science for a changing world

Exhibit 7

GROUND-WATER RESOURCES IN NEW HAMPSHIRE: STRATIFIED-DRIFT AQUIFERS

U.S. GEOLOGICAL SURVEY
WATER-RESOURCES INVESTIGATIONS REPORT 95-4100

Prepared in cooperation with
NEW HAMPSHIRE DEPARTMENT OF ENVIRONMENTAL SERVICES,
WATER RESOURCES DIVISION

GLACIERS AND STRATIFIED-DRIFT DEPOSITS IN THE NEW HAMPSHIRE LANDSCAPE

During The Great Ice Age or Pleistocene Epoch, the landscape of New Hampshire was significantly shaped and carved when thick glacial ice alternately advanced southward, covered the State, and retreated northward by melting. Before the Ice Age, the climate was warm, soils were deep, and the valleys were cut by stream erosion—conditions similar to those in the southern United States today. Starting about 2 million years ago, the climate cooled and continental glaciers formed. Over time, snow in northern Canada accumulated, was compacted by its own weight into glacial ice, advanced southward, and eventually covered New Hampshire with ice as much as a mile thick. As the glacier moved, it picked up loose rock and soil and plucked huge pieces of bedrock along its way. This ice and debris mixture scoured the landscape, streamlined hills, and transformed the stream-eroded valleys into glacially eroded "U"-shaped valleys with rounded valley walls (fig. 7).

Glaciers left two major types of deposits: till and stratified drift. Till consists of unsorted sediments deposited in place directly by melting ice. Sediment sizes generally range from very small to very large—from clays to boulders. Because glaciers covered New Hampshire, till was deposited throughout the State. In today's landscape, till is commonly seen at or near the ground surface in upland areas but it is also found buried beneath other unconsolidated deposits in valleys.

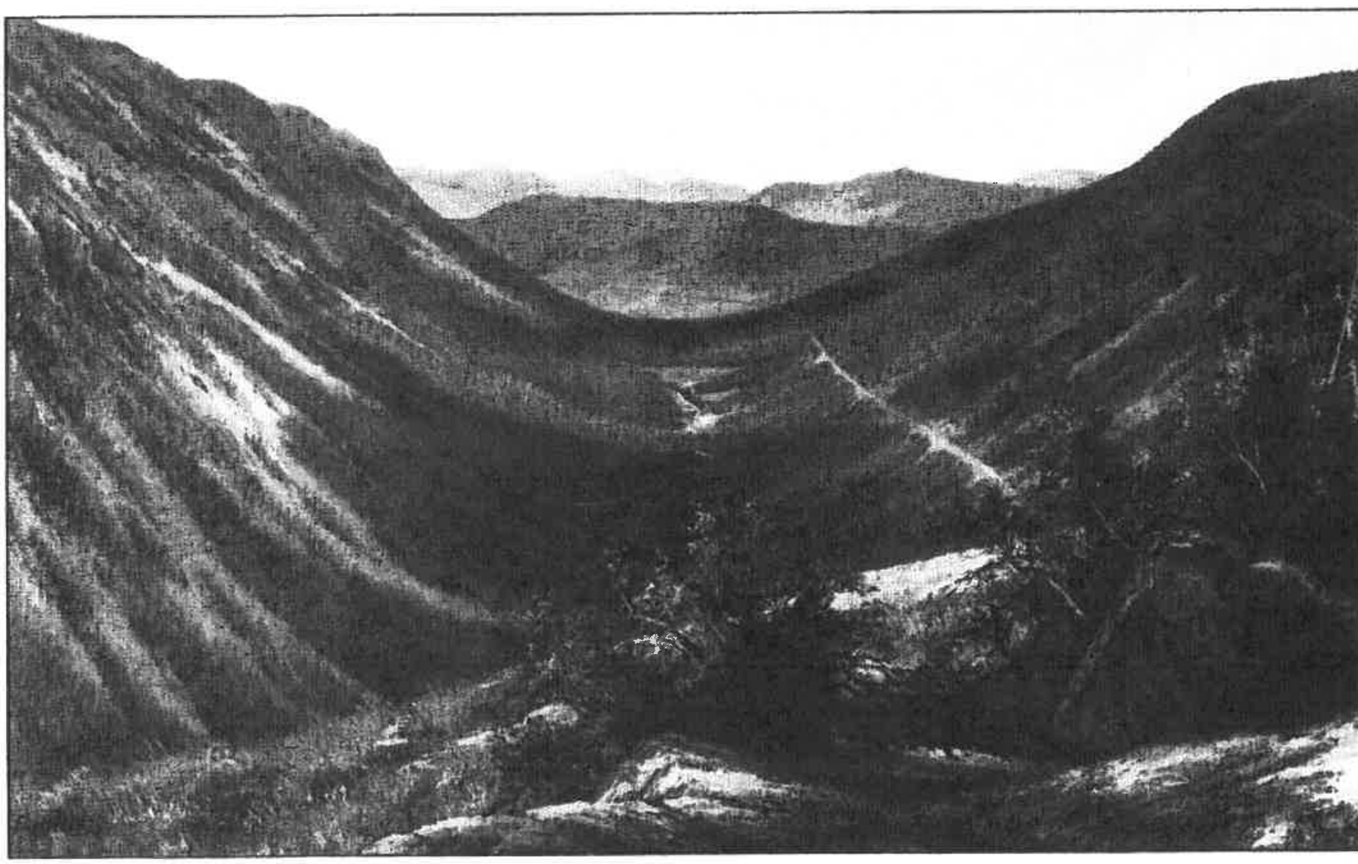


Figure 7. South-facing view of Crawford Notch from Mount Willard in Hart's Location, the heart of the White Mountains in north-central New Hampshire. Twenty-thousand years ago, the broad valley was filled with glacial ice and debris. Now, a glacially scoured U-shaped valley remains. [Sketch reproduced with permission from the New Hampshire Historical Society. (#F 128)]

The other major type of glacial deposit, stratified drift, began to form during late stages of the Great Ice Age, about 14,000 years ago. At that time, the southernmost extent of the most recent continental glacier had melted back, or retreated, from positions on Long Island, New York, to positions in New Hampshire. Throughout New Hampshire and the rest of New England, this glacial retreat is believed to have progressed in a stepwise fashion, with minor local readvances. How this melting occurred affected the location, size, and characteristics of the unconsolidated, stratified-drift deposits that are found today.

Many familiar landscape features composed of stratified-drift deposits were formed during the retreat of the glacier. Eskers, kame terraces, outwash plains, and deltas are good examples of this glacial deposition (fig. 8). Eskers are long sinuous ridges of sand and gravel deposited either in meltwater channels or streams within the glacier or at the ice margin, where the glacier retreated steadily in contact with a glacial lake. As they formed, esker deposits were surrounded by the glacier; when the surrounding ice melted, the esker deposit remained (fig. 9). Kame terraces are terrace-like ridges consisting of sand and gravel deposited by glacial meltwater that flowed between the melting glacial ice and a high valley wall. The kame terraces were left standing after the disappearance of the ice. Outwash plains are gently sloping plains composed chiefly of sand and gravel that was "washed out" from the glacier by meltwater streams. Deltas formed where meltwater streams flowed into a glacial lake or the ocean, in much the same way that present-day rivers form fan-shaped deltas at their mouths (fig. 10). Some glacial deltas formed where glacial ice extended into open water; other deltas formed at some distance from the retreating glacial ice where meltwater streams flowed

Carl Koteff, a geologist with the U.S. Geological Survey, in 1974 introduced the "dirt machine" concept to account for the enormous quantities of sand, gravel, silt, and clay found in valleys throughout New England. According to this analogy, moving ice is continually sheared up onto the stagnant end section of ice, depositing loose debris that the ice had carried which becomes available for transport by meltwater. This process of deposition keeps repeating itself, like a conveyor belt in a manufacturing plant that continually provides raw material to an assembly station.

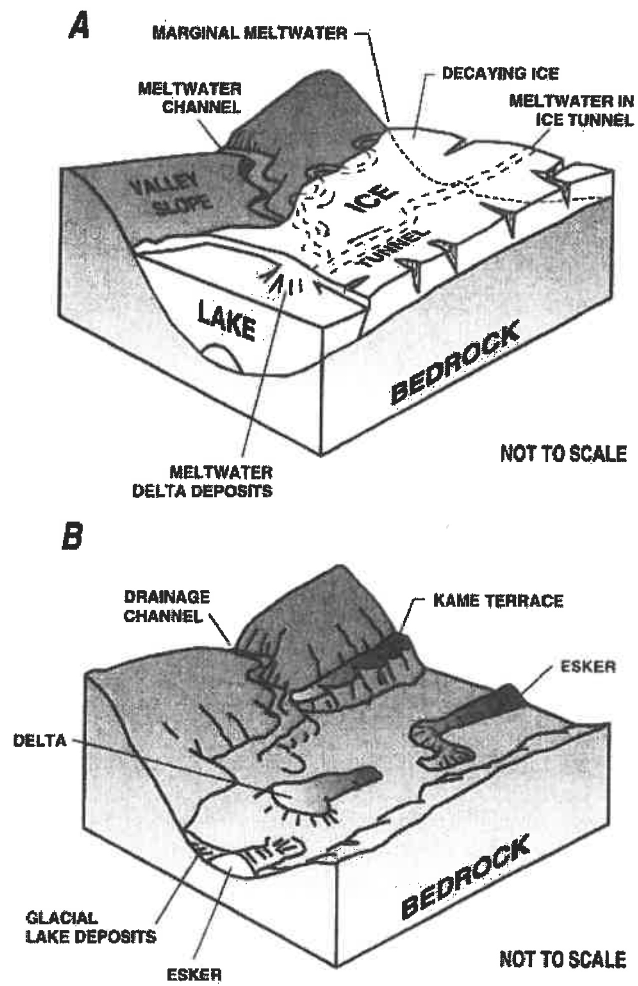


Figure 8. Depositional processes and features of typical stratified-drift deposits in New Hampshire. (*A*) Meltwater has formed a channel beneath the ice along the valley floor. A glacial lake has formed in low-lying areas fed by glacial streams. A delta has formed where the sediment-laden glacial stream flows into the still water of the lake. (*B*) Ice is completely melted, leaving various deposits of glacial origin: an esker, a kame terrace, a delta, and lake deposits. (Modified from Chapman, 1974, figs. 8 and 9.)

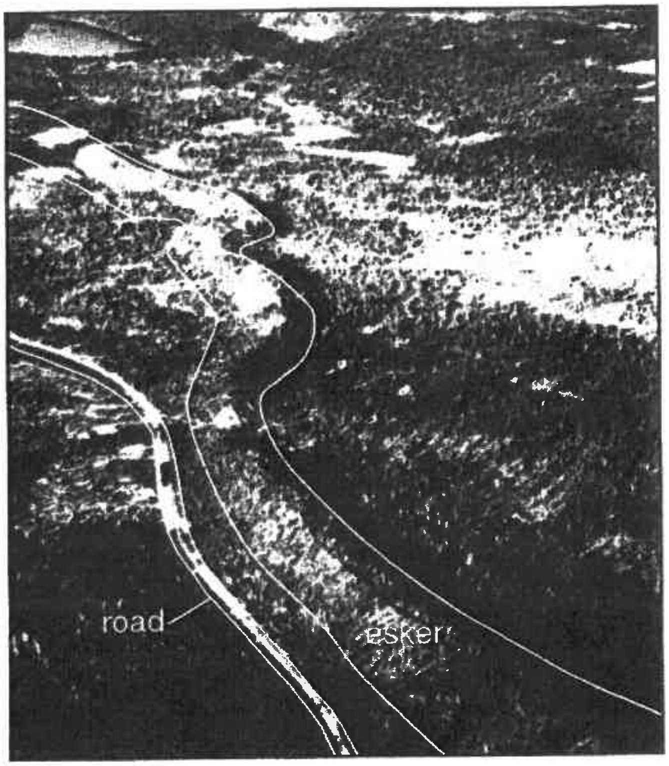


Figure 9. Aerial photograph taken in the 1940's of the Pine River Esker in Ossipee, east-central New Hampshire. Sand and gravel from this esker was used to build the road seen next to the esker in the photograph. Since the photograph was taken, much of the Pine River Esker has been mined for large construction projects. (From Goldthwait and others, 1951, fig. 20.)

into open water. Also, some deltas were formed soon after retreat of the glaciers by transport and redeposition of materials eroded from the initially barren land surface. In the modern-day landscape, stratified-drift deposits are found primarily in relatively flat or hummocky low-lying areas in stream valleys or near coastal lowlands.

Glacial lakes that ponded in front of the melting ice margin played an important role in the formation of stratified-drift aquifers in New Hampshire. These lakes, which were natural sediment traps, formed in many areas throughout the State during deglaciation, or glacial retreat. The formation of glacial lakes was enhanced where the underlying bedrock surface had been deeply scoured during multiple glaciations. Erosion of the bedrock by the glacier was extensive where the bedrock was already weak or fractured.

The largest of the glacial lakes, called glacial Lake Hitchcock, formed in the present-day Connecticut River Valley. Here, sediment carried by meltwater streams from the uplands accumulated in a long narrow lake that eventually extended 550 mi from central Connecticut to northern New Hampshire and Vermont. The deepest part of this lake was at least 560 ft deep before the deposition of more than 430 ft of layered sediments. A series of small glacial lakes formed along the Merrimack and Pemigewasset River Valley as the glacier retreated northward. Each lake was slightly higher in elevation than the lake to the south and was dammed by sediments that accumulated locally across the valley. Other glacial lakes formed in the Contoocook, Saco, Ossipee, Connecticut, and Androscoggin River Basins (fig. 1). Of these, the lake in the Ossipee area was the deepest; it was greater than 300 ft deep in the center and eventually was filled with more than 280 ft of stratified (layered) glacial deposits.

In the mid-1800s, bricks made from clay (that originated from a glacial lake) in Hooksett were floated down the Merrimack River to Manchester to build "the largest set of textile mills in the world." Similarly, bricks made from Bedford clay deposits were floated through the canal system down the Merrimack River to build mills in Lowell, Massachusetts. Brickmaking was also extensive in Dover, Rochester, Exeter, Epping, and in towns along the Connecticut River.

"Good fences make good neighbors", a line from Robert's Frost poem The Mending Wall (1981), symbolizes a practical use for ubiquitous stony soils, such as those found in New Hampshire. Cobbles and boulders, common in glacial till and ice-contact deposits, are a fact of life for New Hampshire residents.

Figure 10. Delta deposits in Newmarket, southeastern New Hampshire. Ice-marginal deltas, such as this one, formed where sediment carried by the meltwater streams was deposited into the ocean at the edge of the glacier. The flat and sandy land surface shown here is typical of deltaic deposits. The angled layers were deposited as the stream unloaded sediments in gradual increments over time. (Photograph taken by R.B. Moore, U.S. Geological Survey.)

Present-day stratified-drift lake deposits typically are distinguishable by their flat topography and fine-grained sand, silt, or clay composition. Glacial-lake deposits, such as those found in the Connecticut River Valley, can provide high-quality cropland because the fine-grained soils retain water for crops in contrast to sandy soils from which water drains more easily and is lost to plants.

A 1921 student at the Amos Tuck School of Administration and Finance recognized that most of New Hampshire's demographic and geographical development was related to glacial processes and the resulting landscape. The student's analysis related everything from the location of settlements, roads, railroads, and canals; the growth of forests and related industries; and the development of agriculture, water power, manufacturing, and tourism to the most recent glacial episode.

Some glacial lakes formed where the natural drainage to the north was obstructed by the margin of the melting glacier. As the glacier retreated northward, lower drainage outlets were exposed, causing a sudden draining of these ice-dammed glacial lakes and a redeposition of glacial-lake sediments (Moore, 1993). The large volumes of sediment-laden meltwaters that were released sometimes carved deep channels in till and bedrock that became exposed below the new outlets.

The erosive energy of meltwater was so great that in places the underlying rock was smoothed and sculptured into interesting and unusual forms. Evidence of former meltwater channels can be observed in such places as the Sculptured Rocks Natural Area in Hebron, the Lost River Gorge, Kinsman Notch in Woodstock, and Pulpit Rock in Bedford.

Construction sand and gravel deposited by glacial meltwater was valued at $20.7 million in New Hampshire in 1993. The sand and gravel industry employed an average of 252 workers in the State according to the U.S. Bureau of Mines.

Erosion and redistribution of glacial deposits by stream processes after the glacial age has significantly reshaped New Hampshire's landscape. Postglacial (after the glacial period) erosion by rivers and tributaries has formed erosional channels. Deposition of materials has formed alluvial fans at the base of mountains and has formed stream terraces, flood plains, and deltas in all the major valleys. Eolian deposits were formed by wind erosion of largely unvegetated glacial deposits and redeposition. Wind-borne materials were redeposited as either a layer of very fine sand and silt up to 2-feet thick over much of the stratified drift in New Hampshire or as thick dune deposits typically found on the eastern flanks of expansive glacial-lake deposits.

STRATIFIED-DRIFT AQUIFERS

Stratified-drift aquifers consist mainly of layers of sand and gravel, parts of which are saturated and can yield water to wells or springs. The distribution and hydraulic characteristics of stratified-drift aquifers are related to the original environment in which the sediments were deposited. A variety of "depositional environments" are represented by the stratified-drift deposits found statewide including eskers, kame terraces, deltas, and glacial-lake deposits.

Most sand and gravel found in New Hampshire was deposited by water from melting glaciers. Each distinct layer in sand and gravel deposits was caused by a distinct depositional environment and distinguished by different grain-size distributions (fig. 11). Characteristics of the meltwater flow, such as the speed and the turbulence of the current, determined the size of the particles that were transported and deposited. For example, swiftly moving sections of meltwater streams could carry coarse-grained materials. As the slope of the streambed decreased farther away from the source, streamflow velocity decreased and the coarse materials were dropped. These coarse-grained deposits have large pore spaces and, if saturated, generally form high-yielding aquifers. Fine-grained materials, including very fine sands, silts, and clays, were deposited by slow flowing sections of streams and in stagnant water bodies such as lakes and ponds. These deposits do not transmit water freely because pore spaces are minute and the interconnections between pore spaces are small.

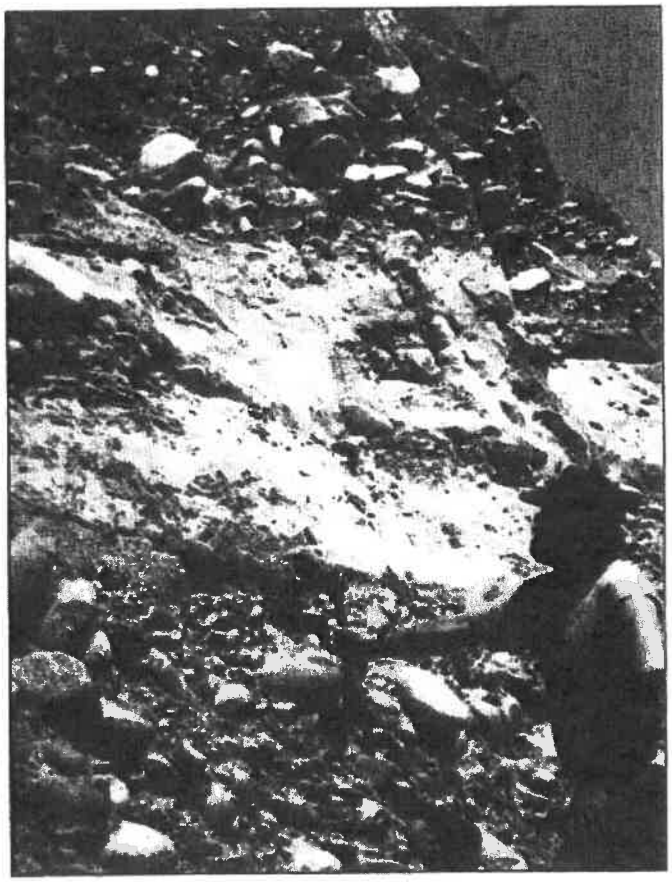


Figure 11. Well-sorted sand layers sandwiched between boulder and cobble layers at a site in Francestown, south-central New Hampshire. (Photograph taken by J.D. Ayotte, U.S. Geological Survey.)

***Stratified drift** - sorted and layered unconsolidated material deposited in meltwater streams flowing from glaciers or settled from suspension in quiet-water bodies fed by meltwater streams*

Bedrock, which universally underlies the unconsolidated deposits at or near the land surface, contains water-filled fractures of varying size, number, and extent that constitute the bedrock aquifer. Because not all towns include areas of stratified-drift aquifer within their borders, the bedrock aquifer represents the only potentially significant source of ground water for some towns. The U.S. Geological Survey is presently (1995) involved in a cooperative program with the New Hampshire Department of Environmental Services to map high-yield zones in the bedrock aquifer throughout the State. When completed, this effort will complement the results of the stratified-drift-aquifer investigations presented here and enhance the statewide picture of ground-water availability.

Types of stratified-drift aquifers found in New Hampshire include: eskers, kame terraces, and deltas formed in contact with the glacial ice; outwash and deltas deposited by meltwater streams flowing in front of the glacier; alluvial fans and deltas formed from flooding after glacial dams were breached; as well as alluvial fans and deltas formed from erosion of the postglacial barren land surface. In some locations, exposed till and other glacial sediments were eroded after the glaciers receded and were redeposited as sand and gravel by streams. Deposits that settled out at or near the glacier margin ice tend to include large materials, such as boulders and cobbles. Deposits that were transported away from the ice by meltwater tend to consist of fine- or small-grained materials. Regardless of the circumstances of deposition, sand and gravel deposits commonly form high-yielding aquifers if there is a significant thickness of saturated material.

Characteristics of Aquifers

The size and arrangement of voids or pore spaces between sediment particles determine the ability of the aquifer material to store and transmit ground water. Porosity is a measure of the space available for ground-water storage. A more useful measure of the ground water available for use is **specific yield**. Porosity is always greater than specific yield for a given section of aquifer because some water remains on the grain surfaces as a result of surface tension and will not drain by gravity. The large, interconnected pore spaces of sand and gravel deposits provide a large volume of ground-water storage and also readily transmit ground water; these deposits are highly permeable. In contrast, silts and clays provide a large volume of ground-water storage but do not readily transmit ground water because surface-tension forces predominate in the small pore spaces. These types of deposits are relatively impermeable.

The ability of aquifer material to transmit water is described quantitatively by its **hydraulic conductivity**. Hydraulic conductivity can be illustrated by a comparative example: fine-grained sand can have hydraulic conductivities between 2 and 15 ft/d; whereas well-sorted, coarse-grained sand can have hydraulic conductivities that range from 50 to greater than 200 ft/d. The variation depends largely upon uniformity and shape of the grains (fig. 12).

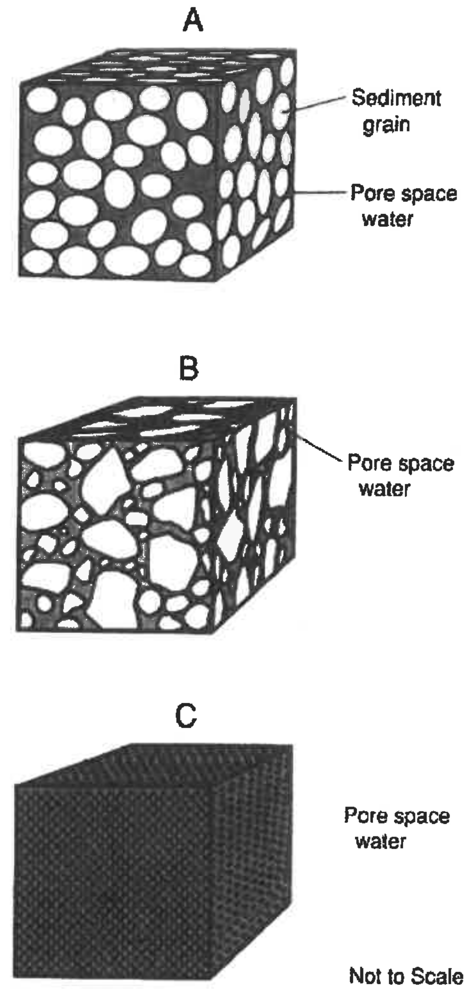


Figure 12. Shape, size, and sorting of sediments determine aquifer characteristics. (*A*) Rounded, coarse-grained, well-sorted material (uniform size) has high porosity and high hydraulic conductivity. (*B*) Angular, poorly sorted material (mixed sizes) has low porosity and low hydraulic conductivity. Small particles "plug up" pores between large particles, impeding flow. (*C*) Flat, fine-grained, well-sorted material has high porosity but low hydraulic conductivity. Because pore spaces are very small, water adheres to the grains by surface-tension force; in other words, by the same natural force of attraction that causes drops of water to cling to a downward- or sideways-facing object seemingly in defiance of gravity.

In the American water-well industry, hydraulic conductivity (k) is commonly expressed in units of gallons per day per foot squared (gal/day/ft^2). This expression, perhaps more intuitive than the equivalent U.S. Geological Survey convention of expressing k in feet per day (ft/d), conveys that k is the rate at which water (gallons per day), or other fluid, moves through a cross-sectional area of aquifer (foot squared). Likewise, transmissivity, being the product of hydraulic conductivity times saturated thickness in feet, is expressed as gallons per day per foot (gal/day/ft) by the water-well industry.

***Hydraulic conductivity** - a measure of the ability of a porous medium to transmit a fluid, expressed in unit length per unit time*

***Saturated thickness (of stratified drift)** - thickness, in feet, of stratified-drift extending down from the water table to the till or bedrock surface*

***Specific yield** - the ratio of the volume of water that can be drained by gravity to the total volume of sediment*

***Transmissivity** - the rate at which water is transmitted through a unit width of aquifer under a unit hydraulic gradient*

Conversions:
To convert hydraulic conductivity in gal/day/ft^2 to ft/d, multiply by 0.1137

To convert transmissivity in gal/day/ft to ft^2/d, multiply by 0.1137.

Aquifer **transmissivity** quantifies the ability of the entire thickness of the aquifer to transmit water. The term is used often by hydrologists to describe the water-producing capability of an aquifer. Technically, the transmissivity of an aquifer is equal to the hydraulic conductivity of its materials multiplied by its **saturated thickness**, in feet. In this report, transmissivity is expressed in units of foot squared per day (ft^2/d).

To summarize, the higher the value of hydraulic conductivity, the more readily water can flow through the aquifer material. Aquifers that have a large saturated thickness, and are composed of material with high hydraulic conductivity, will have a high transmissivity and can readily transmit water to wells.

Methods for Evaluating Stratified-Drift Aquifers

For the assessment of New Hampshire's stratified-drift aquifers, the State was subdivided into 13 study areas that generally corresponded to major watersheds. Many thousands of data records were compiled from existing sources, and additional thousands were added during the course of the study.

For each of the study areas, the evaluation of **stratified-drift aquifers** began with a compilation and assessment of all pertinent information from many sources. Existing data sources included hydrologic map reports from a USGS statewide reconnaissance study (Cotton, 1975a, b, c, and d, 1976a and b, 1977a, b, and c), county Natural Resources Conservation Service (NRCS) soils maps (Latimer and others, 1939; Winkley, 1965; Kelsey and Vieira, 1968; Vieira and Bond, 1973; Diers and Vieira, 1977; U.S. Soil Conservation Service, 1981, 1985a, 1985b), well records registered with the NHDES Water Resources Division, and bridge-boring records from the New Hampshire Department of Transportation. The NHDES, Water Resources Division and New Hampshire Department of Transportation provided more than 20,000 records of subsurface information at specific sites. Surficial-geology maps from the Cooperative Geologic Mapping Program (COGEOMAP—a cooperative program between various states and the USGS) were used when available. In addition, any available information from engineering firms, environmental consultants, and well drillers were compiled.

The first objective of the aquifer study was to determine the extent and hydrologic characteristics of stratified-drift aquifers. Field-data collection usually began with mapping the geographic location of sand and gravel deposits. Using information from USGS topographic and hydrologic-reconnaissance maps, county NRCS maps, and field investigations, the location of the contacts or boundary lines between areas of stratified drift and areas of till and bedrock

***Stratified-drift aquifer**—A coarse-grained sand or sand and gravel deposit that contains a usable supply of water* were determined. For this aquifer study, the contact between sand and gravel and all other materials at the ground surface defined the mapped aquifer boundary. Thus, stratified-drift boundaries are the same as aquifer boundaries. Next, the thickness of the deposits and how much water they stored, were measured.

Depth to the water table and saturated thickness of the aquifer were determined in two ways: drilling (wells, test borings, and bridge borings) and surface-geophysical techniques. Drilling is used to determine certain aquifer parameters such as saturated thickness or depth to the water table and to collect samples of the aquifer materials for analysis. However, drilling is slow, expensive, and provides data at only one location on the ground. Seismic refraction, a surface-geophysical technique that depends on the generation and detection of sound waves below ground, generally yields results faster than drilling and provides a cross-sectional view of the aquifer. The major disadvantages of seismic refraction are that the technique is not usable under all conditions and the interpretation of the data can be variable.

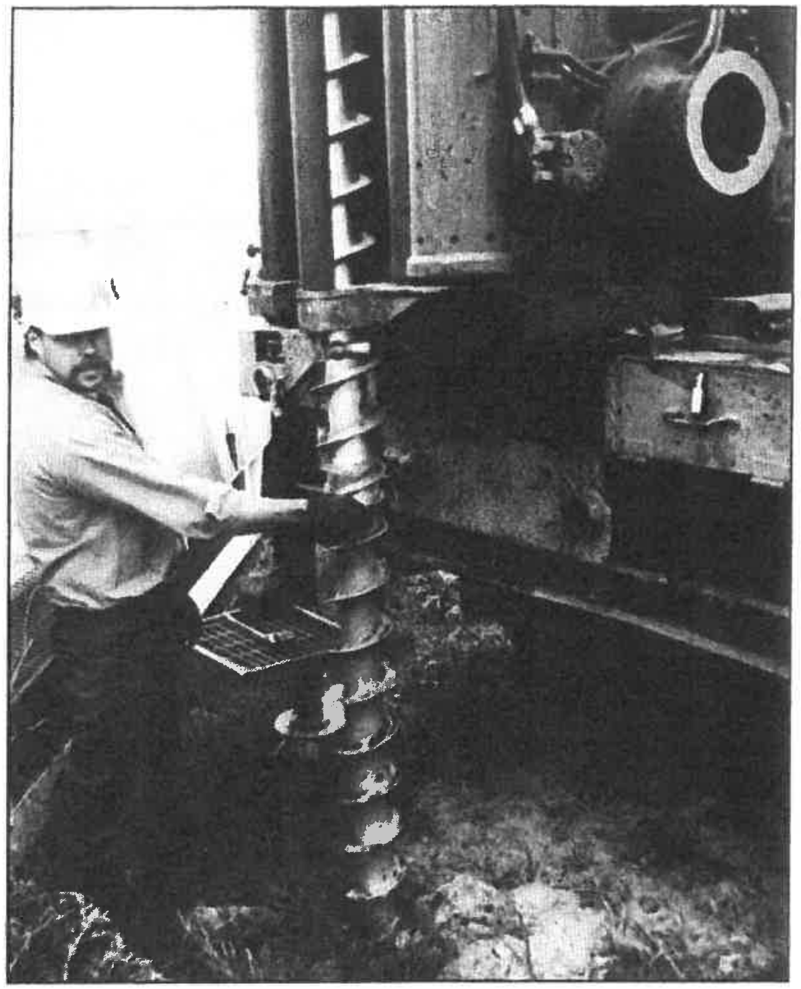


Figure 13. A hollow-stem auger drill rig and operator. This U.S. Geological Survey drill rig was used to drill 674 test holes statewide to collect data on aquifer characteristics and to install observation wells. (Photograph taken by J.R. Olimpio, U.S. Geological Survey.)

USGS crews drilled wells or test holes at 674 sites to supplement existing data (fig. 13). As each hole was drilled, the depth to the water table was measured as the point where the drilling augers first reached saturated materials. Drilling continued until the augers reached bedrock or "refusal". Refusal marks the depth at which the drill auger could not penetrate the underlying bedrock, a large boulder, or till. The vertical distance between the water table and the bottom of the aquifer is the saturated thickness. Samples of the saturated aquifer sands and gravels were collected at 5- or 10-foot intervals for each drilled hole using a split-spoon sampler (fig. 14), which was inserted down through the hollow part of the augers to the bottom of the hole. Aquifer hydraulic conductivities for materials collected at these intervals were estimated from measurements of the proportion of grains that fell into specific size ranges when passed through a series of sieves of different sizes. Transmissivity

Regarding the theory of seismic-refraction, a simple analogy can help to illustrate the phenomenon that sound waves refract at boundaries of earth layers. Stick a pencil in a glass of water. The pencil will appear to bend at the boundary between the air and water layers. This happens because light waves, like sound waves, refract at the boundaries of distinct layers.

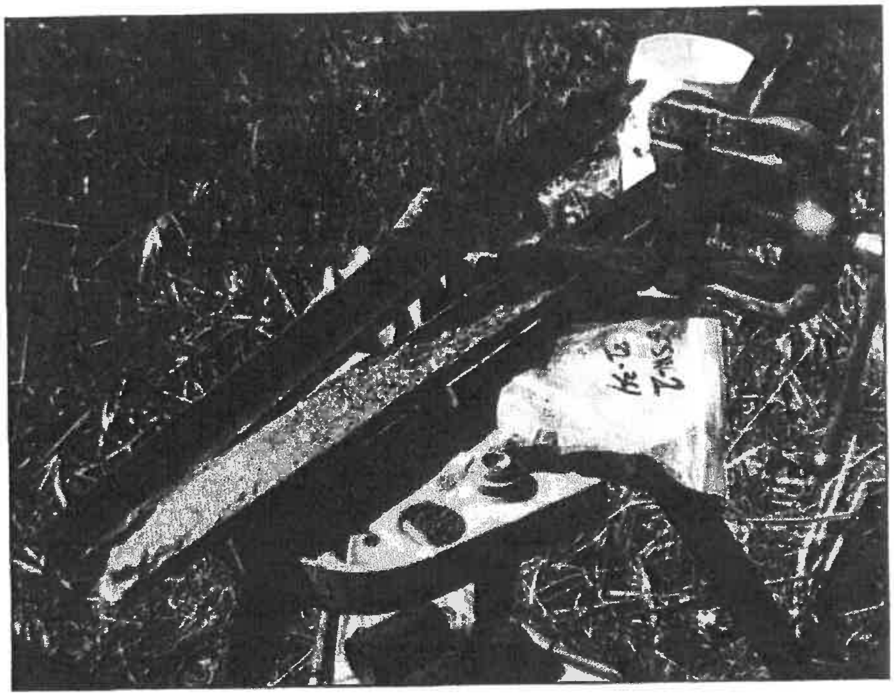


Figure 14. Split-spoon sampler and sediment from a drilled test hole. The sampler was used to retrieve aquifer material from drilled test holes and wells at 5- or 10-foot intervals. Once the sample is obtained, it is stored in the plastic bag for further analysis. (Photograph taken by J.D. Ayotte, U.S. Geological Survey.)

values for the entire saturated thickness of the aquifer were estimated by multiplying the hydraulic conductivity value for an interval by the saturated thickness of that interval and summing the results for each hole. Transmissivity values also were obtained from consultant reports when available.

Seismic refraction provides a shallow cross-sectional view, or slice, through the upper layers of the earth. Specifically, seismic refraction results can be used to determine depth to the water table and depth to bedrock from a line along the surface of the ground. This method utilizes the property that sound waves travel through layers of distinct earth materials at different and known velocities. For example, sound travels through dry sediments at 900 to 2,000 ft/s, through saturated sediments at about 5,000 ft/s, and through bedrock at 10,000 to 20,000 ft/s. In the seismic refraction method (fig. 15), a sound wave is created by detonating a small explosive buried just below the ground surface. The resulting waves are bent (refracted) at the boundaries between distinct layers. By measuring the time it takes for the refracted sound waves to travel to receivers called geophones, which are located at fixed intervals along a line at the ground surface, the rate at which the sound waves traveled can be calculated and matched to the material from which it was refracted. Geophones are so sensitive that they can detect the vibrations of passing traffic and even the motion of roots as trees sway in strong winds. The technique therefore works best under "quiet" conditions. Seismic refraction can be used to determine the thickness of the unconsolidated dry layer and the unconsolidated saturated layer, and the depth to the top of the bedrock layer. Seismic-refraction surveys were conducted at 651 sites for the aquifer studies.

Seismic-reflection surveys, another geophysical method, were conducted in areas throughout the State where large rivers or lakes overlie sand and gravel deposits. This method, which is conducted from a boat traversing the water body, provided data on the thickness of the aquifer below the water body.

Data compiled from previously existing sources and collected from drilling, seismic refraction, and seismic reflection were analyzed and interpreted to produce a set of maps with hydrologic information for each of the study areas. The maps present hydrologic data superimposed on USGS topographic maps at scales of 1:24,000[1] and 1:48,000[2]. Maps of aquifer boundaries were produced from USGS topographic and hydrologic reconnaissance maps, NRCS maps, and field explorations. Maps showing contour lines of equal water-table altitudes were produced using data from drilling, seismic-refraction surveys, water-level measurements at wells drilled by the USGS for this project, altitudes of surface-water bodies and other well, test hole, or bridge-boring data when available. The water-table maps are presented as altitude contours in feet above sea level to make the data consistent with topographic contour lines on standard USGS topographic

[1]One inch on the map represents 2,000 feet on the ground.

[2]One inch on the map represents 4,000 feet on the ground.

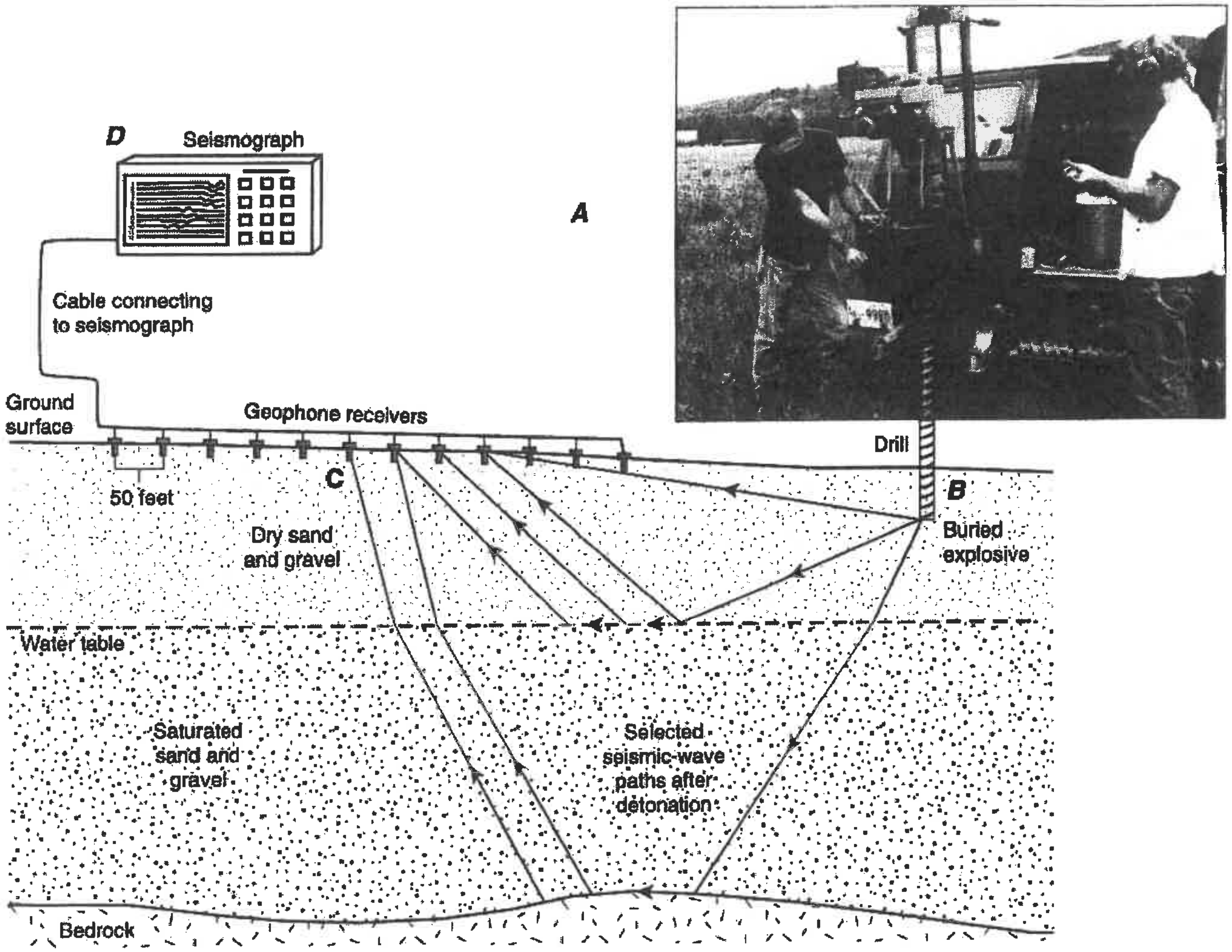


Figure 15. Seismic-refraction survey field work in Sugar Hill, northwestern New Hampshire. (*A*) Technician on the left side is drilling a "shot hole" for the explosive being prepared by the hydrologist on the right. (*B*) A carefully calculated amount of explosive material is used to generate enough sound energy to travel up to 1,100 feet underground and still register a signal. (*C*) Resulting seismic waves are detected by geophone receivers buried 2 inches in the ground. (*D*) A 12-channel seismograph, like an extremely accurate stopwatch, records the time of arrival in fractions of seconds of the first seismic wave detected by each geophone. (Photograph taken by S.M. Flanagan, U.S. Geological Survey).

maps. Maps showing contour lines of equal saturated thickness, in feet, and zones representing ranges of transmissivity values, in foot squared per day (ft^2/d), were produced using data from USGS drill holes, seismic refraction, and other well, test hole, or bridge-boring data if available.

The second objective of the aquifer study was to assess potential water-yielding capabilities for selected aquifers in each study area. These results provide planners with information on potential volumes of water that could be withdrawn from aquifers to supplement existing water supplies or to develop new ones. Aquifers were chosen for this evaluation to represent different types of local aquifer systems. Most of these analyses were done using computer-simulation models based on estimates of hydrologic and other aquifer properties and tested with data collected in the field. Forty-two aquifers were modeled to obtain potential-yield estimates. Potential-yield estimates are included in the section of this report titled "Major Aquifers in New Hampshire."

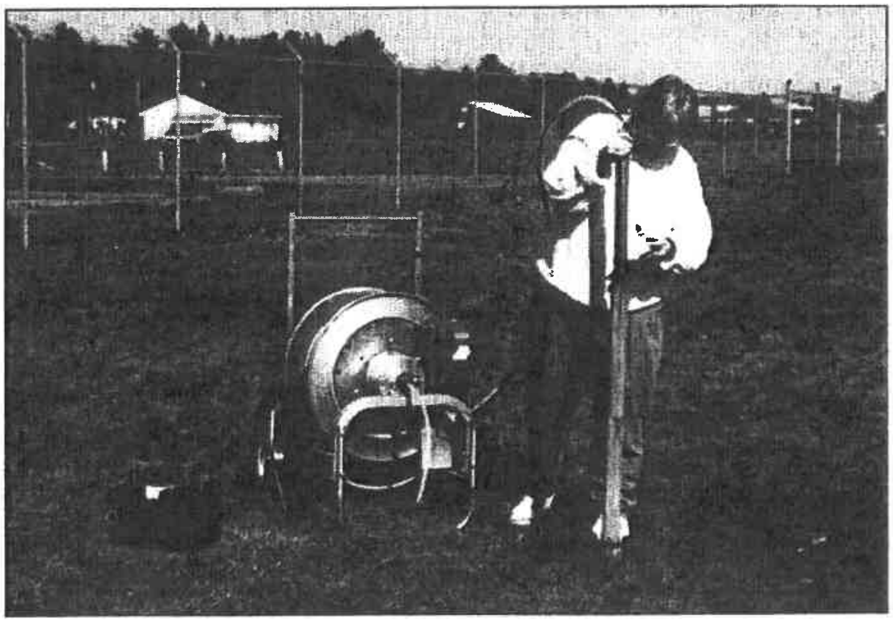


Figure 16. Typical setup for sampling water quality at a well in Concord, south-central New Hampshire.

The third objective of the aquifer study was to broadly define the ground-water quality of the major aquifers. The approach used for meeting this objective was to collect and analyze samples of ground water from springs and wells (fig. 16). This assessment of ground-water quality focused on natural or near-natural conditions in aquifers considered representative of the study area and did not attempt to identify or evaluate sites of possible ground-water contamination. Ground water was sampled in a variety of environments, including forested, agricultural, or residential areas. Samples of ground water from 240 wells and 20 springs were analyzed for a variety of substances including common inorganic, organic, and volatile organic constituents. The assessment of general ground-water quality is discussed in the section of this report titled "Quality of Water from Stratified-Drift Aquifers."

Major Stratified-Drift Aquifers in New Hampshire

General information about stratified-drift aquifers statewide is summarized in figure 17 and below:

- About 14 percent, or 1,299 of the 9,282 mi^2 of New Hampshire, is underlain by stratified-drift aquifers.
- The largest stratified-drift aquifer is in the Ossipee River Basin in the towns of Tamworth, Madison, Ossipee, Freedom, and Effingham.
- Saturated thicknesses range from 0 to more than 500 ft, the thickest being along the Connecticut River in Orford and Haverhill.
- Transmissivity values range from 0 to 26,000 ft^2/d or greater.
- Depth to the water table ranges from 0 to 150 ft below the land surface. Depth to the water table for 50 percent of the wells inventoried is 9 ft or less.
- In general, the most transmissive aquifers are found in localized areas of the central and southern parts of the State.
- Aquifers along the main sections of major rivers tend to be continuous, while those elsewhere tend to be small and discontinuous.

The following points should be kept in mind while reading this discussion of highlights from the individual study areas: (1) All study area boundaries are major watershed divides except for the Nashua Regional Planning Commission Area, whose boundary is defined by town boundaries, and parts of the two adjacent study areas, the Middle Merrimack and Lower Merrimack River Basins. (2) Because aquifers do not end at State boundaries, parts of some New Hampshire aquifers extend into Maine, Massachusetts, Vermont, or Canada. (3) Some towns, such as Dover, may be mentioned in more than one section of this report because separate aquifers are in different study areas. (4) As a general guideline for interpreting the discussion on transmissivities, a transmissivity value above 2,000 ft^2/d constitutes a major aquifer. (5) Thick stratified-drift deposits are not necessarily highly transmissive. For instance, the thick saturated deposits along the Connecticut River are primarily clays from the bottom deposits of glacial Lake Hitchcock that have low permeability and transmissivity.

Upper Connecticut and Androscoggin River Basins

The Upper Connecticut and Androscoggin River Basins in northern New Hampshire have a combined drainage area of 1,629 mi^2, of which 137 mi^2, or about 8 percent of the basin, are underlain by stratified-drift aquifers. Parts of stratified-drift aquifers in the towns of Colebrook, Shelburne, Stark, Stratford, and West Milan have saturated thicknesses greater than 200 ft and transmissivities greater than 4,000 ft^2/d. Stratified-drift aquifers in the towns of Berlin, Colebrook, and Gorham supplied a total of 4.5 Mgal/d of water for municipal public-supply wells in 1990. Results of computer model simulations indicate that stratified-drift aquifers in Colebrook and Shelburne can yield up to 7.7 and 23.2 Mgal/d, respectively (J.R. Olimpio, U.S. Geological Survey, written commun., 1995).

Middle Connecticut River Basin

The Middle Connecticut River Basin in western New Hampshire has a drainage area of 987 mi^2, of which 123 mi^2, or about 12 percent of the basin, are underlain by stratified-drift aquifers. Although saturated thickness of stratified drift exceeds 500 ft in northwestern Orford and western Haverhill, saturated thickness generally is less than 100 ft. High transmissivity values (exceeding 4,000 ft^2/d) were measured in parts of stratified-drift aquifers in southwestern Carroll, northwestern Bethlehem, western Franconia, western Orford, eastern Haverhill, central Easton, and southwestern Lisbon. Transmissivity exceeds 1,000 ft^2/d in 17.5 mi^2 of the study area. In 1990, ground-water withdrawals from stratified-drift aquifers for municipal public-supply wells totalled about 1.5 Mgal/d in Carroll, Enfield, Hanover, Haverhill, Lisbon, Monroe, and Orford. A computer simulation of potential ground-water withdrawals indicated that additional yields of 1.4 to 2.9 Mgal/d could be pumped from aquifers in western Lisbon, central Haverhill, northern Easton, southern Franconia, and western Franconia. Parts of aquifers in Hanover, Haverhill, and Orford extend into Vermont (Flanagan, in press).

Pemigewasset River Basin

The Pemigewasset River Basin in central New Hampshire has a drainage area of 1,022 mi^2, of which 91 mi^2, or about 9 percent of the basin, are underlain by stratified-drift aquifers. Parts of aquifers in Campton, Alexandria, Hebron, and Rumney have saturated thicknesses greater than 100 ft and transmissivity greater than 8,000 ft^2/d. Stratified-drift aquifers in Bristol, Hill, Franklin, Sanbornton (for Franklin), Plymouth, Campton, Woodstock, Lincoln, and Waterville Valley supply ground water for municipal public-supply wells. Many other areas in the basin are potential sites for public-supply wells (Cotton and Olimpio, in press).

Saco and Ossipee River Basins

The Saco and Ossipee River Basins in east-central New Hampshire have a drainage area of 869 mi^2, of which 153 mi^2, or about 18 percent of the basin, are underlain by stratified-drift aquifers. The area contains several large, productive, and potentially productive aquifers. About 11 percent of the area has transmissivity values greater than 1,000 ft^2/d. Transmissivity values equal to or greater than 8,000 ft^2/d have been calculated for aquifers along the Saco River in Carroll, Hart's Location, Bartlett and Conway, and in tributary valleys in Chatham, northeastern Conway, central Madison, eastern Sandwich, western Tamworth, and in sections of Ossipee, Effingham, and Wakefield. The central part of the largest stratified-drift aquifer in New Hampshire underlies the Ossipee River Valley in Tamworth, Madison, Ossipee, Freedom, and Effingham. Saturated thickness in one section of the Ossipee River Valley stratified drift exceeds 280 ft. Sections of aquifers in Chatham, Conway, Effingham, and Wakefield extend into Maine. Water is pumped from municipal public-supply wells in stratified-drift aquifers in Bartlett, Conway, Freedom, Gorham, Jackson, and Madison. Results of model-simulated ground-water flow for the Ossipee River Valley aquifer indicate that more than 7 Mgal/d of water could be pumped from four wells with minimal impact on flows in the Ossipee River (Moore and Medalie, in press).

HYDROGEOLOGY OF STRATIFIED-DRIFT AQUIFERS AND WATER QUALITY IN THE NASHUA REGIONAL PLANNING COMMISSION AREA SOUTH-CENTRAL NEW HAMPSHIRE

By Kenneth W. Toppin

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 86-4358

Prepared in cooperation with the

NASHUA REGIONAL PLANNING COMMISSION and the

NEW HAMPSHIRE WATER RESOURCES BOARD

Bow, New Hampshire

1987

DEPARTMENT OF THE INTERIOR

DONALD P. HODEL, *Secretary*

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, *Director*

For additional information, write to:

U.S. Geological Survey
Water Resources Division
525 Clinton Street
Bow, NH 03301

Copies of this report can be purchased from:

Books and Open-File Reports Section
U.S. Geological Survey
Box 25425, Federal Center
Denver, CO 80225

Litchfield

Located on the eastern side of the Merrimack River (fig. 1), the town of Litchfield has 14 mi² or 93 percent of its area underlain by stratified drift (pls. 5 and 6). The predominant stratified material is fine-grained glacial sediment of Glacial Lake Merrimack (Koteff, 1976). Several good aquifers, in northern and central Litchfield are of permeable, coarse sand and gravel with a saturated thickness greater than 100 ft in some places.

Large quantities of water are pumped from the coarse-grained sand and gravel aquifer centered about Darrah Pond. This aquifer is in a segment of a buried valley occupied by Darrah Pond delta deposits (Koteff, 1976); the deposits are more than 100 ft thick southeast of Darrah Pond, and their transmissivity is greater than 8,000 ft²/d. The coarse-grained deposits of the aquifer are bounded on the west by fine-grained materials. The Darrah Pond well (W-59) has a capacity of 100 gal/min and serves part of central Litchfield. Darrah Pond is the only significant source of water available for induced infiltration into this area.

Northwest of Darrah Pond, two wells (W-56, W-57) are located in the coarse-grained sand and gravel along Nesenkeag Brook, and they each yield less than 100 gal/min. The aquifer along the brook is not as extensive as the Darrah Pond aquifer; its saturated thickness is less than 40 ft, and its transmissivity is less than 8,000 ft²/d.

South of the Darrah Pond aquifer, another coarse sand and gravel aquifer, located near Cutler Road, also is within the same buried valley that follows a north-south course through central Litchfield. The saturated thickness is greater than 60 ft and transmissivity is greater than 8,000 ft²/d. The Weinstein production well (W-36) in this area yields more than 500 gal/min. Additional production capacity from this area probably is limited by potential interference with well W-36 that taps from this small aquifer.

Saturated thickness of the coarse sand and gravel aquifer along Colby Brook exceeds 40 ft, and transmissivity is less than 8,000 ft²/d. Based on the extent and saturated thickness of the permeable material at wells W-1 to W-6, W-34, and W-35 (transmissivity averages 7,000 ft²/d), the yield of this aquifer potentially is as large as that from aquifers near Darrah Pond and Nesenkeag Brook.

Lyndeborough

Lyndeborough is in the upland region of the northwestern corner of the study area (fig. 1) along the eastern base of the Monadnock Mountain Range. Only 2.4 mi² or 8 percent of the town is underlain by permeable stratified drift (pls. 1 and 2). In a few places, the saturated thickness of stratified drift exceeds 10 ft; therefore, most deposits seem to be incapable of yielding more water than may be required for residential use.

The small, thin aquifers in Lyndeborough are widely scattered and discontinuous. In the Piscataquog River, Curtis Brook, and Stony Brook valleys, the stratified drift in kame terraces and eskers is thick, but the saturated thickness is too small to support large well yields; possible exceptions are stratified-drift deposits along the Piscataquog River east of Piscataquog Mountain and those northeast of Piscataquog Mountain near Wilton Road, where the saturated thickness is less than 20 ft and the transmissivity is less than 4,000 ft²/d. However, exploration to determine if sites for large yielding wells are possible would be desirable.

The limited extent and saturated thickness of the stratified-drift aquifers in Lyndeborough (pls. 1 and 2) indicates that a large-capacity municipal water-supply system is not likely to be located in the town. Use of the small, isolated stratified-drift aquifers, which generally have transmissivities less than 2,000 ft²/d, is suited for individual household water supplies.

Merrimack

The town of Merrimack, on the western side of the Merrimack River (fig. 1), has stratified drift beneath about 19 mi² or 57 percent of its area (pls. 3 and 4). Like Litchfield across the river, much of the stratified drift in Merrimack is fine-grained bottom sediment of Glacial Lake Merrimack (Koteff, 1970; 1976). Highly permeable, coarse stratified drift is interspersed with fine-grained materials in local areas along the Merrimack River and Naticook Brook. The deposits along the brook northeast of Naticook Lake and the South Merrimack deposits in the southwestern corner of town form the most important aquifers in Merrimack. Saturated thickness of these two permeable stratified-drift deposits are greater than 80 ft and 60 ft, respectively, and their transmissivity exceeds 8,000 ft²/d. The very large South Merrimack deposits extend northeastward toward Naticook Lake and southwestward into the broad outwash plain in Nashua, Amherst, and Hollis.

Induced recharge potential is greatest in South Merrimack from Pennichuck Pond and Pennichuck Brook and in the Naticook Valley from Naticook Lake and Greens Pond. Three municipal wells (W-15, W-23, and W-148), located in the Naticook Valley aquifer east and northeast of Greens Pond and one in South Merrimack, each yield more than 300 gal/min. These aquifers have the potential to yield additional quantities of water for expanding the municipal-supply system.

Elsewhere in Merrimack, permeable, coarse-grained deposits capable of yielding large quantities of water to wells are located along the Merrimack River. These deposits extend from 1 mile south of the Thorntons Ferry toll gate of the F. E. Everett Turnpike northward to the Bedford town line. However, these discontinuous aquifers are surrounded by finer grained materials. At least three high-yielding production wells, including a Merrimack Village district well (W-30) are screened in coarse-grained deltaic deposits adjacent to the Merrimack River. The transmissivity of aquifers along the river varies from less than 2,000 ft²/d to more than 8,000 ft²/d. Saturated thickness ranges from about 20 to 100 ft; the greatest saturated thickness is between Horseshoe Pond and the Souhegan River. This aquifer has potential for additional high-yield wells, especially north of the Souhegan River because of the large area and saturated thickness of the aquifer and its potential for induced recharge.

Stratified drift in the valleys of Baboosic Brook and Souhegan River west of the F. E. Everett Turnpike, is predominantly fine grained, and its transmissivity is less than 4,000 ft²/d. These deposits are not suited for high-yield production wells, but probably would provide 5 to 10 gal/min, which would be sufficient for individual households.

Milford

Thirty-eight percent of the town of Milford, or about 10 mi², is underlain by permeable stratified drift. These deposits are in two adjoining valleys west of State Route 13 (pls. 1 and 2). One, the Souhegan River valley, contains the largest, most productive aquifer in the town. The other, Great Brook valley, in South Milford, also has a large area underlain by permeable stratified drift.

The Great Brook and Souhegan Valley deposits are generally sand and gravel, overlying glaciolacustrine bottom deposits of fine sand, silt, and clay especially in the deeper parts of each valley. Throughout Great Brook valley are ice-contact sand and gravel (Koteff, 1970) deposits; however, in the lower part of the valley, fine-grained lake-bottom sediments predominate. Saturated thickness within both valleys is less than 80 ft. The greatest saturated thickness in the Souhegan Valley (60 ft) is just south of or directly beneath Souhegan River. The area of saturated thickness in the Great Brook area is around Osgood Pond. Transmissivity greater than 8,000 ft²/d is present at only a few locations within the town. The main Souhegan River valley has an extensive zone of transmissivity of more than 8,000 ft²/d and lesser zones around Osgood Pond and east of State Route 13 along the Souhegan River.

The main Souhegan River valley aquifer consists of six high-capacity production wells having sustained yields of from 200 to 500 gal/min. The wells include the town of Milford's municipal Savage (W-21) and Keyes (W-73) wells, Milford fish hatchery well (W-65), and three industrial wells. To the east of State Route 13 are the town of Milford's Curtis wells (W-72 and W-73), which yield 400 and 700 gal/min, respectively. Sites for additional withdrawals may be located in the high-transmissivity aquifer area south of the Souhegan River.

In the Osgood Pond area of the Great Brook valley, is the town of Milford's well (W-71), which yields approximately 500 gal/min. This aquifer is not as extensive as the Souhegan Valley aquifer. The capacity for induced recharge is greatest along Osgood Pond and Great Brook.

The town of Milford has many areas in which only a few feet of the highly permeable stratified drift is saturated. Large quantities of water induced to flow from surface-water bodies to wells are important, especially where thin aquifers provide limited ground-water storage, such as along Route 13 and near West Milford. In places where the stratified materials are mostly fine grained, such as in the lower Great Brook area, this type of development is not possible.

Mont Vernon

Mont Vernon, in the hilly northwestern part of the study area (fig. 1), has about 0.4 mi² of stratified drift that covers 2 percent of the town's area. Most of the sand and gravel is located between Salisbury Road and the tributary to Lords Brook (pls. 1 and 2). Transmissivity is estimated to be less than 2,000 ft²/d because to the saturated thickness is less than 10 ft.

Several other discontinuous patches of sand and gravel in Mont Vernon may be stratified, but are not areally extensive and have very little saturated thickness. These areas were field checked and were not considered important enough to be placed on the maps. Transmissivities range from 0 to less than 2,000 ft²/d. Mont Vernon does not seem to have any stratified-drift aquifers that could be developed into a municipal water supply. Individual users in Mont Vernon rely mostly on water in the till or bedrock aquifer for household needs.

Nashua

The city of Nashua, located on the western side of the Merrimack River (fig. 1) is underlain by approximately 21 mi² of stratified drift (pls. 3 and 4) or 67 percent of the area of the city. The stratified drift along the Merrimack and Nashua Rivers is nearly continuous in extent but has variable saturated thickness and transmissivity.

The most extensive aquifer is beneath the city and extends southward along the Nashua River and northward towards Pennichuck Pond. The area east of the F. E. Everett Turnpike is underlain by deltaic deposits (Koteff, 1976). Saturated thickness of the deltaic deposits is typically less than 60 ft, and transmissivity is less than 8,000 ft²/d; however, some deposits having higher transmissivity are located along the Nashua River and Salmon Brook. Pennichuck Water Company wells W-126, W-127, and W-128 each yield approximately 500 gal/min in the Salmon Brook area of central Nashua. Sites for new public-supply wells may be difficult to locate in Nashua because a protection zone of at least 400 ft in radius around the well is required by State law; most of the city is too densely populated to provide this protection. Therefore, the aquifer beneath Nashua is probably useful only for industrial use.

West of the F. E. Everett Turnpike, the aquifer extending towards Pennichuck Pond consists of coarse-grained material buried beneath fine-grained deposits. Near Pennichuck Pond, the fine-grained deposits pinch out and the entire section of stratified drift is coarse grained (NAA-213). Saturated thickness of these deposits is generally less than 60 ft and transmissivity of the coarse material is greater than 8,000 ft²/d. Transmissivity of the remainder of the stratified-drift is less than 8,000 ft²/d. The aquifer having the greatest potential for high-yield wells extends from near Pennichuck Pond northward to Pennichuck Brook. Potential yield may be augmented by induced recharge from Pennichuck Brook or Pennichuck Pond; however, resulting streamflow losses due to induced recharge may significantly reduce surface-water inflow to the Pennichuck water supply, which serves Nashua and adjacent towns. The saturated deltaic deposits between Boire Field and the F. E. Everett Turnpike is another potential water source, although the area is thickly settled and heavily developed. The U.S. Fish and Wildlife Service has two wells that yield 100 and 600 gal/min (W-187 and W-188), respectively, west of the F. E. Everett Turnpike and Route 101 interchange.

Other permeable sand and gravel aquifers are located along the Nashua River in the southwestern part of Nashua. This area is underlain by coarse-grained deposits of Glacial Lake Nashua (Koteff and others, 1973). Thickness of these deposits generally is less than 60 ft, and transmissivity is less than 8,000 ft²/d. Three production wells (W-157, W-158, and W-220) yield from 50 to more than 600 gal/min in this area of Nashua. High-yield wells may be developed in this area, but the density of development and water-quality problems in the Nashua River and at the Gilson Road hazardous-waste site may eliminate this aquifer from consideration as a public-water supply.

Along the Merrimack River, north and south of urban Nashua, the saturated thickness of permeable material is less than 60 ft. The most favorable area for ground-water development is in south Nashua near the mouth of Spit Brook where transmissivity exceeds 8,000 ft²/d, where the yield of the aquifer can be augmented by induced recharge from Merrimack River. However, dense industrial development may cause water-quality problems. Elsewhere, large-capacity ground-water development from the stratified drift is limited by fine-grained materials and (or) thin saturated thickness.

Pelham

The town of Pelham in the southeastern corner of the study area (fig. 1) is underlain by 10.7

mi² (40 percent of the area of the town) of stratified drift (pls. 5 and 6). The most extensive and thickest deposits are in the center of the town along Golden and Beaver Brooks. Other outlying deposits are mostly thin, discontinuous pockets of sand and gravel of limited areal extent and saturated thickness (pls. 5 and 6).

Saturated thickness is less than 80 ft along Beaver Brook above the mouth of Golden Brook. In lower Beaver Brook valley, saturated thickness is greater than 100 ft near Nashua Road in central Pelham, but generally less than 60 ft throughout the remainder of the watershed. In the lower valleys of Golden Brook and Island Pond Brook, saturated thickness generally is less than 40 to 60 ft.

The largest stratified-drift aquifer extends from the mouth of Golden Brook southward along Beaver Brook. This aquifer consists primarily of coarse sand and gravel locally overlain by fine material and extends southwestward past Willow Street. Saturated thickness as much as 100 ft and a transmissivity of more than 8,000 ft²/d make this area of central Pelham the best available location for developing ground-water supplies for the town. The school-system well (W-63) yields more than 400 gal/min from this aquifer.

Along Beaver Brook to a point northwest of its confluence with Golden Brook, the stratified drift consists of coarse sand and gravel. This aquifer is not as extensive and does not have as great a storage capacity as the lower Beaver Brook area; however, it does have a transmissivity greater than 6,000 ft²/d. Wells could be located in the permeable materials of this area and designed to induce recharge from Beaver Brook.

Other stratified-drift deposits of limited areal extent, saturated thickness, and transmissivity of less than 4,000 ft²/d are within the valleys of Gumpas Pond Brook, Island Pond Brook, Harris Pond, upper Golden Brook, and the northwestern corner of Beaver Brook. The deposits in these areas are not capable of supplying water at pumping rates that would be sufficient to supply municipal wells.

Wilton

Permeable stratified drift covers 5.2 mi² or about 20 percent of Wilton. These stratified-drift deposits are found in continuous bands along Stony Brook, Blood Brook, a Stony Brook tributary, and the Souhegan River (pls. 1 and 2).

The most important aquifer available for additional development is along the Souhegan River near New Hampshire State Routes 101 and 31 (pls. 1 and 2). This aquifer extends from the Massachusetts border northward toward Wilton Center and westward up the valley of Blood Brook. Seismic-refraction and test-well data indicate the presence of about 80 ft of saturated sand and gravel in this area. Well W-6 in this aquifer has a yield of 500 gal/min. Transmissivity in the most thickly saturated part of this aquifer is greater than 8,000 ft²/d.

The aquifer along Stony Brook south of the Wilton-Lyndeborough town line is of limited areal extent but contains at least 40 ft of saturated sand and gravel. Potential exists for induced recharge from Stony Brook to supplement the yield of this aquifer. Although the transmissivity of this aquifer is less than 8,000 ft²/d, the aquifer may, upon testing, have the capacity to sustain one large-yielding well.

All other stratified-drift aquifers in Wilton, including those in the valleys of upper Blood Brook, Stony Brook tributary and lower Souhegan River contain stratified drift with transmissivity generally less than 2,000 ft²/d; this stratified drift is best suited for supplying water to individual households or other small users.

Estimates of Sustained Yield of Selected Aquifers

To meet the increasing water needs of consumers, wells within several aquifers currently are being pumped at maximum rate. However, many of these aquifers may still be capable of yielding additional quantities of water to wells. This section of the report describes the use of mathematical models for estimating potential yields of six aquifers within the study area. These aquifers were selected because of their importance and to demonstrate model use in various hydrogeological settings. It was considered beyond the scope of this report to assess the yield of each aquifer in the study area. In addition, consideration has not been given to low-flow maintenance or to water-quality ramifications caused by induced recharge in this analysis.

Computations of sustained yield were made with an analytical-mathematical model based on the Theis nonequilibrium equation (Theis, 1935), as modified by image well theory (Ferris and others, 1962) to account for boundary conditions.

These estimates take into account the effects of hydraulic boundaries of aquifers, aquifer hydraulic properties, well-construction characteristics, and possible well interferences (Mazzaferro and others, 1978). Calculation of sustained yield from hypothetical wells involves four basic steps: (1) determination of aquifer and well characteristics, (2) determination of an initial discharge rate, (3) determination of total drawdown in wells from information obtained in steps 1 and 2, and (4) determination of adjusted discharge rate so that total drawdown is at least 1 ft above the screened interval of each pumping well.

Aquifer characteristics incorporated into the models include saturated thickness, transmissivity, and storage coefficient. Using plates 2, 4, and 6, saturated thicknesses are determined for each real or hypothetical well site. Transmissivity (pls. 2, 4, and 6) assigned to each modeled area represents the average transmissivity over the entire model area. Storage coefficients used in model simulations ranged from 15 percent to 20 percent.

Construction characteristics of the real and hypothetical wells are incorporated in model simulations by assigning well-diameter values and the ratio of well-screen length to total saturated thickness. For hypothetical wells, the diameter was assumed to be 1 ft and screened intervals were assumed to be 30 percent of total aquifer saturated thickness; therefore, the total available drawdown at each well is assumed to be 70 percent of saturated thickness. Sustained yield of selected aquifers was determined for 180-day periods with no ground-water recharge; this is assumed to be the maximum no-recharge period in this study area.

The total drawdown at each pumping well is equal to drawdown produced by six basic components: (1) drawdown due to aquifer and well characteristics, (2) drawdown due to dewatering of the aquifer, (3) drawdown due to partial penetration of the aquifer by the pumping well, (4) drawdown due to well loss caused by flow into the screen, (5) drawdown caused by nearby pumping wells, and (6) drawdown (or buildup) caused by hydraulic boundaries.

Hydraulic boundaries that can be simulated with the Theis image-well model are line-source recharge boundaries, barrier (no-flow) boundaries, and open or infinite boundaries. Recharge boundaries represent unlimited sources of water that may be available to aquifers from surface-water bodies such as rivers, ponds, and lakes. Because recharge boundaries act as an unlimited source of water, they limit the cone of depression caused by a pumped well (fig. 5). Impermeable-barrier boundaries can be used to represent the contact between materials that have a large difference in permeability, such as the contact between stratified drift and till/bedrock. Drawdown caused by a pumped well is amplified along a barrier boundary (fig. 6) because there is no flow across this boundary.

Recharging or discharging image wells (Ferris and others, 1962) are used to simulate the effects of hydraulic boundaries. In this particular model, the above-mentioned aquifer boundaries must be idealized as straight lines that enclose a rectangular area in which one of the boundaries remains "open" (figs. 7 through 12).

The model determines the maximum discharge rate for a well such that total drawdown at the well is at least 1 ft above the well screen. In addition, drawdown caused by aquifer and well characteristics must be less than or equal to only 30 percent of saturated thickness at each well site. If drawdown for any well falls outside these limits, an adjustment to the discharge rate is made and drawdown is recalculated. This adjustment process is done iteratively until the above criteria are met.

The adjusted discharge for each pumping well within the modeled aquifer is then totalled to provide an estimate of sustained yield for the aquifer. The reliability of the estimated total sustained yield depends on how closely assumed conditions match actual field conditions in a given aquifer. Consideration also should be given to the actual amount of ground water available by comparing computed yields with low flow in nearby surface waters. Comparison of predicted yields with low flows will indicate if enough ground water is actually available to sustain the predicted yield.

Amherst-Beaver Brook Aquifer

This aquifer is located along Beaver Brook in Amherst from about Thorntons Ferry Road to Merrimack Road (fig. 7). The existing Amherst town well (W-18) is located at the northern end of this aquifer to the west of Beaver Brook. Pumping was simulated at the Amherst well (W-18) and at two additional locations within this aquifer in the model (fig. 7). The two additional locations were selected based upon exploratory drilling done in the area that indicated favorable conditions for well installation.

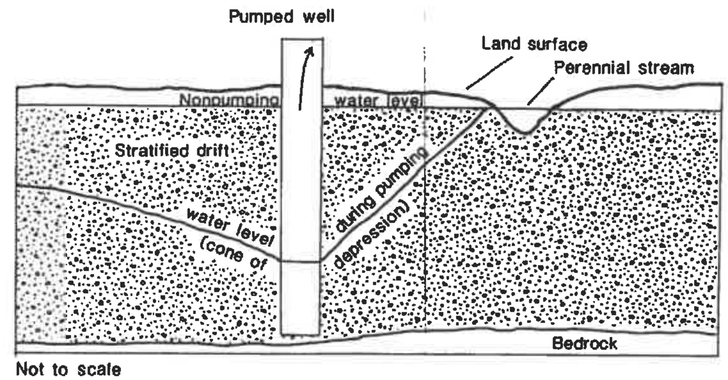


Figure 5.--Effects of a recharge boundary on the cone of depression of a pumped well.

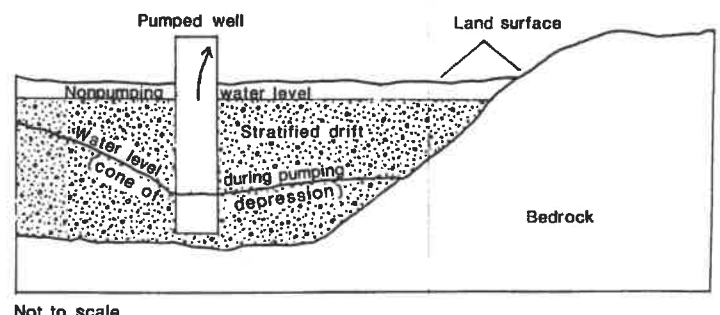


Figure 6.--Effects of a barrier boundary on the cone of depression of a pumped well.

0 1000 2000 3000 FEET

0 400 800 METERS

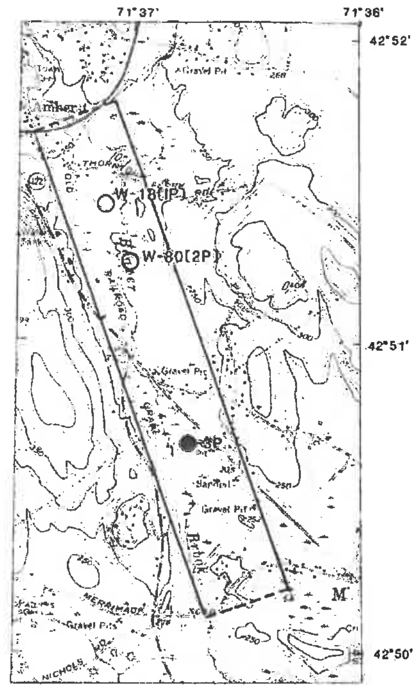
EXPLANATION

○ W-18 EXISTING WELL AND NUMBER

1P WELLS WHERE PUMPING WAS SIMULATED IN THE MODEL

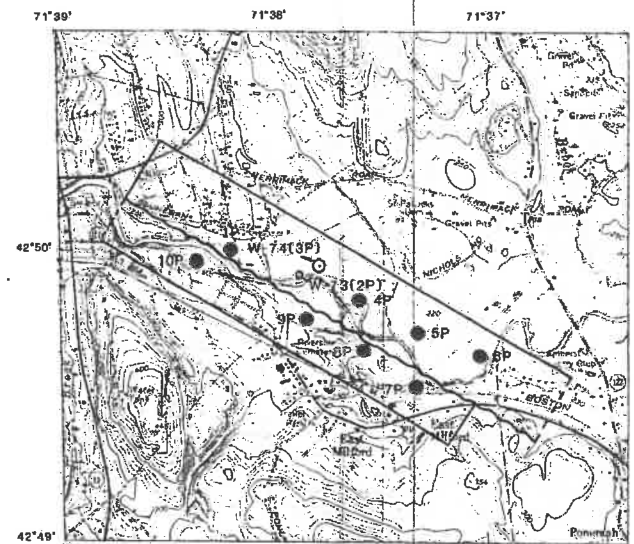
—— BARRIER BOUNDARY

- - - - OPEN BOUNDARY



Base From U.S. Geological Survey 1:24,000
South Merrimack,1968,Photorevised 1985

Figure 7.--Boundaries and well placement for sustained-yield estimate of the Amherst-Beaver Brook aquifer.



Base From U.S. Geological Survey 1:24,000
Milford 1968, Photoinspected 1974,
South Merrimack 1968, Photorevised 1985.

0 1000 2000 3000 FEET

0 400 800 METERS

EXPLANATION

⊙ W-73 EXISTING WELL AND NUMBER

● HYPOTHETICAL WELL SITE

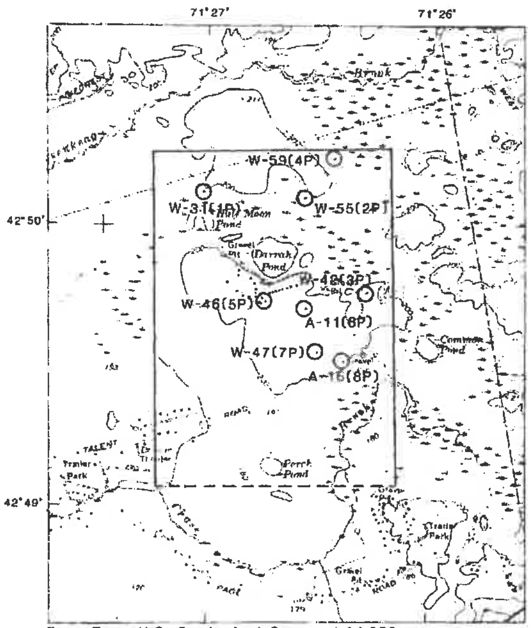
1P WELLS WHERE PUMPING WAS SIMULATED IN THE MODEL

〰 RECHARGE BOUNDARY

—— BARRIER BOUNDARY

- - - - OPEN BOUNDARY

Figure 8.--Boundaries and well placement for sustained-yield estimate of the Amherst-Milford Souhegan River aquifer.



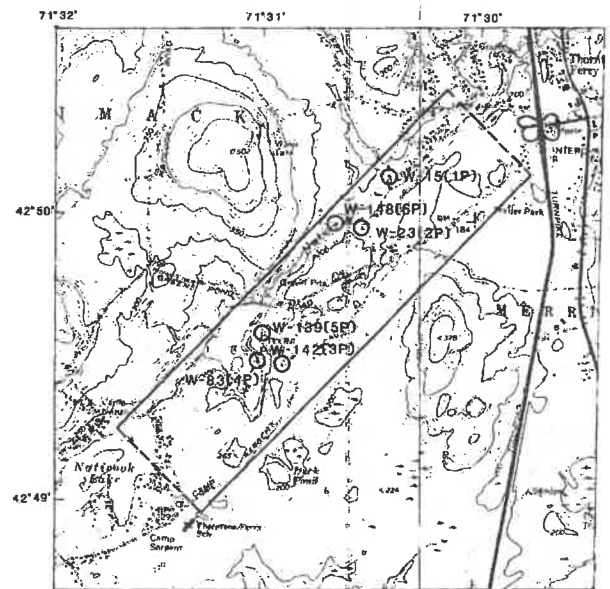
Base From U.S. Geological Survey 1:24,000
Nashua North,1968,Photorevised 1974

0 1000 2000 3000 FEET
0 400 800 METERS

EXPLANATION

⊙ W-59	EXISTING WELL AND NUMBER
⊙ A-11	AUGER BORING SITE AND NUMBER
1P	WELL OR AUGER BORING SITES WHERE PUMPING WAS SIMULATED IN THE MODEL
——	BARRIER BOUNDARY
- - - -	OPEN BOUNDARY

Figure 9.--Boundaries and well placement for sustained-yield estimate of the Litchfield-Darrah Pond aquifer.



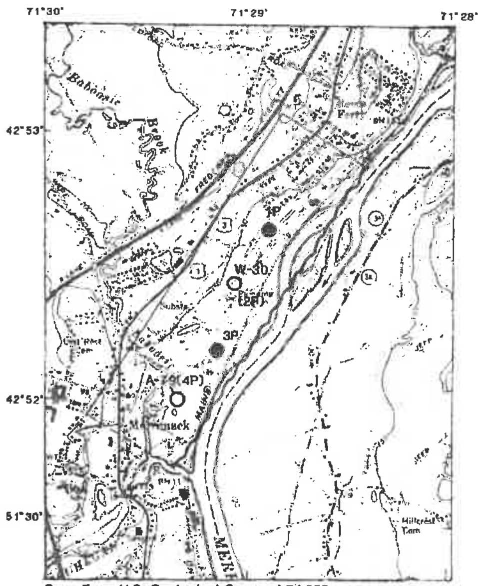
Base From U.S. Geological Survey 1:24,000
South Merrimack,1968, Photorevised 1985
Nashua North, 1968,Photorevised 1974

0 1000 2000 3000 FEET
0 400 800 METERS

EXPLANATION

⊙ W-15	EXISTING WELL AND NUMBER
1P	WELLS WHERE PUMPING WAS SIMULATED IN THE MODEL
——	BARRIER BOUNDARY
- - - -	OPEN BOUNDARY

Figure 10.--Boundaries and well placement for sustained-yield estimate of the Merrimack-Naticook Brook aquifer.



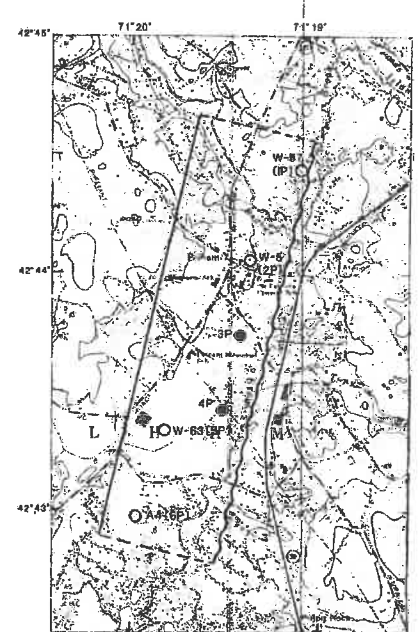
Base From U.S. Geological Survey 1:24,000
Nashua North 1968, Photorevised 1974,
Manchester South 1968.

0 1000 2000 3000 FEET
0 400 800 METERS

EXPLANATION

○ W-30 EXISTING WELL AND NUMBER
○ A-79 AUGER BORING SITE AND NUMBER
● HYPOTHETICAL WELL SITE
P WELL OR AUGER BORING SITES WHERE PUMPING WAS SIMULATED IN THE MODEL
RECHARGE BOUNDARY
BARRIER BOUNDARY
OPEN BOUNDARY

Figure 11.--Boundaries and well placement for sustained-yield estimate of the Merrimack-Merrimack River aquifer.



Base From U.S. Geological Survey 1:24,000
Lowell-Mass.-N.H.,1966

0 1000 2000 3000 FEET
0 400 800 METERS

EXPLANATION

○ W-57 EXISTING WELL AND NUMBER
○ A-4 AUGER BORING SITE AND NUMBER
● HYPOTHETICAL WELL SITE
P WELL OR AUGER BORING SITES WHERE PUMPING WAS SIMULATED IN THE MODEL
RECHARGE BOUNDARY
BARRIER BOUNDARY
OPEN BOUNDARY

Figure 12.--Boundaries and well placement for sustained-yield estimate of the Pelham-Beaver Brook aquifer.

In the model, the contacts between the stratified-drift aquifer and till along the edges of the valley were simulated as two barrier boundaries and because the aquifer continues beyond the modeled area the north and south ends were treated as "open" or infinite boundaries. Beaver Brook was not simulated as a recharge boundary because it has very little flow during summer periods (site 09, table 1). Therefore, the model simulates flow of ground water derived entirely from storage within the aquifer. Saturated thickness ranged from 25 to 50 ft, and transmissivity averaged 5,000 ft²/d in the modeled area (pls. 2, 4, and 6).

Model results indicate that potential sustained yield of 0.6 Mgal/d could be derived from the three wells shown in figure 7. The existing production well (W-18) pumps 0.2 Mgal/d; therefore, under the hydrologic conditions specified above, an additional 0.4 Mgal/d could be pumped from this aquifer. The total estimated yield of 0.6 Mgal/d is probably conservative, because induced recharge from Beaver Brook could occur during periods of increased surface-water runoff in the spring and early summer.

Amherst-Milford Souhegan River Aquifer

This aquifer is situated along the Souhegan River in western Amherst and extends east of Milford center (fig. 8). Two existing Milford town wells (W-73 and W-74) are located in the central part of this model area north of the Souhegan River. Eight additional hypothetical pumping wells were simulated in the model--four to the north and four to the south of the river (fig. 8).

The contacts between the aquifer and till valley walls were simulated as barrier boundaries in the model; the Souhegan River was simulated as a line-source recharge boundary. Because the aquifer is continuous along the valley beyond the modeled area, the end boundaries were left open. The modeled area was assumed to have an average transmissivity of 8,500 ft²/d.

Model results indicate that the aquifer would provide a total sustained yield of 7.6 Mgal/d to the eight wells shown in figure 8. Wells W-73 (2P) and W-74 (3P), have a combined yield of 1.6 Mgal/d. An additional 6.0 Mgal/d could be obtained from the six additional wells simulated in the model (fig. 8). The discharge of the Souhegan River during base-flow conditions, downstream from the aquifer, was measured at 26.5 ft³/s on August 28, 1984 (site 14, table 1, pl. 3). Under the modeled pumping scenario, the discharge of the Souhegan River downstream of this aquifer would be reduced by 9.0 ft³/s (6.0 Mgal/d) if all pumped water were used consumptively.

Litchfield-Darrah Pond Aquifer

The Darrah Pond aquifer is located in central Litchfield and is approximately centered about Darrah Pond (fig. 9). Seismic-refraction profiling and test drilling indicate the presence of a buried valley running north-south through this area. The Darrah Pond well (W-59) is located in the northern part of this aquifer and yields 100 gal/min to residences in central Litchfield. In the model, seven additional wells were simulated at locations where test drilling showed favorable conditions (fig. 9).

The modeled area was simulated as having barrier boundaries to the north, east, and west where saturated thickness of the aquifer is 20 ft or less. The southern boundary of the model was left open to simulate the continuous aquifer deposit in that direction. Average transmissivity was modeled as 5,000 ft²/d.

Model results show that the total sustained yield from this aquifer could be approximately 2.3 Mgal/d. This probably is a conservative estimate of potential yield because the model assumes no significant sources of induced recharge and withdrawal of water is obtained only from storage.

Merrimack-Naticook Brook Aquifer

The Naticook Brook aquifer is located along Naticook Brook northeast of Naticook Lake (fig. 10) in Merrimack. At present, three municipal wells (W-15, W-23, and W-148) located along Naticook Brook in the central part of this aquifer yield 1.3 Mgal/d. Additional pumping was simulated at three locations (W-142, W-83, and W-139) where test drilling showed sites that were favorable for ground-water withdrawal.

The model boundaries were simulated as no flow along the contact of the stratified-drift aquifer and till/bedrock valley walls. The continuous aquifer deposits were simulated with open boundaries on the northeastern and southwestern edges of the model. Because low flow in Naticook Brook was observed to be 0.2 ft³/s or less (table 1), the surface water was not simulated as a recharge boundary. Transmissivity in the modeled area was assumed to average 10,000 ft²/d.

Model results show that a total yield of approximately 3.4 Mgal/d could be obtained from the three existing and three proposed wells, or an increase of 2.0 Mgal/d above the existing pumping rate. This total yield is considered to be conservative, because some recharge could probably be obtained from Naticook Brook at high flows or from Naticook Lake and because some flow of water would probably occur across the till/stratified-drift boundary.

Merrimack-Merrimack River Aquifer

This aquifer is located along the Merrimack River north of the Souhegan River in Merrimack (fig. 11). The Reeds Ferry municipal well (W-30), located in the center of aquifer area, pumps 0.8 Mgal/d. Additional pumping was simulated at three additional sites where drilling showed conditions were favorable for well construction (fig. 11).

In the model, the Merrimack River was simulated as a line-source recharge boundary. The northern and western edges of the model were treated as barrier boundaries to simulate thin saturated thickness and low transmissivity. The southern boundary of the model was left "open" to simulate continuous aquifer material beyond the modeled area. Transmissivity within the model area was assumed to average 7,000 ft²/d.

Model results indicate that the four wells have a total potential yield of 1.9 Mgal/d. At this site, total well yield depends on recharge from the Merrimack River. Flow in the river is sufficient to sustain much greater yields than those simulated with the model.

Pelham-Beaver Brook Aquifer

The aquifer, located along Beaver Brook in central Pelham (fig. 12), extends from the mouth of Golden Brook on the north, to Willow Street on the south. Well W-63 pumps approximately 400 gal/min from the central part of this aquifer. The logs of several test borings (W-57, W-55, W-62, and A-4) in the central part of the valley west of Beaver Brook indicate favorable conditions for well construction. Additional pumping from six locations in the aquifer was simulated.

The model area has a recharge boundary on the east to simulate Beaver Brook and a barrier boundary on the west to simulate the stratified-drift till contact. The northern and southern boundaries were left "open" to simulate continuous aquifer deposits beyond the model area. Saturated thickness ranges from 30 to 100 ft and transmissivity averages 9,000 ft²/d (pl. 6) in the modeled area.

Modeled results indicate a potential total yield of 3.8 Mgal/d from six wells within this aquifer; this represents an increase of 2.3 Mgal/d over the current yield. The measured streamflow in Beaver Brook during base-flow conditions at the downstream end of the modeled area was 11.5 ft³/s (site 44, table 1). Under the modeled pumping scenario, discharge at Beaver Brook would be reduced by about 3.5 ft³/s, if all pumped water is used consumptively.

WATER QUALITY

Stratified-drift aquifers are particularly susceptible to contamination from human activities, because they have thin, highly permeable, unsaturated zones. Contaminants can readily travel from the land surface to the water table with little or no filtration. Land-use activities that can adversely affect ground-water quality include, but are not limited to, underground petroleum storage, fertilizer application, underground waste disposal, and road salting.

Two CERCLA "superfund" sites are within the study area, at Gilson Road in Nashua and Savage well in Milford. More than 1,300 55-gallon drums and 900,000 gallons of hazardous waste were disposed of at the 7-acre Gilson Road site. At present, contaminated ground water at the Gilson site is being collected and treated. At the Savage well site, municipal wells for the town of Milford were contaminated with organic chemicals. Four companies have been working on a plan to address the problem.

The New Hampshire Water Supply and Pollution Control Commission (1982) has identified other land-use activities that could have an adverse effect on the water quality of surface water and ground water in the Nashua region. Discussed in that report are: nonpoint potential pollution sources, such as agricultural, industrial, and domestic waste disposal; and point sources, including landfills, dumps, hazardous-waste sites, and salt-storage areas. Sources of information on point sources of contamination are listed in a report by Metcalf and Eddy, Inc. (1983).

Water-quality samples were collected at 14 surface-water and 32 ground-water locations during November 1-7, 1983, to characterize background water quality in the study area. Water-quality sampling and analytical work was done by the U.S. Geological Survey and by Metcalf and Eddy, Inc., (consultants) according to standard procedures developed by the U.S. Geological Survey (Goerlitz and Brown, 1972) and the American Public Health Association (1980). The water-quality results summarized in subsequent sections of this report have been published by Metcalf and Eddy, Inc., (1983).

Ground Water

The natural chemical composition of ground water derived from unconsolidated aquifers depends on several factors, including precipitation chemistry; subsurface physical, chemical, and biological reactions; and the mineralogy of the aquifer materials. Residence time of water in an aquifer, which depends on the distance and rate that ground water travels from recharge to discharge areas, also is an important factor in natural ground-water geochemistry. Ground water in natural discharge areas generally is higher in dissolved solids than water obtained from recharge areas because of the longer contact time with aquifer materials.

Ground-water quality sampling was conducted on November 1-3 and 7, 1983, at 32 locations throughout the Nashua region including: 15 domestic wells, 11 municipal wells, 6 U.S. Geological Survey observation wells. Sampling locations were specifically selected to avoid any known point sources of contamination to obtain information on background water quality. A summary of results of chemical analysis is shown in table 4, and sampling locations are shown on plates 1, 3, and 5.

Physical and Chemical Properties

Dissolved solids

The dissolved-solids content of natural waters consists mainly of inorganic chemicals such as bicarbonates, carbonates, chlorides, sulfates, and phosphates. Elevated concentrations of dissolved solids can be used as an indicator of human-introduced contamination in areas where concentrations are normally low. The USEPA-recommended drinking-water limits for total dissolved solids are set at a maximum of 500 mg/L, based primarily on taste considerations (U.S. Environmental Protection Agency, 1976).

Concentration of total dissolved solids was typically less than 200 mg/L and did not vary greatly across the region (fig. 13). The highest concentrations, 470 and 580 mg/L, were found in shallow dug wells in Mont Vernon and Nashua (Metcalf and Eddy, Inc., 1983), respectively. The high levels of dissolved solids observed in both wells are due to high levels of sodium and chloride that originated from road-deicing operations. Thirty other wells had a concentration of total dissolved solids that averaged 115 mg/L and ranged from 50 to 210 mg/L (table 4), indicating that background concentrations are relatively low as compared to the USEPA drinking-water recommended limit.

pH

The pH of water is a measure of the hydrogen-ion activity and is used in expressing the acidity or alkalinity of water on a scale of 0 to 14. At pH 7.0, water is considered neutral, increasingly acidic at values less than 7.0, and increasingly alkaline at values greater than 7.0. Natural water generally has a pH range of from 6.5 to 8.5 (Hem, 1970), which is also the range of USEPA drinking-water recommended limit (U.S. Environmental Protection Agency, 1976). The pH of ground water is primarily controlled by interaction with carbon-dioxide gas and with carbonate and bicarbonate ions. The hydrogen-ion activity is important in that it affects taste and corrosivity of drinking water. At a pH of less than 6.5, metals from plumbing and water-distribution systems, such as copper, zinc, cadmium, and lead, can dissolve in water and cause health problems.

The average pH of 32 samples was 6.2 and ranged from 5.0 to 7.3 (table 4). Water from 28 wells had a pH below that of the USEPA drinking-water recommended limit of 6.5 to 8.5.

Chloride

Recommended limits for chloride concentrations in drinking water are based on taste rather than on health considerations. The USEPA recommended maximum limit for chloride is 250 mg/L (U.S. Environmental Protection Agency,

Table 4.--*Summary of ground-water quality*

[Modified from Metcalf and Eddy, Inc., 1983.]

Constituent or property	Number of samples	Average concentration, in milligrams per liter	Range, in milligrams per liter		
Chloride (Cl)	32	37.97	230.0	-	2.0
Chemical oxygen demand (COD)	22	13.0	82.0	-	5.3
Specific conductance (microsiemens per centimeter at 25 °C)	29	217	880	-	47.0
Nitrate (NO_3 as N)	31	1.59	6.0	-	.018
pH	32	6.17	7.3	-	*5.0
Total dissolved solids	32	140.25	*580.0	-	50.0
Total organic carbon (TOC)	23	6.3	90.0	-	.37
Barium (Ba)	33	.018	.097	-	.001
Silver (Ag)	8	.002	.006	-	.001
Arsenic (As)	1	.05	--		--
Copper (Cu)	27	.059	.642	-	.001
Cadmium (Cd)	5	.00068	.001	-	.001
Chromium (Cr)	2	.029	.045	-	.012
Iron (Fe)	28	*3.63	*78.2	-	.006
Manganese (Mn)	32	*.20	2.01	-	.001
Sodium (Na)	32	*23.9	*119.0	-	1.7
Nickel (Ni)	6	.008	.024	-	.003
Zinc (Zn)	25	.021	.076	-	.001
Lead (Pb)	6	.015	.02	-	.01

*Exceeds maximum drinking water limit set by the U.S. Environmental Protection Agency, 1976.

1976). Chloride is not readily absorbed by rock and soil particles and is, therefore, highly mobile in water. Elevated concentrations of chloride may indicate contamination from highway deicing chemicals, salt-storage piles, landfills, and municipal and domestic sewage-disposal systems.

All chloride concentrations in the samples analyzed were below the USEPA drinking-water recommended limit of 250 mg/L. The highest concentrations, 180 and 230 mg/L, were detected in shallow dug wells in Mont Vernon and Nashua, respectively. Water from these two wells were far above the average concentration of 33 mg/L detected at 30 additional wells (table 4).

Sodium

A maximum sodium concentration of 20 mg/L has been recommended by USEPA for drinking-water supplies to help regulate sodium in the diet, which, in excess amounts, can lead to cardiac disease, renal disease, and cirrhosis of the liver (U.S. Environmental Protection Agency, 1976). As much as 40 percent of the public-water supplies of the United States had natural or added sodium concentrations above the 20-mg/L limit. Sodium is one of the most common cations in nature, but the natural sodium content is augmented in many areas by stored and spread highway-deicing salts, sewage-disposal systems, and industrial and agricultural waste.

Sodium concentrations averaged 24 mg/L across the study area, ranging from 1.7 to 119 mg/L (table 4). The USEPA drinking-water recommended limit of 20 mg/L (U.S. Environmental Protection Agency, 1976) for sodium was exceeded at 11 of the sampling sites. The maximum value of 119 mg/L was observed in water from a shallow dug well in Mont Vernon in an area where the water in many wells is affected by highway salting.

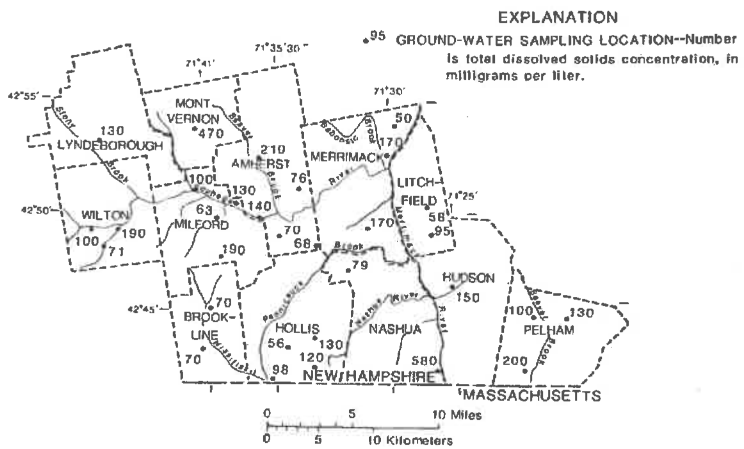


Figure 13.--Distribution of total dissolved solids at ground-water-sampling sites.

Nitrate

The predominant form of inorganic nitrogen found in natural waters is nitrate nitrogen, which results from oxidation of nitrogenous compounds. The USEPA drinking-water recommended limit for nitrate as nitrogen is set at 10 mg/L (U.S. Environmental Protection Agency, 1976) primarily because greater concentrations can cause or contribute to methemoglobinemia or "blue baby" disease. Concentrations greater than the standard may indicate contamination by excess application of fertilizer, leachate from domestic waste disposal from animal feedlots, and municipal sewage effluent. Nitrate concentrations in the study area were below USEPA drinking-water recommended limits, averaged 1.6 mg/L, and ranged from 0.02 to 6.0 mg/L (table 4).

Iron and manganese

Elevated levels of iron and manganese are common in ground water from stratified-drift aquifers. Chemically reducing conditions in ground water promote solution of iron and manganese, which, when exposed to the atmosphere, precipitate out as iron and manganese oxides. The USEPA maximum recommended limits for iron and manganese in drinking water are 0.3 and 0.05 mg/L, respectively (U.S. Environmental Protection Agency, 1976). The standards are based on aesthetic considerations because high levels of iron and manganese can cause unpleasant tastes, staining of laundry and plumbing fixtures, and growth of iron bacteria in water-distribution systems.

Iron and manganese concentrations averaged 3.6 and 0.20 mg/L (table 4), respectively, in samples from 32 wells, 7 wells exceeded both standards and 3 wells exceeding the manganese standard only. Iron concentrations ranged from 0.01 to 78 mg/L, and manganese concentrations ranged from 0.001 to 2.0 mg/L. Three out of the 11 public-water supplies sampled also exceeded either the iron or manganese standard. Treatment to remove elevated concentrations of iron and manganese may be necessary in areas where water is otherwise acceptable for drinking. Removal of iron and manganese from ground water currently is being practiced on water that supplies the Milford

Fish Hatchery, because high levels of these constituents are harmful to trout and salmon fry.

Trace elements

Water samples were analyzed for the following trace elements: Arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, nickel, silver, and zinc. Natural waters usually contain most of these elements in trace quantities, and many are essential for metabolism. Water from Pelham well W-55 had an arsenic concentration of 0.05 mg/L, which is the USEPA recommended drinking-water limit for arsenic (U.S. Environmental Protection Agency, 1976). Water from all other wells had concentrations of arsenic and other trace elements below USEPA drinking-water limits throughout the region.

Organic chemicals

The TOC (total organic carbon) determination is useful in assessing the degree of organic loading of natural waters. Organic substances generally are found in low concentrations in ground water, and excess amounts may indicate human-introduced pollutants. TOC is a measure of suspended and dissolved organic materials. Natural waters are known to have TOC concentrations ranging from 1 to 30 mg/L (Hem, 1970); and, although there are no specific regulatory criteria established for TOC, waters containing less than 3.0 mg/L TOC have been described as relatively clean (Environment Canada, 1977).

The highest concentration of TOC (90 mg/L) was from a shallow dug well in Nashua (Metcalf & Eddy, Inc., 1983), which also had water with elevated concentrations of total dissolved solids, sodium, and chloride. The average concentration of TOC for all wells (except the shallow dug well in Nashua) was 2.5 mg/L, ranging from 0.37 to 15 mg/L (table 4).

Specific organic analysis conducted on all water samples included the following groups of organic compounds: Volatile organics, acid extractables, base/neutral extractables, pesticides, and polychlorinated biphenyls. In none of the samples were organics found above the detection limit for each compound listed in the report by Metcalf & Eddy, Inc. (1983). This was determined after resampling several wells that originally contained organic contaminants which later were determined to be laboratory contaminants.

Surface Water

Rivers and streams across the Nashua region generally are classified as Class B (New Hampshire Water Supply and Pollution Control Commission, 1982). Class B waters are acceptable for bathing and recreation, fish habitat, and public-water supply after adequate treatment. Disposal of sewage or wastes is not allowed unless adequately treated.

Class A waters include the Witches Brook and Pennichuck Brook drainages, which are the watershed lands for the Pennichuck Water Company surface-water-supply system. The Stony Brook tributary in Wilton is the only other Class A system and supplies water to the Wilton Reservoir. Class A waters are potentially acceptable for public-water supply after disinfection and if they receive no discharges of sewage or other wastes.

Class C waters include the mouths of Pennichuck Brook and Salmon Brook, the entire reach of the Nashua River from the Massachusetts State line to the Merrimack River, and the Merrimack River from the confluence with the Nashua River to the Massachusetts State line. Class C waters are acceptable only for recreational boating, fishing, and industrial water supply with or without treatment.

These classifications are based on regulations set by the New Hampshire Water Supply and Pollution Control Commission and the U.S. Environmental Protection Agency (1971). Where induced infiltration of Class A or Class B surface water occurs, the overall quality of ground water is considered to be unaffected. Induced infiltration of Class C water is considered to degrade the quality of ground water from that suitable for public supply to that suitable only for industrial water supply.

Surface-water samples were collected at 14 locations in most of the major drainage basins within the study area. The sampling was conducted on November 1-3, 1983, when flow in rivers of the study area was at a rate that was equalled or exceeded 90 percent of the time (Blackey and others, 1984). The dissolved-solids concentration of surface water is inversely related to streamflow; the highest concentration is at low flow when streamflow is largely derived from ground-water discharge.

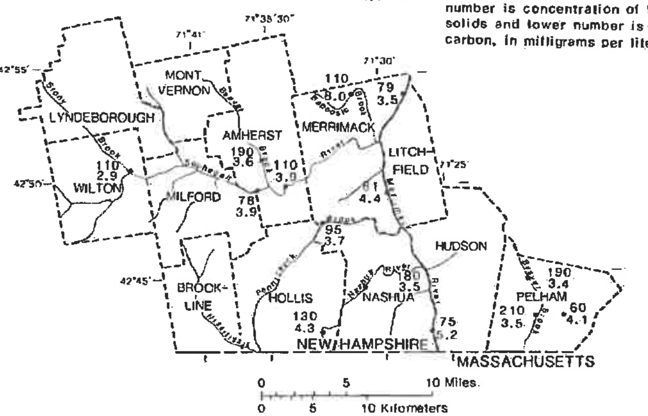


Figure 14.--Distribution of total dissolved solids and total organic carbon at 14 surface-water-sampling sites.

Concentration of total dissolved solids in surface-water samples averaged 121 mg/L (fig. 14) and ranged from 60 to 210 mg/L (table 5), indicating that under low-flow conditions, the overall chemical quality of streams is good. Components of the total dissolved-solids determination, sodium and chloride, average 15.0 mg/L and 27.3 mg/L, respectively, which are well below the USEPA drinking-water limit.

Concentrations of TOC ranged from 2.9 mg/L to 8.0 mg/L (fig. 14), averaging 4.2 mg/L across the region. Concentration is relatively low and evenly distributed throughout the region except for the sample from Baboosic Brook in northern Merrimack, which had the highest concentration of TOC (8.0 mg/L).

The COD (chemical oxygen demand) of surface water averaged 20.5 mg/L and ranged from 7.3 to 50.0 mg/L. The highest COD's observed were 34.0 mg/L at the Souhegan River in Wilton and 50.0 mg/L at the Nashua River in Nashua. Historical data from U.S. Geological Survey gaging stations on the Nashua and Merrimack Rivers show COD concentration of 35 mg/L and 18 mg/L, respectively. Other COD's of miscellaneous streams in southern New Hampshire generally ranged from about 10 to 50 mg/L.

The pH of surface-water samples was slightly on the acidic side, ranging from 5.9 to 6.7 and averaging 6.4.

Trace metals were generally within USEPA recommended limit for drinking-water supplies except for iron and manganese. Iron averaged 0.33 mg/L and ranged from 0.07 to 0.71 mg/L; manganese averaged 0.045 mg/L and ranged from 0.022 to 0.094 mg/L. These data show the wide distribution of naturally occurring iron and manganese throughout the Nashua region.

No widespread organic compounds or polychlorinated biphenyls were detected in surface-water samples from across the region. The pesticide endrin aldehyde was found at the Nashua River in Hollis at a concentration of 0.394 mg/L.

Table 5--*Summary of surface-water quality*

[Modified from Metcalf and Eddy, Inc. 1983.]

Constituent or property	Number of samples	Average concentration, in milligrams per liter	Range, in milligrams per liter		
Chloride (Cl)	14	27.3	60.0	-	14.0
Chemical oxygen demand (COD)	14	20.5	50.0	-	7.3
Specific conductance (microsiemens per centimeter at 25 °C)	14	155	270	-	77.0
Nitrate (NO_3 as N)	14	.29	.92	-	.02
Nitrite (NO_2)	2	.02	.024	-	.02
pH	12	6.37	6.7	-	5.9
Total dissolved solids	14	121	210	-	60.0
Total organic carbon (TOC)	13	4.23	8.0	-	2.9
Barium (Ba)	14	.012	.029	-	.007
Iron (Fe)	14	*.333	*.714	-	.071
Copper (Cu)	8	.006	.020	-	.001
Manganese (Mn)	14	.045	.094	-	.0223
Sodium (Na)	14	15.01	30.1	-	7.5
Zinc (Zn)	7	.006	.009	-	.002
Nickel (Ni)	1	.004	--		--
Antimony (Sb)	1	.02	--		--

*Exceeds maximum drinking water limit set by the U.S. Environmental Protection Agency, 1976.

SUMMARY AND CONCLUSIONS

Stratified-drift deposits cover about 129 mi² or 40 percent of the land area in the 12-community Nashua Regional Planning Commission area in south-central New Hampshire. The stratified-drift deposits are important aquifers where they have sufficient saturated thickness and permeability to yield large quantities of water to wells. The saturated thickness of stratified drift in the study area ranges from less than 20 ft near valley walls to more than 100 ft in the Souhegan River valley in the town of Amherst and in the Merrimack River valley in the towns of Merrimack and Litchfield. The transmissivity of stratified drift ranges from less than 2,000 ft²/d throughout much of the study area to more than 8,000 ft²/d in the communities of Amherst, Brookline, Hollis, Hudson, Litchfield, Merrimack, Milford, Nashua, and Pelham.

At present, the estimated total yield of all community water-supply systems in the study area is 22 Mgal/d. Analytical modeling indicates that an additional 12 Mgal/d could be obtained from six aquifers located in the communities of Amherst, Litchfield, Merrimack, Milford, and Pelham. Other aquifers in the area, not modeled in this study, also could provide increased amounts of water, especially where yields could be augmented by induced recharge from surface water.

The quality of ground water in the study area is suitable for most uses, except for locally elevated concentrations of iron and manganese. Elevated levels of sodium and chloride in shallow dug wells probably reflect the use of highway deicing chemicals in the area. Surface-water quality in major rivers of the study area is suitable for most uses with appropriate treatment. Endrin aldehyde was the only organic compound detected in a surface-water sample from the Nashua River in Hollis.