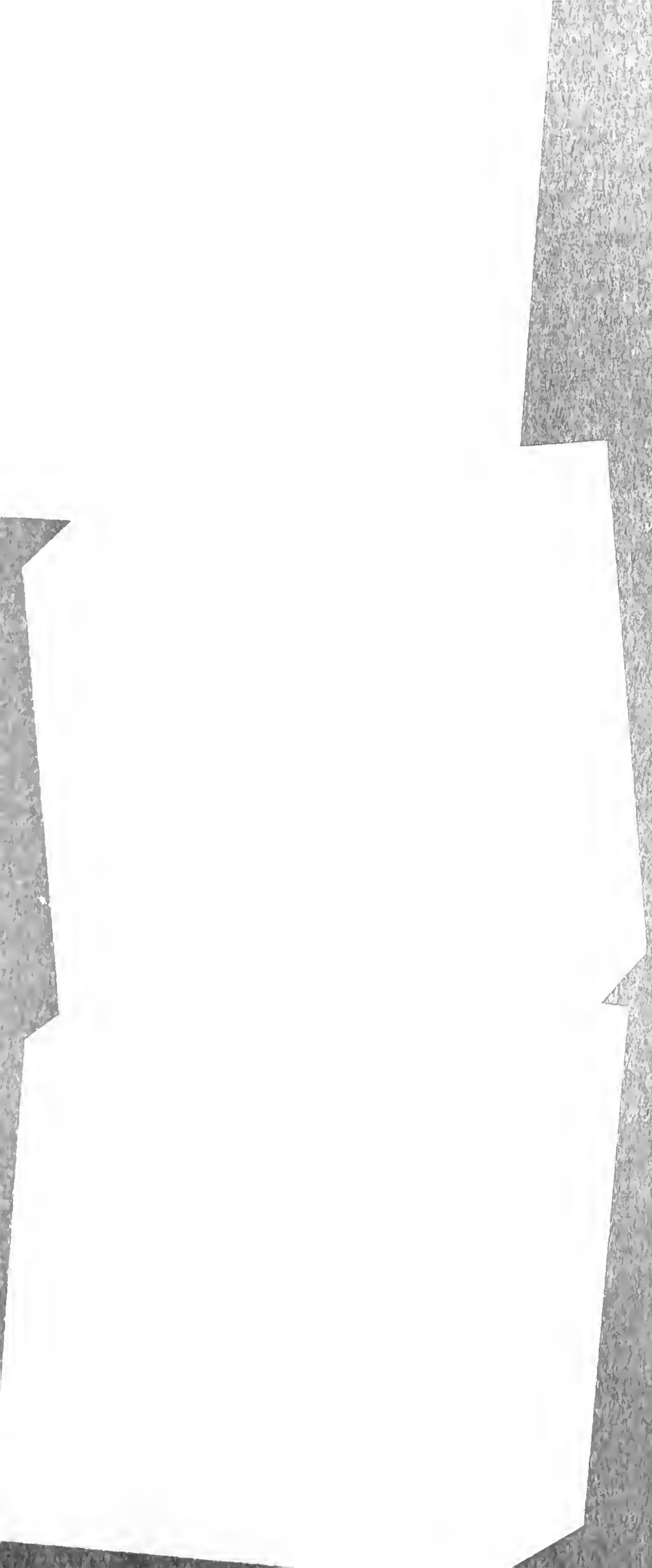


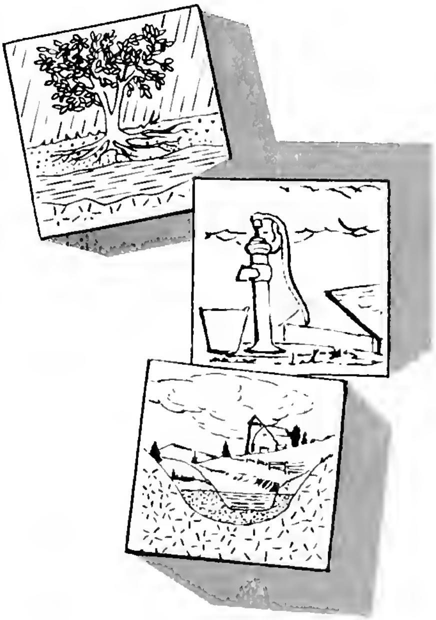
A PRIMER ON GROUND WATER

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

A PRIMER ON GROUND WATER

Helene L. Baldwin

C. L. McGuinness



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Helene L. Baldwin and C. L. McGuinness

THE WATER SEEKERS

Most of us don't have to look for water. We grew up either in big cities where there was a public water supply, or in small towns or on farms where the water came from wells. But there are some people to whom finding a new supply of water is vitally important.

Take John Jones, for instance. He is on the town council of Brownsville, and has just bought a farm a little distance from town, in the same pleasant valley where the town is situated. There is only one small stream in the valley, and it flows all the way across the valley only after heavy rains (fig. 1).

The town needs more water for its municipal system. The present supply comes from widely spaced wells. Some of the councilmen want to consult a dowser, or water witch. As you may know, the dowser claims that he can locate underground water by the use of a magic forked stick. When he is over water, the stick will twist or bend downward of its own accord. Even if you try with all your might to hold the stick upright, it will bend downward—if you have the magic gift of being able to locate water under the ground. At least, that's what people who believe in dowsing say. Others haven't made up their minds on the subject, and still others don't believe in this magic. Scientists who have studied the subject carefully know that, whatever else a dowser can do, he cannot locate water reliably, with or without his rod.

Some twentieth-century water wizards don't use a forked stick, but can tell you where to dig or drill for water much more accurately than the old-time dowser. They are the geologists, engineers, and other scientists who have been trained in *hydrology*. They are called hydrologists, or students of the science of water. They can aid not only in the search for water, but also in its development once the source has been found.

John recommends that the townspeople hire a professional consultant, but he suggests that before they do so they might consult the U.S. Geological Survey in Smith City, where the Survey has set up a local office to manage the studies it is making in cooperation with State agencies. Hydrologists there should know something about ground water in the county where Brownsville is located.

How did John happen to think of the Survey? Many people are not acquainted with its operations, and do not realize that geologists and engineers of the Survey are constantly working with State officials all over the country, mapping and measuring water resources on and below the ground. One day several years ago, John had met a young man who was measuring a well near John's former home. They fell into conversation and John learned that the young man was em-

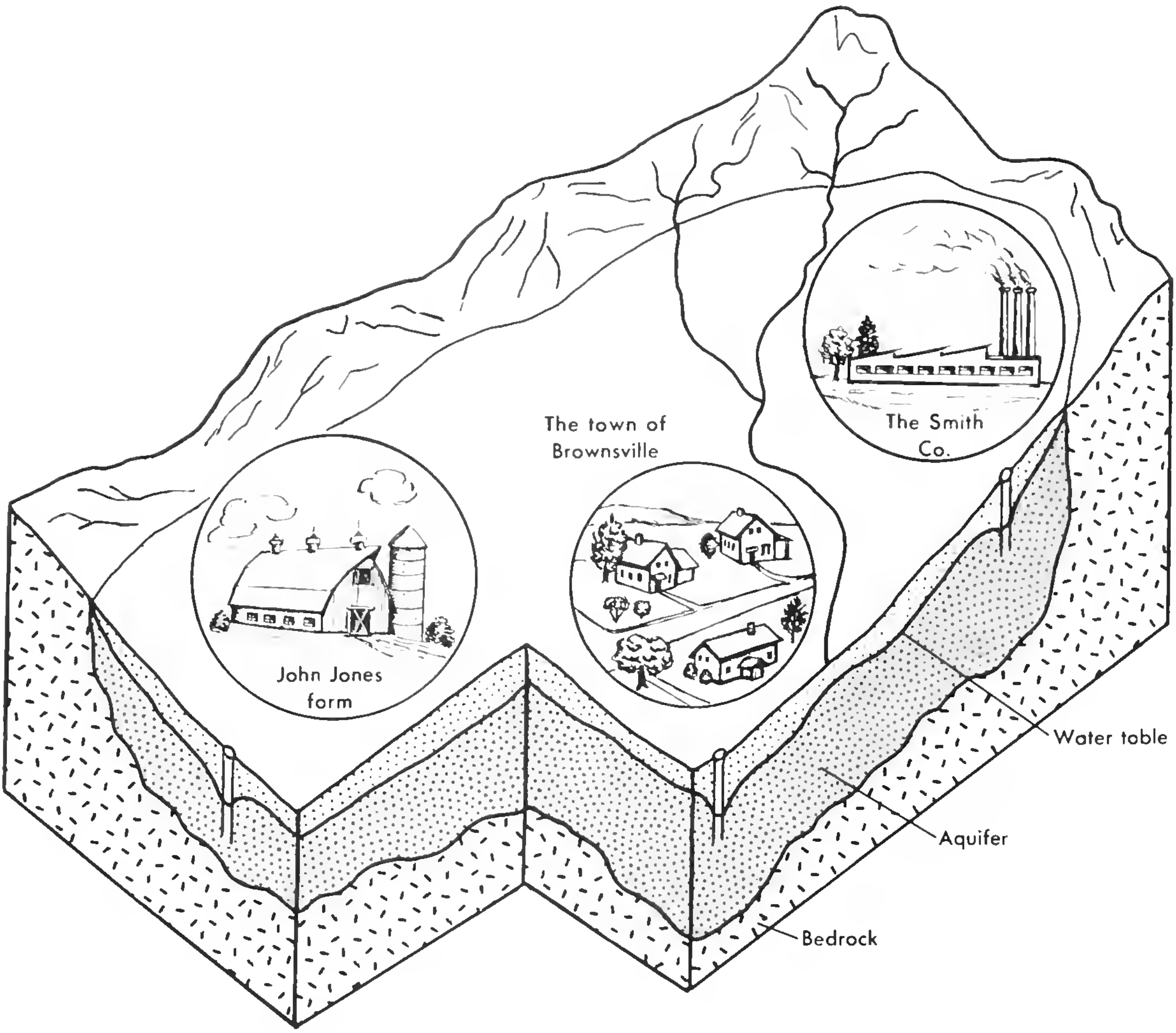


FIGURE 1—*The Brownsville area.*

ployed by the Survey to record the yield and level of water in the wells in the area. He had forgotten about this incident, but now it came back to him. He felt sure that the Survey people could tell the town where the best supplies of ground water might be.

John also hopes the Survey can give him a tip on where and how he might put down a well for his new farm. A friend of his dug a well on a site recommended by the local dowser. The well did provide water—for a while. Then it dried up completely, in the middle of summer, when he needed water desperately for his family, crops, and cattle. John doesn't want that to happen to him. Since his living depends on water, hit-or-miss well sinking won't do. Finding the right location and putting down a well that produces a good, steady supply of water, year in and year out, is a problem for experts—first, hydrologists who can tell John Jones what his prospects are, and then a competent well driller to put the well down.

John, chosen by the council to consult the Survey, went to Smith City and had a long talk with the hydrologists there. Armed with much useful general information, he drove back to Brownsville. As he was driving along, it occurred to him that the assurance of a steady supply of good-quality water might attract new industry to the town. He persuaded the council to contact several small companies, and eventually the Smith Co., which makes electronic equipment, located in Brownsville. The Smith Co. likewise called on the Geological Survey for the available general information, then hired a private consultant to make detailed plans for water development.

State agencies and universities, too, maintain hydrologists on their staffs, and have information on local ground-water conditions. Wherever they are, competent authorities should be consulted. Ground water is not just *water under the ground.* It is water held in the rocks by certain forces, replenished by nature according to the climate and the local geology, and consequently variable in both amount and quality. No magic means are necessary to locate it, just scientific knowledge and plain common sense.

Our purpose in this booklet is to tell you the basic facts about ground water, and what is behind the need for the studies which enabled the Survey to be helpful to the water seekers.

THE WATER WIZARDS

How does the hydrologist know where a well can be drilled with successful results? How does he know where to find water, a good, steady supply of it? He doesn't use a forked stick, like the dowser's. His methods are more complicated, but at the same time much less mysterious. He goes out into the "field" or into a big city—wherever there is a need to know about ground water—armed with his geologist's pick and compass, a steel tape for measuring water levels, a current meter for measuring flow of water, and other equipment needed for water prospecting. Most important, he takes his scientific experience and native curiosity about the why's and wherefore's of water. Before he starts out, he arms himself with the best maps of the area he can find—preferably one of the Geological Survey's own topographic maps. He reads carefully all the publications he can find that relate to the geology and hydrology of his area. In this way he can check his own work against previous work, and will not waste time redoing what has already been done.

Our hydrologist knows that there is no simple way of locating ground water. But he knows something else that most people don't appreciate—locating water is really the least of his worries! There is *some* water under the earth's surface almost everywhere. This simple fact is behind the seeming success of so many dowsers. The hydrologist knows that in nearly all humid areas, and in most arid areas as well, there is at least a little ground water in the rocks below the surface of the earth. The question is: How much? How free is it to come into a well? That is, can it come in fast enough to be useful? The hydrologist has learned from his own experience, and from that of hundreds of others who have studied ground water all over the world, what kinds of rocks water can be found in and where to look for them.

Certain clues are helpful in locating ground-water supplies. For instance, ground water is likely to occur in larger quantities under valleys than under hills. In arid regions, certain types of water-loving plants give the clue that there has to be ground water at a shallow depth underneath to feed them. Any area where water shows up at the surface—in springs, seeps, swamps, or lakes—has to have some ground water, though not necessarily in large quantity, or of usable quality.

But the most valuable clues are the rocks. Hydrologists use the word *rock* to mean both hard, consolidated formations, such as sandstone, limestone, granite, or lava rocks, and loose, unconsolidated sediments such as gravel, sand, and clay. They use the word *aquifer* for a layer of rock that carries a usable supply of water. Gravel, sand, sandstone, and limestone are the best water carriers, but they form only a fraction of the rocks in the earth's outer crust, and not all of them yield useful supplies of water. The bulk of the rocks consist of clay, shale, and crystalline rocks—the term used for the great variety of hard rocks that form most of the earth's crust. Clay, shale, and crystalline rocks are all poor water producers, but they may yield enough water for domestic and stock uses in areas where no better aquifers are present.

The hydrologist first of all prepares a geologic map and cross sections showing where the different rocks come to the land surface and how they are arranged beneath the surface. He will observe how the rocks have been affected by earth pressures in the past. Perhaps they are cracked and broken so as to form openings that will carry water (fig. 5). Or they may be folded or displaced, as shown in figure 2. The geologic map and sections and the accompanying explanations will show just which rocks are likely to carry water, and where they are beneath the surface.

Next he will gather all the information he can on existing wells—their location, depth, depth to water, and amount of water pumped, and what kind of rocks they penetrate. Much of what he is interested in is below the depth of ordinary excavations, and he cannot afford to drill a well or test hole in every place where he needs information. Records of wells where the driller has carefully logged the depth and type of different rock strata are helpful. A really useful well record will include the following: samples of the rocks; information on which strata yield water and how freely; where the water level stood in the well as each successively deeper stratum was penetrated; and data from a pumping or bailing test of each water-bearing stratum showing how much water was yielded and how much the water level lowered at the given rate of pumping or bailing.

The hydrologist will then make a contour map of the *water table*. The water table is the top of the zone of saturation—the zone in which all the rocks are saturated with water (fig. 3). The hydrologist measures the depth from the land surface to the water table at wells. Next he determines, either from a topographic map or by surveying, how high the land is above sea level. Finally, he draws lines to connect all the points of equal elevation of the water table, so that the map shows the shape of the water table, in the same way that a topographic map shows the shape of the land surface. The water-table map is especially important because it gives a clue not only to the depth below which ground water is stored, but also to the direction in which the water is moving. If there is any slope to the water table, the water moves in the direction of the slope (fig. 3).

Where there are no wells, or not enough information on existing ones, the hydrologist may have to put down some test holes. If only a shallow hole has to be put down, a small power auger, which will bore to a depth of about 100 feet, can

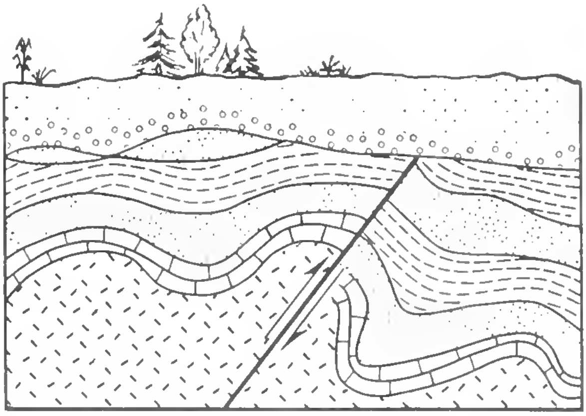
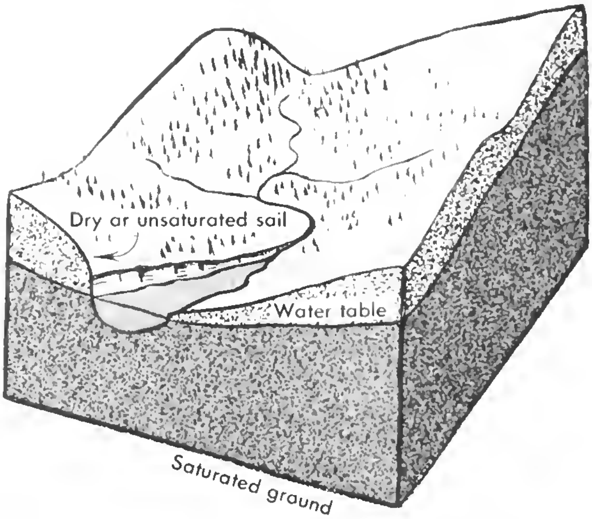
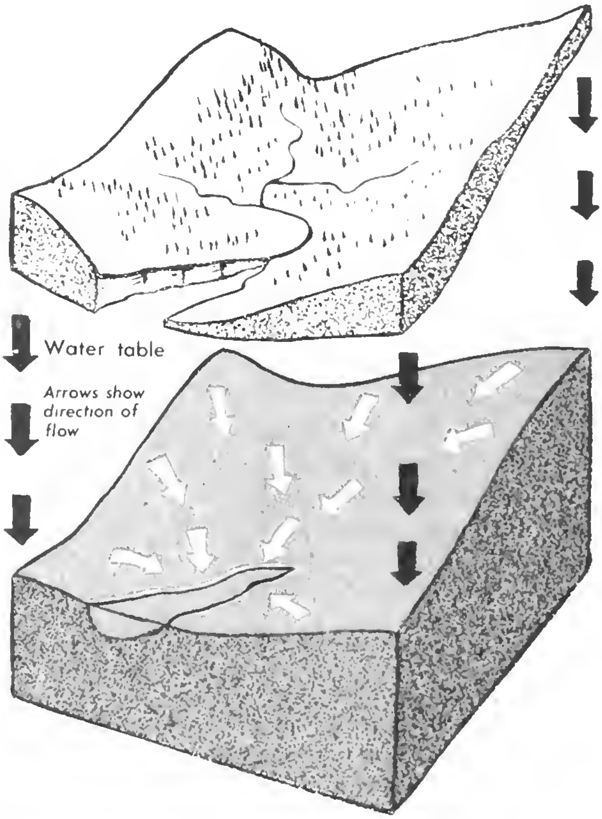


FIGURE 2 *Folded and displaced rocks.*



A.—SMALL STREAM WHERE IT FIRST HAS WATER IN CHANNEL



B.—DRY ZONE LIFTED UP TO SHOW SURFACE OF SATURATED ZONE

FIGURE 3—*The water table and movement of ground water.*

be used. If a deeper hole is to be drilled, a professional well driller may be hired to do the drilling. The samples of earth material brought up by drilling are examined and analyzed to determine which strata are water bearing and how large an area they underlie. Drilling test holes is an expensive business, generally costing a dollar or more and sometimes as much as $30 a foot. A deep hole obviously runs into a lot of money, and unnecessary drilling would be wasteful.

Both on these test wells and on some of the existing wells, the hydrologist will make *pumping tests,* or *aquifer tests.* These scientifically controlled tests are not really tests of the well itself, but are designed to give information on the water-bearing properties of the aquifer tapped by the well. The test enables the hydrologist to determine the amount of water moving through the aquifer, the volume of water in the aquifer that can enter the well, and what the effect of pumping will be on the water level in the pumped well and in other wells in the area.

Because quality is just as important as quantity, he will collect samples of water from certain wells, and have them analyzed chemically. From this he will know what kind of water can be obtained from different aquifers, and if samples are collected over several years, how the quality may change when large quantities of water are taken out.

Thus you can see that there is no magic about the hydrologist's work. It is based on common sense and scientific observation. He uses all the clues he can get—what he can see of the rocks as they are exposed at the land surface or in roadcuts, quarries, tunnels, or mines, and what he can learn from wells.

These ground-water studies vary in completeness with the need for information. If the need is mostly for domestic supplies, an area the size of a county can be studied in a summer, and the report and maps prepared the following winter. The hydrologist's report and maps will show where water can be obtained, what kind of water it is chemically, and in a very general way how much is available. If a very large supply is needed or if there are problems with the present supply, more detailed studies must be made, either in the area where the large need exists or, in some cases, where a future need is anticipated. Whatever the scope of the study, the report is designed to provide a sound basis for whatever may follow it, whether it is nothing more than drilling home and farm wells, or large-scale water projects for a city, an industry, or an irrigation project.

WHAT IS GROUND WATER?

It is hard to picture underground water. Most people have a fanciful notion of an underground lake, or a murky stream moving along slowly in dark underground channels scarcely high enough to stand upright in. There *are* such underground streams in cavernous limestone or lava rock, but they are not common. Mostly, ground water is just the water filling pores or cracks in the rocks (fig. 5).

But if ground water is not a river or lake as we think of them on the surface, how is it carried in the earth? Why doesn't it soak through the earth? It does not because the rocks at great depth lack openings—pores or cracks—through which water can move, or if they have openings they are too tightly packed to let water move through freely.

Between the land surface and the water table there is a space which the hydrologist calls the *zone of aeration* (figs. 4, 5). In the zone of aeration there is usually at least a little water, mostly in the smaller openings; the larger openings in the rocks contain air instead of water. After a heavy rain this zone may be almost saturated; in a long, dry spell it may become almost dry. In the zone of aeration, water is held to the soil and rocks by forces the hydrologists call *capillarity,* and it will not come into a well. These are the same forces that hold enough water in a wet towel to make it feel damp after it has stopped dripping.

When rain falls, the first water that enters the soil is held by capillarity, to make up for the water that has been evaporated or taken up by plants during the preceding dry spell. Then after the thirsty plants and soil have had enough, and if the rain still continues to fall, the excess water will reach the water table—the top of the zone in which the openings in the rock are saturated. Below the water table, all the openings—crevices, crannies, pores—are completely full of water (fig. 5). The raindrops have become ground water, and this water is free to come into a well.

The reason the water below the water table will come into a well, and the water above will not, is a bit technical, but not too hard to understand. The water above the water table, as in the damp

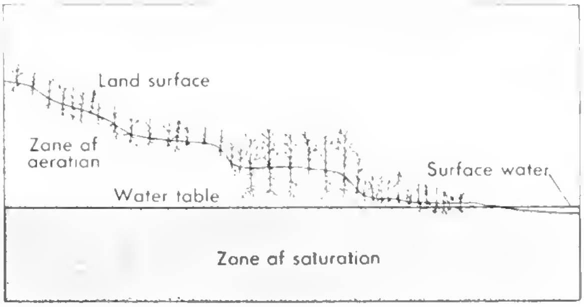


FIGURE 4—*Zone of aeration and zone of saturation.*

towel, is sucked in and held against the pull of gravity. The pressure in the water is less than the pressure of the atmosphere, so it is forced by atmospheric pressure to stay where it is. Below the water table, all the water is under a pressure greater than atmospheric. This pressure is sufficient to force the water to move from one pore into a larger one when the larger one is emptied. A well is nothing but an extra-large pore into which the pressure forces the water to move to replace water drawn out by the pump.

Thus, any well that extends below the water table will fill with water up to the level of the water table. If the well is pumped dry, it will fill up again. The important thing is, will the water come in fast enough to make the well useful for a continuing water supply? A tight rock such as clay or granite, with tiny pores or only a few hairline cracks, may give up its water so slowly that several days would be required for a well to fill up to the level of the water table. Obviously, such a rock would not be a useful water bearer. On the other hand, the openings in the rock may be large enough to let water through freely, so that it can be taken out in useful amounts. The amounts yielded to a well that justify calling a rock *water bearing* range from a few hundred gallons a day, where only a domestic supply is needed, to as much as several million gallons a day.

The word *aquifer* comes from two Latin words: *aqua*, or water, and *ferre*, to bring. The aquifer literally brings water (underground, of course). The aquifer may be a layer of gravel or sand, a layer of sandstone or of cavernous limestone, or

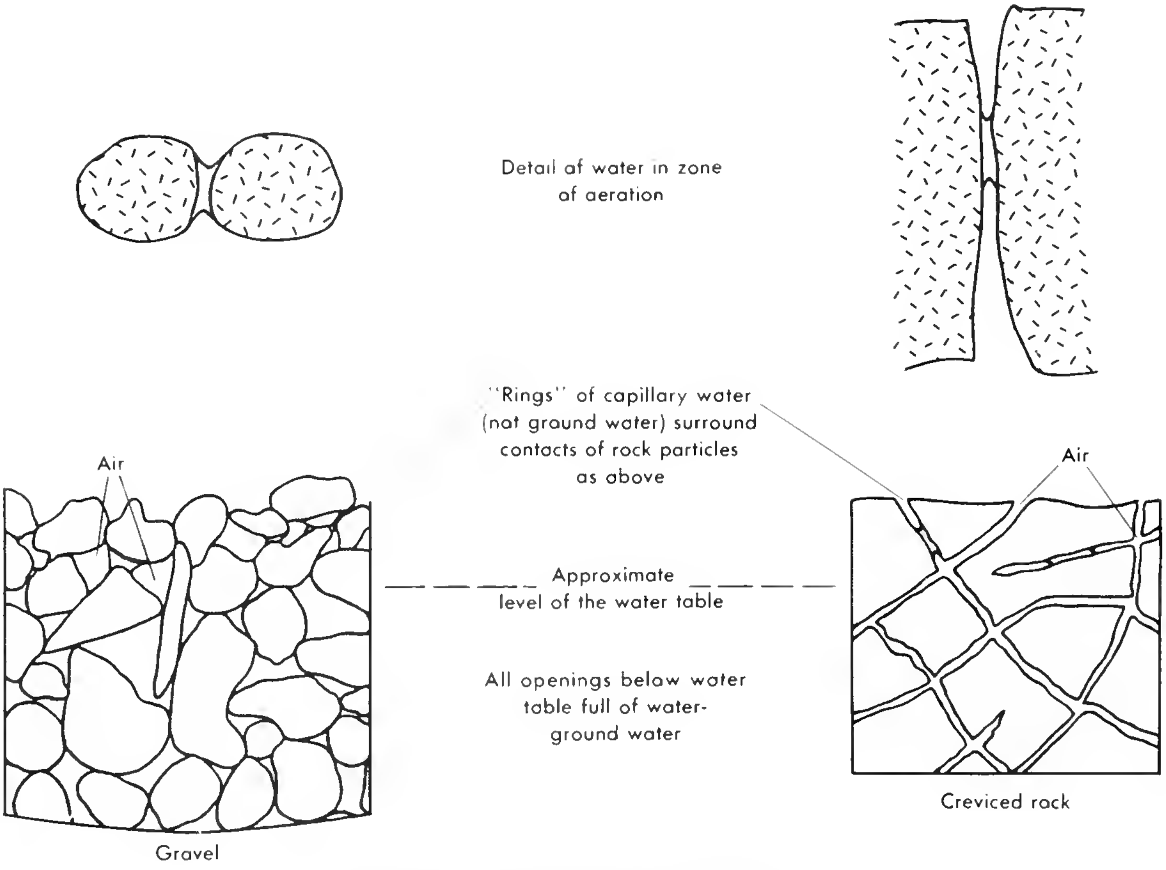


FIGURE 5—*How water occurs in the rocks.*

even a large body of nonlayered rock that has sizable openings.

An aquifer may be only a few feet thick, or tens or hundeds of feet. It may be just below the surface, or hundreds of feet below. It may underlie a few acres or many square miles. The Dakota Sandstone in the West carries water over great distances, across several States. Many aquifers, however, are only local in extent. Underneath the water-bearing rocks everywhere, at some depth, are rocks that are watertight. This depth may be a few hundred feet, or tens of thousands of feet.

The amount of water that a given rock can contain depends on the *porosity* of the rock—the spaces between the grains or the cracks that can fill with water. If the grains are all about the same size, or well sorted, as the geologists say, the spaces between them account for a large proportion of the whole volume. This is true of gravel and sand. However, if the grains are poorly sorted, that is, not all the same size, the spaces between the larger grains will fill with small grains instead of water. Poorly sorted rocks do not hold as much water as well-sorted rocks. The gravel in figure 5 is moderately well sorted.

If water is to move through the rock, the pores must be connected one to another. If the rock has a great many connected pore spaces, of which a large part are sizable so that water can move freely through them, we say that the rock is *permeable.* Large amounts of water are available to a well from saturated permeable rocks. But if the pores or cracks are small, poorly connected, or nearly lacking, the aquifer can yield only a small amount of water to a well. The porosity of different kinds of rock varies widely. In some the porosity is less than 1 percent; in others, mostly unconsolidated rock such as sand and gravel, it may be as high as 30 or 40 percent.

A rock that will be a good source of water must contain either many pore spaces, or many cracks, or both. A compact rock such as granite, almost without pore spaces, may be permeable if it contains enough sizable fractures. Nearly all consolidated rock formations are broken by cracks, called *joints* by geologists (fig. 5). These joints are caused by the same kind of stresses in the earth's crust that cause earthquakes. At first they are just hairline cracks, but they tend to open through the day-to-day action of rain, sun, and frost. The ice crystals formed by water that freezes in rock crevices will cause the rocks to split open. Heating by the sun and cooling at night cause expansion and contraction that produce the same result. Water will enter the joints and gradually dissolve away the rock, enlarging the openings.

If the joints intersect each other, water can move from one to another, much as it flows through the water pipes in a municipal water system. Granite and slate are less porous than sandstone. When water circulates in them, it does so through joint cracks. The water yield of wells drilled in these rocks depends on how many joints are intersected by the well, and how wide they are.

Water will move faster in certain kinds of rocks. A clayey silt having only very tiny pores will not carry water very readily, but a coarse gravel will carry water freely and rapidly. Sandstone is a rock having natural pore spaces through which water will move more easily than it will through tighter rock, such as granite. Some rocks are what we call cavernous; they have hollowed-out openings in them. Some limestone is like this, and water often flows through limestone at a faster rate than through other formations. Gravel has numerous open spaces. Water may travel through it at rates of tens or hundreds of feet per day. In silt or fine sand it may move only a few inches a day. Flow of streams is measured in feet per second; movement of ground water is usually measured in feet per year.

Ground water moves through permeable rocks, and around and in between impermeable ones. Just like surface water, it takes the path of least resistance. Although it moves so slowly, it may travel for miles before it emerges as a spring, or seeps unseen into a stream, or is tapped by a well. Fifty miles is not uncommon. In the Dakota Sandstone beneath the northern Great Plains, water travels hundreds of miles underground.

There isn't necessarily a relation between the water-bearing capacity of rocks and the depth at which they are found. A very dense granite may be found at the earth's surface, as in New England, while a porous sandstone may lie several thousand feet below the surface, as in the Great Plains. However, on the average, porosity and permeability grow less as depth increases. Rocks that yield fresh water have been found at depths of more than 6,000 feet (and salty water has come from oil wells at depths of more than 20,000 feet), but most wells drilled deeper than 2,000 feet find little water. The pores and cracks in the rocks at great depths are closed up because of the weight of overlying rocks.

The flow of ground water from rocks onto the land surface, or *discharge*, takes place in several ways. Water may seep into a stream through the bed and banks, it may emerge as a spring, or it may seep out to the surface in a swampy area.

The area where the aquifer is *recharged* with water is higher than the area of discharge, so that water moves through the aquifer by the force of gravity (fig. 6). The recharge area is usually where a layer of permeable material is close to the land surface. The average amount of recharge is an important consideration in the use of ground water. There are areas in the Western States where pumpage greatly exceeds natural replenishment (fig. 7).

When rain falls, water enters the ground and the water table rises; in times of drought, the water table declines because of drainage to the natural outlets. Because of this fluctuation, a well that is not drilled very far below the current water table may intermittently "go dry" when the water table falls.

The words *aquifer* and *ground-water reservoir* are sometimes used interchangeably, but generally a ground-water reservoir is understood to mean the whole "zone of saturation" from the water table to the depth where openings in the rocks disappear. Ground-water reservoirs provide water for wells and springs and also supply water to streams in rainless periods. We do not know exactly how much these ground-water reservoirs hold throughout the United States, but it is undoubtedly several times as much as all our lakes and surface reservoirs put together.

Though similiar in function, a ground-water reservoir is obviously not quite the same thing as a surface-water reservoir. For one thing, the surface reservoir is used to regulate the flow of streams. Water in the ground-water reservoir, on the other hand, is not so easily regulated. However, the rate of movement is so slow, compared to that of streams, that for all practical purposes these ground-water reservoirs may be considered long-term media of water storage. Ground-water reservoirs have certain practical advantages over surface reservoirs: they do not lose great quantities of water through evaporation, nor do they fill up with sediment.

Besides moving horizontally and downhill, ground water can move upward when it is confined under pressure between two tight layers of impermeable rock such as clay or shale. You know that if the water is turned on and you accidentally puncture the garden hose, water will

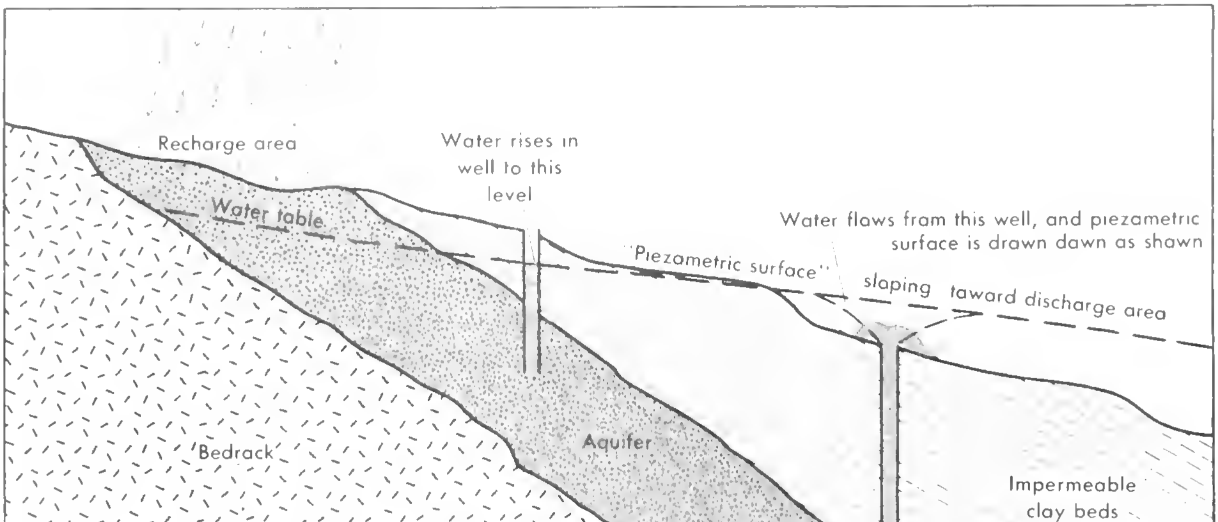


FIGURE 6—*Artesian aquifer and recharge area.*

GROUND-WATER RESERVOIRS WITH PERENNIAL OVERDRAFT

FIGURE 7—*Overdrawn ground-water reservoirs in Western States.*

(From ground water data by H. E. Thomas, 1951, The Conservation of Ground Water: New York, McGraw Hill Co.)

gush from the puncture hole. The water in the hose has been confined under pressure and is released by the accidental puncture. In the same way, if an aquifer confined under pressure between layers of impermeable rock is pierced by a well, water will rise above the top of the aquifer and may even flow from the well spontaneously (fig. 6). Water confined in this way is said to be under *artesian pressure*, and the aquifer is called an *artesian aquifer*.

The word *artesian* comes from the town of Artois in France, the old Roman city of Artesium. It was at Artois that the best known flowing artesian wells were drilled in the Middle Ages.

Deep wells bored into rock to intersect the water table and reach far below it are often called artesian wells in ordinary conversation, but this is an incorrect use of the term. Such deep wells are just like ordinary wells. The word *artesian* can be properly used only when the water is under pressure, and the aquifer is confined between layers of impermeable rock.

When ground water is not confined under pressure, we describe it as occurring under *water-table* conditions. For practical reasons hydrologists need to know whether they are dealing with water under artesian or water-table conditions. Generally, we can assume that artesian water is continuous for some distance under the confining layer of rock, and that it is replenished some distance away. Under water-table conditions, ground water is recharged locally and is more immediately responsive to precipitation. In general, an artesian supply is less reliable for long, continued long, use than an unconfined supply, which is recharged more locally and easily.

Many people wonder what causes springs. From what we have said about rising and falling water tables, it is obvious that occasionally the water table must rise high enough to intersect low places on the land. A spring is a place where there is natural discharge at the land surface of water from a ground-water reservoir that is filled to overflowing. There are different kinds of springs. They may be classified according to the type of geologic formation from which they come, such as limestone springs or lava-rock springs. Or they may be classified according to the amount of water they discharge (large or small), or according to the temperature of the water (hot, warm, or cold), or by the forces causing the springs (gravity or artesian flow).

Thermal springs are the same as ordinary springs except that the water is warm, or, in some places, actually hot. Many occur in volcanic regions, and are fed by ground water that is heated by contact with still-cooling rocks far below the surface. There are many of these thermal springs in Yellowstone National Park. Even where there has been no recent volcanic action, the rocks become warmer with increasing depth. In some such areas, water may descend slowly to considerable depth, getting warmer as it descends. If it then reaches a large crevice in which it can rise more quickly than it descended, it will not have time to cool off completely before it emerges, and we have another kind of thermal spring. The famous Warm Springs of Georgia and Hot Springs, Ark., are of this type.

Geysers are thermal springs which erupt intermittently. Some spout only a few feet, others a hundred feet or more. They may erupt at intervals of a few seconds, minutes, hours, days, or even weeks. Some erupt at intervals of years. These eruptions may occur at more or less regular intervals or quite irregularly. A few geysers erupt into pools of their own making, which are beautifully adorned by deposits of silica. The most famous geyser of them all, Old Faithful at Yellowstone National Park, used to erupt about every 66 minutes to a height of 110 to 160 feet. But, since the earthquake in Yellowstone Park, in 1959, its eruptions have become more irregular.

Ground water slowly dissolves rocks and minerals, most conspicuously in limestone, dolomite, and marble. Water percolating through these rocks gradually dissolves them and forms caverns. Some of these, such as Carlsbad Caverns in New Mexico or Mammoth Cave in Kentucky, are spectacularly large. The underground streams that people so often picture in connection with ground water occur only in such caverns. Elsewhere ground water percolates slowly through the rocks.

You may have wondered how the strangely dramatic stalagmites and stalactites were formed in these great caverns. Dripping water in the caves deposits minerals. Where drops fall from the roof of the cave, part of the water evaporates and the deposits left behind form long mineral "icicles." Those that grow downward are called *stalactites*; those formed where the drops splash on the cave floor and grow upward are called *stalagmites.* Sometimes two of the formations will grow together and form a column.

Where is ground water found in the United States? It occurs nearly everywhere, but the accompanying map (fig. 8) shows areas where aquifers typically will yield more than 50 gallons of water per minute to a well. Three general types of ground-water areas are shown: (1) a perennial stream with the adjoining and underlying water-saturated deposits, shown in solid color; (2) loose sandy and gravelly water-bearing materials, including the productive aquifers of the Coastal Plain, the High Plains, and western valleys, shown dotted; (3) consolidated water-bearing rock, of which limestone, basalt, and sandstone are the most important, shown by diagonal lines. The blank areas on the map are of course not completely empty of ground water. Amounts adequate for domestic use can be obtained in most of them, though not all.

HOW GOOD IS GROUND WATER?

Ideal water, for most people, is spring water—clear, cold, pure, and tasty. Ground water, on the whole, is cleaner and purer than most surface water. The soil and rocks through which it percolates screen out bacteria. But this does not really mean that the water is completely pure. Appearance isn't everything; the unseen qualities are more important. We cannot see them with the naked eye, but the delicious spring water may contain many minerals, which give it the tangy taste we like so much. Without the minerals, it would taste flat and insipid. Some spring and well water, however, may contain so much dissolved matter that it is not fit to drink.

Water is a solvent. From the time rain falls to the ground and begins to run off or pass into and through soil and rocks, it dissolves the rocks and thus picks up from them various mineral constituents.

Because ground water is in contact with rocks and soil longer than surface water, it usually has more dissolved minerals in it. We call these dissolved minerals *salts*, and if there is a very high concentration of them we call the water *saline*. Such salts include, most commonly, sodium, calcium, magnesium, and potassium, plus the chloride, sulfate, and bicarbonate needed to make complete compounds. If the dissolved solids exceed 1,000 ppm (parts per million—that is, 1,000 pounds of salt for each million pounds of water) the water is classed as saline. Water containing more than 500 ppm of dissolved solids is not considered desirable for domestic supplies, though more highly mineralized water is commonly used where better water is not available.

Water that contains a lot of calcium and magnesium salts is said to be *hard*. The hardness of water can be measured according to the following table, in terms of the amount of calcium carbonate (the principal constituent of limestone) or its equivalent that would be formed if the water were evaporated:

Parts per million	
0–60	Soft
61–120	Moderately hard
121–180	Hard
More than 180	Very hard

Very hard water is not good for domestic supplies because soap will not lather easily in it. This is less a problem now than it was before synthetic detergents were introduced, but detergents have introduced problems of their own, as we shall see. Hard water leaves a scaly deposit on the inside of pipes, boilers, and tanks, and this property reduces its suitability for both home and some industrial uses. However, hard water can be made soft at fairly reasonable cost. It is not always desirable to remove *all* the minerals that make water hard. Really soft water is likely to corrode machines and boilers, and is suitable only for laundering, dishwashing, and bathing. Water for a municipal supply must strike a reasonable balance between hardness and softness.

Another quality which must be considered in water, whether from ground or surface sources, is the balance between alkalies and acids. This balance is known as the pH. A pH of 7 indicates neutral water. Above a pH of 7, the water is alkaline; below 7, it is acid. Alkaline water will tend to form scale; acid water is corrosive. Good water should be nearly neutral, neither too alkaline nor too acid.

Excessive iron often occurs in ground water, especially water that is a little on the acid side, and it can be very annoying. It causes reddish stains on fixtures and clothing. Like hardness, an excessive iron content can be reduced rather easily in a waterworks. All that is necessary is to spray the water into the air so that it is exposed to plenty of oxygen. The iron precipitates and can be removed by settling or filtration. Some home water softeners also remove iron.

In high concentrations, certain salts can cause special troubles. Too much sodium chloride (table salt) in the water can be harmful to people who have heart trouble. Boron is a mineral that is good for plants in small amounts, but is poisonous in only slightly larger quantities.

All these and many other salts are present in ground water to a greater or lesser degree. In man's activities it is important to know the chemical content and proportion of salts in the water supply. For this purpose, chemical analyses are made routinely and regularly on municipal and industrial water supplies, whether from ground or surface sources.

Mineral salts are natural ingredients of ground water. However, disposal of industrial wastes into ground and surface water is adding to the accumulation of salts in our water. Industries have always found it convenient to dispose of their wastes in the nearest river, although in recent years community action and legislation have somewhat restrained this practice. When stream water is polluted by industrial wastes, the pollution can affect the water in adjacent aquifers. This is because some ground-water reservoirs are recharged by seepage from streams. For example, the discharge of phenol wastes into the Caloosahatchie River has made it necessary to abandon some wells near Fort Myers, Fla. Oil-well wastes have been dumped into the Canadian and Arkansas Rivers in Oklahoma, and they have contaminated some nearby wells. Chromium-bearing wastes contaminated certain industrial

FIGURE 8—*Ground-water areas in the conterminous*

l States capable of yielding 50 gpm or more to wells.

wells at Waterbury, Conn., and also on Long Island, during World War II.

Chemical fertilizers and pest controls also are contaminating some water supplies. Their use is increasing rapidly. No doubt they are entering fresh-water aquifers from fields and farms, and we simply do not know what the long-term effects of this form of contamination will be.

Synthetic detergents are proving to be another threat to the quality of ground as well as surface water. In some places detergent-bearing water is dumped into streams that are sources of recharge for ground-water reservoirs, or it seeps from septic tanks into the ground-water reservoir. Research is being done to determine at what concentration detergents become toxic, to overcome their interference in conventional water-treatment practices and to develop new materials that are less resistant to natural decomposition than the present ones.

Most people think of water pollution in terms of bacterial pollution from human wastes. This is certainly an important problem. The widespread installation of modern sewer systems has cleaned up the streets of our cities but has had a marked adverse effect on rivers and in some places even on ground-water supplies. Ground water is naturally somewhat protected from the effects of waste disposal by its mere inaccessibility and the filtering action of soil and rocks. However, seepage from sewers and septic tanks can contaminate an aquifer. Or floodwaters may seep into ground-water reservoirs, carrying bacterial contamination along with them. Since it takes an aquifer a long time to purify itself, it is important to keep wells from being contaminated by dirt or sewage. Wells should not be built near privies or barnyards.

On the whole, ground water is of better sanitary quality than surface water. Even where there are sources of contamination, the bacteria tend to be filtered as the water passes through the soil and rocks.

Water of different quality is needed for different purposes (fig. 9). Water for drinking must be free of harmful bacteria, and it must not contain too many minerals, or it will be unpleasant to taste, and may even make people ill. Water used for irrigation should not have too many minerals in it, either, and especially not too much boron or too high a proportion of sodium. Industry requires different kinds of water quality for different processes. Water used to make synthetic fabrics cannot contain too much iron, for it will stain the fabrics. Water used for canning peas and beans and other vegetables cannot be too hard, or the vegetables will be tough. For some processes, such as industrial cooling, cold water of consistent temperature is necessary. For many purposes, ground water if available is preferable to surface water, because of its constant temperature and bacteriological purity. Also, its chemical content tends to remain more stable than that of surface water, even if somewhat higher, and this simplifies any treatment that may be considered necessary for a particular use.

Where permeable rocks are in contact with sea water, wells near the sea may become very salty, if they are pumped excessively. Fresh water is lighter than sea water, and literally floats on the heavier sea water. Pumping upsets the delicate balance between the fresh water and the salt. The salt water then mixes into or encroaches upon the fresh water (fig. 10). If the pumping is reduced, the excess salts may eventually be flushed out by fresh water recharging the aquifer, but it may take many many years for flushing to be complete. When the salt encroachment is severe, the reservoir may be spoiled for future use. In many places, the local economy is dependent on pumping from these wells and a reduction in pumping is not easy to accomplish.

Artificial recharge (figs. 10, 11) is being tried as a remedy for salt-water encroachment. One important example is in the Los Angeles area, where it is vitally necessary to protect the fresh water inland. By artificial recharge we mean that fresh water is injected into an aquifer—in this case, into specially dug wells along the shoreline. The theory is that the fresh water will enter the aquifer and set up a reverse gradient which will force the salt water back (fig. 10).

Radioactive industrial wastes are a potential hazard because wastes from nuclear-energy industries, if not carefully controlled, would contaminate water supplies. Civilian power reactors are being built or are already in use in a dozen States and in Puerto Rico, and others are planned.

Water is the *universal solvent*, capable of dissolving more different substances than any other liquid. Thus, if radioactive materials were released they could be transported in solution.

Water could be contaminated also by radioactive materials buried in the ground. Earth materials tend to attract ("adsorb") certain radioactive substances, and thus can act as filters for these substances so long as their adsorptive capacity is not exceeded. Other radioactive substances, however, may move freely through the ground with the water. These are some of the reasons why, though the nuclear-energy industry is small, considerable effort is being expended in studies of waste control in relation to water supplies to assure the safety of our future supplies.

In the foreseeable future (A.D. 2000), many areas of the United States will require complete use of all their water resources. Water supply is already scarce in some areas where nuclear facilities are installed or are likely to be installed. We cannot risk losing important sources of water by radioactive contamination.

WHAT ABOUT WELLS?

Many people today have never seen a well except in pictures. The wells pictured in books are often the old-fashioned kind with a little cupola over a bucket that comes up when the crank is wound. Such wells were generally dug by hand and were not very deep. However, even a well dug by hand must be lined, or "curbed," to keep the sides from falling in. A properly constructed dug well that taps a permeable aquifier can have a large yield, but most dug wells for home supplies are capable of yielding only 1 or 2 gallons per minute, when pumped steadily.

A well is drilled by means of a cable-tool drilling rig which churns a bit up and down in the hole, or it may be bored with a rotary drill. It is lined with a long metal or plastic pipe called a *casing*, which supports the walls so that rocks or dirt won't fall in, and which also might serve to seal off a zone containing poor-quality water. The pump pipe hangs down inside the casing below the water level. Most wells nowadays use pumps to lift the water instead of only a bucket on a rope. The old-fashioned pitcher or lift pump can still be seen on farms or in villages (fig. 12). Its raucous sound is familiar music to many city dwellers who come from homes in the country. It has a long iron handle; raising and lowering this handle forces air out of the pump. Water enters to fill the empty space left by the air, and comes out in spurts. Most modern pumps are driven by electric motors.

To test a well, you measure the water level; then pump the well at a steady rate. The water level will drop very fast at first and then more slowly, as the rate at which water is flowing into the well approaches the pumping rate. The difference between the original water level and the water level after a period of pumping is called the *drawdown*. The discharge rate is determined by a measuring device attached to the discharge pipe. The ratio between the discharge rate and the drawdown will provide the well's *specific capacity*. For instance, if the drawdown is 10 feet and the discharge rate is 100 gpm (gallons per minute), the specific capacity of the well will be 10 gpm per ft of drawdown. The hydrologist can take the results of carefully controlled pumping tests and use them in formulas which enable him to predict what will happen to water levels in the future.

Pumping water from a well lowers the water table around the well and creates a *cone of depression* (fig. 13). Around small-yield wells in productive aquifiers the cone of depression is quite small and shallow. Wells pumped for irrigation or industry, however, may withdraw so much water that the water table is lowered and the cone of depression may extend for miles.

Locating wells too close together causes more lowering of the water table than spacing them far apart. This process is called *interference*. Such interference may draw water levels so low that pumping costs will be greatly increased.

There is a widespread popular notion that there has been a progressive lowering of the water table all over the Nation. It is true that in many places water levels in wells are lower than they used to be. This may indicate only that more water is being withdrawn, not necessarily that it is being withdrawn too rapidly. The water situation which is grave in a local area is not necessarily symptomatic of trouble throughout the country. For the Nation as a whole there is neither a pronounced downtrend nor an uptrend. Water levels rise in wet periods and decline in dry periods, and in areas that are not heavily pumped they average about the same as they did in the past.

On the other hand, there are sizable areas where ground water is being taken out faster than it is replenished, and the water levels are lower-

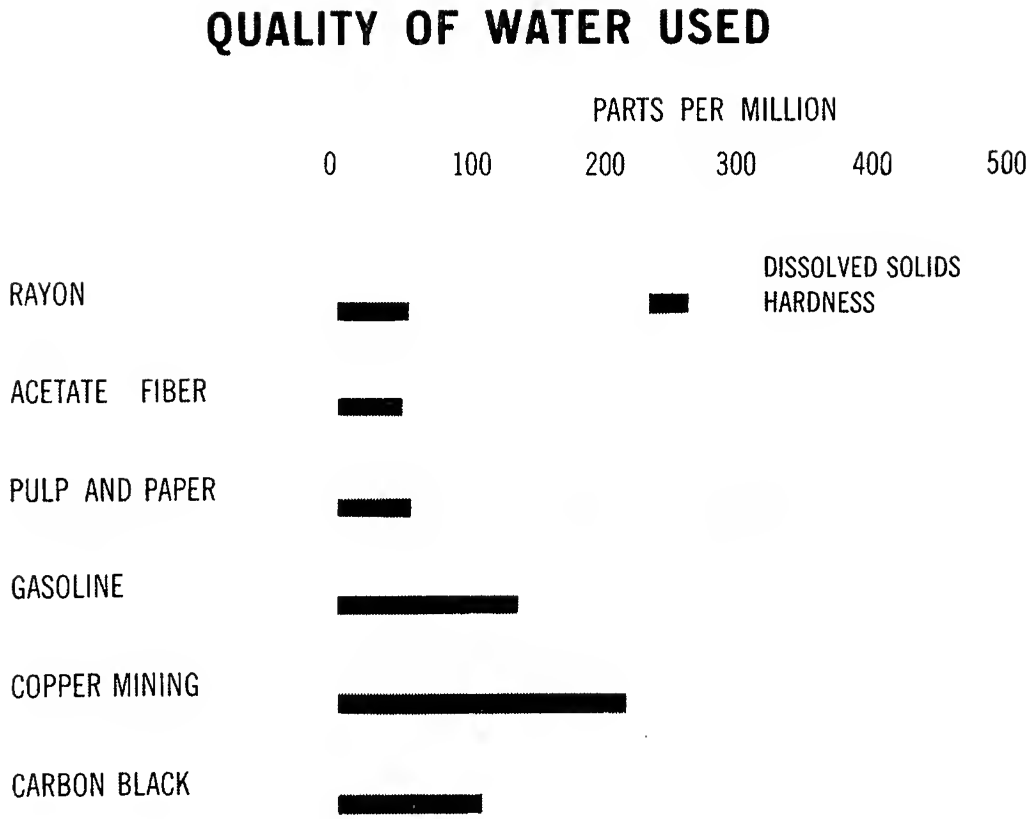


FIGURE 9*a*—*Quality of water in relation to use.*

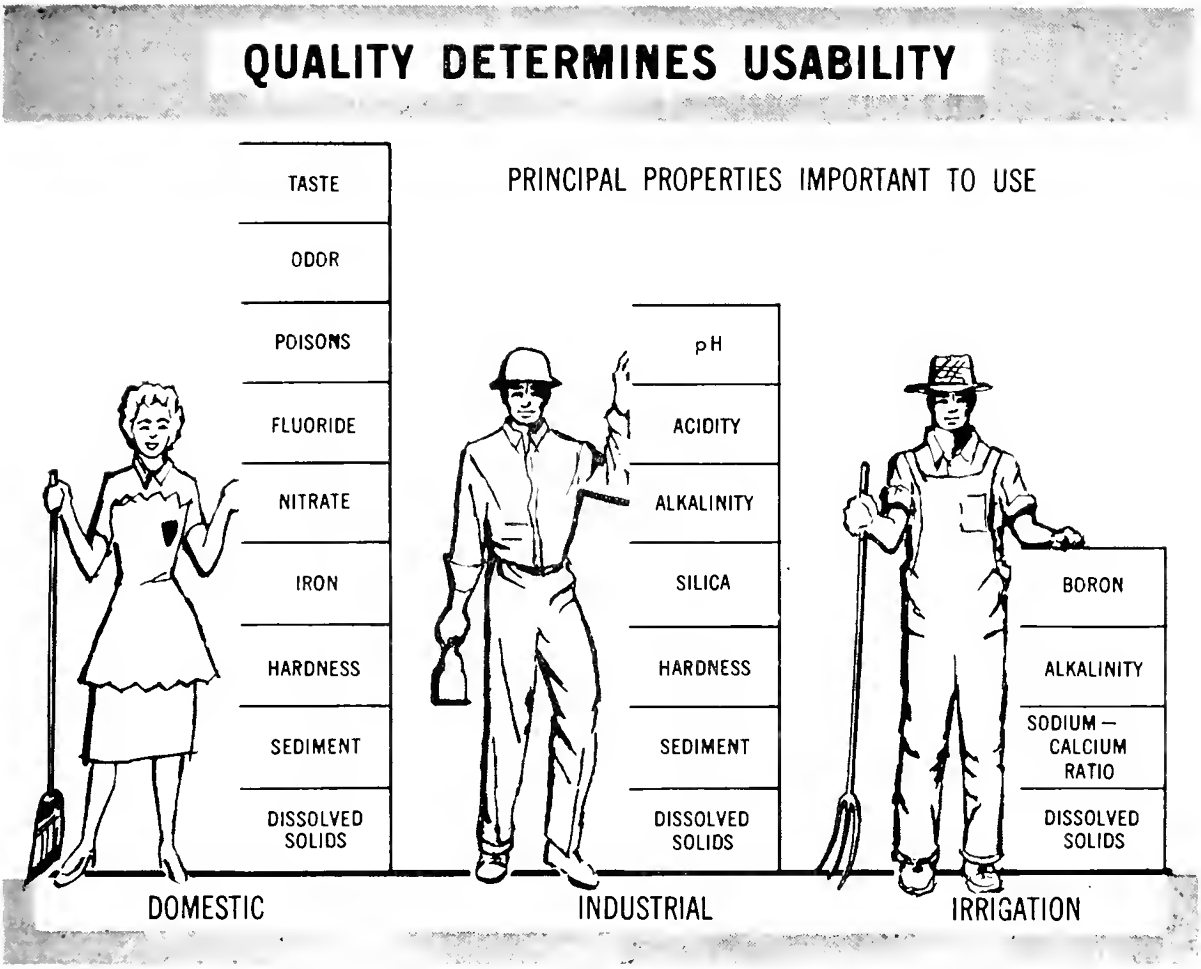
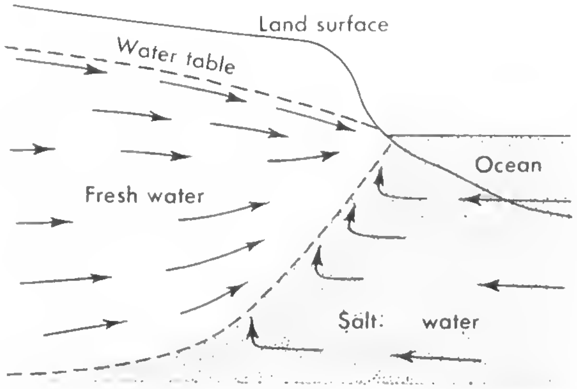
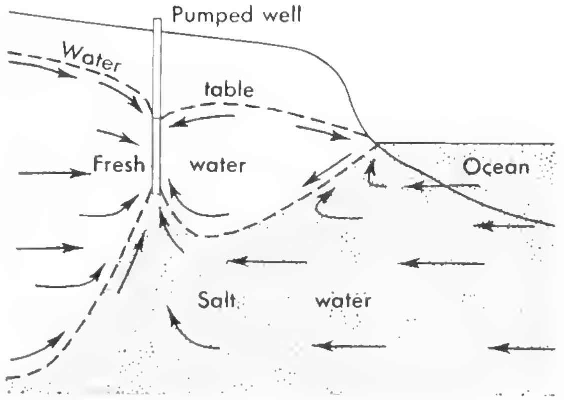


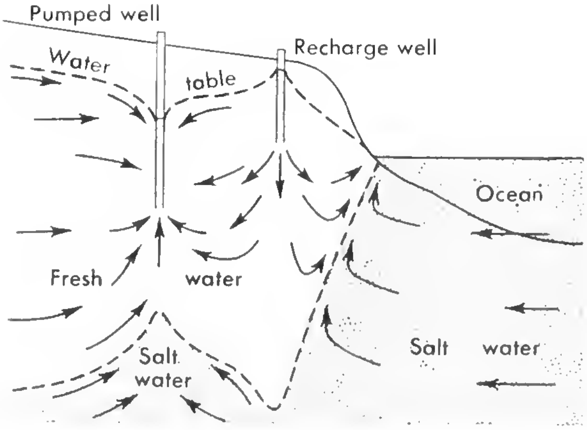
FIGURE 9b—*Quality of water in relation to use.*



NATURAL CONDITIONS



SALT INTRUSION



A REMEDY

FIGURE 10—*Relation of fresh water to salt water in a coastal area.*

ing persistently. Unfortunately, many of these areas are in the dry Southwest, just where water is scarcest (fig. 7).

Where the water table lowers persistently, it means that more water is being taken out of the ground-water reservoir than is being returned to it from precipitation or streamflow. In some places ground water is removed so much faster than it is replenished that the process can be called *water mining*. Obviously, the rates of pumping and of precipitation are both important in this connection. If there are many wells in one area, all pumping at a very high rate, and the rainfall is scanty or nonexistent over long periods of time, then the water table will be lowered. Climate too is important. In many wells, water levels decline when the weather is dry and rise when it is wet. Another factor is the rate of movement through the aquifer. If the rate of movement is slow because the rocks are not permeable, not much water will come into the well very quickly—even though a great quantity of it may be available.

Aquifers are recharged by rain percolating downward from the surface or by seepage from a lake or a stream. The relation of a lake to ground water is like that of a leaky dish or sieve set into a sponge. In most cases, the aquifer will be recharged where the permeable formation is near the land surface. The area of recharge, where rainwater or seepage actually enters the aquifer, may be miles from the wells themselves, and water moves very slowly underground. Or, even if recharge occurs locally, it may occur at a very low rate. Natural refilling of ground-water reservoirs thus may be a very slow process. It has been estimated that if the ground-water reservoir of the High Plains of Texas and New Mexico were emptied, it would take many centuries to refill at the present estimated rate of recharge.

Recharge generally occurs according to the seasons. At different times, because of unusually heavy rainfall combined with reduced evaporation, or of snowmelt, there is enough water to saturate the soil and reach the water table. In a large part of the country, this usually happens in the spring, at the same time that enough water is available to cause floods in the streams (fig. 14).

In the summer, plants and trees use up most of the rainfall, by transpiration through their leaves. Only very heavy rainstorms are likely to recharge ground-water reservoirs during the growing season; thus the water table usually declines during that season. If there are heavy rains in the fall, the water table will rise again, although not usually as high as in the spring. The water table gradually sinks during the winter, and reaches a low point in the spring just before the snow and ice thaw and the spring rains begin. The pattern is somewhat similar in the humid Southeast and South, except that there is no snowmelt, and recharge must depend on rainfall. Floods and recharge thus may occur in the winter. In arid areas of the United States, ground-water recharge from rainfall is similar except that it may be very low or even nonexistent. Western aquifers depend largely on recharge from streams that carry rainwater and snowmelt from the mountains.

Gound-water reservoirs can be recharged artificially (figs. 10, 11). This technique, first used in Denver in 1889, has been adopted in some other parts of the country, especially in California. In the Long Island area of New York City, considerable ground water used for air conditioning is returned to the ground through wells. Some attempts to recharge a ground-water reservoir by artificial means have failed. There is still a lot to be learned about this technique and how or why it succeeds or fails.

There are two chief ways of artificially recharging ground-water reservoirs. One is by spreading water over the land through a spreading ground or through pits, furrows, or ditches. This method is used in the Central Valley of California and in Peoria, Ill., among other areas.

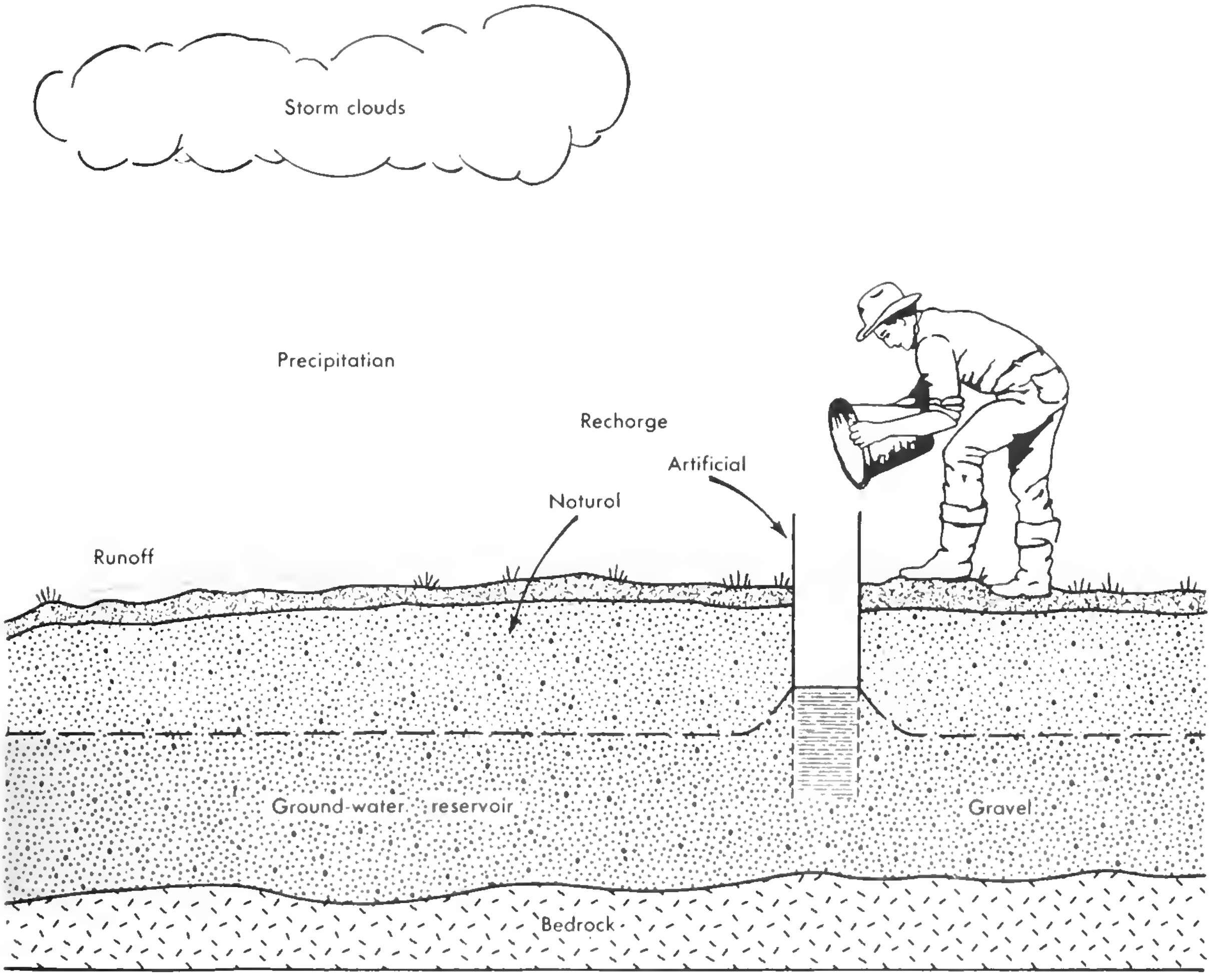


FIGURE 11—*Artificial recharge.*

FIGURE 12—*Old-fashioned lift pump.*

The other way is by pouring or injecting fresh water directly into wells built for the purpose, as in Long Island. This is a more expensive method, and is justified only where the spreading method is not feasible.

You may wonder why anyone would pour water into a well only to haul it up again. Why not keep the water on the surface to begin with, if you have it to spare? But this is not a true picture of what really happens.

Water used for recharge purposes is always surplus water—water that has already been used for some purpose, or water from high-flow periods of a river, which is not needed for use at exactly that season. Such water, if not stored in surface or ground-water reservoirs, would just run down to the sea and be lost for beneficial use by man. The purpose of recharging an aquifer is not only to restore the water table to normal levels, but to store surplus water for times when

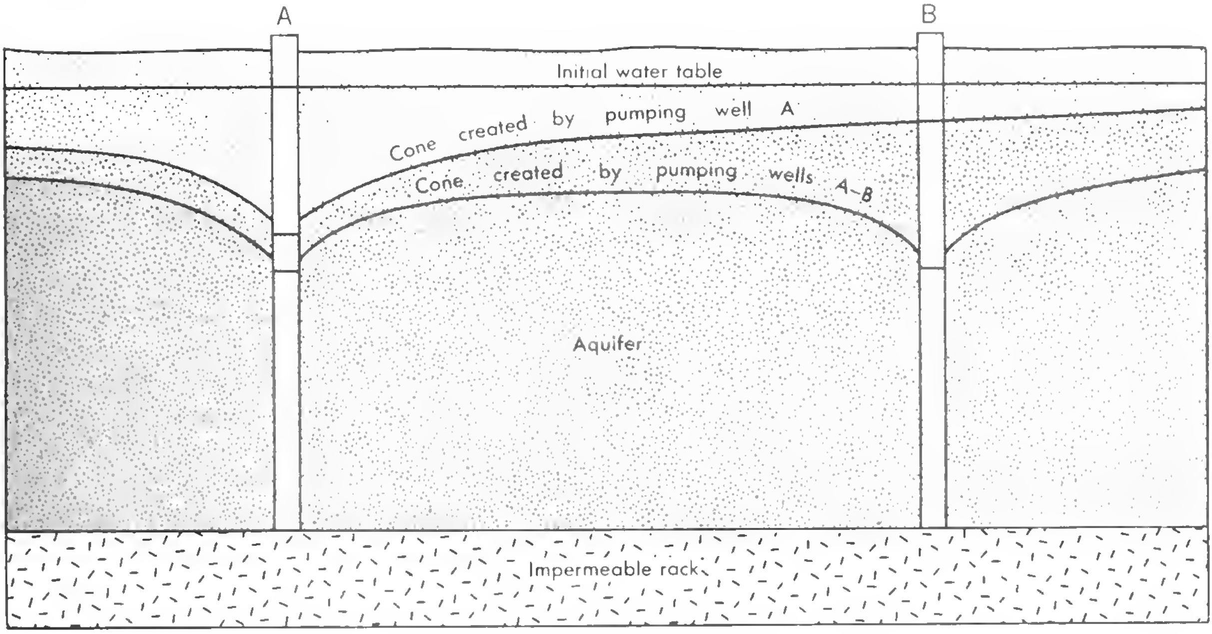


FIGURE 13—*Cones of depression.*

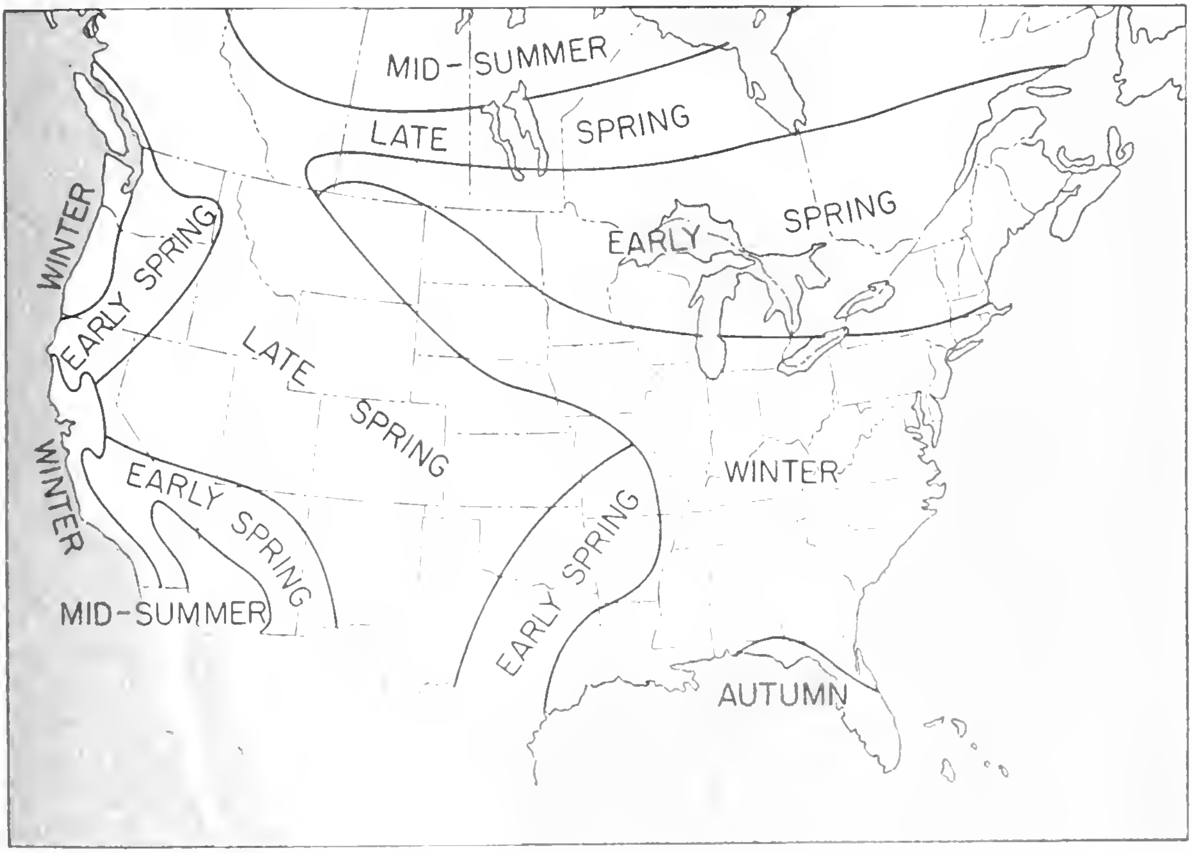


FIGURE 14—*Flood-season map of conterminous United States*
(Flood data by W. G. Hoyt and W. B. Langbein, 1955, Floods. Princeton Univ. Press.)

it will be needed. Storage of surplus water underground has several advantages. The reservoir is already built, though some cost is involved in preparing it for recharge. And, the water is protected to a considerable degree from contamination and loss by evaporation.

Some aquifers are recharged as a byproduct of irrigation. When water is evaporated from growing plants, the dissolved salts are left behind in the soil. If they accumulate, the soil will become unfit for cultivation. For this reason, it is necessary to apply more water than is actually needed for growing plants. The excess irrigation water seeps down and adds to the ground-water supply. In the Shoshone Irrigation Project in Wyoming, a normally dry rock formation became saturated and turned into a ground-water reservoir. The town of Powell, Wyo., has been provided a municipal ground-water supply as a result of this unplanned artificial recharge. In the Snake River Plain of Idaho, seepage from irrigation of the land has increased the water stored in the ground by several million acre-feet (3 acre-feet makes a million gallons). Seepage from irrigation may cause the water table to rise too high, however. If adequate drainage is not also provided, the land may become waterlogged and unusable for farming. The drainage may be achieved by ditches or even by pumping from wells.

Surface reservoirs may add water to the underground reservoirs, in the same way that some natural lakes do. The addition may be accidental, if the reservoir bottom is leaky. But seepage through a permeable bottom may also be deliberate, as in the case of the Santa Clara Valley Water Conservation District in California.

As we have said, there are complications in the artificial-recharge process. A recharge well may become clogged by sediment, chemical precipitates, or growth of bacteria or algae. If a well becomes clogged it must be cleaned or pumped periodically, or the water treated before it is injected. Geologic complications may prevent recharge by water spreading and make it necessary to sink wells for recharging.

Water for artificial recharge of wells or aquifers must be of good quality. If sewage is used it must be thoroughly treated, because once an underground aquifer is contaminated by organic or chemical pollution it may require years before the aquifer can be purified by nature. The more permeable the rocks in the aquifer, the faster the contamination will spread. In very permeable rocks, such as some limestone or basalt, it may move miles in a few days or weeks. In sand or sandstone it will move more slowly. If recharge is done by spreading the water over the land, the soil will act as a filter. The deeper the water table, and the farther the water has to percolate, the freer it will be of bacteria. Chemicals, including synthetic detergents, are not screened out in this way, however.

The increasing use of ground water, especially in the West, has caused ground-water levels to decline in some areas to the point where the water is actually being *mined;* that is, more water is being removed from the ground-water reservoir than is being put back in by nature. To reduce the amount of water pumped would in many cases seriously dislocate the economy. Artificial recharge—where it is economically feasible—will be attempted more and more as a remedy for declining water levels. To accomplish artificial recharge successfully, certain data must be known: the source of natural recharge, the natural direction and rate of movement of the ground water, and the topography and geology of the area. The main difficulty is that each recharge procedure is a separate problem, and must be tailormade to each situation.

MANAGING OUR GROUND-WATER RESOURCES

There is water, more or less of it, more or less accessible, almost everywhere under the earth. As uses of water increase, this ground-water resource is becoming very important. We are using more water than we used to, partly because the population is constantly increasing. But this is not the only reason. Increased uses by industry, for irrigation, and for automatic washing machines, dishwashers, garbage disposers, and swimming pools are all placing an extra burden on the country's water resources. The supply of surface water is so variable that people have tended to use ground water as a more reliable source, where it has been available in needed quantities. But now ground water is being increasingly exploited as a principal source of supply.

Ground-water reservoirs in 1960 supplied a little less than a fifth of the Nation's water withdrawals. Figure 15 is a map which shows the total use of ground water in 1960 by States. Arid and semiarid areas in the West which used to depend on ground water only during times of drought now use more and more of it for irrigation. In fact, irrigation is the largest single use of ground water. During the 1950's the number of irrigation wells in Nebraska, for instance, increased about 25 percent each year. In 1960 there were more than 23,000 irrigation wells in the State, and several billion gallons a day was pumped during the irrigation season.

Even in the East people are now using more ground water than they once did, taking advantage of ground water's special properties. The absence of sediment and bacteria and the constancy of its temperature make ground water more desirable than surface water for many uses. Industrial use of ground water is growing all over the country, but especially in the South and West. Overall ground-water use more than doubled from 1945 to 1960.

The use of ground water for public supplies amounted to 6.3 billion gallons a day in 1960. It was greatest in California, Texas, and Florida. In 1960 there were 10 States each of which pumped a billion gallons a day or more for all uses. California, Texas, and Arizona used far more than a billion a day (11.0, 9.1, and 3.2 bgd, respectively).

In the past, this heavy ground-water development has taken place with relatively little public regulation. Water development was felt to be necessary for economic benefits, and in any case, water rights in States that followed the common law inhibited legal restriction of development. According to common law, rights to ground water are based on ownership of the land. However, in the arid States where water is in short supply, there has been increasing recognition of

FIGURE 15—*Total use of ground water in the United States, 1960.*

the doctrine of "prior appropriation" long used for surface water. Under that doctrine, the first user of water acquires priority to continue that use, whether or not he owns the land from under which the water drains to his wells. Western States that wish to enact legislation to control ground-water development have declared the ground water to be public property. The few Eastern States that have enacted laws so far have tended to depend on the police power to regulate water use in the public interest, under the common law.

The use of so much ground water has created new water problems. Under natural conditions the hydrologic cycle tends to be in balance, but man's use of the water upsets this balance. Use of water without knowledge of the effects of use or in disregard of them might be called exploitation. In contrast, management of water resources is use with knowledge of the probable effects and with planning to minimize adverse effects.

Early development in the High Plains of Texas offers a good example of exploitation of ground water. Largely as a result of heavy pumping in the High Plains, Texas is second only to California in its use of ground water; in Texas it is the sole source of supply for nearly 600 towns and cities in the State, and is the principal source used for irrigation. In 1960 Texas withdrew about a fifth of all the ground water used in the United States. Use of ground water is heaviest in the southern High Plains, where it has been stimulated by a long drought. In 1958 more than 1,000 wells were added to the tens of thousands already in existence, and water levels have been declining for years. In this area, the water reserve is gradually being mined.

The principal aquifer in the southern High Plains of Texas, the Ogallala Formation, originally stored nearly 250 million acre-feet of water, a very large quantity. Unfortunately, because of the semiarid climate and flat surface (which encourage evaporation at the expense of runoff and ground-water recharge), the rate of replenishment of the ground water is very low. At the end of 1961 nearly 50 million acre-feet had already been pumped, and the current rate of pumping is more than 50 times the estimated recharge rate. Actually, the rate of withdrawal will decrease gradually as water levels deepen. Because of the cost of the pumping lift, a balance will be struck long before the aquifer is depleted.

Surplus surface water to recharge the ground-water reservoir artificially is not available. Artificial recharge through wells, using rainwater that accumulates in depressions is being tried. However, this can help the situation only locally and temporarily. Conservation measures to reduce water waste are being used on an increasing scale.

Strict regulation to limit the amount of pumping would alleviate the situation, of course, but it would effect a complete change in the economy of the area. It is true that reversion to dry farming and grazing would reduce the water demand drastically. Conversion of irrigated land to other uses, principally housing, is already marked in a few areas in Arizona and California, but so far not in Texas. The economy of the High Plains area is firmly based on ground-water mining. Just leaving the water in the aquifer is less beneficial than mining it. It is the rate of depletion which causes concern.

What will happen when irrigation pumping decreases greatly, as it inevitably will, is not certain. Under the laws of Texas, underground water conservation districts have been formed in the High Plains and are promoting conservation measures to increase recharge, take advantage of storm runoff for irrigation and artificial recharge, and reduce waste. Minimum well spacing is required, to spread the pumping and reduce the rate of water-table decline. The problem is very much on the minds of the people of Texas, and more and more thought is being given to the future economic adjustments that will have to be made. Thus the term *exploitation*, as it implies development without knowledge of the consequences, no longer applies. It is still too early to use the term *water management*, however.

On the Snake River Plain in Idaho, something opposite to ground-water mining has happened. The Plain is underlain by a very large body of ground water. It also is an area of little precipitation. But here rainfall and snowmelt in the mountains feed the rivers, and much surface water is used for irrigation. Excess irrigation water has filtered into the ground and joined the original ground-water body, increasing the rate of discharge of ground water into the Snake River by nearly 50 percent. In this area as a whole, to date, water has not been mined; it has been put in the bank. A tremendous ground-water reserve has been building up and could be managed to great advantage.

For an example of good water management, consider Louisville, Ky. During World War II, pumping from closely placed industrial wells increased greatly. From 37 million gallons a day, use rose to 75 mgd, and the water levels in some wells declined nearly to bedrock. The city officials and the War Production Board called on the U.S. Geological Survey for advice. Survey hydrologists in cooperation with local and State agencies mapped the aquifer and studied its rate of natural recharge. It became clear that Louisville was living beyond its means, so far as ground water was concerned. The adjacent Ohio River was available, but substitution of its water for that from wells would have been difficult or impossible, in view of shortages of critical materials such as pumps and pipe. Conservation measures were adopted as rapidly as possible to reduce the ground-water draft, and filtered city water from the river was injected into wells at two plants where conditions were most critical. The water was injected during the winter, when it was cold, and thus made the wells even more effective for their principal use, for cooling, when the water was repumped the next summer. The ground-water draft is now stable and water levels have recovered to previous stages throughout most of the area.

Good management of ground-water resources depends upon knowledge of basic water facts. We need more detailed studies of ground water in local areas, and more basic research on replenishment and movement of ground water. We need to know more about ground-water chemistry also. We must continue to improve our methods of storing surplus water in underground reservoirs.

The ground water that seeps into streams provides the base flow of the streams—the low flow that is sustained through the driest part of the year. If water levels decline because of heavy pumping, the base flow of streams will be reduced. Ground and surface waters are inextricably connected and should be studied together. In plans for river-basin development ground water has commonly been neglected, yet plans for river basins may vitally affect the ground-water reservoir, and vice versa. The rate of natural replenishment need not limit the use of ground water if floodwaters can be used to increase recharge artificially. River-basin development might include a coordinated program of flood control and artificial recharge.

However, even the hydrologic facts on ground water are not enough. We must know also what the demand is for water in a given area, what the economic trends are, what the future demand may be. What will be the effects of withdrawal and use of water upon the ground-water reservoir? In our water-resources bank the bookkeeping still is not adequate.

The Geological Survey has collected a great deal of information on ground-water resources, much of this work having been done in cooperation with the States, and some States are making studies on their own. Much remains to be done, however, and there are few areas in which the scale of the program is yet adequate to meet the growing needs.

Are there any ways of saving ground water, or making it go further in areas where it is desperately needed? Ground-water problems are most critical in the Western States. The population of these States is expected to increase faster than the national average. Availability of ground water for agriculture, public supplies, and industry is therefore especially important in the West. There are several measures which, if undertaken on a large scale, would conserve the supply of ground water. Some crops require a good deal of water. Other crops using less water perhaps could be substituted in some areas. Natural replenishment can be increased in many places by increasing the rate of infiltration into the soil or streambeds. Certain nonuseful plants and shrubs, such as saltcedar, consume great quantities of water. Research to discover feasible methods of controlling their growth or eradicating them completely is now active. Reduction of evaporation from reservoirs, and even of transpiration by certain methods of soil treatment, holds some promise. Gradual conversion from irrigation to uses that extract more dollars from a given volume of water is bound to be a principal method, but economic disruptions must be minimized.

Where feasible, water of inferior quality instead of first-quality water could be used for certain industrial processes. For cooling and certain other purposes, the same water can be used several times. The process of desalination of brackish water is being refined and improved, and it is hoped it will eventually become more economical. Irrigation, municipal, and industrial use could all be regulated by the States to maintain economy of use and prevent waste. Surplus surface water could be stored in underground reservoirs. None of these measures is easy or inexpensive, but some or all of them will become necessary as time goes on.

In the past, the problem used to be to locate ground-water supplies. Now, with years of experience behind them, geologists and well drillers can find water very quickly and easily. The real problem is not to find water but to evaluate the ground-water resource and to manage it prudently, once we have found it.

Ground water is our principal reserve source of fresh water. You may not have a well on your property. You, as an individual, may use little or no ground water. Yet your city, the industry where you are employed, or the farm that produces some of your food may depend on ground water for supply or for emergency reserve. If a nuclear war should contaminate surface water supplies, ground-water reservoirs may be the principal or even the only uncontaminated sources of water.,

Thus, every individual has a stake in our ground-water resource, whether he is a well owner or not. Groups of individuals in a community will have to make decisions regarding water supply and disposal—decisions which may affect the ground-water resource, or be affected by it. The citizen can make a sounder decision if he has some understanding of the principles of ground-water occurrence. Even the simple facts contained in this primer can help people make wiser judgments about the use of our ground-water resource.

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