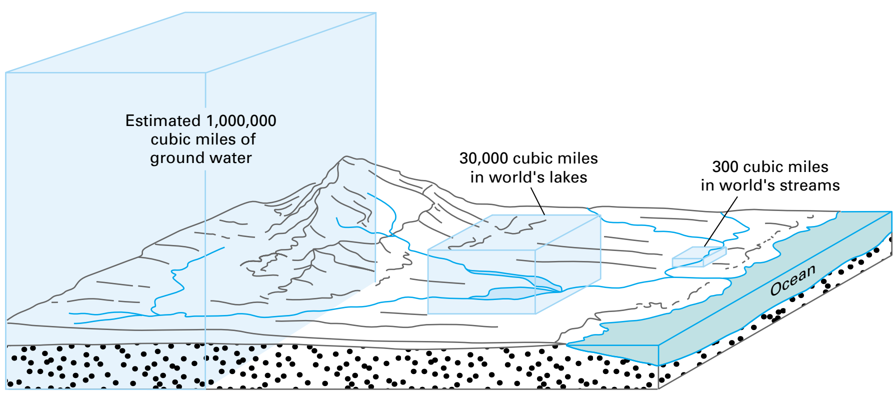
Ground Water

Some water underlies the Earth's surface almost everywhere, beneath hills, mountains, plains, and deserts. It is not always accessible, or fresh enough for use without treatment, and it's sometimes difficult to locate or to measure and describe. This water may occur close to the land surface, as in a marsh, or it may lie many hundreds of feet below the surface, as in some arid areas of the West. Water at very shallow depths might be just a few hours old; at moderate depth, it may be 100 years old; and at great depth or after having flowed long distances from places of entry, water may be several thousands of years old.

Ground water is stored in, and moves slowly through, moderately to highly permeable rocks called *aquifers*. The word *aquifer* comes from the two Latin words, *aqua*, or water, and *ferre*, to bear or carry. Aquifers literally carry water underground. An aquifer may be a layer of gravel or sand, a layer of sandstone or cavernous limestone, a rubbly top or base of lava flows, or even a large body of massive rock, such as fractured granite, that has sizable openings. In terms of storage at any one instant in time, ground water is the largest single supply of fresh water available for use by humans.

Springs in Snake River Plain, Idaho.

Ground water has been known to humans for thousands of years. Scripture (Genesis 7:11) on the Biblical Flood states that “the fountains of the great deep (were) broken up,” and Exodus, among its many references to water and to wells, refers (20:4) to “water under the Earth.” Many other ancient chronicles show that humans have long known that much water is contained underground, but it is only within recent decades that scientists and engineers have learned to estimate how much ground water is stored underground and have begun to document its vast potential for use. An estimated one million cubic miles of the world’s ground water is stored within one-half mile of the land surface. Only a fraction of this reservoir of ground water, however, can be practicably tapped and made available on a perennial basis through wells and springs. The amount of ground water in storage is more than 30 times greater than the nearly 30,000 cubic-miles volume in all the fresh-water lakes and more than the 300 cubic miles of water in all the world’s streams at any given time.



Comparison of the amount of fresh water in storage.

Water-use specialists at the U.S. Geological Survey report that about 341 billion gallons of freshwater a day was used in the United States in 1995 for public supplies, rural domestic and livestock uses, irrigation, industrial and mining uses, and for thermoelectric power. About 22 percent of this water, or 76.4 billion gallons a day, was ground water that was obtained from wells and springs. The use of ground water in seven States — Arkansas, Florida, Hawaii, Kansas, Mississippi, Nebraska, and Oklahoma —

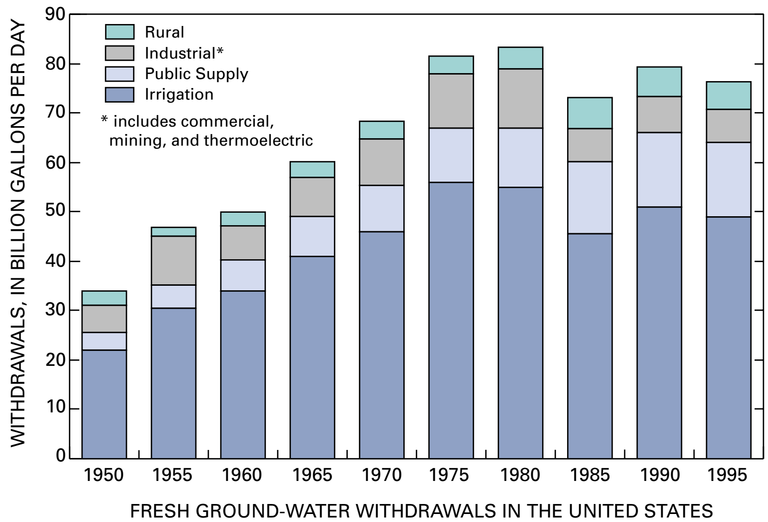
Comparison of ground-water use with total water use in the United States, 1995

[Bgal/d, billion gallons per day. Number in parentheses represents the percentage of ground water as part of total water use for each category]

Type of use	Total water use in Bgal/d	Ground-water use in Bgal/d
Public supplies	40	15 (38)
Rural domestic and livestock	9	6 (63)
Irrigation	134	49 (37)
Industrial	26	6 (23)
Thermoelectric	132	1 (0)
Totals	341	76 (22)
Totals, (excluding thermoelectric)	209	75 (36)

Source: U.S. Geological Survey Circular 1200—Estimated use of water in the United States in 1995

exceeded the use of surface water. Five western States — California, Idaho, Kansas, Nebraska, and Texas — used about 35 billion gallons per day of ground water. This average daily water use of 35 billion gallons accounts for about 46 percent of the total volume of ground water used in the Nation during 1995. The use of ground water increased steadily from 1950 to 1980 and generally has decreased since 1980. About 51 percent of the Nation's population depends on ground water for domestic uses.

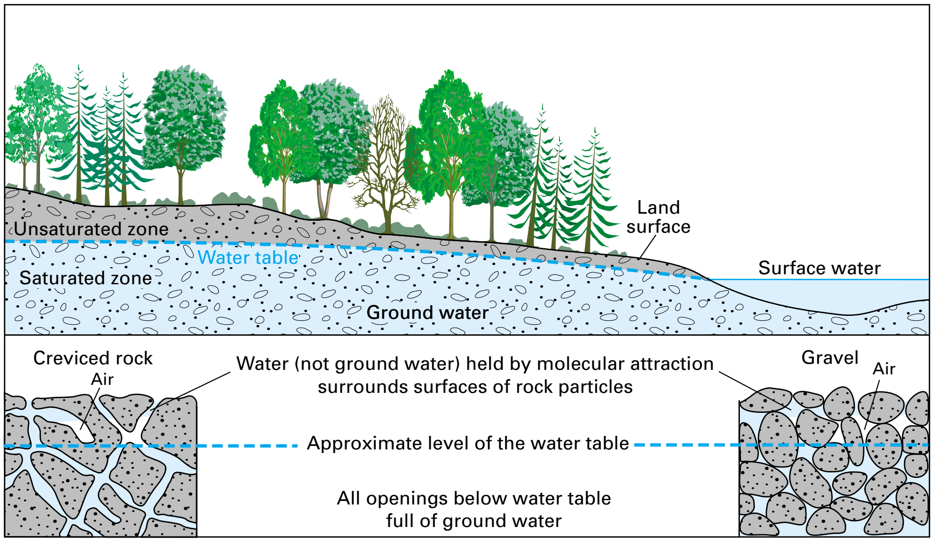


Withdrawals of fresh ground water, 1950 to1995.

The Nation's total supply of water is large. Average annual streamflow in the conterminous (48) States is about 1,200 billion gallons a day or about three times the present water use. Much of the flow is sustained by discharge from ground-water reservoirs. The distribution of water in both space and time is irregular, and some areas already face serious regional water shortages because of using some water faster than it is naturally replenished. Further development of energy, mineral, and agricultural resources is dependent largely upon adequate water supplies. Therefore, ground-water resources will become even more valuable in the years ahead as the Nation copes with growing natural-resource and environmental problems and increased water demands.

How Ground Water Occurs

It is difficult to visualize water underground. Some people believe that ground water collects in underground lakes or flows in underground rivers. In fact, ground water is simply the subsurface water that fully saturates pores or cracks in soils and rocks. *Ground water* is replenished by precipitation and, depending on the local climate and geology, is unevenly distributed in both quantity and quality. When rain falls or snow melts, some of the water evaporates, some is transpired by plants, some flows overland and collects in streams, and some infiltrates into the pores or cracks of the soil and rocks. The first water that enters the soil replaces water that has been evaporated or used by plants during a preceding dry period. Between the land surface and the aquifer water is a zone that hydrologists call the unsaturated zone. In this *unsaturated zone*, there usually is at least a little water, mostly in smaller openings of the soil and rock; the larger openings usually contain air instead of water. After a significant rain, the zone may be almost saturated; after a long dry spell, it may be almost dry. Some water is held in the unsaturated zone by *molecular attraction*, and it will not flow toward or enter a well. Similar forces hold enough water in a wet towel to make it feel damp after it has stopped dripping.



How ground water occurs in rocks.

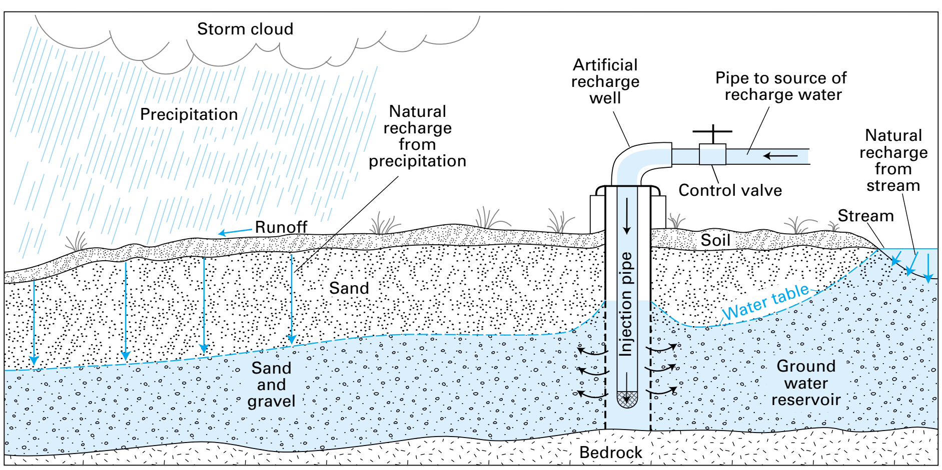
After the water requirements for plant and soil are satisfied, any excess water will infiltrate to the *water table* — the top of the zone below which the openings in rocks are saturated. Below the water table, all the openings in the rocks are full of water that moves through the aquifer to streams, springs, or wells from which water is being withdrawn. Natural refilling of aquifers at depth is a slow process because ground water moves slowly through the unsaturated zone and the aquifer. The rate of recharge is also an important consideration. It has been estimated, for example, that if the aquifer that underlies the High Plains of Texas and New Mexico — an area of slight precipitation — was emptied, it would take centuries to refill the aquifer at the present small rate of replenishment. In contrast, a shallow aquifer in an area of substantial precipitation may be replenished almost immediately.

Aquifers can be replenished artificially. For example, large volumes of ground water used for air conditioning are returned to aquifers through recharge wells on Long Island, New York. Aquifers may be artificially recharged in two main ways: One way is to spread water over the land in pits, furrows, or ditches, or to erect small dams in stream channels to detain and deflect surface runoff, thereby allowing it to infiltrate to the aquifer; the other way is to construct recharge wells and inject water directly into an aquifer as shown on page 8. The latter is a more expensive method but may be justified where the spreading method is not feasible. Although some artificial-recharge projects have been successful, others have been disappointments; there is still much to be learned about different ground-water environments and their receptivity to artificial-recharge practices.

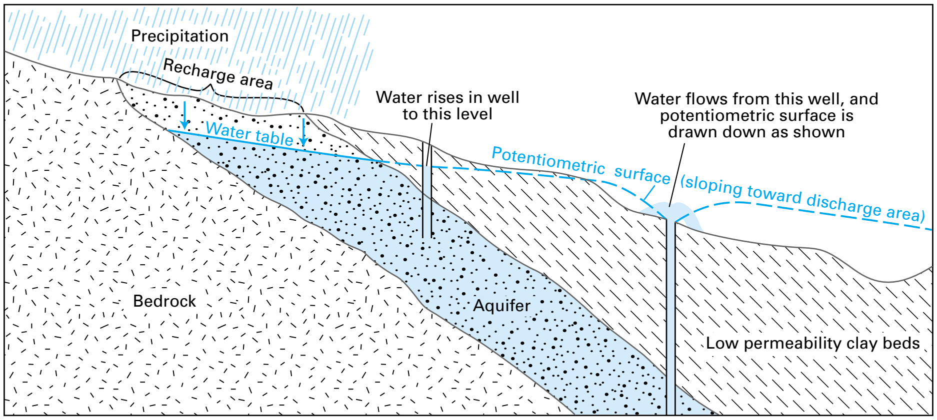
A well, in simple concept, may be regarded as nothing more than an extra large pore in the rock. A well dug or drilled into saturated rocks will fill with water approximately to the level of the water table. If water is pumped from a well, gravity will force water to move from the saturated rocks into the well to replace the pumped water. This leads to the question: Will water be forced in fast enough under a pumping stress to assure a continuing water supply? Some rock, such as clay or solid granite, may have only a few hairline cracks through which water can move. Obviously, such rocks transmit only small quantities of water and are poor aquifers. By comparison, rocks such as fractured sandstones and cavernous limestone have large connected openings that permit water to move more freely; such rocks transmit larger quantities of water and are good aquifers. The amounts of water that an aquifer will yield to a well may range from a few hundred gallons a day to as much as several million gallons a day.

An aquifer may be only a few or tens of feet thick to hundreds of feet thick. It may lie a few feet below the land surface to thousands of feet below. It may underlie thousands of square miles to just a few acres. The Dakota Sandstone, for example, carries water over great distances beneath many States, including parts of North Dakota, South Dakota, Montana, Wyoming, Colorado, Nebraska, Kansas, New Mexico, and Oklahoma. On the other hand, deposits of sand and gravel along many streams form aquifers of only local extent.

The quantity of water a given type of rock will hold depends on the rock's *porosity* — a measure of pore space between the grains of the rock or of cracks in the rock that can fill with water. For example, if the grains of a sand or gravel aquifer are all about the same size, or "well sorted," the water-filled spaces between the grains account for a large proportion of the volume of the aquifer. If the grains, however, are poorly sorted, the spaces between larger grains may be filled with smaller grains instead of water. Sand and gravel aquifers having well-sorted grains, therefore, hold and transmit larger quantities of water than such aquifers with poorly sorted grains.



Natural and artificial recharge of an aquifer.



Artesian aquifer. Both wells are artesian wells, although only one flows.

If water is to move through rock, the pores must be connected to one another. If the pore spaces are connected and large enough that water can move freely through them, the rock is said to be *permeable*. A rock that will yield large volumes of water to wells or springs must have many interconnected pore spaces or cracks. A compact rock almost without pore spaces, such as granite, may be permeable if it contains enough sizable and interconnected cracks or fractures. Nearly all consolidated rock formations are broken by parallel systems of cracks, called *joints*. These joints are caused by stresses in the Earth's crust. At first many joints are hairline cracks, but they tend to enlarge through the action of many physical and chemical processes. Ice crystals formed by water that freezes in rock crevices near the land surface 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 may gradually dissolve the rock or erode weathered rock and thereby enlarge the openings.

A relationship does not necessarily exist between the water-bearing capacity of rocks and the depth at which they are found. A very dense granite that will yield little or no water to a well may be exposed at the land surface. Conversely, a porous sandstone, such as the Dakota Sandstone mentioned previously, may lie hundreds or thousands of feet below the land surface and may yield hundreds of gallons per minute of water. 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 30,000 feet. On the average, however, the porosity and permeability of rocks decrease as their depth below land surface increases; the pores and cracks in rocks at great depths are closed or greatly reduced in size because of the weight of overlying rocks.

After entering an aquifer, water moves slowly toward lower lying places and eventually is discharged from the aquifer from springs, seeps into streams, or is intercepted by wells. Ground water in aquifers between layers of poorly permeable rock, such as clay or shale, may be confined under pressure. If such a confined aquifer is tapped by a well, water will rise above the top of the aquifer and may even flow from the well onto the land surface. 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, where the best known flowing artesian wells were drilled in the Middle Ages. The level to which water will rise in tightly cased wells in artesian aquifers is called the *potentiometric surface*.

Deep wells drilled into rock to intersect the water table and reaching far below it are often called artesian wells in ordinary conversation, but this is not necessarily a correct use of the term. Such deep wells may be just like ordinary, shallower wells; great depth alone does not automatically make them artesian wells. The word artesian, properly used, refers to situations where the water is confined under pressure below layers of relatively impermeable rock.

Water being pumped from a well.

Water under artesian pressure flowing from a well.

Where ground water is not confined under pressure, it is described as being under *water-table* conditions. Water-table aquifers generally are recharged locally, and water tables in shallow aquifers may fluctuate up and down directly in unison with precipitation or streamflow.

A *spring* is the result of an aquifer being filled to the point that the water overflows onto the land surface. There are different kinds of springs and they may be classified according to the geologic formation from which they obtain their water, such as limestone springs or lava-rock springs; or 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 spring — gravity or artesian flow.

Thermal springs are ordinary springs except that the water is warm and, in some places, hot. Many thermal springs occur in regions of recent volcanic activity and are fed by water heated by contact with hot rocks far below the surface. Such are the thermal springs in Yellowstone National Park. Even where there has been no recent volcanic action, rocks become warmer with increasing depth. In some such areas water may migrate slowly to considerable depth, warming as it descends through rocks deep in the Earth. If it then reaches a large crevice that offers a path of less resistance, it may rise more quickly than it descended. Water that does not have time to cool before it emerges forms a thermal spring. The famous Warm Springs of Georgia and Hot Springs of Arkansas are of this type. *Geysers* are thermal springs that erupt intermittently and to differing heights above the land surface. Some geysers are spectacular and world famous, such as Old Faithful in Yellowstone National Park.

Quality of Ground Water

For the Nation as a whole, the chemical and biological character of ground water is acceptable for most uses. The quality of ground water in some parts of the country, particularly shallow ground water, is changing as a result of human activities. Ground water is less susceptible to bacterial pollution than surface water because the soil and rocks through which ground water flows screen out most of the bacteria. Bacteria, however, occasionally find their way into ground water, sometimes in dangerously high concentrations. But freedom from bacterial pollution alone does not mean that the water is fit to drink. Many unseen dissolved mineral and organic constituents are present in ground water in various concentrations. Most are harmless or even beneficial; though occurring infrequently, others are harmful, and a few may be highly toxic.

Water is a solvent and dissolves minerals from the rocks with which it comes in contact. Ground water may contain dissolved minerals and gases that give it the tangy taste enjoyed by many people. Without these minerals and gases, the water would taste flat. The most common dissolved mineral substances are sodium, calcium, magnesium, potassium, chloride, bicarbonate, and sulfate. In water chemistry, these substances are called *common constituents*.

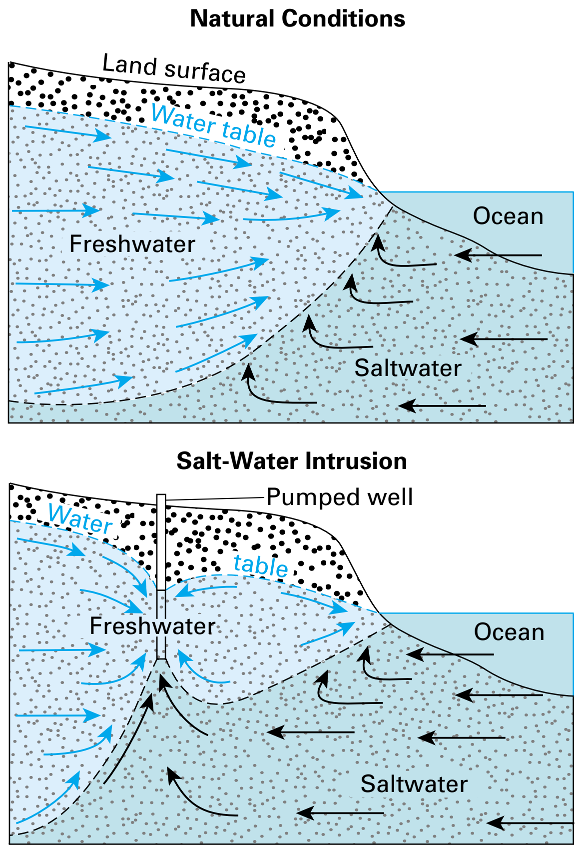
Water typically is not considered desirable for drinking if the quantity of dissolved minerals exceeds 1,000 mg/L (milligrams per liter). Water with a few thousand mg/L of dissolved minerals is classed as slightly *saline*, but it is sometimes used in areas where less-mineralized water is not available. Water from some wells and springs contains very large concentrations of dissolved minerals and cannot be tolerated by humans and other animals or plants. Many parts of the Nation are underlain at depth by highly saline ground water that has only very limited uses.

Dissolved mineral constituents can be hazardous to animals or plants in large concentrations; for example, too much sodium in the water may be harmful to people who have heart trouble. Boron is a mineral that is good for plants in small amounts, but is toxic to some plants in only slightly larger concentrations.

Water that contains a lot of calcium and magnesium is said to be *hard*. The hardness of water is expressed in terms of the amount of calcium carbonate — the principal constituent of limestone — or equivalent minerals that would be formed if the water were evaporated. Water is considered soft if it contains 0 to 60 mg/L of hardness, moderately hard from 61 to 120 mg/L, hard between 121 and 180 mg/L, and very hard if more than 180 mg/L. Very hard water is not desirable for many domestic uses; it will leave a scaly deposit on the inside of pipes, boilers, and tanks. Hard water can be softened at a fairly reasonable cost, but it is not always desirable to remove all the minerals that make water hard. Extremely soft water is likely to corrode metals, although it is preferred for laundering, dishwashing, and bathing.

Ground water, especially if the water is acidic, in many places contains excessive amounts of iron. Iron causes reddish stains on plumbing fixtures and clothing. Like hardness, excessive iron content can be reduced by treatment. A test of the acidity of water is pH, which is a measure of the hydrogen-ion concentration. The pH scale ranges from 0 to 14. A pH of 7 indicates neutral water; greater than 7, the water is basic; less than 7, it is acidic. A one unit change in pH represents a 10-fold difference in hydrogen-ion concentration. For example, water with a pH of 6 has 10 times more hydrogen-ions than water with a pH of 7. Water that is basic can form scale; acidic water can corrode. According to U.S. Environmental Protection Agency criteria, water for domestic use should have a pH between 5.5 and 9.

In recent years, the growth of industry, technology, population, and water use has increased the stress upon both our land and water resources. Locally, the quality of ground water has been degraded. Municipal and industrial wastes and chemical fertilizers, herbicides, and pesticides not properly contained have entered the soil, infiltrated some aquifers, and degraded the ground-water quality. Other pollution



How intensive ground-water pumping can cause salt-water intrusion in coastal aquifers.

problems include sewer leakage, faulty septic-tank operation, and landfill leachates. In some coastal areas, intensive pumping of fresh ground water has caused salt water to intrude into fresh-water aquifers.

In recognition of the potential for pollution, biological and chemical analyses are made routinely on municipal and industrial water supplies. Federal, State, and local agencies are taking steps to increase water-quality monitoring. Analytical techniques have been refined so that early warning can be given, and plans can be implemented to mitigate or prevent water-quality hazards.

Appraising the Nation's Ground-Water Resources

Although there are sizable areas where ground water is being withdrawn at rates that cause water levels to decline persistently, as in parts of the dry Southwest, this is not true throughout the country. For the Nation as a whole, there is neither a pronounced downward nor upward trend. Water levels rise in wet periods and decline in dry periods. In areas where water is not pumped from aquifers in excess of the amount of recharge to the aquifer — particularly in the humid central and eastern parts of the country — water levels average about the same as they did in the early part of the twentieth century.

A major responsibility of the U.S. Geological Survey is to assess the quantity and quality of the Nation's water supplies. The Geological Survey, in cooperation with other Federal, State, and local agencies, maintains a nationwide hydrologic-data network, carries out a wide variety of water-resources investigations, and develops new methodologies for studying water. The results of these investigations are indispensable tools for those involved in water-resources planning and management. Numerous inquiries concerning water resources and hydrology are directed to the Survey and to State water-resources and geological agencies.

To locate ground water accurately and to determine the depth, quantity, and quality of the water, several techniques must be used, and a target area must be thoroughly tested and studied to identify hydrologic and geologic features important to the planning and management of the resource. The landscape may offer clues to the hydrologist about the occurrence of shallow ground water. Conditions for large quantities of shallow ground water are more favorable under valleys than under hills. In some regions — in parts of the arid Southwest, for example — the presence of "water-loving" plants, such as cottonwoods or willows, indicates ground water at shallow to moderate depth. Areas where water is at the surface as springs, seeps, swamps, or lakes reflect the presence of ground water, although not necessarily in large quantities or of usable quality.

Rocks are the most valuable clues of all. As a first step in locating favorable conditions for ground-water development, the hydrologist prepares geologic maps and cross sections showing the distribution and positions of the different kinds of rocks, both on the surface and underground. Some sedimentary rocks may extend many miles as aquifers of fairly uniform permeability. Other types of rocks may be cracked and broken and contain openings large enough to carry water. Types and orientation of joints or other fractures may be clues to obtaining useful amounts of ground water. Some rocks may be so folded and displaced that it is difficult to trace them underground.

Next, a hydrologist obtains information on the wells in the target area. The locations, depth to water, amount of water pumped, and types of rocks penetrated by wells also provide information on ground water. Wells are tested to determine the amount of water moving through the aquifer, the volume of water that can enter a well, and the effects of pumping on water levels in the area. Chemical analysis of water from wells provides information on quality of water in the aquifer.

Evaluating the ground-water resource in developed areas, prudent management of the resource, and protection of its quality are current ground-water problems. Thus, prediction of the capacity of the ground-water resource for long-term pumpage, the effects of that pumpage, and evaluation of water-quality conditions are among the principal aims of modern-day hydrologic practice in achieving proper management of ground water.

Ground water, presently a major source of water, is also the Nation's principal reserve of fresh water. The public will have to make decisions regarding water supply and waste disposal — decisions that will either affect the ground-water resource or be affected by it. These decisions will be more judicious and reliable if they are based upon knowledge of the principles of ground-water occurrence.

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