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PRELIMINARY INVESTIGATION OF THE GROUND-WATER RESOURCES OF THE MERRIMACK RIVER DRAINAGE BASIN NEW HAMPSHIRE AND MASSACHUSETTS

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INTRODUCTION

Purpose and Scope of Investigation

In October 1951 the United States Federal Security Agency, Public Health Service, cooperating in the New England-New York Inter-Agency Committee, requested the United States Geological Survey to report on the ground-water resources of the Merrimack River basin and their potential development.

W. B. Allen, L. M. Page, and M. A. Pistrang, geologists of the Ground Water Branch, U. S. Geological Survey, spent part of the period from October through December 1951 collecting hydrologic and geologic data in the area. The investigation was under the immediate supervision of H. N. Halberg, Engineer-in-charge, and the general direction of M. L. Brashears, Jr., District Geologist for New York and New England, Ground Water Branch, U. S. Geological Survey.

Topographic maps showing locations of sand and gravel deposits and a surficial geologic map of New Hampshire were furnished by the New Hampshire State Highway Department and the State Planning and Development Commission. Soil-survey maps from the U. S. Department of Agriculture Soil Survey reports were used for interpreting glacial geologic features in Massachusetts. Subsurface geologic information and some hydrologic data were obtained from well drillers, consulting engineers, and the New Hampshire and Massachusetts Departments of Health. Owners of wells and superintendents of water companies were consulted about their water supplies. Detailed information on a large number of foundation test borings was obtained from offices of the New Hampshire Highway Department, the Massachusetts Department of Public Works, and the U. S. Corps of Engineers. Most of the data consist of logs of wells and test holes, observations of ground-water levels, yields, drawdowns, temperatures, and water analyses.

Many reports describing the geology of the Merrimack River basin have been published, but no systematic survey of the ground-water resources has been made. A report on artesian wells in New Hampshire[1] gives general information on wells penetrating bedrock. This report represents the results of a reconnaissance of the source, occurrence, quality, utilization, and potential development of ground water in the Merrimack basin.

1/ Goldthwait, R. P., Artesian wells in New Hampshire: New Hampshire State Planning and Devel. Comm., Concord, N. H., 1949.

Location and General Features of the Basin

The Merrimack watershed, 5,006 square miles in area, occupies the central and southern portions of New Hampshire and the northcentral and northeastern portions of Massachusetts. (See pl. 1.)

Physiographically the basin ranges from high rugged mountains in the north and west to low plains along the seacoast in the south and east. One or more ice sheets that covered the area during Pleistocene time moved in a southeasterly direction, smoothing out the northwestern slopes of hills but leaving the leeward slopes rough and broken. Preglacial valleys were filled with drift, with the result that present streams flow over glacial deposits in part of their courses. Rock basins scoured by the ice sheets are now occupied by lakes and ponds.

The Merrimack basin is drained by a major river system consisting of the Merrimack River and its many tributaries. The altitude of the bottom of the major river valley ranges from about 800 feet above sea level in the upper reaches of the Pemigewasset at Lincoln, N. H., to sea level along the Merrimack River where it enters the Atlantic Ocean at Newburyport, Mass. Most of the large cities and towns are in the valley bottoms. Ground water is used for public supply by a large number of municipalities.

GEOLOGY AND GROUND WATER

The occurrence of ground water, its movement, storage, and methods of recovery are determined by the character, distribution, and structure of water-bearing formations. A basic knowledge of the general geology of the Merrimack basin is essential, therefore, to an understanding of the ground-water resources. The water-bearing beds of the basin may be divided into two general classes: the unconsolidated surficial deposits and the underlying consolidated bedrock formations. Ground-water conditions in these two groups of materials are quite different.

Consolidated Rocks

The consolidated rocks, or bedrock, of the Merrimack basin consist of igneous and metamorphic rocks that may be divided into several recognized geologic formations. In general, however, all these rocks have a very low porosity (ratio of pore space to the total volume of rock) and therefore a detailed subdivision of the geologic formations is of little significance in considering the occurrence, movement, storage, and recovery of ground water. Of more importance are the joints and fractures formed after the rocks were deposited. Such openings are produced by stresses that accumulate until rupture of the rocks occurs. They are generally most numerous near the surface, becoming fewer and smaller with increasing depth. Where joints are numerous and open they not only allow relatively free movement of ground water but permit the storage of moderate quantities. Wells drilled into bedrock yield at least a small quantity of water at almost any locality in the Merrimack basin. Most of the bedrock wells are used for domestic and farm supplies but a few have been drilled at industrial plants. The largest reported yield is about 120 gallons per minute. In a study of

1,482 wells in New Hampshire, Goldthwait states:[2] "It is normal to get 6½ gallons of flow per minute in New Hampshire. Half the wells get more, half less."

2/ Goldthwait, R. P., op. cit., p. 15.

Unconsolidated Deposits

The consolidated rocks of the entire basin are covered by unconsolidated deposits, which range in thickness from a few inches to more than 200 feet. In general, these deposits are not as thick on the highlands as in the major valleys, and bedrock crops out mainly at the summits of ridges and projecting cliffs.

Because the unconsolidated deposits were laid down under a complex set of natural conditions, they differ widely in character within short distances, both horizontally and vertically. Most of the unconsolidated deposits consist of materials formed directly or indirectly by the movement of glacial ice sheets and are called "glacial drift." Some deposits of Recent age, composed of gravel, sand, silt, clay, and peat, have accumulated along the major rivers and in ponds and marshes. These deposits are not very thick, however, and are not an important source of ground water. The glacial drift is a source of water available at shallow depth, and because it is highly porous it acts as a reservoir to hold water and feed it into the cracks and joints of the underlying bedrock. These characteristics of glacial drift are important factors in the ground-water supply of the entire Merrimack basin.

Glacial drift can be divided into two groups on the basis of origin—deposits of unstratified materials (till) and beds of water-laid or stratified materials (outwash).

Till--Till is a heterogeneous mixture of rock fragments that range from clay to boulders. It is found at the surface in nearly all parts of the basin except along the major stream valleys and summits of ridges. Great variation in thickness is indicated by the fact that till is absent on many bare ledges but in some places is built into mounds or drumlins as much as 100 feet thick. Its average thickness is about 20 feet.

Masses of till are of particular significance in ground-water studies because of their widespread occurrence, their easily accessible small supplies of water at shallow depth, their variable thickness, and their influence on both vertical and horizontal flow of ground water.

In general, in the Merrimack basin, wells in till yield small supplies of ground water sufficient for farm and household use. In recent years many of these shallow wells have been abandoned or have been replaced by deeper wells drilled into the bedrock. Bedrock wells generally yield supplies that are more reliable, particularly in times of drought.

Outwash--The stratified drift was laid down by streams that issued from the melting ice and because of the sorting action of flowing water was deposited in fairly distinct layers and beds of sand, gravel, silt, and clay. Individual beds vary greatly in thickness and in places feather out in comparatively short distances.

In the valleys of most of the larger streams in the Merrimack basin and in the lowlands of Massachusetts the consolidated rocks are to a great extent overlain by deposits of outwash. Some deep preglacial valleys have been only partly filled by glacial outwash. Others have been wholly filled and concealed so that present streams flow high above the old bedrock floors, or have been diverted to new channels. According to available well and test-boring records, the outwash deposits range greatly in thickness, being thickest in the buried valleys. For example, in the vicinity of Lowell, Mass., the preglacial channel of the Merrimack River is buried beneath more than 100 feet of outwash. Also, thick deposits of outwash are along the main stem of the Merrimack River from Franklin, N. H., to Newburyport, Mass., and in several of the major tributaries. Table 1 indicates the magnitude of thickness that may be expected in known buried valleys within the Merrimack basin.

Table 1.—Thickness of outwash deposits in major buried valleys of the Merrimack River drainage basin

Name of river and location	Altitude of river level (feet above mean sea level)	Altitude of bedrock surface (feet above or below mean sea level)	Thickness of outwash deposits (feet)
Pemigewasset River (main stem of Merrimack River) at Franklin Falls, N. H. . .	320	200	120
Merrimack River at Concord, N. H.	230	100	130
Merrimack River at Nashua, N. H.	100	50	50
Merrimack River at Lowell, Mass.	90	-10	100
Merrimack River at Groveland, Mass. . . .	5	-65	70
Merrimack River at Newburyport, Mass. . .	0	-70	70
Nashua River at Ayer, Mass.	240	160	80
Sudbury River at Lincoln, Mass.	120	20	100

Elsewhere in the river valleys thick deposits of outwash may occur, but available data are insufficient to indicate their thickness and location. Outside the river valleys the outwash deposits are relatively thin and generally do not exceed 30 feet in thickness.

A geologic section across a typical buried valley in the Merrimack basin would show from bottom to top the following: (1) a thin basal layer of unsorted sand, gravel, clay, and boulders (till) overlying the bedrock, (2) stratified material (outwash), 50 to more than 100 feet thick in the deepest part of the valley bottom, and (3) coarse sand and gravel (terrace deposits) overlying the outwash on the lower part of the valley walls. The till, generally the thinnest of all the unconsolidated deposits, is exposed on the upper parts of the valley walls, and at many places in the upland, bedrock is exposed. The cross section (fig. 1) is typical of buried valleys in the Merrimack basin, but it should be noted that at many localities conditions are different from the generalized diagram. For instance, at some places the basal till does not extend across the entire valley and at others the coarse sand and gravel deposits do not occur along the valley walls.

Large supplies of ground water can be obtained from the buried-valley deposits, but the thinner deposits of outwash scattered through the basin, except where they are extensive or contain bodies of surface water, yield only small supplies. Data for wells ending in outwash indicate a range in yield from 3 to 900 gallons per minute.

Within any municipality in the basin there is at least 1 square mile of unconsolidated stratified deposits. A typical aquifer or ground-water reservoir of this size with an average saturated thickness of 30 feet would contain about 836 million cubic feet of water-bearing material. With an estimated specific yield of 10 percent the quantity of ground water

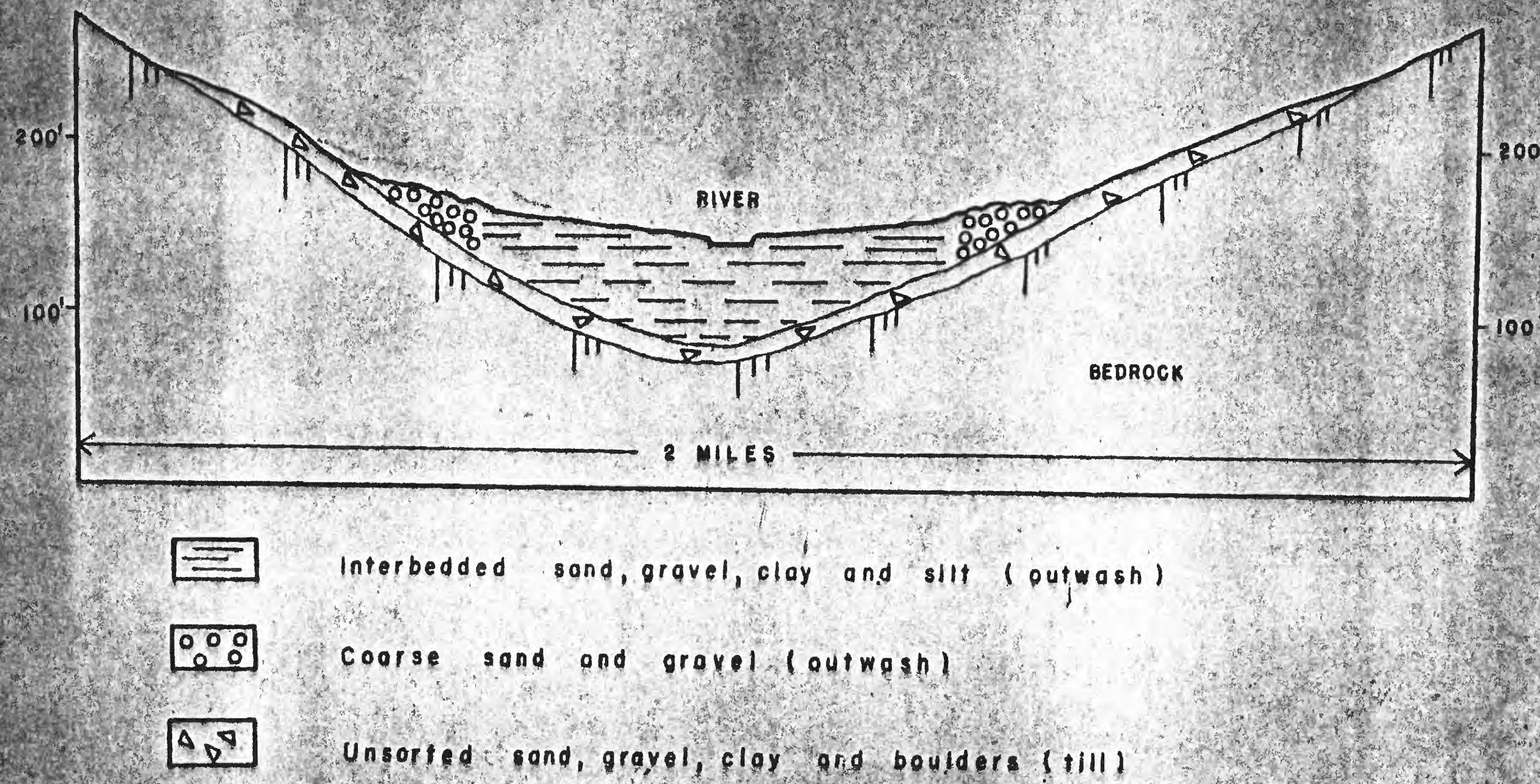

Figure 3 Geologic cross section of typical buried valley

available for withdrawal by properly constructed wells from this 1 square mile would be approximately 625 million gallons.

Potential Yield of Wells

A map of the Merrimack River basin (pl. 1) shows the predicted yields to be expected from properly constructed wells. Data used in the preparation of this map consist of well and boring records obtained during the course of the present investigation and on file at the Boston ground-water office of the U. S. Geological Survey and examination of surficial geologic maps and features of the basin. The uncolored area of plate 1 represents till and bedrock. Wells penetrating the materials can generally be expected to yield as much as 50,000 gallons per day. The shaded area represents outwash deposits, which may yield about 50,000 to 1,000,000 gallons per day from one or more wells. Estimates of predicted yield are based on extent and thickness of outwash deposits, possibilities of surface-water recharge, and yields of existing wells in the area. The red areas represent beds of stratified sand and gravel, which may yield more than 1,000,000 gallons per day to properly constructed wells. In such areas large-capacity wells have been developed in thick deposits of valley fill (or outwash), where surface-water recharge is available.

More information is required before the ground-water possibilities of the Merrimack River basin can be understood in detail. Plate 1 gives only an indication of the potentialities of the area. Any development of ground water should be preceded by critical examination of all factors involved.

Quality of Ground Water

Detailed analyses of the mineral constituents of water from wells in the Merrimack basin are not available. Determinations of hardness, iron, and pH value have been made by the New Hampshire and Massachusetts Departments of Public Health for all municipal supplies. Hardness is a property of water highly important in domestic and industrial use. It is recognized by the increased quantity of soap required to produce a lather, and by the deposit of insoluble mineral scale in boilers or kettles. Water with a hardness of less than 50 parts per million is considered soft and does not require treatment to soften it further. Hardness of between 50 and 100 parts per million does not seriously affect the use of the water for most purposes, although the use of soap is increased somewhat. The ground water from public supplies in the Merrimack basin ranges in hardness from 7 to 69 parts per million (pl. 2).

The iron content of ground water in the Merrimack River basin generally is low (less than 0.3 part per million). However, along the Merrimack River from Lowell, Mass. to the seacoast at Newburyport, it appears to be higher than elsewhere in the basin. The highest iron content reported in this area before treatment for a public supply was 25 parts per million at Amesbury, in 1947.

The pH value indicates the acidity or alkalinity of water. A low pH value or acidic condition combined with the presence of carbon dioxide or oxygen may make a water corrosive to certain types of metal pipe. Corrosive waters are known to exist in a few localities within the Merrimack River basin but regional distribution cannot be determined at present.

An important factor concerning the quality of ground water is the poor chemical quality of many of the surface waters. In the Merrimack basin, the water in much of the main stream and the major tributaries is contaminated by chemicals from industrial wastes. Wherever pumping wells are located near contaminated streams and the ground water is replenished by infiltration of river water, the well water is likely to become contaminated by the soluble chemicals in the surface water.

Temperature of Ground Water

Ground water below a depth of a few tens of feet normally has a temperature that varies but slightly during the year and is generally slightly higher than the mean annual air temperature. According to figures compiled by the U. S. Weather Bureau, the mean annual air temperature at Concord, N. H., and Lowell, Mass., is 43.6° F and 48.4° F, respectively. The mean annual air temperature ranges within wide limits in the Merrimack River basin but that at Concord and Lowell is assumed to be fairly representative of the basin as a whole. Thus the average temperature of ground water in the basin at depths of 50 to 60 feet below the land surface may be expected to range from about 46° to 50° F where not subject to surface-water infiltration or other artificial influences. Water supplies developed by induced infiltration from surface-water bodies will range considerably in temperature during the year, but the range will be smaller than that of the surface water.

Water temperatures are of great importance in industrial uses involving cooling. Ground-water temperatures, in the summer, are lower than surface-water temperatures and therefore ground water is more desirable for such purposes as milk cooling and air-conditioning.

Utilization of Ground Water

Withdrawals of ground water in the Merrimack basin for municipal, institutional, and industrial supply are estimated to be about 32 million gallons per day. Of this amount, 24 million gallons is pumped in Massachusetts and 8 million gallons in New Hampshire. Domestic consumption is estimated to be between 10 million and 15 million gallons per day.

Table 2 shows municipal and industrial ground-water use in the Merrimack River basin. The quantities shown for municipal use are based principally on data furnished by the New Hampshire and Massachusetts Departments of Health. The quantities shown for some municipal and all industrial use are based on data collected by the Ground Water Branch of the U. S. Geological Survey.

Municipal supplies--The chief use of ground water in the Merrimack River basin is for public water supply. It is estimated that 22 million gallons is supplies daily by 40 municipalities in the basin and about 2 million gallons by a military establishment and two State institutions.

The largest municipal ground-water supply is furnished by the City of Lowell, Mass. This system consists of about 350 small-diameter wells and several large-diameter gravel-packed wells at three main locations.

They obtain their water from various deposits of glacial sand and gravel in the area. All the gravel-packed wells are in the preglacial buried valley of the Merrimack River, which leaves the present channel of the Merrimack upstream from the city of Lowell and swings around to the south of Lowell. Treatment of the water includes chlorination, iron removal, and pH control. The average pumpage from the Lowell wells, which serve about 97,000 people, is about 6,800,000 gallons per day.

The city of Nashua, N. H., is served by the privately-owned Pennichuck Water Works, the average daily consumption being about 3,020,000 gallons. A group of 2-inch driven wells obtain water under artesian pressure from a bed of sand lying from 20 to 30 feet below land surface. Water flows from the top of the wells into ditches and thence by gravity into a collecting reservoir. It is then chlorinated and pumped to the distribution system.

Industrial supplies--Industry in the Merrimack basin is concentrated in the urban areas and nearly all their demands for water have been met by municipal supplies. However, some industries have developed their own supplies. The greatest pumpage is at Fitchburg, Mass., where several industries pump about 2,500,000 gallons per day. At Lowell, industries pump about 1,200,000 gallons per day, and at Nashua, about 1,150,000 gallons per day.

Irrigation supplies--In the Merrimack basin little ground water is used for irrigation. According to the U. S. Department of Agriculture Soil Conservation Service, about 90 million gallons per year is used in the Massachusetts part of the basin. No information was obtained in New Hampshire, but the quantity used is believed to be small.

Table 2.--Municipal and industrial use of ground water in the Merrimack River drainage basin

New Hampshire

City or town	Municipal (mgd)	Industrial (mgd)	Total (mgd)
Alton	0.27	-	0.27
Amherst a/	.20	- a/	.20
Belmont a/	.04	- a/	.04
Bristol	.23	-	.23
Derry	.45	-	.45
Franklin	.38	-	.38
Greenville	.06	-	.06
Henniker a/	.05	- a/	.05
Hill a/	.02	- a/	.02
Hookset	- a/	0.5 a/	.5
Hudson	.20	-	.20
Merrimack	.02 a/	.08 b/	.10
Milford	.27	-	.27
Nashua	3.02 b/	1.15 b/	4.17
Pembroke a/	.60	- a/	.60
Plymouth a/	.25	- a/	.25
Wilton	-	.08	.08
Total	6.06	1.81	7.87

Massachusetts

City or town	Municipal (mgd)	Industrial (mgd)	Total (mgd)
Acton	0.18	-	0.18
Amesbury	.74	0.05	.79
Andover	-	.32	.32
Ashland	.74	-	.74
Ayer c/	1.89	.77 c/	2.66
Bedford	.22	.02	.24
Billerica	.52	-	.52
Chelmsford	.42	-	.42
Clinton	-	.17	.17
Dracut	.38	-	.38
Dunstable	.01	-	.01
Fitchburg	-	2.5	2.50
Framingham	.63	.01	.64
Groton	.79	-	.79
Lawrence	-	.40	.40
Littleton	.22	.45	.67
Lowell	6.80	1.2	8.0
Merrimac	.26	-	.26
Natick	1.60	-	1.60
Newburyport	.5	.03	.53

Table 2.--Municipal and industrial use of ground water in the Merrimack River drainage basin--Continued

Massachusetts

City or town	Municipal (mgd)	Industrial (mgd)	Total (mgd)
Pepperell	0.38	-	0.38
Shirley	.10	-	.10
Shrewsbury	.20	-	.20
Sterling	.06	0.02	.08
Sudbury	.05	-	.05
Tewksbury d/	.35	- d/	.35
Townsend	.20	-	.20
Wayland	.41	-	.41
West Boylston	.13	-	.13
Westford	.18	-	.18
Westminster d/	.13	- d/	.13
Total	18.09	5.94	24.03
Total for basin (approximate)	24	8	32

a/ Estimated.
b/ Partly estimated.
c/ Includes 1.51 mgd for military use.
d/ Used by State institutions.

include detailed geological studies, geophysical investigations, test drilling, and test pumping to estimate more accurately the potential ground-water supply in the basin.