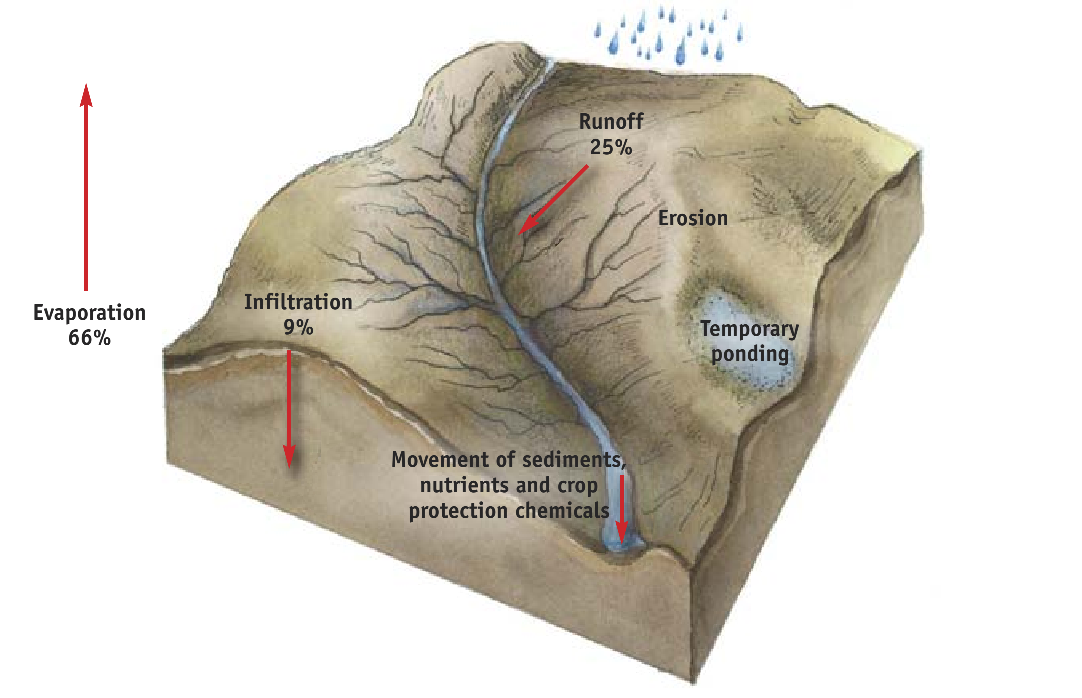
PRINCIPLES OF SOIL WATER AND CROPLAND DRAINAGE

How water passes through your cropland soils is determined by many factors. Key among them are the soils' properties, as well as time of year, topography, depth to water table, and your management. This chapter sets out the key principles of soil water and how it moves over and through cropland. Understanding these principles will help you manage cropland soil and water more effectively.

HOW WATER CYCLES THROUGH CROPLAND

WATER FALLING ON BARE CROPLAND



Best management practices for soil improve water infiltration rates. Keep reading for more information on BMP options.

Most soil water in Ontario comes from precipitation and snowmelt. Some comes from groundwater discharge.

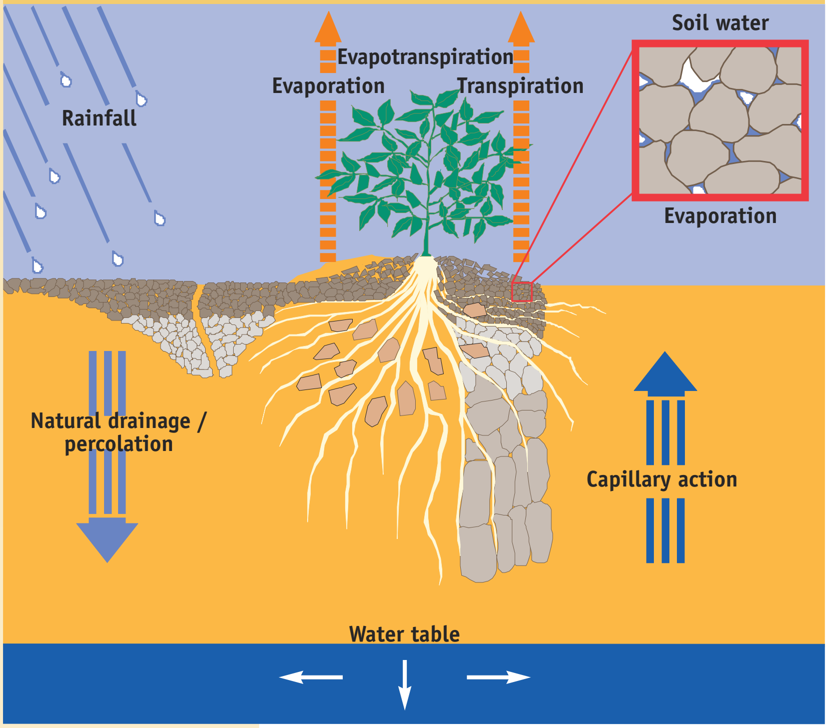
The amount of soil water is constantly fluctuating, closely reflecting the patterns of an annual water cycle. During the early part of the growing season, the soil is usually near saturation. Roughly 66% of water falling on cropland will evaporate, 25% becomes runoff, and 9% will infiltrate the ground surface.

In eastern North America, we have a humid temperate climate where precipitation will exceed evapotranspiration and soil storage capacities – resulting in excess water. When water supply exceeds the storage capacity of cropland soils, then precipitation, snowmelt and floodwaters will:

- keep soils saturated
- pond in depressional areas
- run off from sloping sites in sheets and rills – especially on bare soils or in frozen soil conditions, or
- follow natural drainage pathways, such as converging slopes, to run off as concentrated flow.

On frozen soils, considerably more water runs off than infiltrates. Runoff volumes often exceed infiltration by a 3:1 ratio during spring floods.

FATE OF INFILTRATING WATER



The portion of rainfall that infiltrates the soil will do one of the following:

- percolate through pores and cracks to the depth of saturation
  - the depth of saturation is the water table or the level of the groundwater in the soil
  - the water table is often in motion, moving laterally towards a lake, stream, river, drainage channel, ditch or low area where it will return to the surface as baseflow for streams (maintaining flow between rainfall events) or springs
- continue downward as deep percolation to recharge groundwater aquifers
- be held by soil particles or between the soil particles (in the soil pores)
- move back towards the soil surface by capillary action
  - water held in the soil pore spaces can be taken up by crop roots along with nutrients for plant growth
- reach the soil surface where it evaporates
- transpire to the atmosphere – some of the water taken up by crops returns to the atmosphere.

SOIL WATER AND GROUNDWATER

INFILTRATION

Infiltration is the process by which water enters the soil surface and displaces air. The rate of infiltration is directly related to local topography, surface soil properties, and site conditions. In most cases, soils with poor infiltration will benefit from a combination of soil management BMPs and subsurface drainage. However, in some extreme soil conditions, water does not infiltrate into the soil adequately to get the benefits of the subsurface drainage system – no matter how well-designed it may be.

Infiltration rates are higher in soils with large pores and aggregates, and soils covered with forage, crop residues, or a cover crop. Conversely, bare soils with small pores (fine materials) and poor seedbed conditions have low infiltration rates. Silty and clayey soils have inherently low infiltration rates.

Other soils subjected to compaction or excessive tillage may seal to the point of greatly reducing infiltration rates.

Lower infiltration rates caused by soil degradation are a soil management issue that should be corrected with BMPs such as adding organic matter (cover crops or green manures) – not by adding drainpipes.

HYDRAULIC CONDUCTIVITY

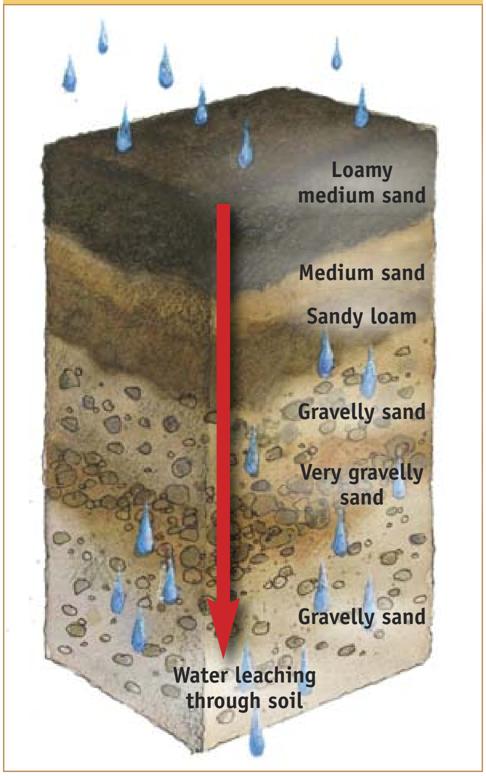
Once water moves into the soil, gravity helps it move from near the surface down through the soil profile.

Hydraulic conductivity is the rate at which water passes through (permeates) the soil. This rate is mostly linked to porosity, texture, structure, depth to restricting layer, and depth to water table. Soils with a lower hydraulic conductivity can benefit from subsurface drainage.

Soils with a high permeability are those with:

- ▶ continuous large pores (macropores)
- ▶ coarse or sandy soil materials (texture), or
- ▶ a high percentage (>33%) of coarse fragments (e.g., gravels, stones, etc.).

WATER MOVEMENT IN SOIL



Soils with a high hydraulic conductivity are sometimes described as permeable soils or having higher permeability.

Less permeable soils are more likely to benefit from subsurface drainage.

Soils with a low permeability are those with a restricting layer due to:

- ► no easy pathways such as cracks or macropores
- ► bedrock
- ► a naturally compacted layer (hardpan)
- ► a finer-textured (clayey) layer within the top metre or,
- ► a high water table – the water can only move with gravity to the depth of the water table.

Water movement in soil can be temporarily influenced by the presence of cracks and large pores such as worm holes. Many of these pathways close up once the soil becomes saturated.

Hydraulic conductivity also varies with moisture content. Water moves more quickly through moist soils than dry soils. In dry soils, the downward movement (by gravity) of the wetting front will be slowed by the counter-effect of suction by the soil materials. See Capillary Zone on page 17.

SOIL WATER

Not all soil water is equal. Some is held so tightly that it is virtually unavailable to plants; other soil water flows freely and isn't held in soil.

The amount of soil water is critical to crop uptake and crop needs, as well as temperature, workability, soil aeration, and crop root exploitation.

Soil water can be classified as *gravitational, capillary* or *hygroscopic.*

Gravitational water – water that moves through soil due to gravitational forces. It is the portion of soil water in excess of hygroscopic and capillary water.

Gravitational or drainage water fills cracks and large pores in the soil. The intent of cropland drainage is to remove this water – early in the growing season or after rain events at a predetermined rate – so that air and not water fills large pores and cracks in the root zone (top 60 cm or 2 ft) of the soil. Water will not drain (move by gravity) until the soil has reached a maximum capacity for capillary water – held by tension, much like a sponge.

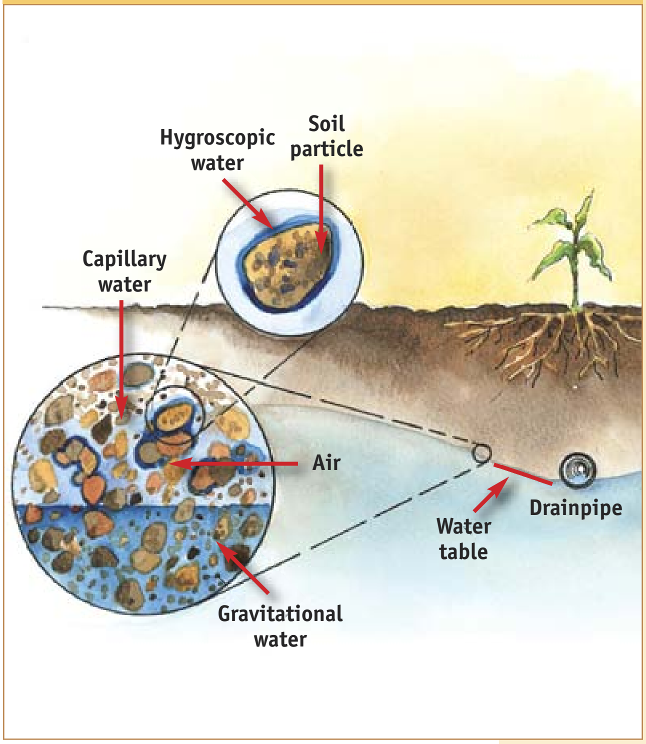
Gravitational water can be static, as is the case in a water table. However, a water table is an oxygen-free environment where crop roots cannot grow.

Capillary water – the part of soil water held cohesively as a continuous layer around particles and in spaces, most of it being available to plant roots.

Crops can only use soil moisture in a certain range of water volume and tension. By definition, only capillary water is available to crops.

Hygroscopic water – water held within 0.0002 mm of the surface of a soil particle. Hygroscopic water is held too tightly to be accessible to plants. This water is essentially non-mobile and can only be removed from the soil through heating.

SOIL WATER



There are three types of soil water: gravitational (excess water), capillary (available to plants), and hygroscopic (held tightly by soil particles).

Most fine- and medium-textured soils cannot be over-drained. However, some sandy soils have poor capillary action and can suffer if subsurface drains are placed too deep below the soil surface.

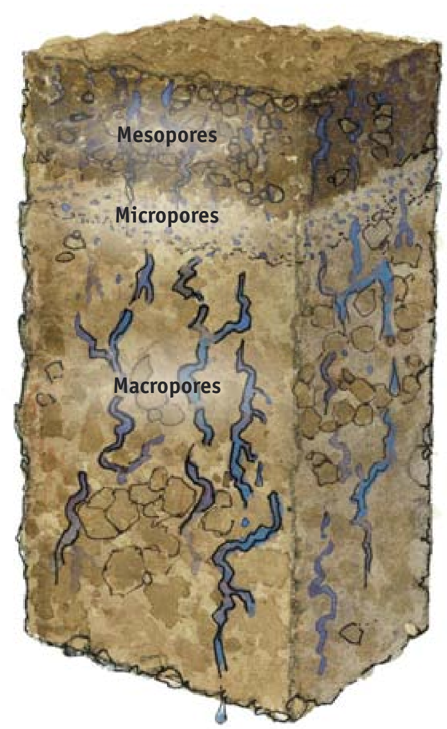
The amount of available soil water closely follows soil texture:

- ► loams, silt loams, and clay loams can hold the most available water
- ► clay soils have high surface areas and many fine pores, and therefore the highest proportion of hygroscopic water – but it is unavailable to plants.

From a drainage perspective, silty and clayey soils, because of their higher porosity and higher proportion of fine pores, contain more gravitational water at saturation but will not release it very quickly. While coarse soils (e.g., sandy) contain more large pores, they drain more quickly but don't contain as much water.

Gravity is the most important force in saturated soils.

MACROPORES



Pores can occupy up to 50% of soil volume between soil particles. Soil pores come in all shapes and sizes.

Micropores are the smallest and are usually filled with capillary water. Mesopores hold capillary and gravitational water. Macropores are most often cracks or worm channels.

Continuous macropores can transmit gravitational water through the soil to the water table or drainpipe.

WATER TABLE

The upper surface of groundwater is called the *water table.* Soils with a high water table will most often benefit from subsurface drainage.

The water table's depth fluctuates over the year according to levels of precipitation, evapotranspiration, and deep percolation. In late fall, precipitation generally exceeds evapotranspiration rates, causing the water table to rise. The water table stays high and peaks in early spring following snowmelt and accumulated rainfall.

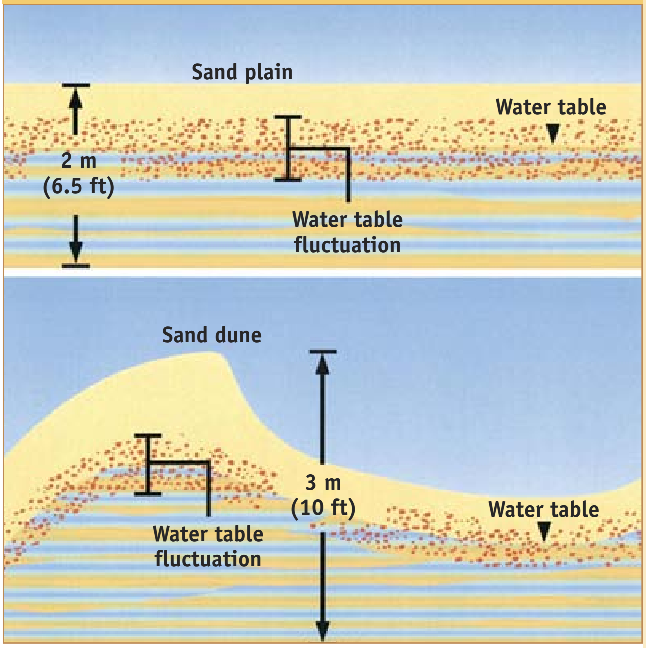
The water table drops throughout the growing season as crops mature, and precipitation falls off (normally) in July and August. Evapotranspiration rates are the highest during the summer months. In most cases, the water table is at its lowest (deepest) levels in early September.

One way to estimate the depth to water table is to excavate a posthole. After one day, measure the depth from the soil surface to the top of standing water in the posthole.

Water tables fluctuate up and down, and groundwater also moves laterally from areas of higher elevation to areas of lower elevation – the technical term is *hydraulic gradient.* This moving water can:

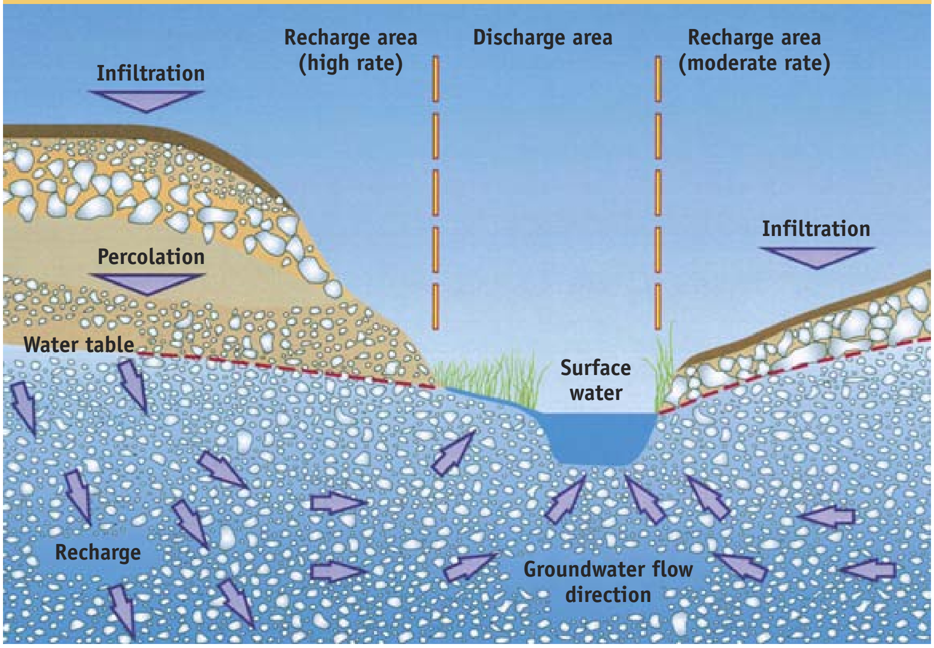
- ► increase moisture levels in lower areas (raise the water table)
- ► emerge along the slopes as side-hill seepage or springs, or
- ► replenish surface waters, rivers, streams, ditches, ponds and wetlands (baseflow).

SOIL AND WATER TABLE PROFILE



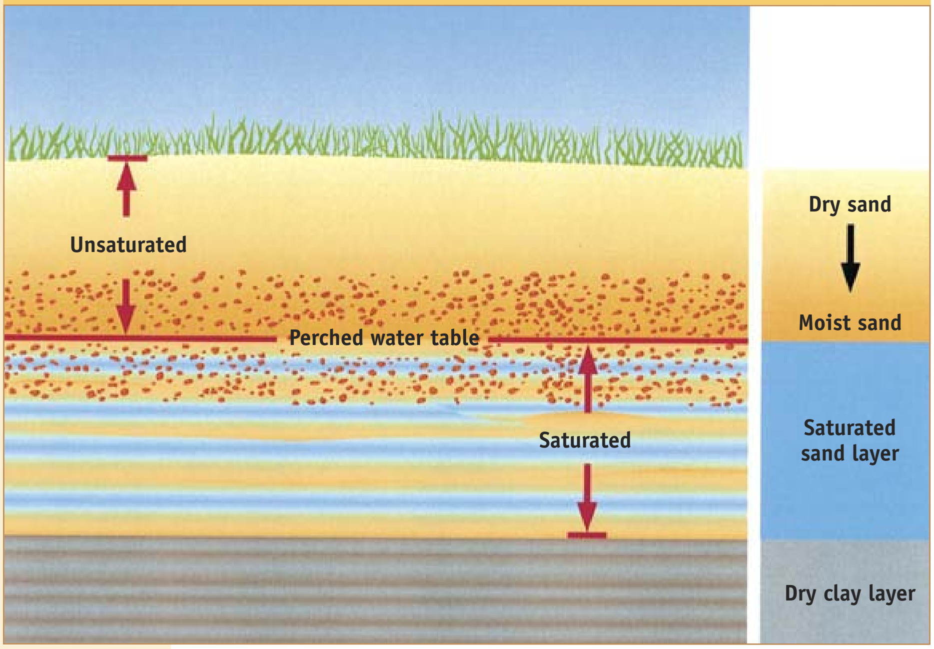
By observing soil colours, you can get a good idea of the seasonal fluctuations of soil water tables. Dull, grey (gley) colours indicate zones or depths of permanent saturation, whereas layers in the soil with rust spots (mottles) indicate a fluctuating water table. Soil water tables normally mimic local topography, but tend to be deeper on hills and knolls and closer to the surface in depressional areas.

GROUNDWATER RECHARGE



The excess portion of infiltrating water that isn't taken up by plants or absorbed by soil particles will move downward (percolate) through the unsaturated zone. When percolating water reaches the water table, it becomes groundwater recharge. Recharge replenishes water in aquifers, or is discharged in springs, streams, lakes or wetlands.

PERCHED WATER TABLE



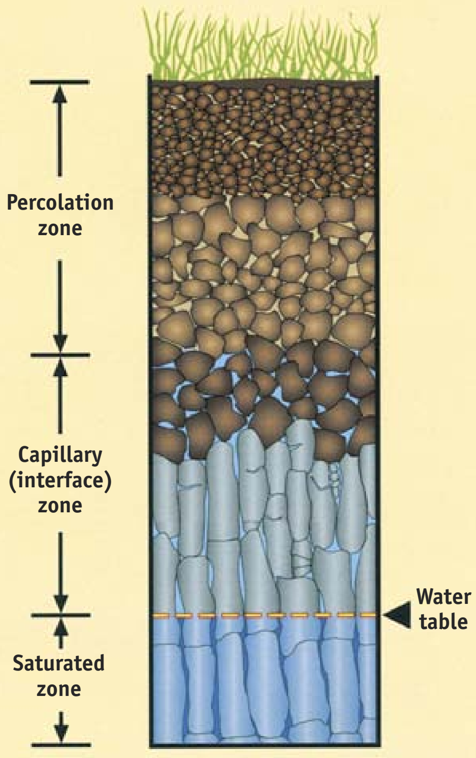
Not all water tables are equal. In some cases, the depth to the water table is not the upper limit of groundwater. Soils that have a naturally compacted layer (hardpan) or strongly contrasting textures (e.g., sand over clay) can have a perched or temporary water table condition. A perched water table – or zone of saturation – will develop in the upper soil material just above the compacted or clay layer. The soil material below the compacted or clay layer is not saturated.

It's essential to know whether you have a perched or normal water table when designing a subsurface drainage system.

CAPILLARY ZONE

Soil above the water table is unsaturated, as all gravitational water has been moved out. But it's not dry. There is a zone above the water table that contains moist soil, known as the *capillary zone.* As crops use the available water, more water is drawn up from the water table. Subsurface drainage will not remove capillary water from cropland soils.

CAPILLARY RISE



The thickness of the capillary zone will vary with overall soil texture and porosity, structural and textural changes in soil horizons, and rainfall.

SOIL PROPERTIES AND SUBSURFACE DRAINAGE

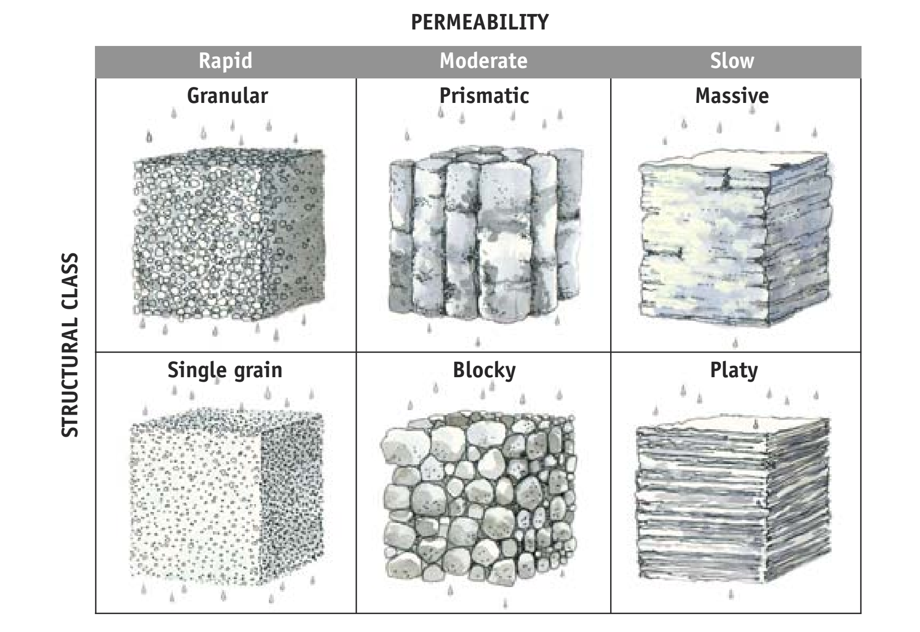
Soils have physical, chemical and biological properties. Historically, much attention has been paid to soil chemical properties when managing soil because they are central to soil fertility.

In recent years, attention has broadened to include soil biological properties such as organic matter content, and its fate as affected by soil flora and fauna.

Although very important to managing soils, soil chemical and biological properties are less important than physical properties (e.g., soil material, depth, depth to water table, etc.) in understanding soil water and drainage.

Soil texture is the relative coarseness or fineness of a soil based on the relative proportion of soil particle sizes. Sandy (coarse) soils have large pores, drain quickly, and don't retain much water. Clay (fine) soils have small pores, drain slowly, and retain lots of water in small pores.

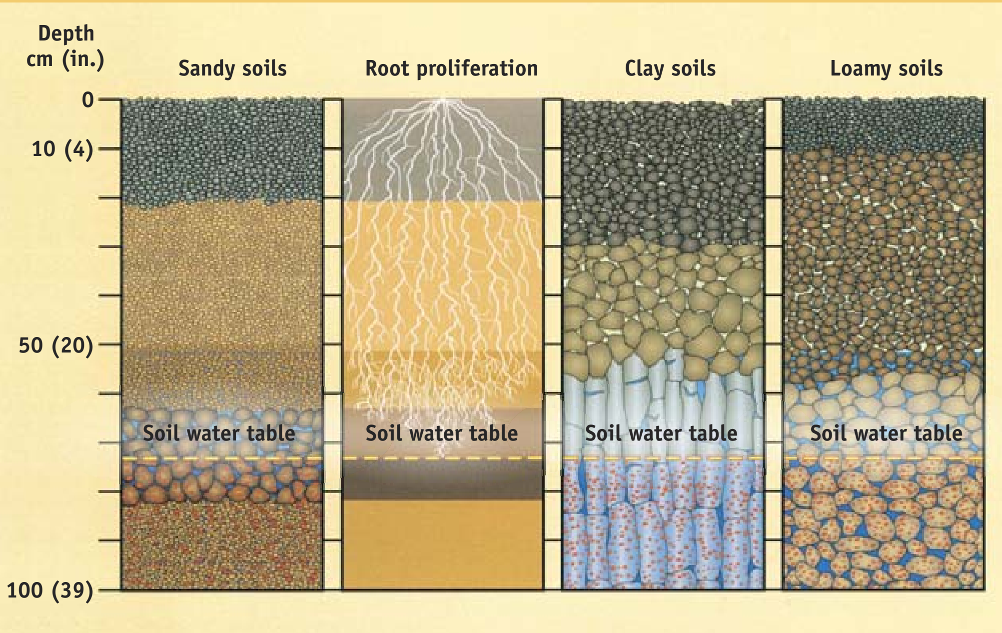
SOIL STRUCTURE AND DRAINAGE



<u>Soil structure</u> describes how soil particles are arranged and organized in the soil. Soil structure and its porosity greatly influence drainage, aeration and water retention. A well-formed and stable soil structure drains more quickly than a poorly formed structure (e.g., massive clays).

Granular structure is often associated with topsoil in loamy and clayey soils – especially those rotated with forage crops. Soils with a granular structure drain freely. Blocky and prismatic structures are normally found in clayey subsoils and parent materials, giving them large continuous macropores. These structures enhance the drainage from these soils. Platy structures are found in compacted soils with high silt and very fine sand contents. Platy structures can slow drainage substantially.

SOIL POROSITY AND DRAINAGE

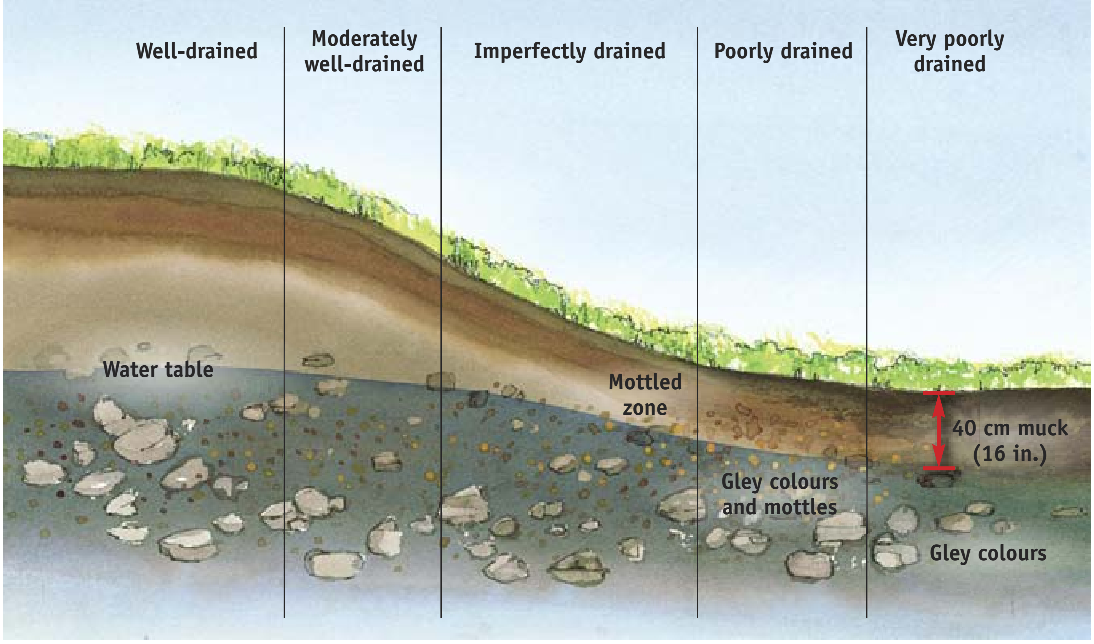


<u>Soil porosity</u> is the fraction of the soil volume filled with air. Soils with a high proportion of large pores, such as sands or well-structured clays, will drain more quickly. Subsurface drainage only removes gravitational water, which increases aeration. Porosity allows roots to breathe, thus improving crop growth. In this illustration, plant roots thrive in the moist pores above the soil water table.

Soil colour refers to the richness, intensity and brightness of soil colour. Dull, grey colours indicate depth to seasonal water table. The depth to a zone of rust spots (mottles) indicates the levels of a fluctuating water table.

For more information on soil biological and physical properties and soil management, see BMP *Soil Management*. For more information on soil chemical properties, refer to BMP *Managing Crop Nutrients*.

SLOPE POSITION AND SOIL DRAINAGE CLASS

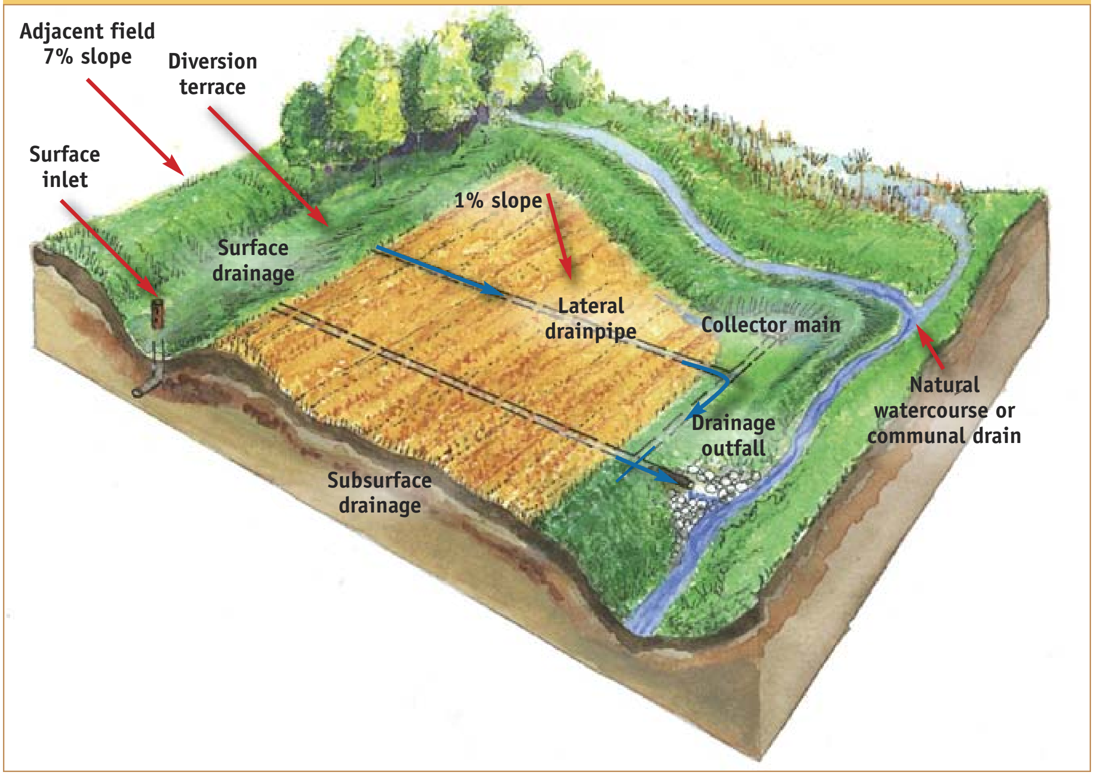


Texture is less important where water table activity close to the soil surface is evident. Soils that are permanently saturated with a very high water table are classed as *very poorly drained* – dull grey (gley) in colour and without spots or mottles. (In Ontario, mottles are often orange in colour due to iron.) Moving upslope, soils that have gley colours in the upper 50 cm (20 in.) of the soil profile and are often mottled throughout are classed as *poorly drained*. *Imperfectly drained soils* may have gley colours in the lower part of the profile and are often mottled throughout. *Moderately well-drained soils* have some mottling in the lower part of the profile or are fine-textured.

AGRICULTURAL DRAINAGE SYSTEM COMPONENTS

Agricultural drainage is a system with several components: surface drainage and erosion control, subsurface drainage, drainage outlets, and drainage channels. Subsurface drainage is usually made up of a network of smaller drainpipes (laterals) – typically 100 mm (4 in.) diameter. These are connected to a larger-diameter main collector pipe.

CROPLAND DRAINAGE SYSTEM



If surface and subsurface drainage components have been installed on cropland, only a portion of the water that infiltrates the soil surface is collected by the subsurface system.

The collected water is moved to the collector main by gravity, where the flow rate is metered by the diameter and slope of the collector main until it reaches the outfall (outlet point). That will almost always occur when the soil above the subsurface drainpipe is saturated (i.e., the water table is above the drainpipe). At all other times, no water is removed.

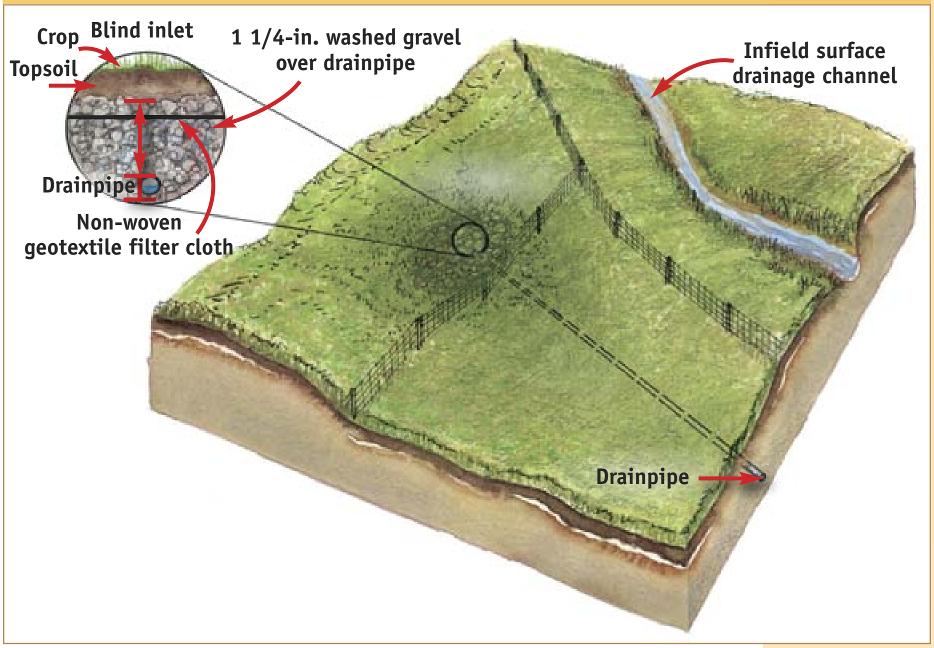
At the outfall, the water is introduced into open channels such as natural watercourses or drainage channel systems.

SURFACE WATER MANAGEMENT

Surface drainage helps move water from the surface of croplands, using various methods such as shallow open ditches, land grading, and surface inlets. If water is added to the soil surface faster than it can infiltrate into the soil, surface water will move and follow the slope of the land to a receiving point – which could be a drainage channel, creek, stream, pond, low spot, depressional area of a field, or constructed ponding area.

Water that is ponded in depressional areas will remain there until it evaporates, infiltrates the soil (eventually), or moves toward a surface water body due to a surface drainage BMP.

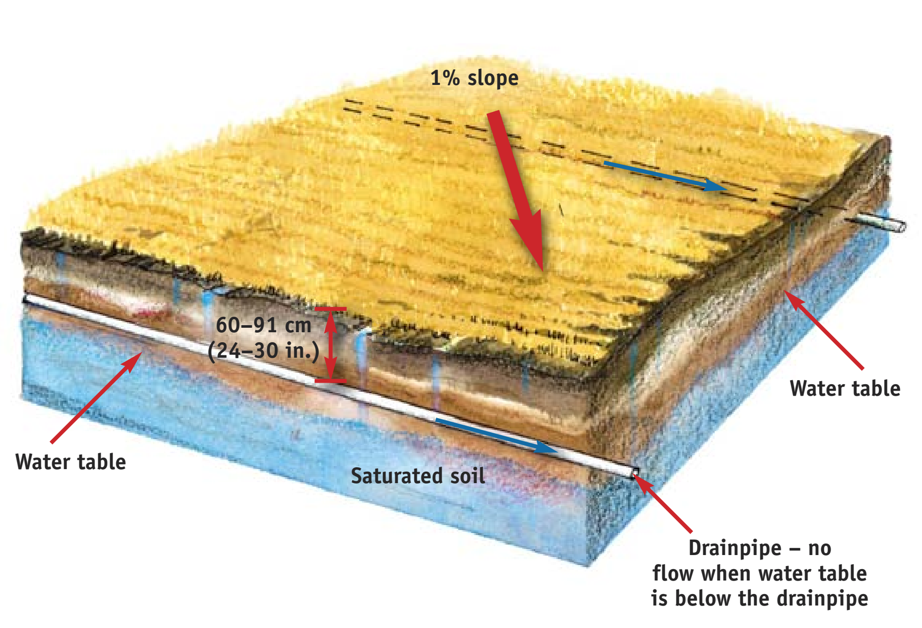
SURFACE DRAINAGE COMPONENT



Surface drainage often includes erosion control structures such as grassed waterways, water and sediment control basins (WASCoBs), terraces, and rock chutes. Erosion control structures take concentrated surface flow (runoff) and safely convey it to a proper outlet. Without such structures, surface water runoff can and does cause significant soil erosion.

SUBSURFACE DRAINAGE

SUBSURFACE COMPONENT

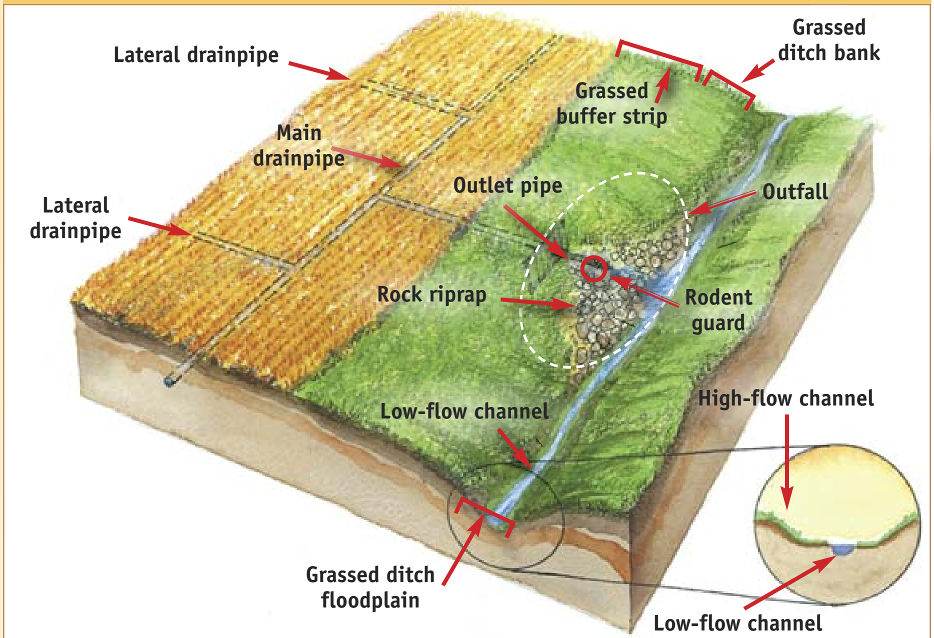


Subsurface drainage removes excess soil moisture (gravitational moisture) from the soil profile using plastic tubing, clay tile and concrete tile. Only excess water in the soil profile above the drainpipe (usually installed at 60–91 cm or 24–36 in. depth) is removed.

With a subsurface drainage system in place, the excess (gravitational) water seeps into the drainpipe, either through small holes in the plastic tubing or through the small space between the ends of adjacent clay or concrete tile. Subsurface drainpipes convey this excess water from above the drainpipe, plus water collected from surface inlets, to a larger-diameter collector drainpipe or main. The drainpipe will continue to remove the gravitational water until the water table is lowered to the bottom of the drainpipe.

DRAINAGE OUTLET

DRAINAGE OUTLET



The larger-diameter collector drainpipe or main will control the flow rate of drained water before it moves to an outlet (outfall). The collector is installed deeper than the lateral drainpipe, and is there mainly to collect and convey water from the lateral drainpipe. It does not contribute much to drainage.

The outfall is the interface between the private subsurface drainage system and the receiving drainage channel system.

COMMUNAL DRAINAGE

Drainage water will pass from the subsurface drainpipe though the outlet pipe at the outfall location into a natural water body (e.g., stream, creek, river, lake) or a communal drainage (drainage channel) system.

A communal drainage system is one that has been constructed through a public body such as a municipality or road authority, or through the cooperation of a group of landowners. Communal drainage components are in the form of open channels or buried larger-diameter drainpipes. These drains are often called *municipal, mutual agreement, award*, or *private* drains.

COMMUNAL DRAINAGE COMPONENT