillary forces. Exact details for performing the percolation test vary according to local and state municipalities. For further details see, for example, Tchobanoglous and Schroeder (1987).

Mathematical and computer prediction of percolation rates is complicated not only because of the non-uniformity of the soil layer but also because of the difficulty in prescribing boundary conditions at both the near surface or root zone end and at the capillary end of the vadose zone (see *Transport*). One approach to modeling is to partition the soil conceptually into groups consisting of flow paths, which experience approximately the same average percolation rate. This may be accomplished, for example, by approximating the hydraulic conductivity of Equation (1) by piece-wise linear segments given by

$$P_i = k_i(\theta) = K_i - 1 + [K_i - K_{i-1}]\left[\frac{\Theta - M_{i-1}}{M_i - M_{i-1}}\right] \quad (2)$$
$$i = 1, 2, ..., n$$

where n is the number of capillary bundles with mobile water, M_i is the upper limiting moisture content of the ith capillary



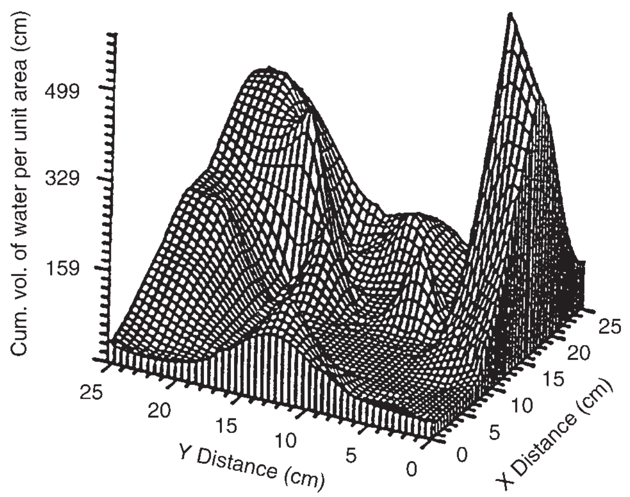


Figure P9 (a) The cumulative volume of water per unit area that flowed through the tilled soil column after 30 days as a function of location (reproduced from Andreini and Steenhuis, 1990). (b) The cumulative volume of water per unit area that flowed through the no-till soil column after 30 days as a function of location (reproduced from Andreini and Steenhuis, 1990).

bundle, K_i is the upper limiting value of the conductivity and P_i is a constant, average percolation rate in the ith capillary bundle. Equation (2) applies to percolation rates within the range of fluxes described by Darcy's Law. Macroporous flow may be modeled by including additional pore groups, say $n+1$ to N with higher percolation rates. Assuming that gravity is the major force acting on percolating water, then the transport equation for each capillary bundle may be expressed as (Stagnitti et al., 1995).

$$\frac{\Delta\theta_i}{\delta t} + v_i \frac{\delta\theta_i}{\delta z} = A_i(z,t) \quad i = 1, 2, ..., n, .., N \qquad (3)$$

where t is time, z is distance downward with $z = 0$ being the soil surface, θ_i is the moisture content in the ith capillary bundle, v_i is a constant related to the average percolation rate in the ith capillary bundle, $A_i(z, t)$ is a source-sink term which models the effect of precipitation and evapotranspiration on the ith bundle and mixing with other capillary bundles. Notice that the same convective transport equation is applied to n micropore and N-n macropore capillary bundles. This approach was successfully used to predict moisture and solute transport on a number of different soil types.

The term percolation has both qualitative and quantitative connotations and the use of the term by different disciplines may have different meanings (Hill, 1979). However, the amount of water that percolates through the soil is very important in understanding drainage design, irrigation scheduling, sewerage and waste disposal. The percolation rate is highly dependent on soil structure and weakly dependent on characteristics of the water. Calculation of a single average percolation rate for many soils may be misleading for predicting the movement of toxic chemicals resulting from land application given the complex network of preferential flow paths.

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Cross-references

Capillary Pressure
Carbon Sequestration in Soil
Conductivity, Hydraulic
Conservation
Dispersion
Drainage
Fertilizers, Inorganic
Fertilizers, Organic
Humic Substances
Infiltration
Leaching
Permeability
Soil Drainage
Soil Pores
Soil Variation
Soil Water and Its Management
Tillage
Transport Processes
Water Budget in Soil
Water Movement
Wetting Front

PERIGLACIAL

Used to designate an area, or features or processes within an area, which is, or was, adjacent to an ice sheet or glacier, so that the action of freezing and thawing, is or has been dominant in forming or modifying the landscape.

PERIODIC TABLE IN SOIL SCIENCE

The Periodic Table is a creation of the nineteenth century and according to Rouvray and King (2004) there were six independent discoverers: de Chancourtois 1862, Newlands 1864, Odling 1864, Hinrichs 1867, Meyer 1868, and Mendeleev 1869. Mendeleev's version became the most famous and it marks the starting point for later developments.

Figure P10 is a modern, long form of the Periodic Table with the elements arranged in order of increasing atomic number (alternative arrangements are considered by Katz, 2001). The vertical columns are called Groups and the horizontal lines, Periods. The members of a Group have the same outer electron configuration but different quantum numbers at that outermost level. The (Roman) number of valence electrons equals the Group number. The (Arabic) number of the period is the quantum number of the outer electrons. Within the table a number of blocks are labeled in terms of the nature of the orbital occupied by the highest energy electron in the atomic ground state of any element in the block. The following blocks are recognized.

1. s-block: highest energy electron (outermost) is s^1 or s^2.
2. p-block: outermost electrons are p^1 to p^6.
3. d-block: outermost electrons are d^1 to d^{10}, also called "transition elements"
4. f-block: outermost electrons f^1 to f^{14}.
5. g-block: predicted by quantum theory, not found in nature.

Periodicity in chemical and physical properties occurs as a reflection of the fact that the outermost electronic structure may repeat in going from a lower to a higher quantum number

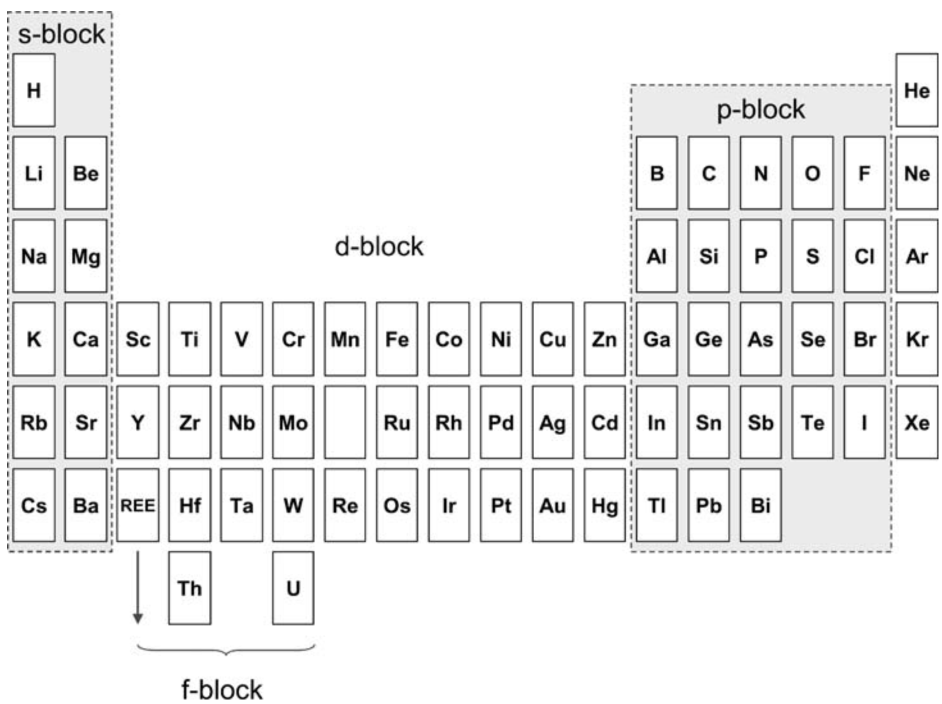

Figure P10 Periodic table of the elements. Note that hydrogen is anomalous in that it does not fit well into any one group. Only naturally occurring elements are shown. IUPAC sanctioned atomic weights are shown in Table P5.