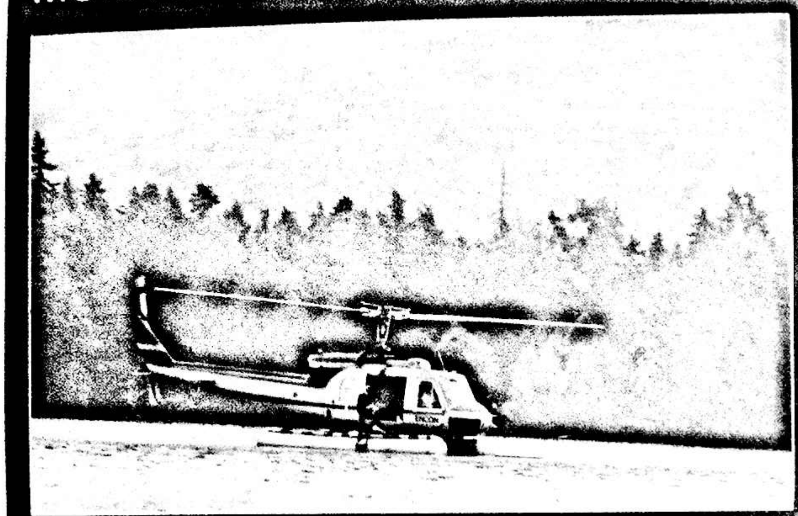
TOPIC VIII
MOISTURE AND ENERGY BUDGETS



Scientists are studying the damaging effects of acid rain on this Adirondack lake.

CHAPTER 12
Water in the Earth

You will know something about the water in the earth if you can:

1. Describe the water cycle.
2. Identify the factors affecting water once it reaches the earth's surface as precipitation.
3. Describe the zones of subsurface water.
4. Discuss the problems of the earth's water supply, including pollution.

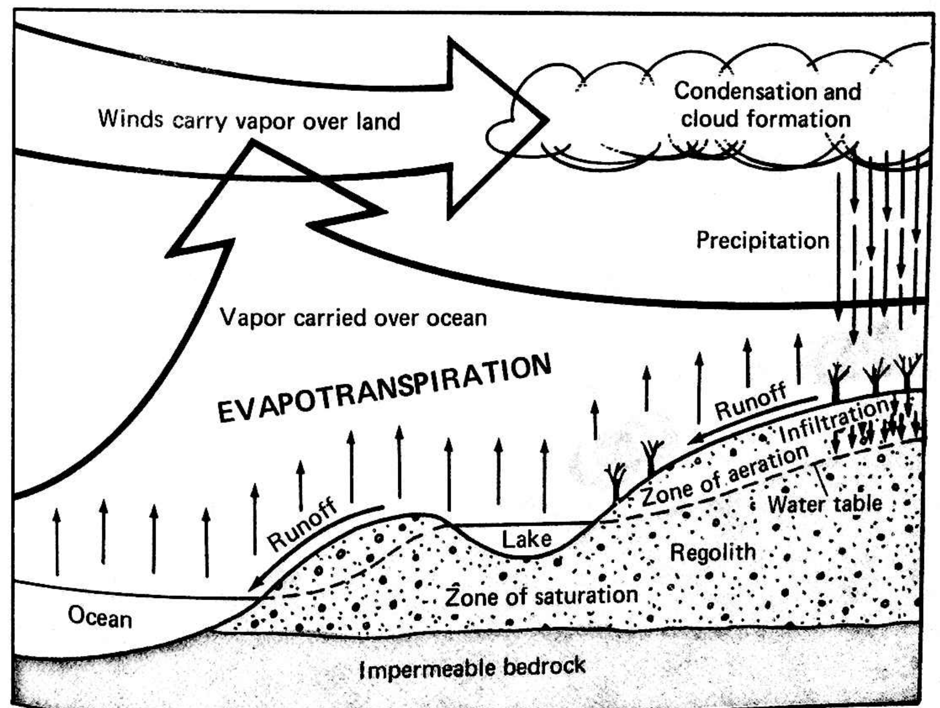
The part of the earth that is water is called the hydrosphere. When you think of the hydrosphere, you probably imagine the vast oceans first. Then you may recall the lakes, rivers, and streams of the land and the frozen water in glaciers and in the polar ice masses. Perhaps you may even include a rainstorm. Is anything missing from this picture? Yes. A very important part of the hydrosphere is a part we almost never see—the part that is in the rocks and soil of the lithosphere. How does water get into the ground? How does it move underground? How does it leave? This chapter deals with these questions.

FROM HYDROSPHERE TO LITHOSPHERE

The Water Cycle. In Chapter 11 we examined the processes of evaporation and transpiration, which tend to "fill" the atmosphere with water. We also studied the processes of condensation and precipitation, which tend to "empty" the water out of the atmosphere. Since the oceans and other major bodies of water do not seem to be drying up, or steadily rising and flooding the land, there must be a balance between these processes. Water lost from the hydrosphere by evapotranspiration must be returning by condensation and precipitation. This constant circulation of water from hydrosphere to atmosphere and back again is called the *water cycle,* or the *hydrologic cycle.* Its main features are illustrated in Figure 12-1.

The ride that a molecule of water takes around the water cycle may be short and simple. It may leave the ocean by evaporation, become part of a cloud by condensation, and fall right back into the ocean as part of a raindrop. On a water-covered earth, that's about all that would happen. There would be nothing much to say about it, and in fact, there wouldn't be much "earth science." But the earth has a lithosphere, part of which sticks up above the oceans as land. And some precipitation falls on the land.

Figures 12-1. The water cycle. Water lost from the atmosphere by precipitation is returned to it by evapotranspiration, thus maintaining a dynamic equilibrium.



Now the story becomes quite complicated—and also quite interesting. For the next few chapters of this book, we will be talking mostly about how the land is affected by the water that falls upon it.

Where Rain Goes. Picture in your mind a long, steady drizzle such as might occur with the passage of a typical warm front. Where does all that water go? In a town or city, rain that falls on the paved roads runs down the gutters and into sewer drains. But most of the countryside consists of open fields or wooded areas. What happens to rain that falls on ground like that? Think about what you have observed and you will realize that water usually sinks into the ground. This process is called *infiltration.*

Sometimes when it rains very hard, or rains for several days on end, the ground gets soggy and muddy. It seems to have soaked up as much water as it can. Puddles of water collect in the low spots. On slopes, little streams run downhill over the surface. Water flowing over the surface is called *runoff,* and some rain always becomes runoff, at least for a while.

Finally the rain stops. Usually within a few hours the puddles have disappeared and the ground is dry again. Some of the water has evaporated into the air. However, the evaporation rate is too slow to account for the rapid disappearance of so much water. We have to conclude that most of the water has soaked into, or *infiltrated,* the ground.

To sum up, water that falls on the ground as precipitation may *run off* the surface, or it may *evaporate* into the atmosphere. Most of it, however, *infiltrates* the surface. To find out what happens to it after that, we have to dig down and look below the surface.

Infiltration. The infiltration of water into the lithosphere can occur wherever the surface is *permeable,* that is, wherever there are spaces, or *pores,* which the water can enter. If the pores of the surface layers of soil or rock become filled with water, no more water can infiltrate, and the excess water becomes runoff.

Another factor that affects infiltration is the slope of the land. Infiltration takes time to occur. If the slope is gentle, the water has time to infiltrate the ground. But when the slope of the land is very steep, the water tends to run off before much infiltration can occur.

As you know, surface water always runs downhill because of the force of gravity. Gravity continues to act on water as it infiltrates the surface. Water below the surface (which is called *subsurface water)* therefore tends to run "downhill" also. However, the flow of subsurface water is greatly slowed by the resistance of the material through which it flows.

The amount of water that can infiltrate the ground, as well as the rate at which this can occur, depend on two properties of the surface material: *porosity* and *permeability.* These two properties are related, but they are different. Porosity refers to the amount of space into which water could go. Permeability refers to the ease with which water can enter and flow through these spaces. In the following sections we will discover how the characteristics of rocks and soil affect their porosity and their permeability.

SUMMARY

1. The water cycle is the circulation of water from the surface of the earth into the atmosphere and back again.
2. Precipitation may infiltrate the earth's surface, run off, or evaporate.
3. Infiltration can occur if the surface is permeable and unsaturated, and if the slope of the land is gentle enough.
4. The rate of infiltration is determined by the porosity and permeability of the soil.

POROSITY

What happens when you pour water on sand? It sinks right in. But why? The water infiltrates quickly because there are so many spaces between the sand grains. To a varying degree, all soils, and even rocks, have pores. It is the total amount of empty space that determines how much water a soil or rock sample can hold. This gives us the definition of porosity: *porosity* is the percentage of open space in a sample compared with its total volume.

There will be a more complete examination of different kinds of soils in Chapter 14, but for now let's consider the porosity of two very different types—sandy soil and clayey soil. You can see from Figure 12-2 that the particles in the sandy soil are many times larger than those in the clayey soil. You may also notice the difference in shape of the particles and the way they are packed together. What effects do these differences have on the porosity of a sample of soil? Let's examine these facts separately.

Particle Shape. The *shape* of the particles in a soil sample is an important factor in determining porosity. You can see from Figure 12-3 that a sample made up of rounded particles is going to have a greater porosity than one consisting of particles with

Figure 12-2. Two types of soil. Samples of soil vary with regard to the size, shape, and variety of the particles they contain.

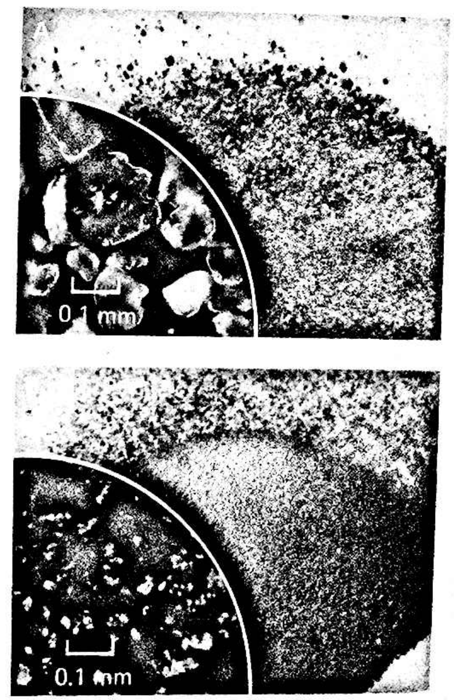
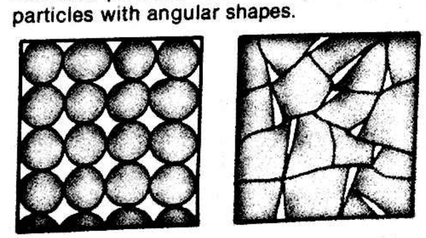


Figure 12-3. Effect of shape on porosity. Rounded particles have more porosity than particles with angular shapes.



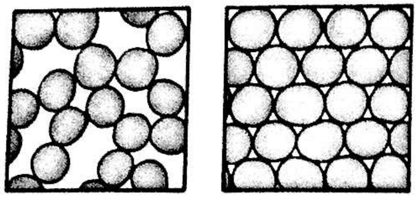


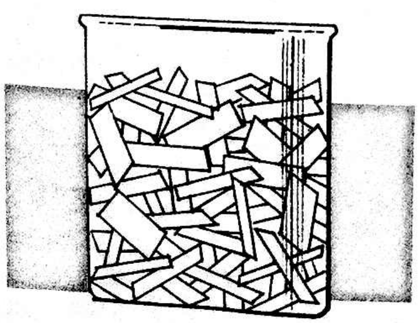
Figure 12-4. Effect of packing on porosity. Loosely packed particles have more porosity than closely packed particles.

angular shapes. The rounded particles just cannot fit together as closely as particles with flat edges.

Packing. Even if the particles in two samples have the same shape, their porosity may differ if one is more tightly *packed* than the other. In Figure 12-4 you can see that the porosity in a loosely packed sample is going to be greater than that in a tightly packed sample. Where the particles are packed closely together, the relative amount of empty space in the sample is decreased, and hence porosity is decreased.

Rounded particles, such as those of sand, usually have only one way of settling together. But what about the

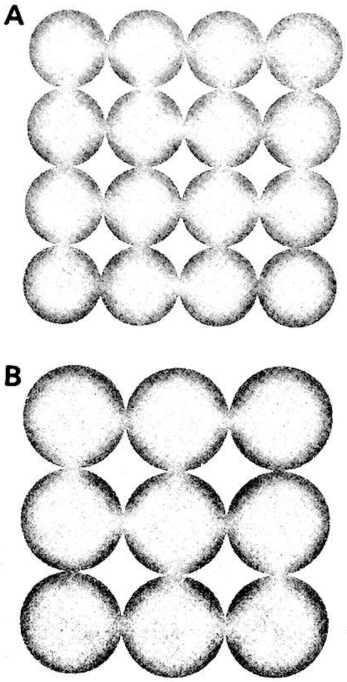
Figure 12-5. Packing of flat particles. Cards thrown into a container at random are likely to be loosely packed with large amounts of empty space between them. If the container is shaken, the cards will settle into a more tightly packed arrangement.



flat particles, such as those of clay? What would happen if cards of irregular shapes were thrown into a container? If the cards were thrown in randomly, the porosity could be quite high (see Figure 12-5). But if the cards are then shaken or pushed down, their porosity drops sharply. *Freshly* deposited clays, in which the particles are mostly flat like cards, may have a porosity of over 90%. But as more material is deposited on top of them, the clay particles become pressed down and tightly packed, and the porosity drops.

Particle Size. What about two soil samples that have particles of the same shape and degree of packing, but of different size? In this case, the two samples can hold about the same

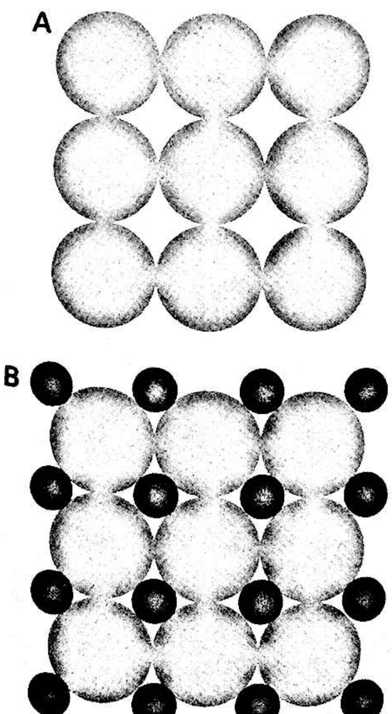
Figure 12-6. Effect of particle size on porosity. Rounded particles of different sizes have about the same porosity, if the particles in each sample are well sorted by size.



amount of water in their pores. Figure 12-6 shows two samples—one packed with *large* rounded particles, the other with *small* rounded particles. It is true that the individual spaces between the large particles are bigger than those between the small particles. But the *ratio* between the size of the spaces and the size of the particles is about the same. Therefore the *percentage* of empty space is the same in both cases. The porosity of tightly packed round particles is about 35%.

On the other hand, Figure 12-7 shows what would happen if we made up a sample with rounded particles of *two* sizes. The small particles would fill some of the spaces between the large particles. The total volume of

Figure 12-7. Effect of sorting on porosity. If particles of different sizes are mixed together *(B)*, the mixture will have less porosity than well-sorted particles *(A)*.



the sample is the same, but the amount of space is less. Therefore, the porosity of this sample would be less than that of the two samples shown in Figure 12-6.

In each sample of Figure 12-6, the particles are said to be *sorted*— they are all approximately the same size. In soils where the particles are sorted, the porosity is greater than in those that are *unsorted*. In unsorted samples, the smaller particles tend to fill in some of the spaces between the larger particles, thus reducing the porosity. Most soils are poorly sorted, or even completely unsorted—that is, they consist of particles of many different sizes, and so they generally have a relatively low porosity—somewhere between 10% and 25%.

Porosity of Rocks. Porosity in rocks is measured in the same way as porosity in soils. However, in soil the particles are loose and separate. They can shift around, and the porosity can change. In rocks, the particles are stuck together in various ways. In some rocks the particles have been locked together by tremendous pressures. In others, the particles are held together by a natural cement. Still other rocks are formed by crystallization of molten material. But in each type of rock there can be some pores left.

Some rocks, such as sandstone, have a porosity of 20 to 25%. In this case the pores are spaces between the grains of what was sand when the material was first deposited. Some rocks consist of crystals that have intergrown, filling most of the spaces between them. The pores in such rocks quite often amount to less than 1% of the total volume.

SUMMARY

1. Porosity is the percentage of open space in a sample compared with its total volume.
2. Porosity is determined by the shape of the particles, how they are packed, and whether or not they are sorted by size.

PERMEABILITY

A material through which water can pass is said to be *permeable*. When considering the permeability of a material, we are mainly concerned with how *rapidly* water can pass through it. Obviously, a rock or soil must have pores if water is to pass through it at all. But the degree of permeability—that is, the rate at which water can pass through—depends not so much on the amount of pore space as on the size of the pores and their interconnections.

Relationship between Porosity and Permeability. Sand has a high porosity. It also has a high permeability. However, the permeability of sand is due not only to its high porosity, but to the fact that the pores are large and interconnected. There is little resistance to the flow of water into and through the pores. On the other hand, a soil made of very small but well-sorted particles may have a high porosity, but low permeability. Water in very small pores is in contact with a large amount of particle surface. Friction and attraction between the water molecules and the particle surfaces prevent rapid flow of water through such a material. (See Figure 12-8.)

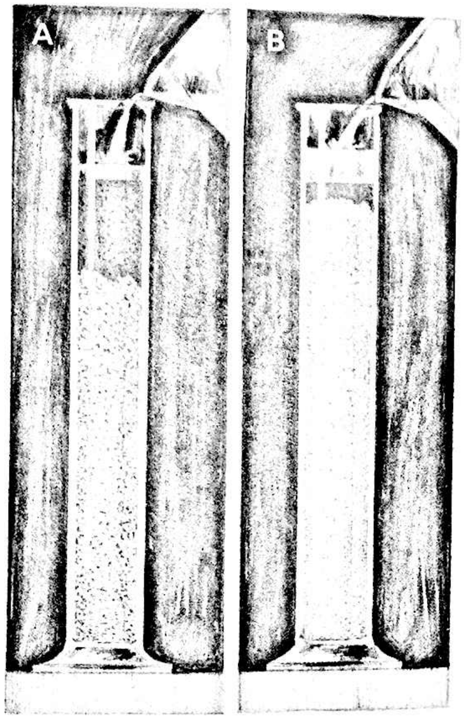


Figure 12-8. Effect of particle size on permeability. Water flows quickly through coarse sand *(A)*, but slowly through very fine sand *(B)*, even though both have about the same porosity.

A rock may have low porosity, but still be highly permeable. For example, it may have many cracks running through it. Geologists refer to this as *secondary porosity*. The total volume, of the cracks may be only a small percent of the volume of the rock, but water can flow through the cracks quite rapidly. On the other hand, a rock with high porosity may be almost impermeable if its pores are sealed off from one another by cementing mate-

rial. And in some rocks, such as limestone, water may have increased both the porosity and the permeability by dissolving away some of the rock material.

Infiltration and Permeability. Downward infiltration of water must stop when an impermeable layer is reached. This may happen quite close to the surface, or it may occur at a considerable depth. Is there a limit to the depth of the permeable layer? Evidently, there is. Almost no water can be obtained from wells that are more than 3 km deep, no matter what type of rock is present. Geologists reason that the increasing pressure as depth increases gradually closes all the pores and cracks in the rock structure.

Runoff and Permeability. When rainfall cannot infiltrate the soil, the result is runoff—the water literally runs off over the surface of the land. Runoff will occur when the soil is saturated and can hold no more water. But it can also occur when the ground is not saturated; for example, in a very heavy downpour the rate of infiltration cannot keep up with the rainfall, so the water runs over the surface of the land. Runoff is also common on steep slopes, where the water runs downhill faster than it can sink into the ground. Plantings on hillsides sometimes hold the rainwater long enough for it to infiltrate more or less completely. But of course, in a very heavy storm, there is always the chance that the plantings themselves will be washed away by heavy runoff!

Runoff may gradually infiltrate unsaturated areas of the surface, or it may continue to flow over the surface in streams and rivers. Most runoff eventually reaches the oceans.

SUMMARY

1. The permeability of a material is a measure of the rate at which water can pass through it.
2. Permeability depends on pore size and on whether or not the pores are interconnected.
3. The permeability of loose material increases with increased pore size.
4. Surface runoff can occur when rainfall exceeds the permeability rate, when the soil is saturated, or when the slope of the surface is too great to allow time for infiltration.

ZONES OF SUBSURFACE WATER

We have said that water moves downward in response to gravity until it reaches an impermeable layer. From this statement you might incorrectly conclude that the upper portions of permeable ground are dry except when a recent rainfall is draining through. If this were the case, no plants could grow where the permeable layer extended down very far. Most grasses, for example, have root systems that never go more than about 50 cm into the soil. They would have a hard time between rains where the permeable layer was 3 km deep! Let us take a closer look at what happens to water that infiltrates the surface.

Wetting Action of Water. Dip a finger into water and take it out, and you find that your finger is wet. A thin film of water clings to the surface of your skin. Even violent shaking will not throw it off, although it will gradually evaporate. Water clings to most solid surfaces in this way. It is held on the surface by a force of attraction between the water molecules and the molecules of the other material. This attraction between a liquid and a solid is called *adhesion*.

As water infiltrates the ground, a thin film of water is left behind on all the particles of the soil and on the walls of all the pore spaces through which the water passes. Thus, the upper portions of soil retain moisture that plants can use.

Capillary Action. Dip the corner of a paper towel into water and watch the water wet the towel as it is drawn up into it. Have you ever wondered how water could defy the law of gravity in this way? This behavior of a liquid is called *capillary action*. It is observed whenever the liquid is in contact with very narrow spaces. It can be seen very easily in glass tubes dipping into water, as illustrated in Figure 12-9. Water is drawn up into the tubes by capillary action. The narrower the tube, the higher the water rises in it.

Capillary action is the result of two different forces acting on the molecules of the liquid. One force is the force of adhesion between the liquid and the walls of the tube. The other is the force of attraction between the liquid molecules themselves, called *cohesion*. When a glass

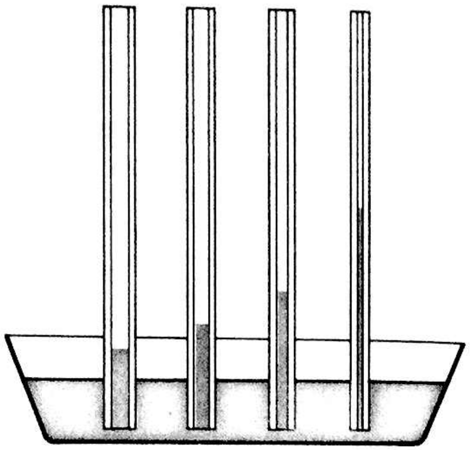


Figure 12-9. Capillary movement of water. Water is drawn up into the glass tubes by capillary action. The water is pulled higher in tubes of smaller diameter.

tube is placed in water, adhesion causes water molecules to climb up the inner walls of the tube. As these molecules move upward, they pull a column of water up behind them by the force of cohesion. The column stops rising when the weight of the water exactly balances the upward force of adhesion. Since a narrow column of water weighs less than a thicker one of the same height, the water can be pulled higher in the narrow column before an equilibrium of forces is reached.

The spaces between the fibers of a piece of paper act like fine tubes. Water rises into these spaces by capillary action. Water will also be drawn upward into the pore spaces of rocks and soil by capillary action from water that has accumulated at lower depths. Depending on the diameter of the pore spaces, water will rise in them to heights of from a few centimeters to a meter or so.

Water clinging to the surfaces of particles in the upper portions of the soil is called *capillary water*, because it is held there by the same forces that cause capillary action. If there is enough capillary water, it will form a continuous film that coats the walls of the pore spaces. If some of the capillary water is drawn off by plant roots, the water may be replaced by a spread of the capillary film from nearby regions. This mainly horizontal movement of water within the soil is called *capillary migration*. It is a very slow process.

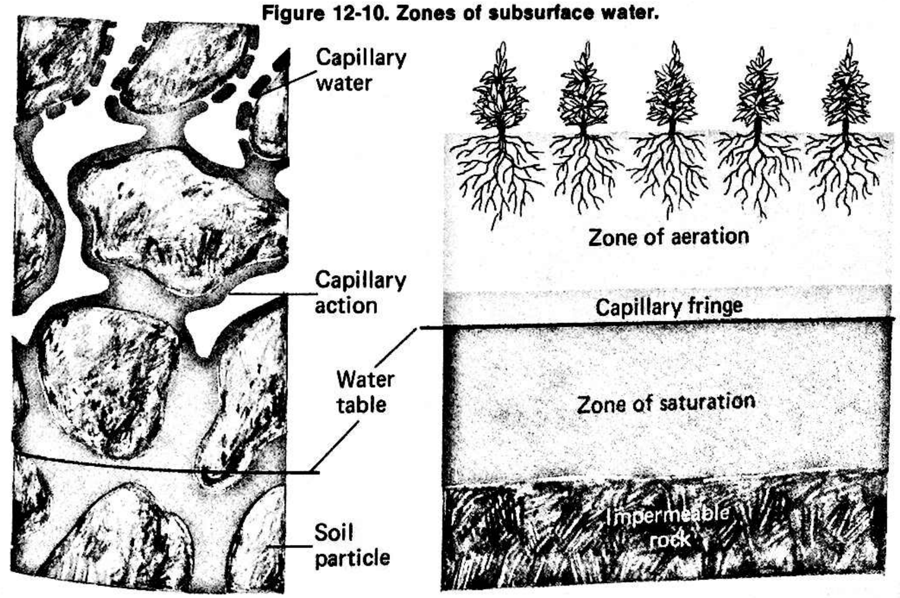
There is an inverse relationship between the permeability of a soil and the amount of capillary water it can retain. In a soil with large pores and high permeability, such as a sandy soil, the amount of surface to which water can adhere is relatively small. In soils with small pores and low permeability, such as clayey soils, there is a relatively large amount of surface for holding capillary water.

Zones of Subsurface Water. Infiltration, retention of capillary water, and capillary action combine to produce several distinct regions, or zones, within a permeable surface layer. Compare Figure 12-10 with Figure 12-9 as we discuss these zones of subsurface water.

The Zone of Saturation. Water infiltrates the ground until it reaches an impermeable layer of rock. The water then fills up the pore spaces above this layer under the action of gravity, forming the *zone of saturation*. This corresponds to the water in the container in Figure 12-9. The water in the zone of saturation has settled to its lowest possible level. This water is called *ground water*. The top of the zone of saturation is called the *water table*. If you dig a hole down into the zone of saturation, the hole will fill with water up to the level of the water table.

The surface of the water in the container in Figure 12-9 is horizontal. The

Figure 12-10. Zones of subsurface water.



water table is usually not horizontal, because water infiltrating the ground also flows slowly "downhill" below the surface. The water table usually shows a pattern that is similar to the "ups" and "downs," or changing elevation, of the surface above.

The Capillary Fringe. Above the water table there is a zone in which the pores are filled by water drawn up by capillary action. This zone is called the *capillary fringe*. The smaller the pores, the higher the water will rise in the capillary fringe. However, as already noted, this is seldom more than 1 meter and is often only a few centimeters.

Although the pores are filled with water in the capillary zone, a hole dug into this zone will not fill with water. The small pore spaces are needed to hold water at this level.

The Zone of Aeration. Above the capillary fringe the pore spaces are not filled with water, but they are not completely dry, either. As we have seen, water is clinging to the surface of the soil particles here in the form of a thin film. The walls of the pores are wet, but their interior contains air. It is in this *zone of aeration* that most plant roots are found. You might not think there would be enough water there for a plant's needs. But this is not the case. There is plenty of water in the zone of aeration. True enough, it is spread out in the form of a thin film coating the soil particles, but the total surface area of these particles is enormous. Tiny root hairs by the millions, along the tips of growing roots, penetrate the pores and absorb the moisture clinging to the soil particles.

Changes in the Subsurface Zones. Let us review what happens to rainfall that infiltrates the ground. A large part of it clings to soil particles in the zone of aeration as it sinks in. Some of it, however, ends up in the ground water and the capillary fringe. What happens between periods of precipitation? In the zone of aeration, water gradually evaporates from the pore surfaces into the twisting air passages upward to the atmosphere. Water is also removed from this zone by absorption into plant roots and transpiration in the plants. The zone of aeration therefore slowly dries out between periods of rain.

In the capillary fringe, water also evaporates into the pore spaces above. However, this water is replaced by capillary action from below as fast as it is lost by evaporation. Thus, the level of the capillary fringe remains at a constant height above the water table.

The water table itself, however, gradually drops during dry periods, as the ground water slowly flows downward into streams and lakes, or directly into the oceans near seacoasts. As the water table drops, the capillary fringe drops with it.

During and after rainy periods, all these effects are reversed. Water is returned to the surface film of the zone of aeration, to the ground water, and to the capillary fringe.

Subsurface Water and the Water Cycle. From this description of what happens to water beneath the earth's surface, we can see how this water returns to the atmosphere to keep the water cycle going. Water in the zone of aeration returns to the atmosphere mainly by evapotranspiration. On the other hand, very little of the ground water returns naturally to the atmosphere until it has made its way through permeable layers to bodies of water exposed to the air.

We purposely put the word "naturally" into the last sentence in the paragraph above. Much ground water is removed today by human activity. Wells are dug down to the water table, and water is pumped out for our numerous industrial, agricultural, and human needs. Human activities have begun to have serious effects on the water table in many parts of the world. This will be one of the topics we will think about in later sections of this chapter.

SUMMARY

1. Soil particles and pore spaces near the surface are coated by a film of water that clings by the force of adhesion.
2. Water moves upward into pore spaces by capillary action.
3. The extent of capillary action increases with a decrease in the size of soil particles and pore spaces.
4. The lowest portion of a permeable surface layer is saturated with water. Water in this zone of saturation is called ground water, and the top of this zone is called the water table.
5. Above the water table is the capillary fringe in which the pores are kept filled with water by capillary action.
6. The upper portion of the surface layer is the zone of aeration, where the pores are coated with water, but also contain air.

THE WATER SUPPLY

What would you consider to be the most precious substance on earth? Gold? Diamonds? Well, even if you had all the money in the world, it would be of no use to you if you lacked one thing—water. Without water there could be no life as we know it on earth.

Our earliest records show that the quest for water has always been important. Great civilizations rose where fresh water was plentiful, as along the Nile River in Egypt. Today we continue to search for unlimited water supplies, but we are not likely to find them. If you look at Figure 12-11 on the next page, you will see that 97% of the earth's water is salt water, which we cannot use unless the salt is first removed. Only 3% of the earth's water is fresh water, and three-fourths of this exists as ice in glaciers and ice sheets. So, less than 1% of the earth's water is found as fresh surface water or ground water. From these figures you can see that although much of the surface of the earth is covered with water, only a small percentage of this is readily available to us.

In ancient times, large populations could exist only where there were large supplies of fresh water in lakes or rivers. Even today, most centers of population are found where there is enough surface water within a reasonable distance to meet a modern society's needs. Still, many people have

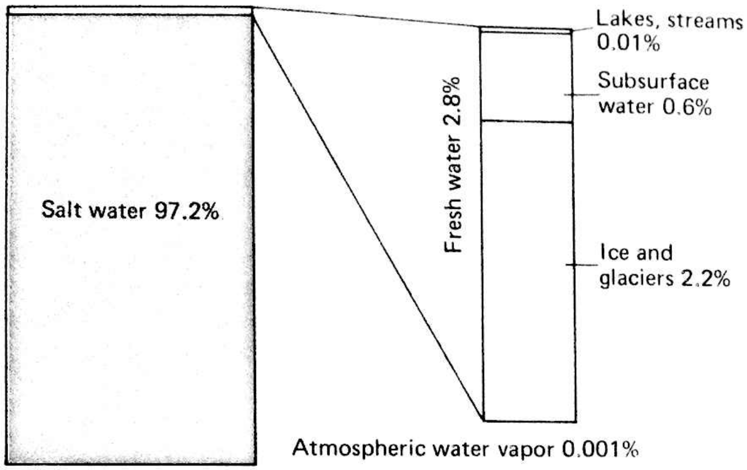


Figure 12-11. Distribution of the hydrosphere. Less than 1% of the hydrosphere is available as fresh water for plants and animals.

always managed to live where there is practically no fresh surface water. Somehow they have made use of the subsurface water stored in the ground. This is usually done by digging wells.

Gravity Wells. If you have ever dug a hole in sand on the shore of a lake or ocean, you may have seen that you don't have to go very far before the hole begins to collect water. You have dug a gravity well.

Most wells are gravity wells, which are holes that are dug or drilled into the ground until they reach the water table (see Figure 12-12). The shaft of a dug well may be lined with brick or a similar material, while in a drilled well, the shaft is a steel pipe. In both types of wells there must be holes around the bottom to allow water to seep in. The water must then be pumped up to the surface. As long as usage does not exceed the rate of infiltration of water into the well, the well will provide water. However, gravity wells depend on precipitation

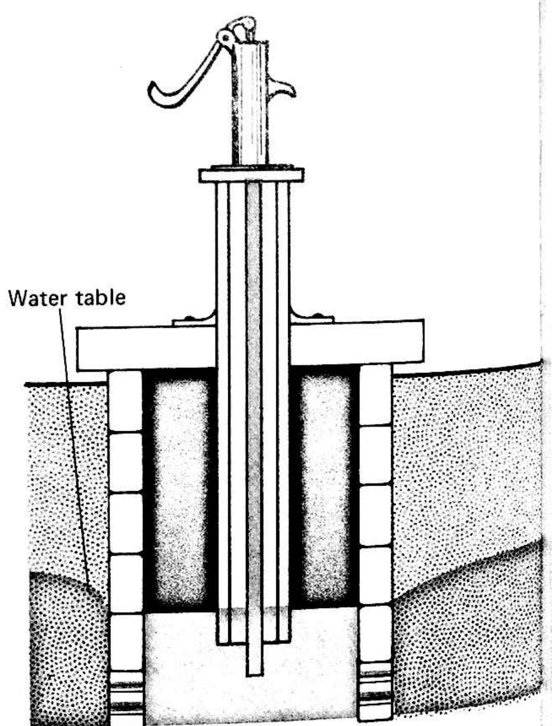


Figure 12-12. A gravity well. In a gravity well, water must be pumped or lifted to the surface.

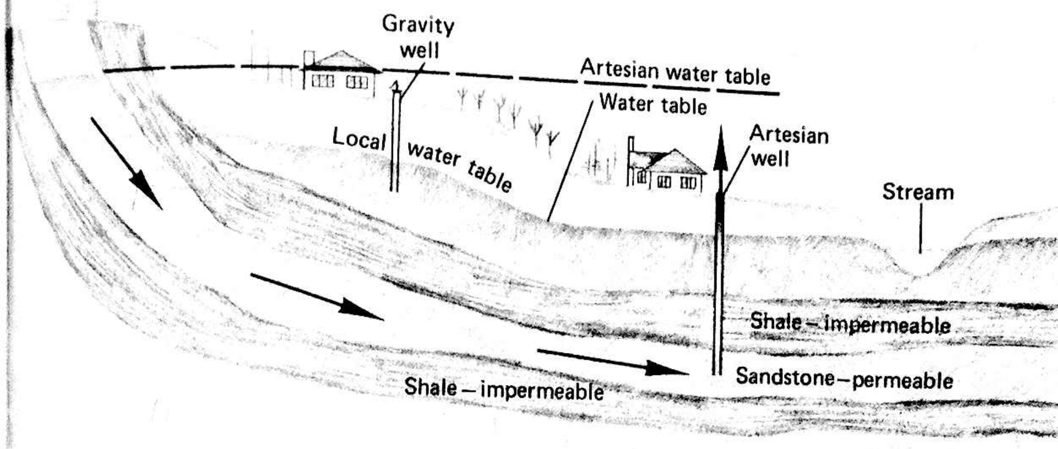


Figure 12-13. Source of water for an artesian well. An artesian well is a well that is dug through an impermeable rock layer to a permeable layer saturated with water. If the water table in the permeable layer is higher than the ground level at the well, water will flow from the well under its own pressure.

in their immediate area. So during prolonged dry periods, the level of the water table may drop, leaving the well dry.

Artesian Wells. A second type of well is the artesian well, which may or may not depend on local rainfall for its water supply. Wherever you can dig down deep enough to reach the water table, you can have a gravity well. But artesian wells can be dug only where there is a layer of permeable material sandwiched between two layers of impermeable material. Figure 12-13 shows the conditions necessary for an artesian well. The precipitation that supplies this type of well may be falling only a short distance away on the top of a nearby hill, or it may be hundreds of kilometers away in a distant mountain range.

As you can see from Figure 12-13, a typical artesian formation might consist of a layer of sandstone, which is highly permeable, sandwiched between layers of shale, which is impermeable to water. The sandstone layer, which can hold great quantities of water, is exposed on a hilltop. It then runs underground in between the layers of shale. Precipitation on the hilltop infiltrates the sandstone layer. The water is under pressure from the weight of the water above it, just like water in a sloping pipe. When a well is dug into the sandstone layer, the water, since it is under pressure, will rise into the well, often all the way to the surface.

In many parts of the world, artesian wells are a major source of water. In some cases the artesian wells are at a great distance from the source of precipitation. This is true in the Great Plains region of the United States. Here the water comes from precipitation high in the Rocky Mountains. It fills the sandstone bed of a tremendous artesian formation that extends for hundreds of kilometers through Kansas, Nebraska, and North and South Dakota. Similar artesian formations are found in dry plains next to mountains in other parts of the world.

In some areas natural cracks, or fissures, in the earth allow artesian springs to appear at the surface. Some oases in the desert are really natural artesian outlets. It is possible that in some desert regions artesian formations far below the surface could provide life-sustaining water if only they could be tapped.

Glaciers. As we saw in Figure 12-11, three-fourths of the earth's fresh-water supply is in the form of ice, which for the most part is not used by man. There are a few cities that are near enough to use the melt water from glaciers and snow fields in the mountains. Boulder, Colorado, for example, owns a glacier in the Rocky Mountains, which supplies part of the city's water. But this is very unusual. There have been numerous schemes devised for using some of the fresh water stored as ice. It has been proposed that icebergs could be towed to locations in need of water and then melted, but so far there has been no practical test of this idea.

SUMMARY

1. Gravity wells are holes in the ground that extend down to the water table. The water must be pumped to the surface.
2. Artesian wells are found only where a layer of permeable material is sandwiched between two layers of impermeable material. Water in such artesian formations is under pressure, and will often rise to the surface without pumping.

WATER POLLUTION

Since only 3% of the earth's water is fresh water, it seems logical that we should do everything possible to preserve this most vital of all earth resources. The chemical and physical properties of water, however, present a problem that is unique to this substance. Water comes very close to being the "universal solvent". This means that most substances, natural or manufactured, will dissolve in water. When they do, they change or *pollute* the water. Even though the study of water pollution is really just beginning, we already cannot cover the information known about this rapidly-expanding subject. A few examples of water pollution problems should highlight its critical nature.

Sources of Pollution. Some water pollution may occur naturally. For example, a stream may cut its way through a deposit of sulfur compounds in the earth. The sulfur contaminates the water, and may kill fish and other forms of aquatic life. Most pollution, however, is the result of human activities.

There is a direct relationship between pollution and population. As the population has increased, pollution of the environment has increased, sometimes to the point of threatening human life.

A student of history would point out that most cities were established where they are because of the availability of water, often a river or lake. It seemed logical to dump unwanted waste into the water and let the water dissolve the

sewage or simply carry it away. As the rate of dumping increased, the natural cleansing process of the water became overburdened. In an attempt to help nature, cities have built expensive sewage treatment plants and industries have spent large sums of money to treat their waste products before they enter the environment.

A special type of pollution problem, called *eutrophication*, occurs in many lakes. As the population around lakes has increased, chemicals present in fertilizers and detergents have seeped into the lakes, where they provide nourishment for certain simple green plants called *algae*. At first, the algae grow in enormous numbers, and form a thick layer on the top of the lake. Algae at the bottom of the layer cannot receive needed sunlight, and die. The process of decay of the dead plants uses up the available oxygen in the water, and all fish and other oxygen-using organisms quickly die off. With eutrophication, the whole process for keeping the lake clean breaks down.

Even groundwater can become polluted. Areas that depend on well water for their water supply must constantly test for harmful bacteria brought in by sewage. Wells near the ocean can become contaminated with salt water. If water is drawn from the well at too high a rate, the level of ground water can drop below sea level. When this happens, salty ocean water enters the water supply. This is an especially serious problem in heavily populated coastal areas, such as Long Island, New York, southern Florida, and parts of California.

Remember that we said that water is almost the "universal solvent"? This chemical property of water becomes a serious problem when we try to dispose of some of the wastes of our industrial society. The Environmental Protection Agency (EPA) estimates that 71 billion gallons (270 billion liters) of hazardous wastes are produced each year in the United States. The EPA has also listed hundreds of old chemical dumps that must be cleaned up before more damage is done to the water supply. This is not really a new problem. Recently, Parisians discovered that part of their water supply is threatened by contamination from a dump used by Napoleon's army to dispose of horse carcasses!

Radioactive wastes cause a special problem since their decay rate into harmless material may be in hundreds of thousands of years. Power plants, whether using traditional fuel or nuclear, present a problem known as *thermal pollution*. These utilities take cold water from rivers and other waterways and use it to remove waste heat. The large quantities of warmed water from the cooling towers are then returned to the waterway. The warmer water can hold less oxygen than the cooler water, and these changes in oxygen concentration and temperature can kill off fish and other organisms.

The high temperature may also stimulate the activity of *aerobic* (oxygen-using) bacteria in the water, which further depletes the oxygen supply. This may eventually lead to an increase in the number of *anaerobic* bacteria (bacteria that do not need free oxygen), and these bacteria and their waste products are themselves pollutants.

One of the most publicized environmental issues of recent years has been that of acid rain. This form of industrial pollution has evidently caused widespread damage to the northeastern United States and Canada. Similar situations have heavily damaged forests in Scandinavia and Germany.

Acid rain forms when sulfur dioxide and nitrogen oxides combine with water in the atmosphere to form sulfuric and nitric acids. The actual chemical pathways traveled by the pollutants is a subject of intense study. Clouds are now considered to be complex "chemical factories" in which the acids are produced in a series of reactions. Small variations such as in the temperature or the pressure of the cloud will greatly change the amount of acid rain and snow delivered to the land below. Other researchers are now finding that the type of soil the acid precipitation flows through must also be considered. An acidic soil will intensify the effect, while a basic soil will minimize it.

Before 1900, lakes in the northeastern United States teemed with fish, and the wildlife in the wilderness was abundant. By the 1920s, trout began to vanish from many of the lakes. Soon, many species of fish and wildlife became scarce. There were many suspected causes such as overlumbering of the forests. It wasn't until the early 1970s that scientists began to identify the cause. Airborne pollution from sulfides produced by industries in the midwest and Canada dissolved in the water vapor in the air to produce acid rain and snow. By the mid-1980s, almost 200 lakes in the Adirondacks of New York had been declared critically acidic. This means that these lakes will not sustain life because of their acid content. Almost 300 other lakes are considered endangered: on their way to becoming critically acidic.

Many agencies, governmental and private, are trying to solve the problem. One method involves 'liming' the lakes. Lime (calcium carbonate) is a *basic* substance. Bases neutralize acids. Adding lime to the lakes reduces their acidity. This is a temporary solution, however, since the lime must be added each year.

One of the major sources of the pollutants causing acid rain is the coal used by midwestern industries. Changing to another fuel would be tremendously expensive, and would have many economic side effects. However, scientists who have studied this problem feel that waiting will only make the solution more expensive. Some worry that we may already be too late.

SUMMARY

1. Pollutants are added to the hydrosphere through the activities of individuals, communities, and industrial processes.
2. Hydrospheric pollutants include dissolved and suspended materials, including organic and inorganic wastes; heat, or thermal energy, from industrial processes; radioactive substances; and abnormal concentrations of various organisms.
3. An increase in temperature or an increase in the activity of aerobic bacteria lowers the concentration of oxygen dissolved in water.

4. Acid rain is a form of industrial pollution that results when oxides of sulfur and nitrogen combine with water vapor in the atmosphere to form weak acids.

REVIEW QUESTIONS

Group A

1. What is the *water cycle?*
2. What three things can happen to precipitation?
3. Under what conditions will infiltration occur?
4. What factors determine the rate of infiltration?
5. Define *porosity.*
6. What determines the porosity of a sample?
7. Define *permeability.*
8. What factors determine the permeability of a sample?
9. How is the permeability of loose material related to pore size?
10. Under what conditions can runoff occur?
11. In what form is water present in soil near the surface?
12. How does water move upward in the soil?
13. What is the relationship between the *extent* of capillary action and the size of soil particles and pore spaces?
14. What is the *water table?*
15. What are the characteristics of the zone of aeration?
16. What is a *gravity well?*
17. What conditions are necessary for an artesian well?
18. What factors are contributing to the pollution of the hydrosphere?
19. Name the various types of pollutants found in the hydrosphere.
20. What types of industry are thought to produce the pollutants that cause acid rain?
21. Where does acid rain occur?
22. Why is acid rain an expensive problem to fix?

Group B

1. Trace the route of a water drop as it travels the complete water cycle. Show some of the "choices" that have to be made as to which part of the cycle the drop follows at various places. You may want to use a diagram to make your explanation easier.
2. a. Describe the characteristics of a soil in which there would be a high infiltration rate.
   b. Describe the characteristics of a soil in which there would be a low infiltration rate.
3. Describe the difference in the characteristics of the zone of aeration and the zone of saturation in the soil. Locate the water table and the capillary fringe in relation to the two zones. A diagram may be used to help you answer this question.
4. What are some of the problems people have in trying to provide themselves with enough water? If you know of any special problems your community is having, describe what these problems are.