How Water Moves Through Soil

A Guide to the Video

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Program opens with a Dedication to Dr. Walter Gardner

I. Introduction

NARRATOR: How water moves through soil is a basic concept of soil and water science. Plants must have an adequate supply of water and nutrients to thrive. In fact, water makes up over eighty five percent of the weight of growing plants.

Water carries nutrients and gases to plants through the soil. Percolating water can also carry contaminants from a number of sources into underlying groundwater. Sources include poorly constructed landfills, chemicals spills, leaking underground storage tanks, agricultural fields, golf courses, or septic leach fields.

In this video, Dr. Jack Watson, a water specialist at the University of Arizona, College of Agriculture, will help us explore some of the key principles of soil and water interaction.

Watson on camera

II. Soil Types and Texture

A. Examples of Various Soil Types

Watson on camera

Video of U.S. Soils Map

NARRATOR: There are thousands of different kinds of soils in the United States. Soil scientists define and describe soil properties, and use that information to classify U.S. soils.

Examples of major soil types are: Wind Deposited Coarse Sands (highlight NE sand hills and south Texas coastal area) . . . Loams (highlight Midwest cornbelt area) . . . Glacial Deposited Materials (highlight northern Montana to Maine glaciated area) . . . Upland Marine Sediments (highlight North Carolina to Louisiana terrace) . . . Recent River Alluvium (highlight lower Mississippi River delta) . . . and soils associated with ancient sediment eroded from mountains. Concepts of water retention and movement presented in this video apply to all soils.

B. Examples of Three Basic Soil Textures

Video of relative particle size chart of three soil textures

NARRATOR: There are thousands of combinations of soil characteristics in the world. Mineral soil particles are a combination of sand, silt and clay sized soil particles as well as organic matter. Sand particles are the largest, while clay particles are very small and highly reactive. Silt particles are intermediate in size and reactivity.

III. Pore Size Differences in Soil

A. Discussion of Differences in Height of Rise of Water in Soils with Different Pore Sizes

Watson on camera

Video of colored water between glass plates

NARRATOR: Soil pore size is a significant factor in how water moves through soil. Here, the space between the glass plates represents spaces between different size soil particles. The glass plates are further apart on the left side, and closer together on the right side. The closer the plates are together, the higher the water rises. This rise is **not** due to pressure squeezing the water upward, but solely because capillary forces cause the water to rise higher when the distance between the plates is narrower.

The same phenomenon occurs in soils. At the bottom of the soil columns near the water source, water rises more rapidly in the sandy soil because the capillary conductivity of the larger pores is greater. The clay soil has small pores and attracts water more strongly than the sandy soil with large pores, but transmits it more slowly.

When the soils are wet, water moves through the larger pores between the sand particles faster than it moves through the smaller pores between the clay particles. However, water eventually rises higher in the clay soil because the pores are smaller and closer together. The rise is due to the forces of adhesion and cohesion. This is called capillary rise. Both the rate of water movement and the amount of water retention are related to pore sizes in a soil.

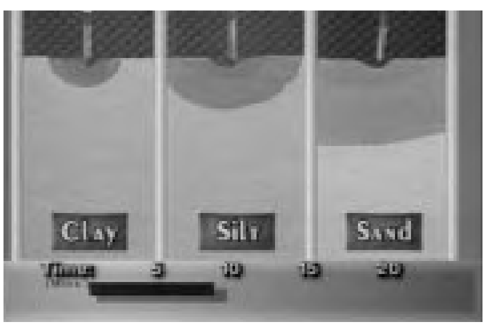
B. Discussion of 12 Soil Textures Using Soil Triangle

Watson on camera

Video of soils triangle, highlighting sand, silt and clay

NARRATOR: In this video, soil layers are assumed to be homogeneous and uniformly mixed, which is rarely the case in nature.

C. How Texture Affects Water Movement Through Soils



NARRATOR: Just as soil types vary in texture and structure, they also vary in their ability to conduct and hold water. Using the model of the three general soil types, we see that soil water moving by gravity flows through open pores between soil particles.

The size of the pores varies with the soil texture and structure. In general, water moves through large pores — such as in sandy soils — more quickly than through smaller pores, such as in silty soils, or through the much smaller flat-shaped pores found in clay soils. In clay soils very little gravitational or free water moves through pore spaces due to the small size and shape of the pores.

Video of three texture model showing different rates of water flow

NARRATOR: This model represents water movement under ponded conditions into a land surface depression, such as an irrigation furrow or an open drain. When the water is first applied to dry soil, it moves outward almost as far as it moves downward.

However, as the soil becomes saturated, gravity becomes the dominant force moving water downward.

Water is nearly always moving in soils, either as a liquid or a vapor . . . and water can move in any direction. It moves downward after rain or irrigation . . . upward to evaporate from the soil surface . . .

Video of cypress swamp from Mississippi

. . . or up through plant roots and leaves and eventually into the atmosphere through transpiration.

Video of road cut with cut-away of soil and rock layers.

NARRATOR: Water can also move horizontally through soil, such as when it encounters a restrictive layer of compacted soil or bedrock that impedes its downward movement.

There are frequent attempts to prevent water movement through soils, such as when liners are used below sanitary landfills to prevent the movement of leachate water into underlying groundwater.

IV. Capillary and Gravitational Action

NARRATOR: Two forces primarily affect water movement through soils, gravity and capillary action. Capillary action refers to the attraction of water into soil pores — an attraction which makes water move in soil. Capillary action involves two types of attraction — adhesion and cohesion.

Adhesion is the attraction of water to solid surfaces. Cohesion is the attraction of water to itself. Some surfaces appear to repel, rather than attract water. This occurs when the cohesive force of the water is much stronger than the attractive force of the solid. For this reason, water drops form on leaves with a waxy surface.

Video of aftermath of forest fire

NARRATOR: A similar phenomenon is frequently observed after a forest fire, when plant resin films coat the surface soil particles and rainfall runs off rather than infiltrating the soil.

Video of waterfall

NARRATOR: The other force governing water movement through soils is gravity. Gravity pulls water downward.

Video of tube filled with silica sand, pouring colored water into tube

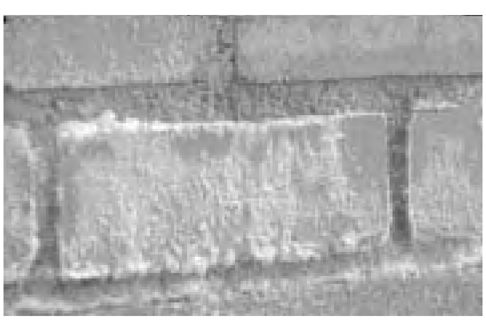
NARRATOR: Capillary forces can move water in any direction. The force of gravity is most evident in saturated soils.

Once water enters the soil, the principles of water movement by capillary action and gravity hold true no matter what the source of the water.

Water can also move upward through soil or other materials by capillary action, as Dr. Watson explains . . .

Watson on camera

Video of water line on brick building



NARRATOR: Capillary action can move water through porous materials other than soil. When the soil around a structure made of brick, limestone or sandstone is wetted, water moves up through the stone material. When the water evaporates, it often leaves salt or other chemicals behind showing how high the water rose.

Video of drip irrigation system in turf grass area

NARRATOR: The same principles of water movement apply to landscaped areas where water is delivered through an underground irrigation system. When the soil below the turf grass becomes saturated, capillary action draws water upward to the roots . . . nurturing the lawn.

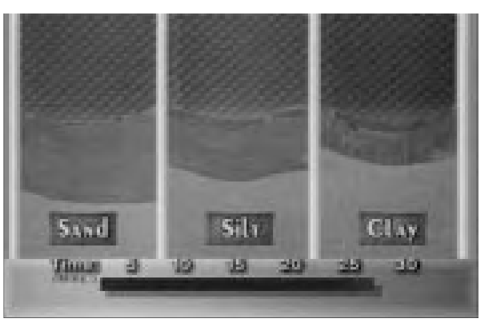
V. Soil Water Holding Capacity

Watson on Camera

Video of handfuls of two different soils: loamy sand without organic matter and sandy loam with organic matter

NARRATOR: Any factor that affects soil pore size and shape will influence capillary water retention and movement. Examples of such factors, other than texture, are: organic matter, soil structure, and soil density.

Elevation above a free water table also affects the water retained by a soil at a given elevation. Together, these factors affect the water holding capacity of a soil as well as the rate of water movement. The portion of soil water available to plants is often referred to as available soil water.



Video of three soil textures: water holding capacity

NARRATOR: In this demonstration, equal amounts of water are applied to three soils with different textures.

Sandy soils have less pore volume than silt or clay soils. Note that the water penetrates more rapidly and more deeply in the sandy soil than in either the silt or clay soils. This is because sandy soils have larger pores that absorb water faster, and hold less water per unit of depth. Consequently, sandy soils require more frequent but lighter water application to maintain adequate water for plant growth and minimize losses below the root zone.

Video of flooded cotton field

NARRATOR: Soils with more clay hold more water within the normal plant root zone, thus, plants grown in soils with more clay can do well with less frequent and heavier applications of water.

This is not to say that over-irrigation is not possible in clay soils. A frequent consequence of over-irrigation in such soils is oxygen depletion in the root zone, which limits plant root development. Whether soils are sand or clay in texture, it is important to time irrigations to replace the soil water extracted by the plant roots.

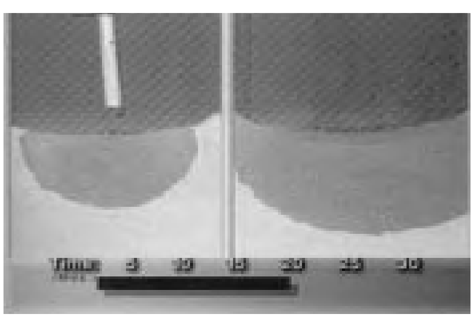
VI. Saturated Versus Unsaturated Soil Conditions

Watson on camera

Video of water flow — ponded water versus precipitation model

NARRATOR: In unsaturated soil, the primary forces causing water to move laterally are capillary. Once the soil becomes saturated, gravity is the primary force causing downward water movement.

Video of single versus multi-drip demonstration



NARRATOR: Capillary action is the primary force affecting water movement in unsaturated soils.

On the left is a single drip source, similar to a drip irrigation system in a garden. On the right is a multi-drip source representing rainfall or sprinkle irrigation.

Initially, the pores in both soil profiles are unsaturated. Water flows primarily through the smaller pores, due to capillary forces. On the left, lateral and vertical movement occurs at nearly the same rate. Also, downward movement of the wetting front is approximately the same for the single drip source as for the multi-drip source.

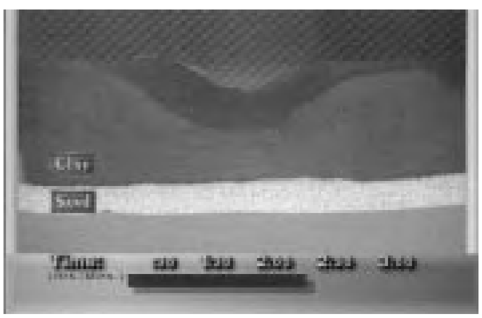
Eventually, the wetted soil pore spaces on the right are filled to near saturation . . . because the water is being applied at a faster rate than it can be moved by capillary action. Since the larger pores in the soil on the right are now filled with water, they conduct water more rapidly than the unsaturated soil pores on the left. Since capillary forces are not as great in the larger pores as in the smaller pores, gravity becomes more important in moving the ponded water downward through the soil.

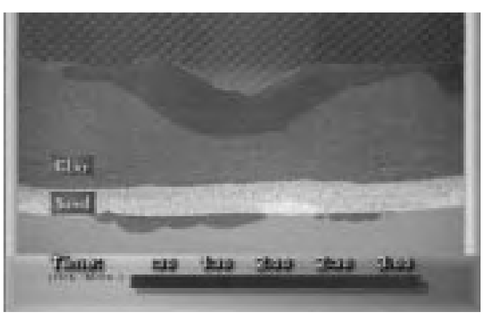
VII. Stratified Soils: Different Textures as Layers

Video showing different soil layers with shots of a road cut

NARRATOR: Soil is sometimes formed in layers of different textures near the surface. Each layer may have a different pore size, which affects the way water moves through the soil.

Video of clay over sand demonstration



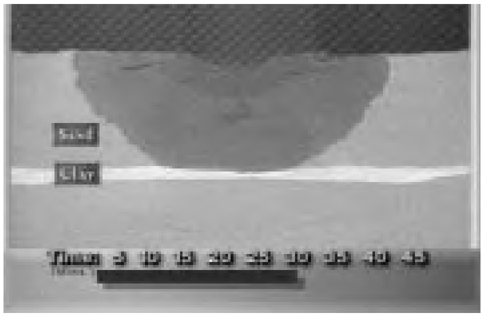


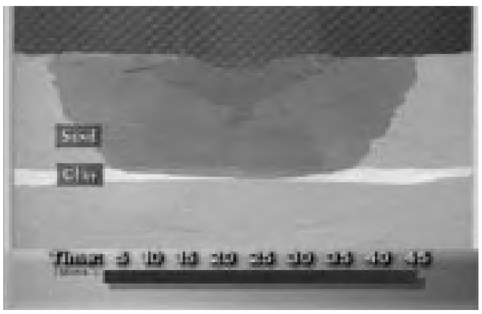
NARRATOR: Abrupt changes in pore size affect water moving by capillary action. This soil profile shows soil with small pores overlying a layer of soil with large pores. Capillary force, also known as soil tension, refers to the soil's ability to attract and hold water. Capillary force is greater in the soil layer with small pores.

Many soils, especially those formed in alluvium or marine sediments, are layered . . . resulting in abrupt changes in pore size. Water is held back at each of these contacts, and will not move downward until the clay layer above the sand is saturated. Therefore, some soil horizons will hold more water than the available water capacity would otherwise indicate. When enough water has been added, gravitational forces will exceed capillary forces — and water moves downward into the coarse sand below.

Once water enters the coarse material, it moves rapidly and soon penetrates the bottom layer below the sand.

Video of sand over clay model





NARRATOR: When soil with large pores overlies soil with small pores, water moves by gravity relatively quickly and uniformly through the upper soil layer.

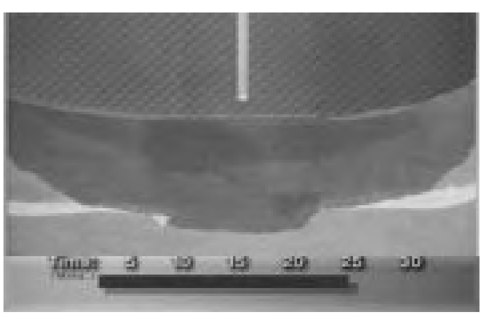
Below the boundary, capillary forces in the underlying clay soil layer immediately draw water downward. Typically, water moves more slowly through the lower layer, so water accumulates at the boundary. This underlying clay layer has a relatively high water holding capacity, and a high soil tension. Therefore, this clay layer can absorb and hold a large quantity of water.

Under field conditions, little or no water percolates to soil horizons below the clay layer until the clay layer becomes saturated.

Video showing wetlands

NARRATOR: This condition is desirable for growing rice or for maintaining wetlands. It is not desirable for growing most other plants. An underlying clay layer can be desirable in a number of other circumstances . . . such as below a sanitary landfill.

Video of model showing partial clay layers

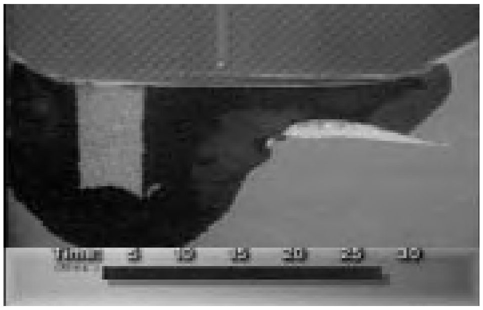


NARRATOR: Partial subsoil layers can redirect water flow so that some areas receive little water, while others receive a great deal. All of these factors can impact plant growth, and cause water quality concerns. The downward flow pattern of water depends on the location and orientation of these layers.

VIII. Soil Layer Open/Not Open to Free Water

Watson on camera

Video of root channel model



NARRATOR: On the left, the soil void is held open by the sand to the soil surface. Such voids can be created by decayed vegetational root channels, worm holes, cracks and seams.

As water initially rushes in to fill the void, the rate of water movement depends solely on gravity. Once the void is filled, pressure created by ponded water speeds water movement to small pores. For example, residue management creates numerous voids open to the soil surface — resulting in improved water infiltration.

The void on the right is not open to free water, so water moves primarily by capillary action around the void.

Video of root channel filled with sand

NARRATOR: When a root channel open to free water becomes partially blocked by soil particles, water will not flow freely into the channel. Soil particles may be moved by tillage, water, wind or other soil stirring action.

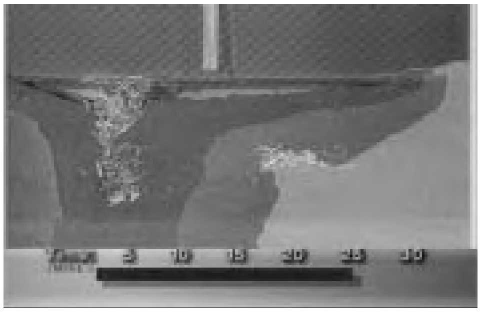
Water movement is due primarily to capillary forces until the soil becomes saturated.

Video of organic matter open to free water. Begin with water flowing into model

NARRATOR: On the left side of this model, organic matter is exposed to the soil surface. On the right, organic matter has been buried by tillage.

When organic matter is mixed with the surface soil and exposed to free water, water moves easily into the soil.

Video of minimum tillage operation



NARRATOR: Minimum tillage maintains organic matter near the soil surface. When organic matter is used to keep soil pores open to the surface, downward water movement can be greatly enhanced.

For example, the right side of this model shows organic matter buried under the surface of the soil. Under these conditions, the organic matter restricts the downward flow of water.

IX. Multidirectional Flow

A. Soluble Chemical/Pesticide Movement In Soils

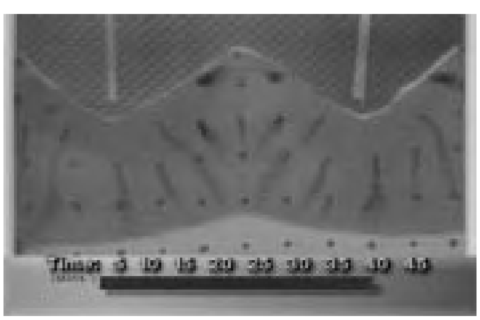
Video showing lawn fertilizer application

NARRATOR: Water and chemicals can move in several directions at the same time in soil. When applying water-soluble fertilizer, pesticides or other chemicals to soil, it is important to recognize that these chemicals will move according to capillary and gravitational forces in the soil.

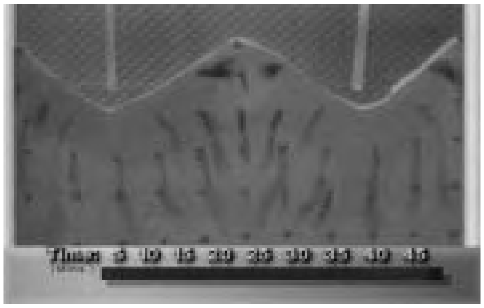
Pollutants such as spilled chemicals, motor fuel, bearing lubricants and cleaning solvents also move with water.

Video of model showing dye dot demonstration

NARRATOR: The dye dots in this demonstration represent soluble chemicals such as nitrate nitrogen added to the soil. As the wetting front contacts the dye dots, the chemical dissolves and moves radially with the water as dictated by capillary action.

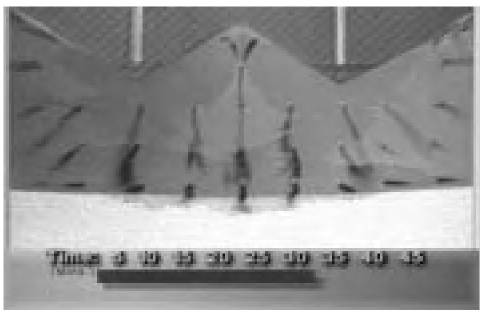


Capillary forces even pull water above the source. Note the middle dye dot at the same level as the water in the furrow. As the two wetting fronts connect in the center of the model, there is a change in the pattern of water movement. Water moves up into the dry soil above, and down into dry soil below. When the wetting fronts first connect, the dye spot in the middle shows little movement because water above the dye spot flows up, and below the spot it flows down.



Later, when the soil becomes saturated, gravity dominates areas where the dye first moved radially by capillary action . . . causing the dye to move downward.

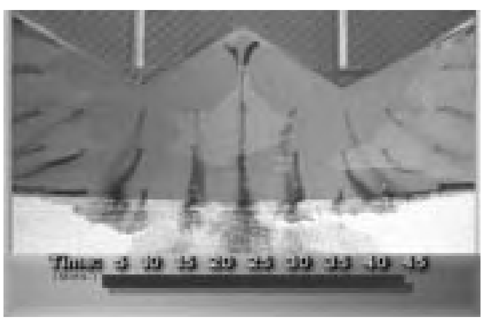
Video showing the effects of buried sand layers



In this demonstration, water movement slows down when the wetting fronts reach a buried sand or gravel layer, as shown at the bottom of this model. The water also changes direction where the soils meet, moving laterally along the top of the layer instead of downward.

Notice that the dye spots disperse as they move through the soil. Water soluble chemicals applied to soil disperse in the same manner.

Video showing dye patterns near completion of experiment



NARRATOR: In practical application, soluble chemicals moving with the water would trace out patterns similar to the dye shown in the demonstration. For example, fertilizer must be placed considering the wetting pattern because soluble fertilizers moving upward with water will tend to accumulate in the surface.

Evaporation may concentrate chemicals on the soil surface, affecting water infiltration and perhaps harming plants. Also, excess water movement through and below the plant root zone may move chemicals into groundwater aquifers.

Video of blue dye in pit at Maricopa Agricultural Center, The University of Arizona

NARRATOR: Here, scientists are studying the movement of water and soluble chemicals through soil.To visualize the process, blue dye was added to irrigation water flooded across the field. Later, the soil was excavated to a depth below the root zone. Patterns created by the dye tracer were then observed.

The crack on the left had a short but effective seal at the soil surface. Consequently, the free water with the blue dye did not move through a preferential flow path as it did in the crack on the right. In this instance, the dyed water moved into the soil through a large channel open to the soil surface. The dyed area of the soil shows how the water moved freely through the channel.

X. Summary of Program

Summary Point #1

Video with columns of sand and clay

NARRATOR: Pore size is one of the most fundamental soil properties affecting water movement through soils. The rate at which water moves through soil is primarily a function of soil texture and soil structure. Larger soil pores, such as in sand, conduct water more rapidly than smaller pores, such as in clay.

Summary Point #2

Video of sand and clay columns at the end of the demonstration

NARRATOR: The two forces that make water move through soil are gravitational forces and capillary forces. Capillary forces are greater in small pores than in large pores.

Summary Point #3

Video of dye dot demonstration

NARRATOR: Capillary and gravitational forces act simultaneously in soils. Capillary action involves two types of attraction — adhesion and cohesion.

Adhesion is the attraction of water to solid surfaces. Cohesion is the attraction of water molecules to each other.

Gravity pulls water downward when the water is not held by capillary action. This force is evident in saturated soils.

Summary Point #4

Video of models of sand, silt and clay

NARRATOR: Sandy soils contain larger pores than clay soils . . . but do not contain as much total pore space as clay soils. Sandy soils do not retain as much water per unit volume of soil as clay soils.

Summary Point #5

Video of straw in open channel

NARRATOR: Factors that affect water movement through soil include soil texture, structure, organic matter and bulk density. Any condition that affects soil pore size and shape will influence water movement. Examples include tillage . . . compaction . . . residue . . . decayed root channels . . . and worm holes.

Summary Point #6

Video of clay over sand model

NARRATOR: The rate and direction of water moving through soils is also affected by soil layers of different material. Abrupt changes in pore size from one soil layer to the next affect water movement. Capillary forces are greater in soil layers with small pores, such as clay, than in soil with large pores, such as sand. Therefore, when clay soil overlies sand, downward water movement will temporarily stop at the sand/clay interface until the soil above the interface is nearly saturated.

The rate of water movement is slower in clay soil than in sand. So when a coarse textured soil such as sand overlies clay, the downward rate of water movement slows once the wetting front contacts the clay soil. This can result in a long term build up of a perched water table above the sand-clay interface . . . if water continues to infiltrate the soil surface.

Watson on camera

The End