Getting Up to Speed

NEW ENGLAND'S GROUND WATER RESOURCES

THE ZONES

Water that falls to the earth in the form of rain, snow, sleet, or hail continues its journey in one of four ways: It might land on a water body and, essentially, go with the flow; it might run off the land into a nearby water body or storm drain; it might evaporate from a water body or land surface; or it might seep into the ground. Water that seeps into the ground moves in a downward direction, passing through the **pore spaces** between the rock and soil particles in what is known as the **zone of aeration**, or **unsaturated zone.**

Eventually the water reaches a depth where the pore spaces are already filled, or saturated, with water. When water enters this **saturated zone**, it becomes part of the **ground water**. Ground water is essentially everywhere at varying distances below the surface of the earth, wherever there are spaces, pores, or cracks in the soil or rock for it to fill. The process whereby precipitation or surface water infiltrates the soil and replenishes the ground water is called **ground water recharge**.

The top of the saturated zone is called the **water table**. The water table may be very close to the ground surface, which is often the case in New England when it is next to a surface water body, or it may be as much as 200 to 600 feet deep, which is the case in many areas of the southwestern United States.

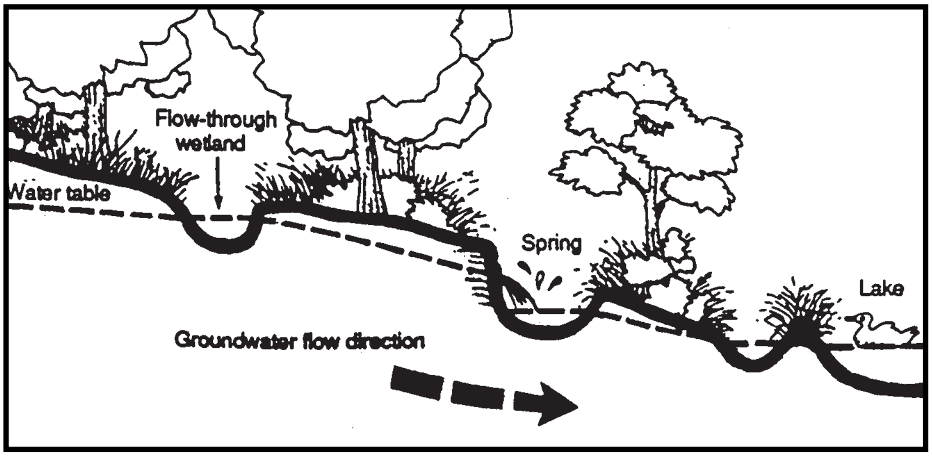
The saturated zone is underlain by **impermeable** rock or soil (e.g., a clay layer), which prevents further downward movement of water. When the water reaches this impermeable area, it begins to collect in the overlying soil pore spaces or rock fractures, thereby creating the saturated zone, or ground water area.

GROUND WATER DYNAMICS

Ground water is very much a part of nature's hydrologic cycle. Like water on the earth's surface, ground water tends to flow downhill under the influence of gravity and eventually discharges, or flows out of the ground, into streams or other surface water-dependent areas, such as wetlands. In New England, it is common to see ground water emerging from a hillside as a spring or seeping out of a road cut. During winter months, the ground water often freezes into long icicles as it seeps out of the rocks.

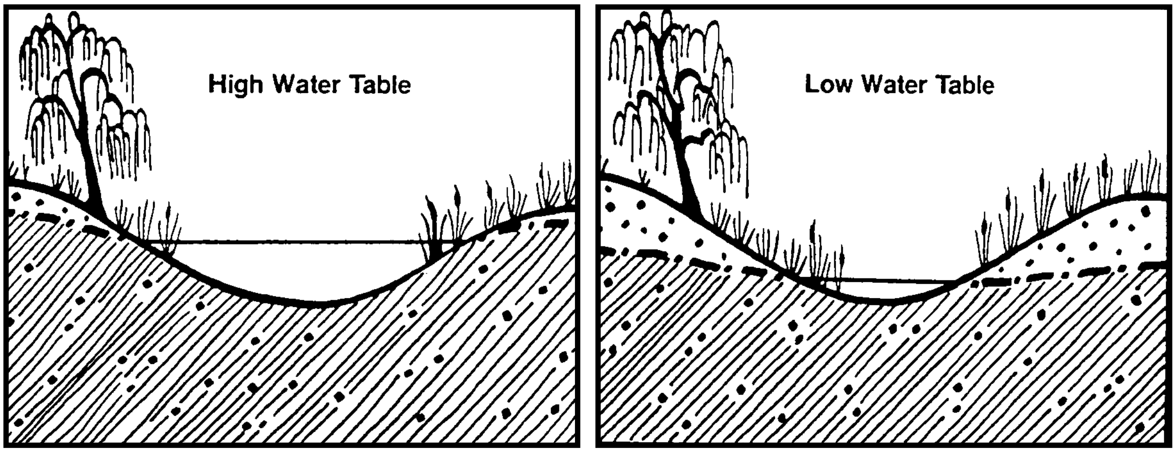
In such **discharge areas** (see Figure 1), the water table is at or near the land surface. In fact, most

Figure 1 GROUND WATER DISCHARGE AREA



Source: Lyle S. Raymond Jr. *What is Groundwater?* Bulletin #1. Cornell University. July 1988

Figure 2 WATER TABLE LEVELS



Source: Massachusetts Audubon Society. *An Introduction to Groundwater and Aquifers.* Groundwater Information Flyer #1. January 1993.

streams in New England keep flowing during the dry summer months because ground water discharges into them from the saturated zone. It is only when the water table falls below the level of the stream bed that a stream may dry up completely. Under certain conditions the flow may be reversed and the surface water may recharge the ground water.

Compared with water in rivers and streams, ground water moves very, very slowly—from as little as a fraction of a foot per day in clay, to as much as 3-4 feet per day in sand and gravel, to tens of feet per day in bedrock formations.

The speed at which ground water moves is determined by the types of material it must flow through and the steepness of the gradient from the recharge area to discharge area. Water moves more easily through the large pores of sand and gravel, for example, than through material that contains fine silt and clay.

The water table doesn't remain at the same level, or depth, all the time. The rise and fall, or **fluctuation**, of the water table occurs seasonally and is a natural part of the ground water system. In late winter and early spring, melting snow and rain infiltrate the soil, causing ground water levels to rise. The water table typically reaches its annual high level at this time. By late spring and into the summer months, when water is typically taken up by growing vegetation, little ground water recharge occurs, and the water table lowers. Ground water is recharged again during the fall rains after the growing season. In the winter, the ground is frozen and very little precipitation enters the ground water. In the spring, the snow melts, the rain falls, and the cycle begins anew.

The water table also responds to cyclical periods of drought and heavy precipitation that can last for several years (see Figure 2). For example, from 1979 to 1981, much of New England experienced a drought. The water table dropped steadily during those years. By the end of that period, the water table in many places was several feet lower than normal. In 1982, the drought ended when heavy rains fell and the ground water levels began to rise again. By early 1983, the water table was so high that many cellars that had never been wet before were flooded with ground water.

Surface waters also have a very dynamic relationship with ground water. Depending on the level of the ground water table, streams either receive ground water discharges, called **gaining streams**, or lose water to the adjacent ground water, called **losing streams**. In New England, where ground water levels are often relatively close to the ground surface, streams tend to receive ground water discharges. In this situation, the level of water in the stream is the same as that of the water table. This is true for wetlands, ponds, and lakes as well. More than half of the total flow of some streams during dry periods may derive from ground water discharge.

Ignoring the natural fluctuations in ground water levels can lead to expensive problems. For example, septic systems, drainage systems, and foundations designed and built for ground water conditions during drought conditions, when the water table is very low, can be flooded when the water table returns to more normal levels. In New England, the average depth to ground water ranges from 8 to 20 feet.

OUR WATER BUDGET

A **water budget**, similar to a household financial budget, can be developed to track water movement through the hydrologic cycle. The "receipts" are the water coming into the drainage basin, or **watershed**, and consist of the **precipitation** that falls within the basin as rain or snow. The "disbursements" consist of water vapor released by evaporation or by transpiration from green plants (collectively called **evapotranspiration**) and the water that is carried away into streams and rivers as **runoff**. Finally, the "savings" consist of surface water stored in lakes, ponds, and other water bodies, and ground water stored beneath the earth's surface. Water is continually withdrawn (discharged) from these storage areas and deposited (recharged).

The water budget within a drainage area depends not only on the water received as rain and snow, but also on how rapidly water leaves the basin. Topography, geology, soils, vegetation, and land use can all affect the rate of water storage and loss. Much of the precipitation that falls on steep slopes or on **impervious** surfaces, such as roofs and pavement, flows over the surface of the ground as runoff to streams that eventually carry it out of the basin. Rain falling on flatter, unpaved areas, however, can **infiltrate** into the soil. Vegetation can intercept precipitation as it falls to the earth and slow runoff so the water has a chance to infiltrate. the water budget is also affected when water is withdrawn from one basin and then discharged into another basin after it is used (e.g., when water is piped out of one basin to a wastewater facility, where it is treated and then discharged into a different basin.)

DRAWING WATER FROM A WELL

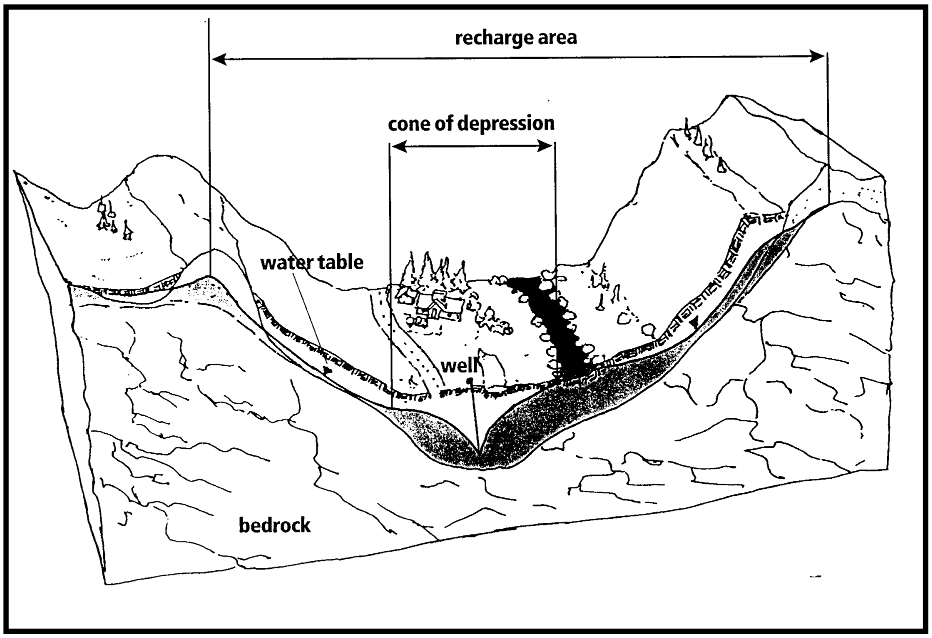
When people use ground water as a water supply source, the water is withdrawn from the ground by way of a **well**. Wells tap ground water as it flows through surficial deposits or cracks and fractures in bedrock. In almost all wells, the water must be pumped from the ground water to the surface.

Pumping depresses the water table around the well, forming a **cone of depression** (a low-pressure zone in the shape of an inverted cone), causing water to flow toward the well from all directions. The cone of depression can range from tens or hundreds of feet in radius for small bedrock wells to several thousand feet for high-volume public wells that draw water from sand and gravel aquifers. (See Figure 3.)

Not all ground water can be drawn into wells. To yield significant quantities of water, wells must be located in aquifers. An **aquifer** is a water-bearing soil or rock formation that is capable of yielding enough water for human use. All the spaces and cracks, or pores, between particles of rock and other materials in an aquifer are saturated with water. In bedrock aquifers, water moves through cracks, or **fractures**. Some types of bedrock—such as sandstone—can absorb water like a sponge; other types of bedrock—such as granite—do not. They hold water only in their fractures. The part of the aquifer that contributes recharge to a well is called the **zone of contribution**.

As wells pump out ground water, they reduce the amount of water in the ground water system,

Figure 3 WELLFIELD RECHARGE AREA



Source: Hust, R. and J. Murphy. *Protecting Connecticut's Groundwater: A Guide for Local Officials.* CTDEP. Hartford. 1997

causing the water table to fluctuate over time. Ideally, the amount of water withdrawn from a well will be balanced by the amount of recharge entering the system by way of rain, snow melt, or surface water body.

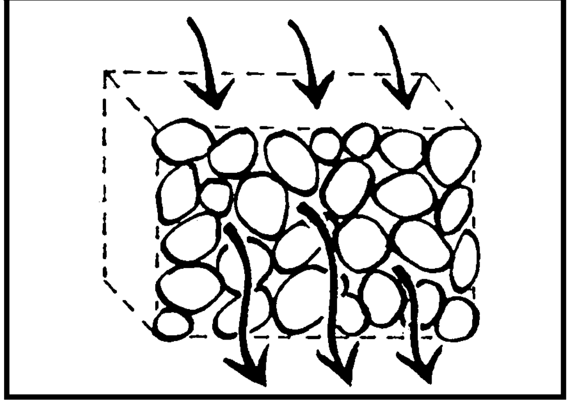
The **porosity** of a material determines how much water it will hold—the more pore space, the more water. Porosity is expressed as a percentage of the total volume of a material. For example, the porosity of a certain sand might be 30 percent; that is, 30 percent of the total volume of the sand is pore space and 70 percent is solid material. It means that 30 percent can be filled with water, or more than 2 gallons of water per cubic foot!

The ability of a material to transmit water is called it's **permeability** (See Figure 4). Permeability is a function of the size and shape of the soil particles, the amount of pore space between the particles, and whether or not the pore spaces interconnect. In consolidated rock, such as granite, permeability depends on how well the fractures in the rock are interconnected. In an unconsolidated material, such as sand and gravel, permeability depends on the size of the pore spaces between the grains of material.

Porosity and permeability are related, but they are not the same thing. A material can be very porous and hold a large volume of water but not be very permeable. For example, clay may be twice as porous as sand, but a pumping well will not be able to pull the water from the pores between clay particles fast enough to supply the well. Very small pore spaces create a resistance to flow that reduces permeability. The best aquifers are both porous and permeable.

When evaluating a ground water system in terms of its suitability as a water supply aquifer, hydrogeologists commonly use the term **hydraulic conductivity**, which is a function of permeability. It is important to understand the concept of perme-

Figure 4 PERMEABILITY:
Water Moving Through Pores



Source: Massachusetts Audubon Society. *An Introduction to Groundwater and Aquifers.* Groundwater Information Flyer #1. January 1993.

ability/hydraulic conductivity because it is one of the key factors used to determine whether ground water can actually be drawn into a pumping well. The three primary factors that determine how much water can be withdrawn by a well are the steepness of the slope of the water table, the hydraulic conductivity, and the thickness and extent of the aquifer.

WHERE ARE OUR AQUIFERS?

■ In Bedrock

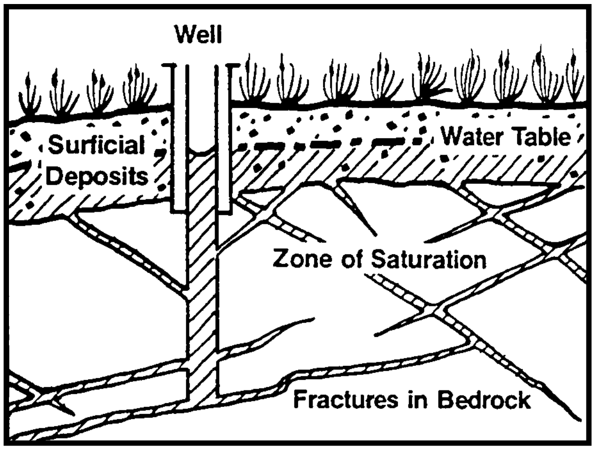
Solid rock can't yield water. Ground water in rock is mostly found in cracks, fractures, or in channels created when water enlarges the fractures in certain carbonate rocks (such as limestone).

Bedrock (see Figure 5) is the rock that lies beneath all the **unconsolidated materials** (soil and loose rocks) on the surface of the earth. It is the earth's crust. (In New England, bedrock is commonly called ledge.) If a well is drilled into bedrock fractures that are saturated with water, bedrock can serve as an aquifer.

In most of New England, however, bedrock is not highly fractured. Fractures generally occur within the first 100 to 150 feet of the surface, and they tend to be rather small, with few interconnections. Consequently, wells that intercept rock fractures can usually yield only enough water for private, domestic supplies. However, there are some highly fractured zones known as faults, where yields in the range of 200,000 to 400,000 gallons per day (gpd) have been developed, primarily for industrial use.

In western Massachusetts and parts of Maine, there are a few areas where bedrock is composed of limestone, a soft carbonate rock. Over time, water can form solution channels in this rock by dissolving the surface of the fractures along which it flows. The solution channels can become very large. They can hold and transmit enough water to provide a sustained yield to large wells. For instance, ground water found in solution channels in limestone is the major source of drinking water in other parts of the country (e.g., Florida).

Figure 5 BEDROCK AS AN AQUIFER



Source: Massachusetts Audubon Society. *An Introduction to Groundwater and Aquifers.* Groundwater Information Flyer #1. January 1993.

■ In Surficial Deposits

Most people would refer to **surficial deposits** as soil, but geologists call the sand, gravel, soils, rocks, and other loose material that lie on top of bedrock surficial deposits. Porous, permeable surficial deposits make good aquifers. Some surficial deposits are porous and permeable. Most are not. What makes the difference?

Most surficial deposits are **heterogeneous**. They consist of a wide variety of material types and sizes. In these deposits, almost all of the spaces between the large material are filled with smaller particles. For example, the spaces between pebbles and large stones may be filled with sand, and the spaces between the grains of sand may be filled with clay. This leaves few pore spaces for ground water storage and makes it difficult for water to move through the pores. Thus, deposits that are a mixture of types and sizes of materials are not usually porous and permeable enough to serve as aquifers.

In other surficial deposits, particles are similar in size and do not fit closely together. This creates many interconnecting pore spaces that can hold water. Some of these deposits contain very fine-grained silt and clay. They are porous but not permeable because the pores are too small to transmit water easily. In some surficial deposits of similar-sized particles such as coarse sand, the pores are large and water can flow through them easily. These deposits are both porous and permeable and are excellent aquifers.

LARGE-VOLUME WELLS NEED LARGE SOURCES OF WATER

The capacity of an aquifer to produce water is determined by the amount of porous, permeable materials that are present and the quantity of water that is available in that material. These factors can be determined for specific aquifers by geologic studies and pumping tests.

To supply a large public well, there must be enough water in storage in the aquifer or a nearby source such as a river or a lake that is connected hydrologically with the aquifer. Often, several wells are needed to supply all the water required by a municipality, but even small public wells are considerably larger than private wells serving single households. A small public well might yield 100,000 gpd, while a private well serving a single home might yield only 500 to 1,000 gpd.

Though most areas contain aquifers that are adequate for private, domestic wells, public wells must be located in aquifers that are large enough to sustain a consistently high yield over a long period of time. Aquifers that are large enough to supply public wells are found only in locations with certain geologic and hydrologic conditions. Protecting them for future use is of great importance.

YOUR WATER SOURCE?

Water supplies are derived from either private or public water systems. A **private water system** is defined by the federal **Safe Drinking Water Act** as a well that provides water for less than 15 service connections or a well that serves less than 25 people. Private water systems are not regulated by the Safe Drinking Water Act. These systems include rural homeowners and farms.

A **public water system** is one that has 15 or more service connections or that regularly serves at least 25 people for 60 or more days per year. Public water systems can be either publicly or privately owned and are subject to minimum water quality standards specified by the Safe Drinking Water Act. Common examples of public water systems include community wells, a well serving a school (with more than 25 students and employees), and wells used by trailer parks. Public water systems derive their water from either surface water (e.g., reservoirs or rivers) or ground water sources.

GLACIERS CREATED OUR AQUIFERS

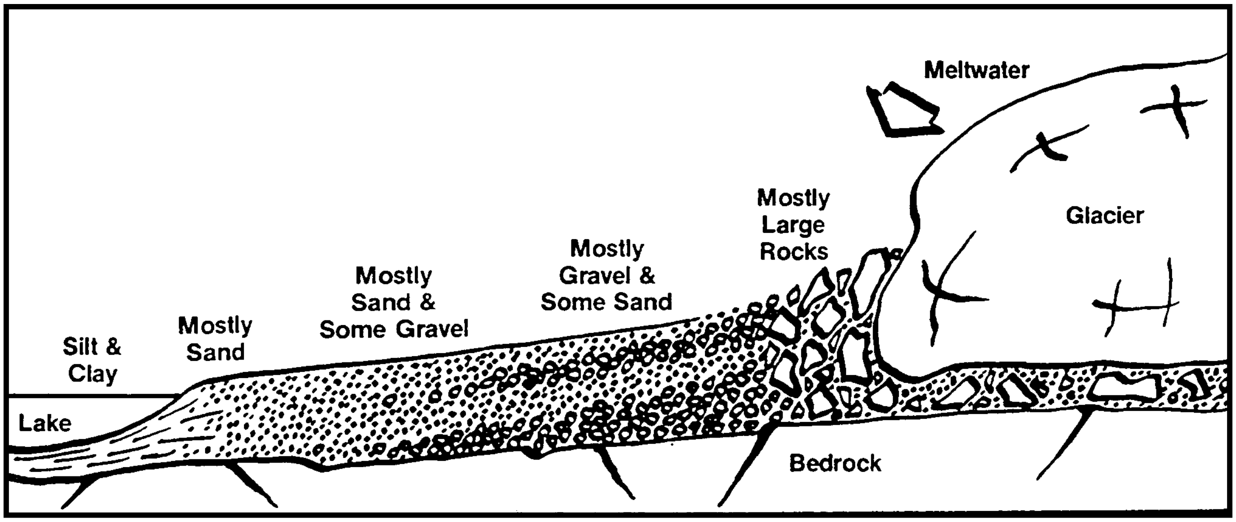
In New England, porous, permeable surficial deposits were created by melting glaciers. Most of New England was covered by continental glaciers a number of times in the past 2 million years. Each glacier moved down over the region from the north, carrying with it large quantities of rocks and soil that it had scraped and plucked from the bedrock as it moved across the land surface. When the last glacier finally melted about 11,000 to 13,000 years ago, it redeposited this material as glacial debris. The region's surficial deposits are mostly glacial debris, topped with a thin layer of soil that has formed since the last glacier melted.

■ Stratified Drift: A Good Aquifer Material

Some glacial debris was carried away by torrents of water that flowed off the melting ice in meltwater streams. At the front of the glacier, these streams flowed so fast that they could transport glacial debris of all sizes except large boulders. As the meltwater moved further away from the glacier, it slowed down. The slower-moving water could no longer carry pebbles and gravel, so that debris settled out. Further along, when the water slowed more, sand grains settled out. Still further downstream, the water reached a lake or the ocean, and slowed completely. By this time, only very small particles remained suspended in the moving meltwater stream (see Figure 6).

When the water stopped flowing after it entered

Figure 6 GLACIAL MELTWATER STREAMS



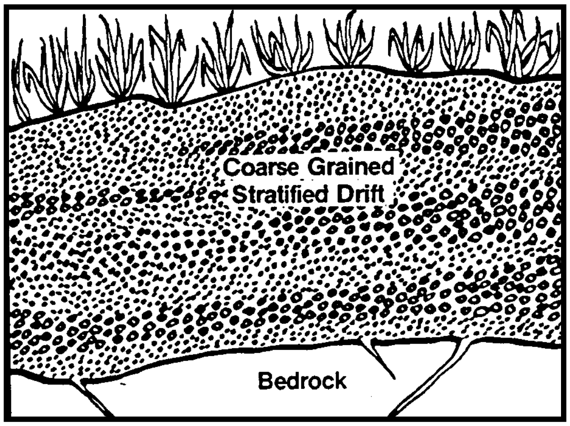
Source: Massachusetts Audubon Society. *An Introduction to Groundwater and Aquifers.* Groundwater Information Flyer #1. January 1993.

the lake or ocean, the small particles settled out to form very fine deposits of silt and clay on the bottom of the lake. Thus, as they moved away from the glacier, the meltwater streams sorted the rock fragments they carried into separate layers of gravel, sand, and fine sand. These sorted deposits are called **stratified drift (**see Figure 7).

■ Glacial Till: A Poor Aquifer Material

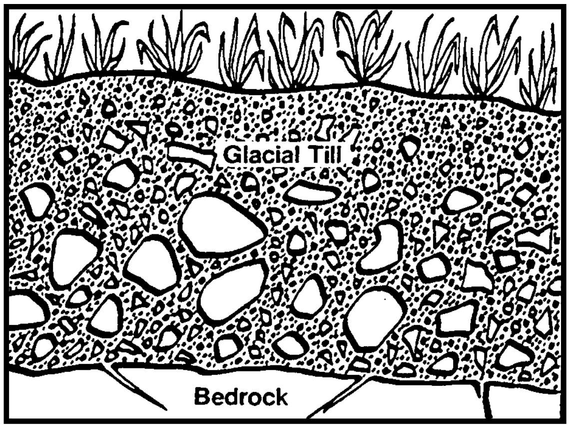
Most glacial debris was plastered onto the landscape as the last glacier advanced. Some slumped off the glacier into piles, was left up against the sides of valleys, or was formed into spoon-shaped hills called drumlins, when the glaciers moved over the debris. These types of glacial debris are called glacial till. They consist of an unsorted mixture of all sizes of soil and rock fragments and are usually not very porous or permeable. Therefore, public supply wells are not located in glacial till (see Figure 8).

Figure 7 STRATIFIED DRIFT



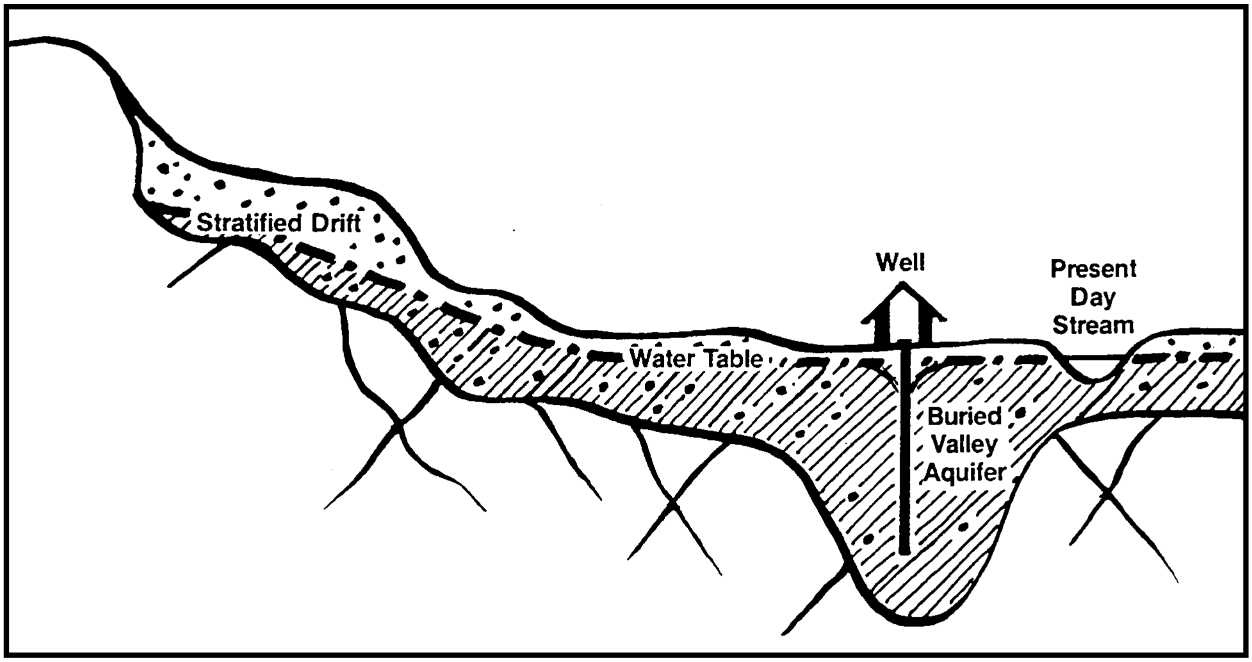
Source: Massachusetts Audubon Society. *An Introduction to Groundwater and Aquifers.* Groundwater Information Flyer #1. January 1993.

Figure 8 GLACIAL TILL



Source: Massachusetts Audubon Society. *An Introduction to Groundwater and Aquifers.* Groundwater Information Flyer #1. January 1993.

Figure 9 BURIED VALLEY AQUIFER



Source: Massachusetts Audubon Society. *An Introduction to Groundwater and Aquifers.* Groundwater Information Flyer #1. January 1993.

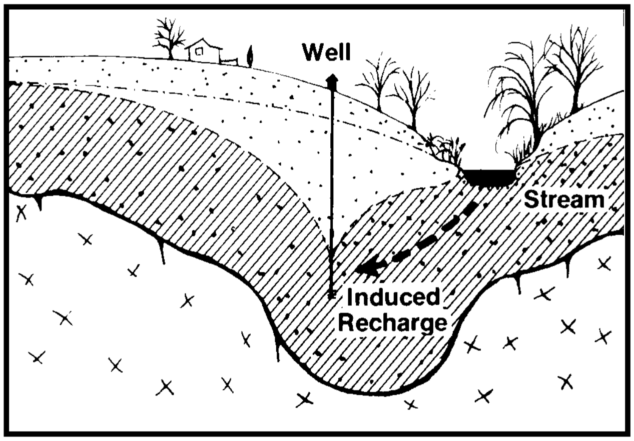
WHERE ARE THE GOOD PUBLIC WELL SITES?

■ Ancient River Valleys

In much of New England, meltwater moving away from the front of the glaciers flowed into existing river valleys. These valleys had been carved into the bedrock over millions of years by the rivers that drained the continent. In these ancient streambeds, the glacial debris settled out of the meltwater as stratified drift in the process described previously. Some of these ancient streambeds contain more than 200 feet of porous, permeable stratified drift. These buried valley aquifers (see Figure 9) are the sites of the majority of the larger public supply wells throughout New England.

Most public wells are located in buried valley aquifers that are connected hydrologically with a nearby river or stream. The pumping well may lower the water table below the level of the river, drawing water from the river into the well. This phenomenon is called **induced recharge** (see Figure 10). If this action takes place, however, it is important that wetlands and endangered plants and animals are not compromised and that surface water being withdrawn into the well is of adequate quality.

Figure 10 INDUCED RECHARGE



Source: Massachusetts Audubon Society. *An Introduction to Groundwater and Aquifers.* Groundwater Information Flyer #2. January 1993.

Most ancient streambeds correspond to present-day river and stream valleys, but the courses of a few rivers have changed since the glaciers melted. In those places, the aquifer is not located under and alongside the present river. Other small tributary streams have completely disappeared, leaving behind valleys filled with stratified drift. Geologic investigations can locate these ancient buried valleys, and the aquifers can be tapped for water supply.

■ Outwash Plains

In southern New England, glacial meltwater also formed excellent aquifers, but not in ancient river valleys. The last ice sheets to cover Massachusetts ended there. When they melted, the meltwater carried glacial debris from the front of the ice in a myriad of small parallel streams. Eventually, the stratified drift from the meltwater streams formed broad surfaces called outwash plains. These excellent aquifers differ from valley aquifers in that they are generally spread out over a larger area, but usually have no large sources of induced recharge.

Outwash plains and many valley aquifers are large enough to supply public wells. Smaller, coarse-grained stratified drift deposits can be aquifers for private domestic wells. Coarse-grained stratified drift deposits also readily absorb precipitation and thus commonly serve as important recharge areas.

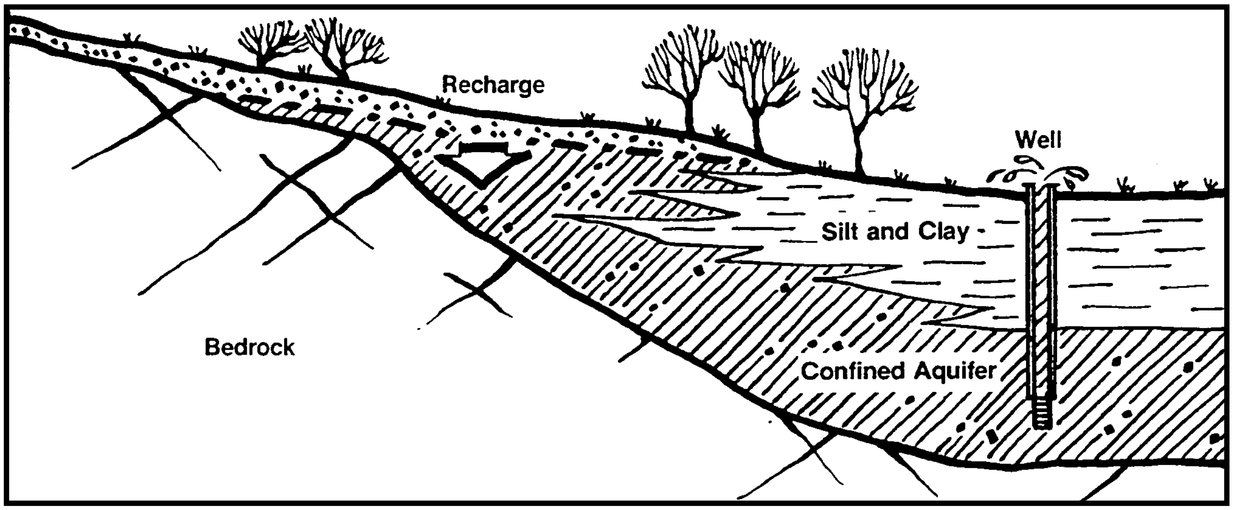
■ Confined Aquifers

The aquifers described so far are unconfined, or water table, aquifers. The top of this type of aquifer is identified by the water table. Above the water table, in the zone of aeration (or unsaturated zone) interconnected pore spaces are open to the atmosphere. Precipitation recharges the ground water by soaking into the ground and percolating down to the water table. The majority of the public wells in New England, and many private wells, tap unconfined aquifers.

Some wells in New England, however, are located in **confined aquifers**. These aquifers (see Figure 11) are found between layers of clay, solid rock, or other materials of very low permeability. Little or no water seeps through these confining layers. Recharge occurs where the aquifer intersects the land surface. This recharge area may be a considerable distance from the well.

In confined aquifers, often called artesian aquifers, water is under pressure because the aquifer is confined between impermeable layers and is usually

Figure 11 CONFINED VALLEY AQUIFER



Source: Massachusetts Audubon Society. *An Introduction to Groundwater and Aquifers.* Groundwater Information Flyer #1. January 1993.

recharged at a higher elevation than the top confining layer. When a well is drilled through the top impermeable layer, the artesian pressure will cause the water in the well to rise above the level of the aquifer. If the top of the well is lower than the recharge zone of the aquifer, water will flow freely from the well until the pressure is equalized.

HOW DO YOU FIND AN AQUIFER?

Since aquifers are tucked away beneath the surface of the ground, how do we figure out where they are located? Historically, many people used water dowsers—people who use divining rods—to locate underground water supplies. Today, we have acquired the scientific and technical wherewithal to more accurately locate ground water supplies.

In New England, soils were often laid down in several layers over time. Therefore, surface soils are not always good indicators. It helps to use several sources of information to identify aquifers. The best place to begin is by finding out what natural resource maps—local soils maps, topographic maps, surficial geology maps, bedrock geology maps—are available for the area in question. (See the "Revealing Stories—Resource Maps Tell All" activity and the "Resource File" for more information about map availability.)

To better understand regional soils, local health departments usually require that well logs be completed and submitted when drinking water wells are installed. In this case, well drillers (experts hired by local landowners or a community to install a well) must describe changes in the soil profile as they drill beneath the ground. This information is recorded in a document called a "well log." This information is useful because it allows hydrogeologists to better understand changes in the surficial deposits below the ground.

Another clue to consider is whether bedrock outcrops or ledge are common in the area. This may indicate shallow soils in the region.

KEY TERMS

- **Aquifer**
- **Bedrock**
- **Cone of Depression**
- **Confined Aquifer**
- **Discharge Area**
- **Evapotranspiration**
- **Fluctuation**
- **Fractures**
- **Gaining Stream**
- **Ground Water**
- **Ground Water Recharge**
- **Heterogeneous**
- **Hydraulic Conductivity**
- **Impermeable**
- **Impervious**
- **Induced Recharge**
- **Infiltration**
- **Losing Stream**
- **Permeability**
- **Pore Spaces**
- **Porosity**
- **Precipitation**
- **Private Water System**
- **Public Water System**
- **Runoff**
- **Safe Drinking Water Act**
- **Saturated Zone**
- **Soil**
- **Stratified Drift**
- **Surficial Deposits**
- **Unconsolidated Materials**
- **Unsaturated Zone**
- **Water Budget**
- **Water Table**
- **Watershed**
- **Well**
- **Zone of Aeration**
- **Zone of Contribution**

"Getting Up to Speed" for section B, "New England's Ground Water Resources" is adapted from Massachusetts Audubon Society's *Ground Water Information* Flyers #1 and #2.