B.C. Agricultural Drainage Manual

Chapter 3

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Water 3

3.0 The Role of Water in Drainage

Water is an essential component of crop production. It is present in the environment in several forms: gas, liquid, and solid. In terms of field management, water in its liquid form is of greatest concern to a farmer. Water problems become most obvious when it flows over or ponds on the soil surface. Water in soil, called soil water, has a strong impact on soil management.

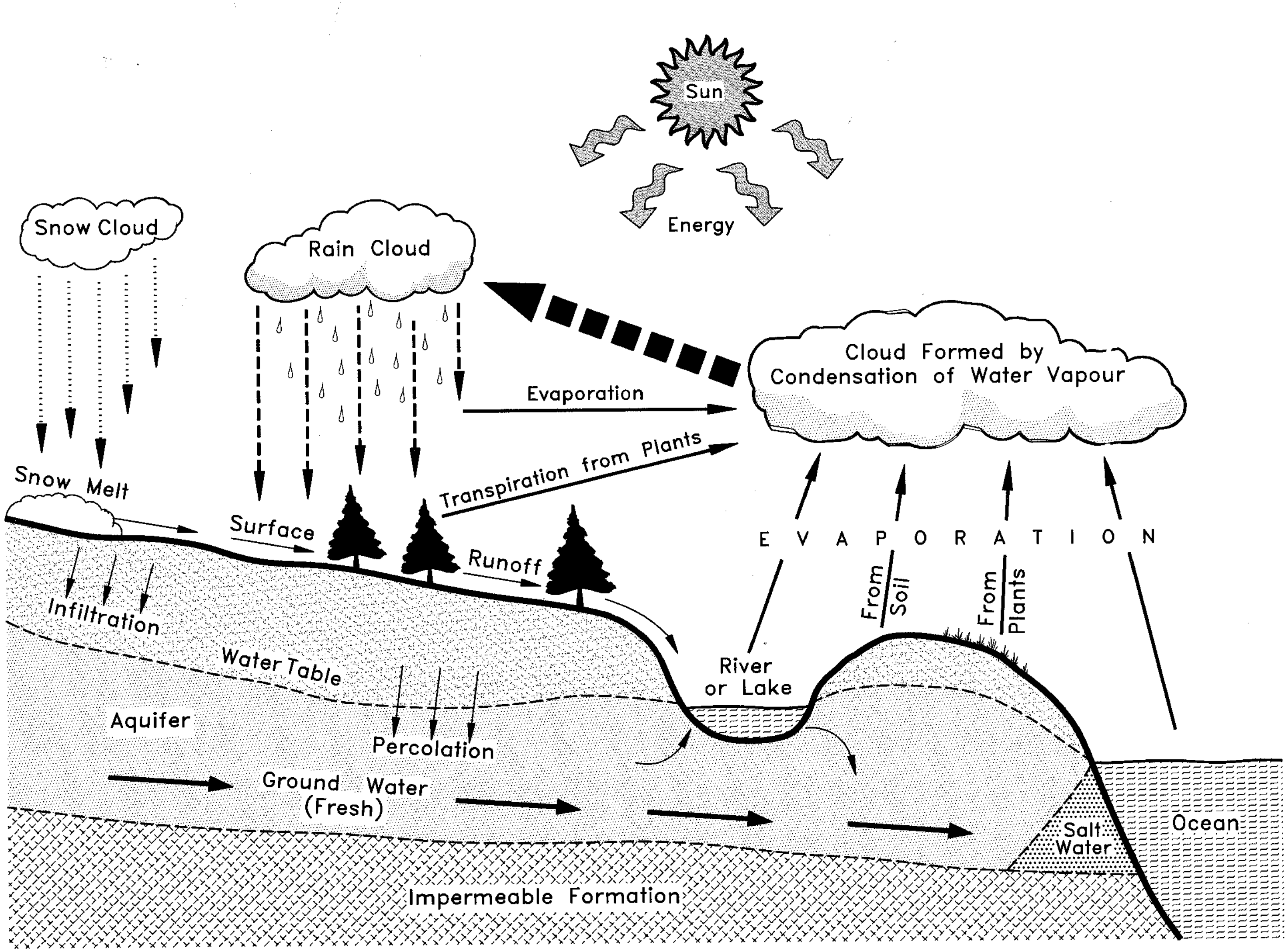
The total amount and distribution of precipitation and the resulting soil water play a significant role in agricultural productivity. Heavy rainfall during the fall, winter and spring often causes saturation, flooding and water erosion for most soils. Low rainfall during the summer period often causes a water deficit for most crops. High water tables and water deficit conditions are both detrimental to optimum crop production. Both of these conditions may be largely overcome with drainage, irrigation and appropriate tillage and soil management practices.

The movement of water through the environment of a field is controlled to a large degree by soil characteristics and amount of plant cover present. Chapter 2 of this manual covered many aspects related to the characteristics of soils. This chapter will discuss the various components of the hydrologic cycle, including the many aspects of soil water, its movement in the soil and the role of the various soil water components in drainage.

3.1 Hydrologic Cycle

Hydrologic cycle refers to the overall cycling of water through the environment. It may be specific to a small watershed on a local creek or general to include the movement of water through an entire large river watershed such as the Fraser River. The hydrologic cycle includes rain or snow that falls on the ground and water that either runs off the surface or infiltrates into the soil. Infiltrated water can be stored either in the soil as capillary water, or gravitational water. Gravitational water is stored in lakes and rivers or as ground water in aquifers. Figure 3.1 shows a schematic representation of the hydrologic cycle.

A drainage system becomes part of the hydrologic cycle of a small watershed when it is installed. Water infiltrating into the soil causes the local water table to rise. This water then enters the drainage system and is carried to a ditch which empties in a stream. Surface runoff may be collected by the same system through surface inlets or enter the ditch via overland flow. The water in the stream eventually finds its way to the ocean. Along the way, water can evaporate, be used for irrigation or percolate deep into the soil where it becomes ground water.



Adapted From: Palmquist, 1991

Figure 3.1 Hydrologic Cycle

3.2 Ground Water

Ground water refers to underground water that is found in aquifers, in the underlying soil, bedrock and parent materials in a landscape. This is water that has infiltrated the soil surface and then percolated through the soil to the local water table. Ground water is usually only accessible through deep wells or when it seeps to the surface as springs. Ground water at the top of the water table is at atmospheric pressure and is often referred to as gravitational water. That is water that is affected by gravity rather than the adhesion and suction forces of soil particles or plant roots.

Ground water flow results from differences in water elevation in the soil. These differences usually approximate the soil surface topography and cause hydraulic gradients. Flowing ground water may reach the surface as springs or enter creeks or lakes below their surface. Ground water flow can often surface as wet spots in fields well away from any obvious sources of surface water.

The water table of an area may or may not be the ground water elevation of that area. Perched water tables often form as the result of impervious or slowly permeable layers in the soil. Water tables that essentially have no bottom, or are the ground water of a region, are referred to as deep water tables. Figure 3.2 shows both deep and perched water tables. Perched water tables may be the result of geologic formations such as rock or densely compacted glacial till. They may also be the result of cultural activity on the soil which leads to soil compaction and a plow or traffic pan.

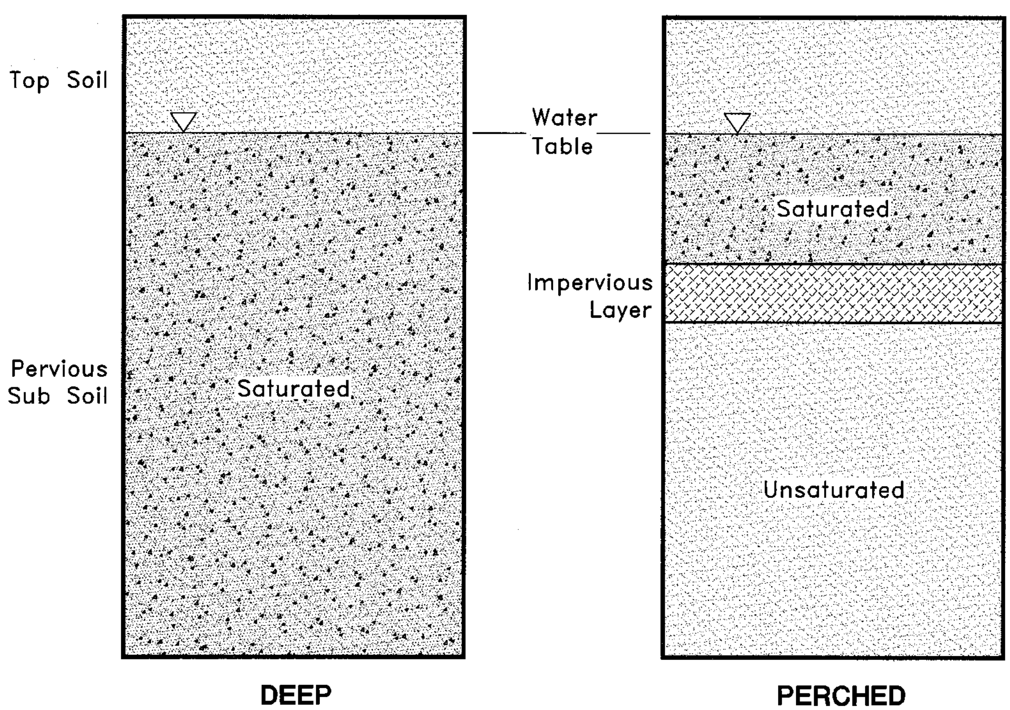


Figure 3.2 Two Types of Water Tables

3.3 Soil Water

Soil water can be divided into two categories: capillary ("held") and gravitational ("free") water. Plants require the right amount of water and air for growth. Held or capillary water is useful soil water for plant growth, which originates either from infiltration or from capillary rise from the water table. Infiltration or gravitational water moves freely to fill all of the open pores in the soil. Drainage removes gravitational water to allow air to replace water in the soil macropores.

Distinguishing between capillary and gravitational water can be visualized with the following simple scenario.

Step 1: A cylinder, closed at the bottom, is filled with soil. The cylinder has a valve installed at the bottom. Close the valve and slowly add water to the soil from the top.

Step 2: Continue adding water until it runs over the top of the cylinder indicating that the soil is completely saturated.

Step 3: Now place a container under the valve and open it. Water immediately runs out of the valve. First rapidly but gradually slower and slower until it finally stops completely.

Step 4: Measuring the amount collected we find that it is approximately half the amount which was required to saturate the soil.

The water, which we collected, yielded freely to the pull of gravity, and for this reason it is called gravitational free water. It is this water which impedes plant growth and is, therefore, undesirable. Only gravitational water is affected by drainage. Some of the water that was poured into the cylinder did not run out. The remaining water, which gives soil its wetness, and is available to plants, is called capillary or "held" water.

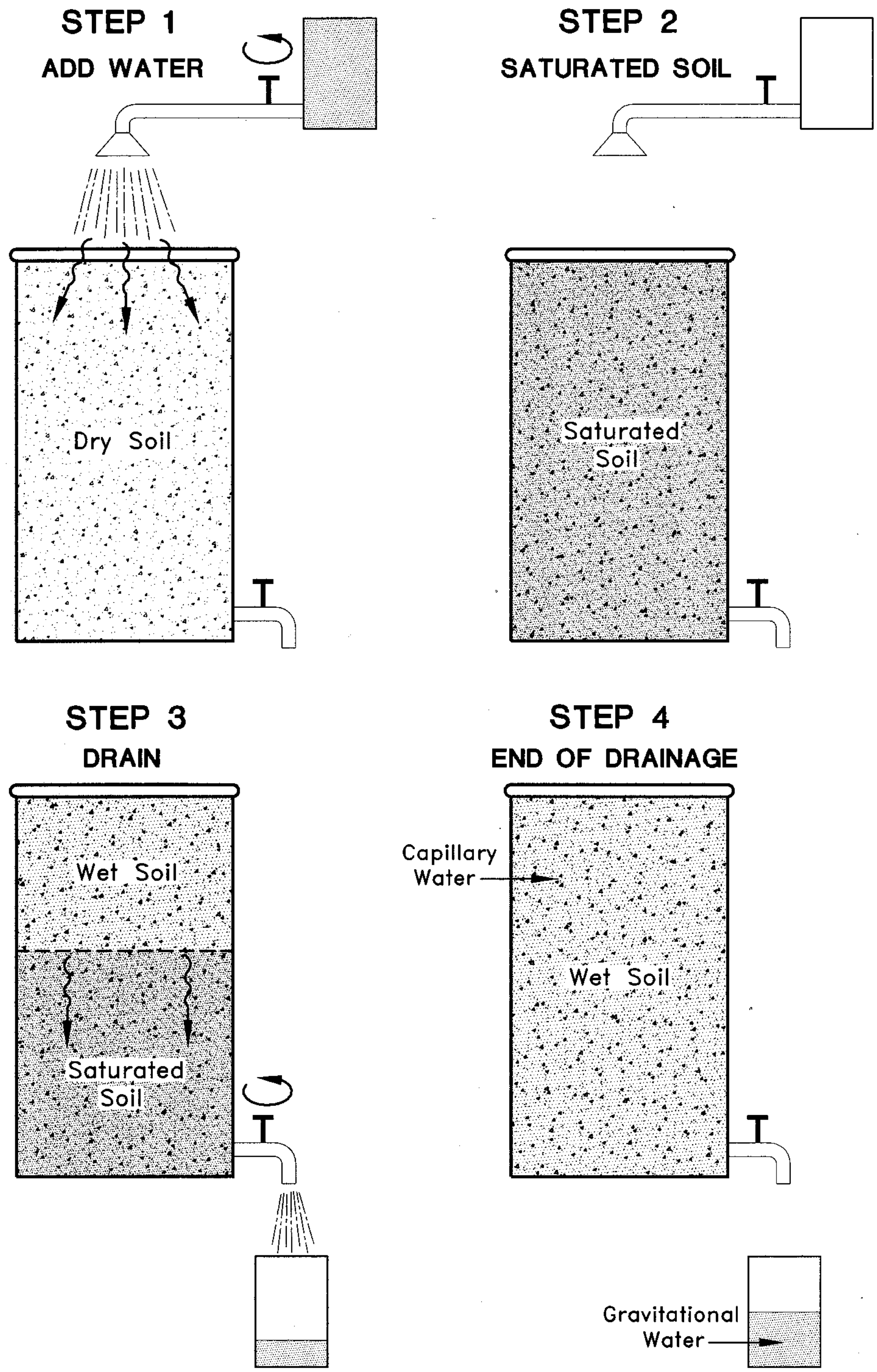


Figure 3.3 Capillary and Gravitational Water

3.4 Capillary Water

From a chemistry standpoint, both capillary and gravitational water are essentially the same. They are regarded as different only if they are held or not by the soil in the presence of free drainage. The water remaining in a soil after it has been drained of gravitational water is held by a force. This force is essentially the same as the force which causes water to cling to the surface of an object after it has been submerged. The force of attraction between the water molecules and soil particles is known as adhesion. Water held in the soil is called capillary water, because it is predominantly present in the soil micropores of the soil called capillaries.

Capillary water is held as a continuous film surrounding the soil particles by means of surface tension. This water is available directly to the plant and is replaced by means of infiltration into the soil or by capillary rise from the water table. The capillary fringe is the zone where there is a transition from capillary water to gravitational water. Figure 3.4 is an illustration of the capillary fringe within a soil profile.

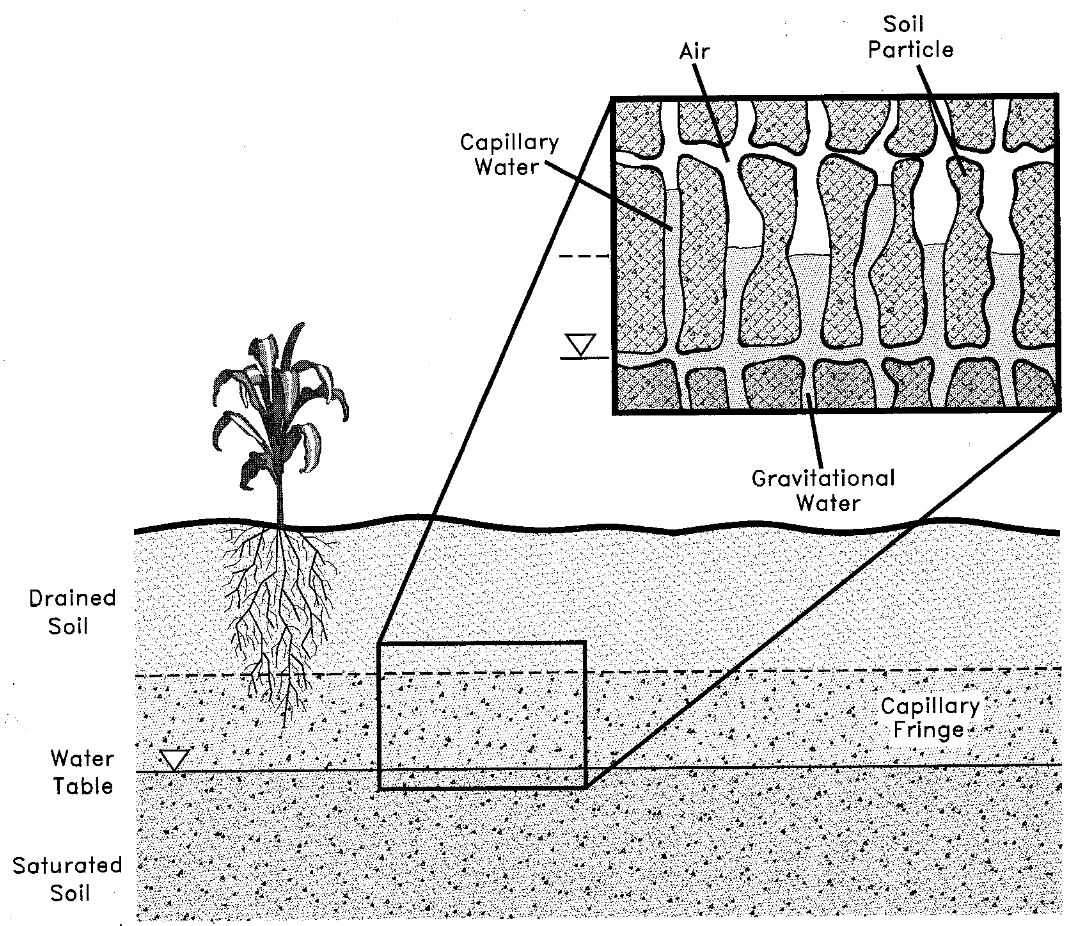


Figure 3.4 Capillary Fringe

Most of the capillary water in soil is used by plants and it cannot be removed by drainage practices. The only way capillary water can be removed from the soil is by applying greater tension or suction than is exerted by the soil particles. This is often done in the laboratory to determine the amount of water that can be held by the soil under various tensile forces. This information can tell us much about the properties of that soil. Since we know the amount of tension that can be exerted by the plant roots, we can easily determine how much water in the soil is available to the plants. This information is used to determine water holding capacity of a soil. It is also required to help determine irrigation needs. Refer to Section 3.4.2 on water retention for more details.

3.4.1 Capillary Rise

The differences between capillary and gravitational water were discussed in Section 3.4. The capillary fringe, or zone of capillary rise, is the unsaturated wetted zone above the water table. Figure 3.4 indicates the relative location of the capillary fringe in the soil profile. The thickness of the zone depends on whether the water table is rising or falling. It is also very dependent on soil texture and the size, shape, distribution and continuity of pores within a soil. Defining the top of the capillary fringe or the top of the water table in a soil is difficult because it is a constant state of flux. This movement of the capillary fringe results from additions and losses of water within the soil. Subirrigation, irrigation or rainfall will result in a rise in the capillary fringe. Drainage or evapotranspiration from the soil and crop will result in a reduction in the capillary fringe.

Both the terms capillary fringe and water table are conceptual for soil water near the zone of saturation, where both the forces of gravity and adhesion are at play. The thickness of the capillary fringe can be estimated by using the following equation:

$$Hc = \frac{0.3}{d} \qquad \textbf{(EQ 3.1)}$$

Where:

Hc = the capillary rise in centimeters, cm

d = average size of the soil particles in centimeters, cm

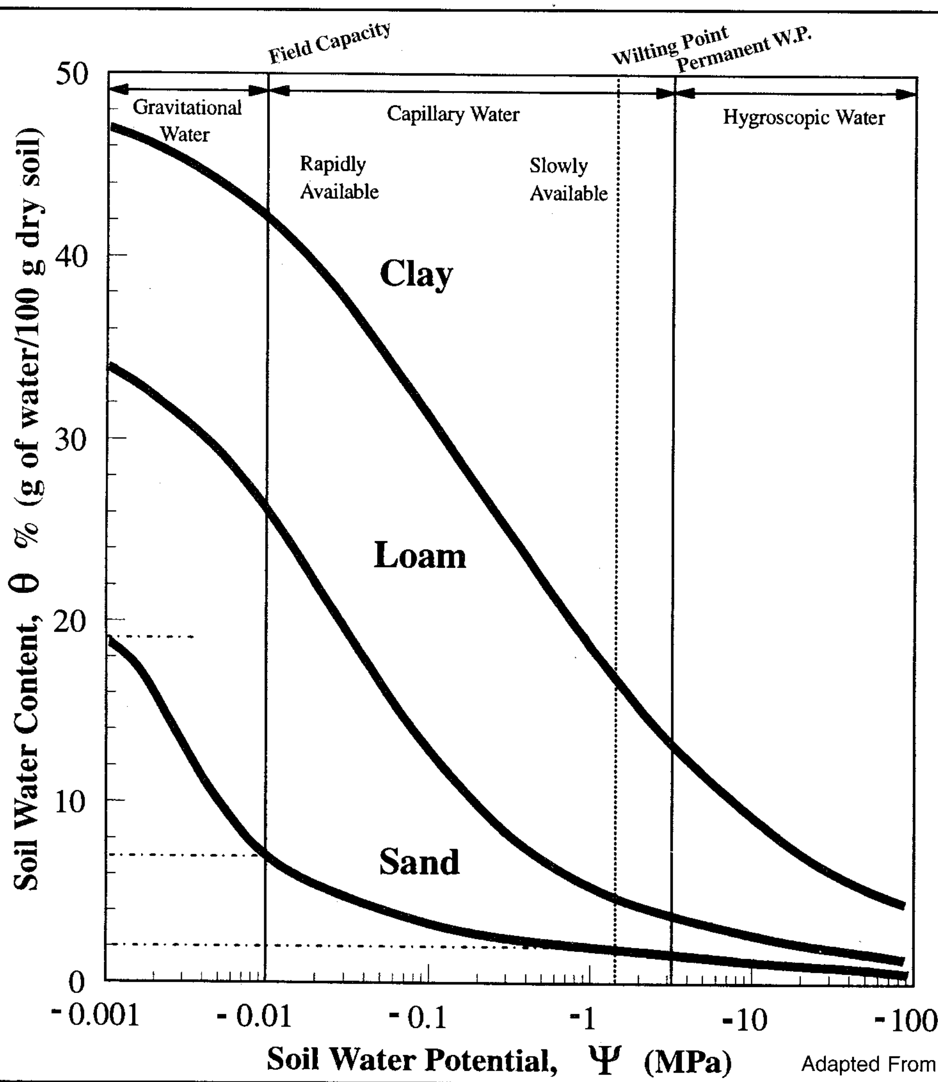
For example , in a sandy loam with an average particle size of 0.06 mm (0.006 cm), the capillary rise would be about 50 cm. As the soil texture increases in coarseness, the capillary rise will decrease.

Capillary rise becomes an important factor in development of subsurface irrigation or controlled drainage systems. The depth of the controlled water table and the height of the capillary rise must be such that they provide water to the root zone of the crop without causing waterlogged conditions. See Chapter 11 for more details on the design of controlled drainage and subirrigation systems.

3.4.2 Water Retention

Water retention refers to the amount of water retained in the soil at various levels of soil water potential (ψ). Soil water potential refers to the differences in energy resulting from the force of gravity, the adhesive forces of the soil matrix or solids and osmotic or ionic attractions in the soil solution.

At various levels of soil water potential, water is free to drain, available to plants or tightly held by the soil. These various moisture conditions are known as gravitational or drainage water, capillary or available water and hygroscopic water. The division between gravitational and capillary water is referred to as field capacity. The division between capillary and hygroscopic water is known as "permanent wilting point". Figure 3.5 is an illustration of the soil water retention curves for three soil textures. The figure also indicates the numerical values for the field capacity and wilting point. From the graph the water content at saturation for a clay is 47% and 19% for sand. Gravitational water in clay accounts for a 5% (47% - 42%) change in the soil water content. Gravitational water in sand accounts for a 12% change. The range for capillary water for clay is 26% and 5% for sand. This information gives an indication of why sands drain more quickly and clays hold more moisture that will be available to crops.



Adapted From: Brady, 1990

Figure 3.5 Soil Water Potential

The last point about soil water retention is related to downward flow of water in a soil. As a water table drops from an initial elevation to a lower elevation, the soil water content must equilibrate to the new depth. Remembering that the capillary fringe rises above the water table, it is important to note that the soil water content above the falling water table will cover a range from saturation to field capacity. If the water table drops quickly the change in soil water content curve will lag behind the water table. If the water table moves slowly, the water content curve will follow the water table drop more closely.

3.5 Water Table

Rain falling on a dry soil is held in place, much like water in a sponge. There is a limit to the amount of moisture that can be held by the soil. This amount differs from one soil to another. The capacity to hold a certain amount of water is known as the water holding capacity. As more and more water enters the soil, a point is eventually reached where the water holding capacity of the soil is exceeded. Any additional water entering the soil cannot be retained as 'held' (capillary) water and moves down as 'free' (gravitational) water. Gravitational water is pulled downward by gravity and moves through the soil macropores until it is stopped by an impervious barrier. As more water collects over the barrier it builds up to form ground water. The surface of the gravitational water is called the "water table".

Normally, the water table continues to rise with precipitation until it finds a natural outlet or a drain tile. If neither are present, the water table rises to the surface of the soil where it can interfere with plant growth. It is important to note that the water table rises as precipitation infiltrates the soil surface and percolates down through the soil. The soil does not fill with water from the top down, but rather, from the bottom up.

The water table is not static. It exists in a continual flux, being influenced by rainfall, seepage, runoff, crop removal and daily changes in gravitational pull. In summer, plant growth is vigorous, high temperatures prevail and little precipitation occurs. Water is therefore removed from the soil more rapidly than it is added, hence, the water table recedes. It may drop to a depth greater than 3 m depending on the weather and site conditions. For Coastal regions under winter conditions, temperatures decrease, plant growth decreases or ceases completely and rainfall becomes frequent and heavy. Much more water is added to the soil than is removed and the water table rises to, or even above, the ground surface where it usually stays for most of the winter and early spring.

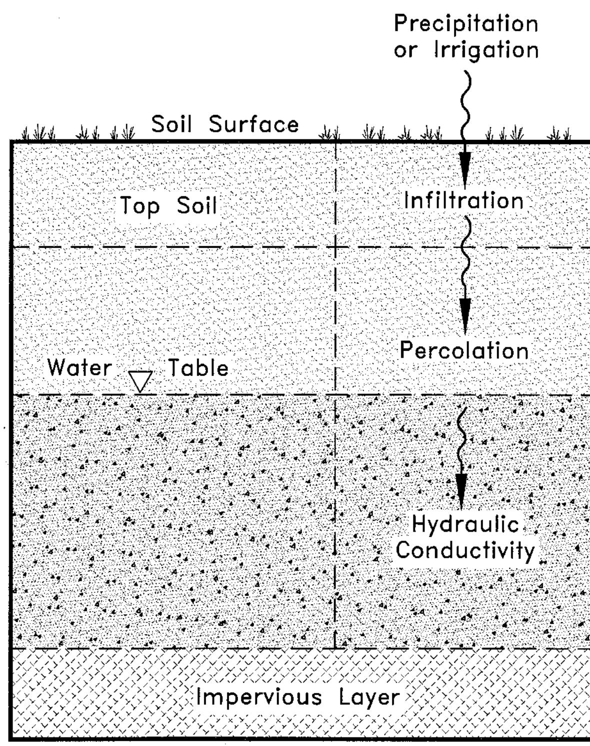
The rate of rise and fall of the water table is mainly controlled by climatic factors. To lower the water table in fields more rapidly, drainage systems, ditches and pumps can be used. Regional drainage can also influence the position of the local water table. Other influences such as topography and proximity to large bodies of water that experience freshet flows or tides can exert strong control on the movement of a water table.

As discussed previously in Section 3.2, water tables exist in the soil in two basic types, deep or perched. Perched water tables are usually more transient than deep water tables and generally exist as a result of slowly permeable layers in the soil. A compacted layer or layer of clay within a gravely soil may cause a perched water table which lasts from a few hours to days. Perched water tables are often associated with temporary wet spots in fields. These wet spots are not to be confused with ponding resulting from puddled soils or flooding resulting from runoff.

Both deep and perched water tables may result in water laying on the soil surface. However, the soil must be saturated from a slowly pervious layer to the surface, in the case of the perched water table, or from below the root zone, in the case of a deep water table. Flooding occurs when surface water spills in to a field and covers the soil surface. Ponding, which is a temporary event, occurs when the soil surface layers are sealed or puddled. Puddling restricts the movement of water downward through the soil causing a pond to form. See Section 4.3 for further details on investigation of these problems.

3.6 Soil Permeability

Soil permeability refers to the capacity of a soil to transmit a fluid such as water. It is a qualitative term used to describe this property. Permeability may also be used to describe the relative ease with which the fluid will move through the soil as in 'slowly' or 'rapidly' permeable. The numerical measurement of permeability can be either infiltration rate, percolation rate or hydraulic conductivity. Figure 3.6 indicates the relationship between the three rates and some aspects of permeability.



FLOW CONDITION	MEASUREMENT TECHNIQUE	OBJECTIVE OF MEASUREMENT
Unsaturated	Infiltrometer	Irrigation Application
Nearly Saturated	Falling Head Percolation Test	Septic Drain Fields
Saturated	Auger Hole Method	Subsurface Drainage Design

Figure 3.6 Aspects of Soil Permeability

In Section 2.7, the term porosity was discussed in relation to the movement of air and water in a soil. Porosity and permeability are interrelated terms. Porosity is a measure of the total volume of pores in relation to a given volume of soil and is given in percent. A well structured silt loam soil will have a porosity of about 50%. Porosity does not measure the size of pores or their connectivity. As mentioned above, permeability refers to the ability of the soil to transmit water. Large connected pores will tend to transmit water more rapidly than smaller or unconnected pores.

3.6.1 Infiltration

The movement of water into a soil through its surface layers is known as infiltration. Water may move into a soil uniformly over its entire surface, as under the influence of rainfall, or it may enter through cracks or large pores. Infiltration rate, is measured as the depth of water moving through a particular surface area of soil over time. The usual units of measure for infiltration rate are millimeters of water per hour (mm/hr). The rate at which water moves through the surface is influenced by the soil's texture, structure as well as the type and amount of crop cover. A well structured or coarse textured soil, or a soil with a grass crop, or a significant amount of crop residue, will generally have a high initial infiltration rate. Table 3.1 shows infiltration rates from different soils. The initial infiltration rate is very high until the soil has been "wetted". The final or steady state infiltration rate relates more closely to the transmission capability of the soil layers below the surface. Figure 3.7 displays the relative movement of water throughout a growing environment.

Table 3.1 Typical Steady State Infiltration Rates for Various Bare Soils

Soil Type	Steady State Infiltration Rate (mm/hr)
Sand	> 20
Sandy and silty soils	10 - 20
Loams	5 - 10
Clay	1 - 5
Sodic clay soil	< 1

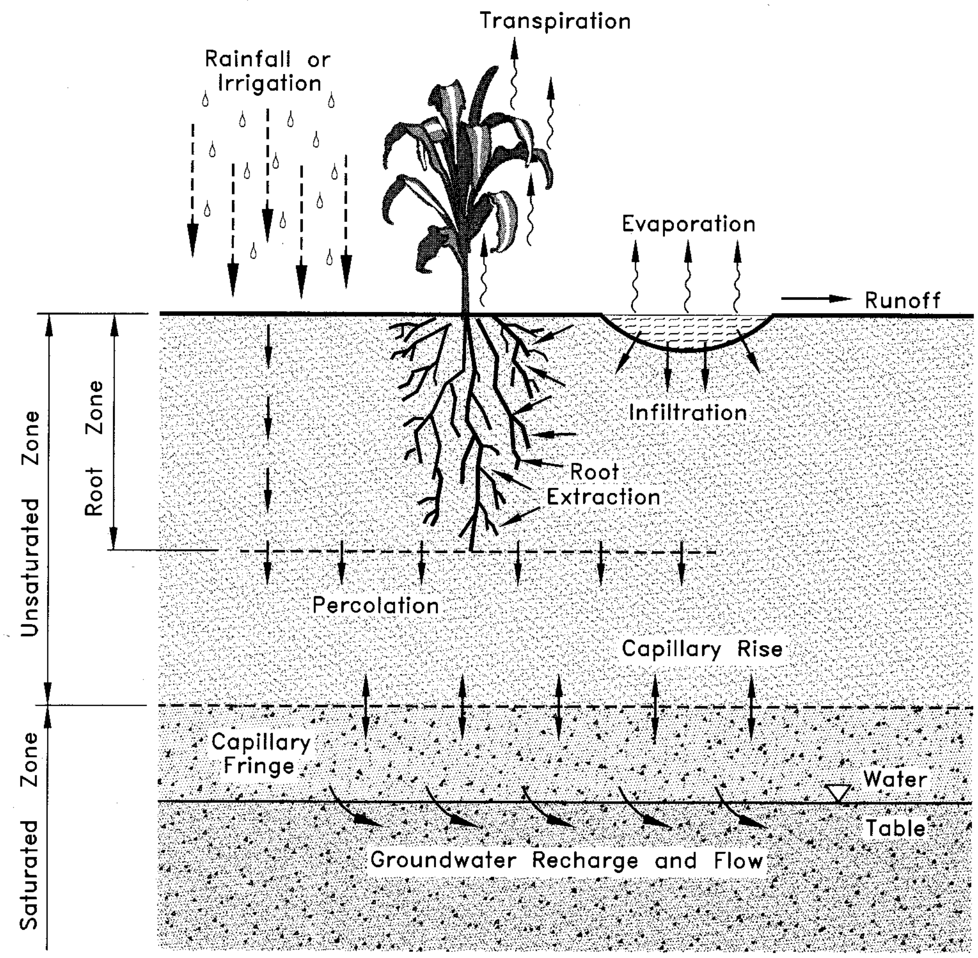


Figure 3.7 The Soil Water Balance in the Root Zone

If rainfall intensity or irrigation rate, surface water conditions, or snow melt exceed the infiltration rate, runoff or ponding will occur. Infiltration also controls the amount of water available to replenish the groundwater.

The overall rate of infiltration is dependent on soil macropores. When the soil is in permanent grass cover or cover cropped, the infiltration rate is much higher than with bare soil. Poor farming practices such as grazing or traffic on wet fields or tillage of wet soils, will degrade the fragile soil surface structure and reduce infiltration. In order to control soil loss by uncontrolled surface runoff, the infiltration rate should be maximized. Maximizing the infiltration rate will result from the appropriate use of soil management practices such as tillage, residue management and cover cropping.

3.6.2 Percolation

Following from the discussion of infiltration, the continued movement of water through the unsaturated zone of the soil toward the water table is known as percolation. This is the flow of water, under the influence of gravity, in a general downward direction. Percolating water moves when the soil below the surface is unsaturated to nearly saturated. The rate of flow is predominantly controlled by gravity and the matrix potential gradient of suction that is placed on water by soil pores.

Percolation is sometimes felt to be the movement of water in the soil below the root zone. Figure 3.7 illustrates where percolation occurs in the soil in relation to the root zone and water table. The soil surface condition and application rate of water through rainfall or irrigation initially controls the infiltration rate. The rate at which water enters the soil also initially controls the amount of water flowing through a soil. As the soil becomes wet, the infiltration rate declines and the control then shifts to the soil's permeability. This new rate of flow, controlled by soil permeability, is often referred to as the percolation rate.

3.6.3 Hydraulic Conductivity

Hydraulic conductivity, rather than being strictly the rate of water flow in soil, is best described as the resistance factor of soil to the flow of water. The hydraulic conductivity depends on the properties of the liquid (ground water) and the porous medium (soil). These soil properties are the size, continuity and total volume of soil pores which are dependent on texture and structure.

From a theoretical standpoint hydraulic conductivity is the proportionality constant (K) from Darcy's Law:

$$v = -Ki. \qquad \textbf{(EQ 3.2)}$$

Where :

v = the flow velocity of water in the soil, m/day
i = hydraulic gradient, m/m
K = hydraulic conductivity, m/day

Hydraulic gradient is the loss of head (Δh) per unit length (L) of flow path ($i = \Delta h/L$). Units for hydraulic conductivity in this manual are in m/day. From a practical standpoint, hydraulic conductivity is the flow of water in the saturated portion of the soil profile, below the water table.

The saturated hydraulic conductivity (K) must be calculated for the different soil types to determine the drain spacing and depth requirements. If the hydraulic conductivity is to be measured, the auger hole method is suggested. This method is limited to areas where a water table exists and in soils where an auger hole of known dimensions can be maintained throughout the test. Refer to Section 8.2.3 for a description of the auger hole method of measuring and calculating hydraulic conductivity. Table 3.2 indicates a range of hydraulic conductivities for some common soil textures.

Table 3.2 Soil Hydraulic Conductivity (to be used for approximations only)		
General Soil Textural and Structural Characteristics	**Hydraulic Class**	**Hydraulic Conductivity, K (m/day)**
Clay (dense massive structure, bulk density ≥ 1.6 g/cm^3, no macropores)	Very slow	0.004 - 0.04
Clay Loam (cemented or compact layers, massive to blocky structure, few channels, bulk density ≥ 1.4 g/cm^3	Slow	0.04 - 0.12
Loam (weak or poorly structured, few cracks or channels, bulk density 1.4 - 1.6 g/cm^3)	Moderately slow	0.12 - 0.36
Fine Sandy Loam (weak blocky or granular structure, some combination of cracks and channels, low bulk density)	Moderate	0.36 - 1.2
Sandy Loam or Fine Sand (strong blocky or granular structure, cracks and channels present, bulk density < 1.5 g/cm^3)	Moderately rapid	1.2 - 3.6
Coarse Gravelly Sand (loose friable structure with no compacted or cemented layers, bulk density < 1.25 g/cm^3)	Very rapid	> 12.0
Peat and Muck (conductivity varies with the degree of decomposition and presence of macropores or channels)	Moderately slow to rapid	0.12 - 6.0