PREPARED IN COOPERATION WITH THE
COMMONWEALTH OF MASSACHUSETTS DEPARTMENT OF ENVIRONMENTAL MANAGEMENT
DIVISION OF WATER RESOURCES
BOSTON, MASSACHUSETTS

GENERAL HYDROLOGY

HYDROLOGIC CYCLE AND GROUND-WATER-FLOW SYSTEM

The hydrologic cycle (fig. 11) is a continuous circulation of water between the ocean, atmosphere, and land. The water is transmitted to the atmosphere through evaporation from oceans, lakes, streams, and the land, and through transpiration from plants. It returns to earth as precipitation on land and water, and that which falls on land either runs off into streams, lakes, and oceans, or infiltrates into the soil and enters the ground-water system. The ground-water system is dynamic in that water is continously in motion from areas of recharge to areas of discharge (fig. 11). In a typical ground-water-flow system, this movement occurs through many different layers of geologic materials.

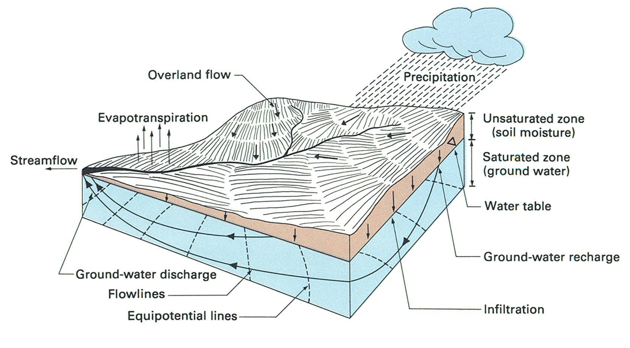

FIGURE 11.—Generalized hydrologic cycle and ground-water-flow system.

GROUND-WATER-FLOW SYSTEM

In an idealized pattern of ground-water flow in thick sand and gravel aquifers in the southeast part of the Westfield River basin, precipitation infiltrates the soil as recharge, percolates downward to the saturated zone, and flows downgradient toward the Westfield River where it discharges as streamflow (fig. 12). This idealized pattern, however, does not always occur. For example, in upland areas of the lower Westfield River basin, ground-water flow in the upper (shallow) parts of the aquifer discharges into upland tributary streams, whereas ground water deeper in the aquifer flows beneath tributary streams and discharges into the Westfield River (fig. 12). The actual flow pattern generally is more complex than shown because of variations in hydraulic conductivity of aquifer materials.

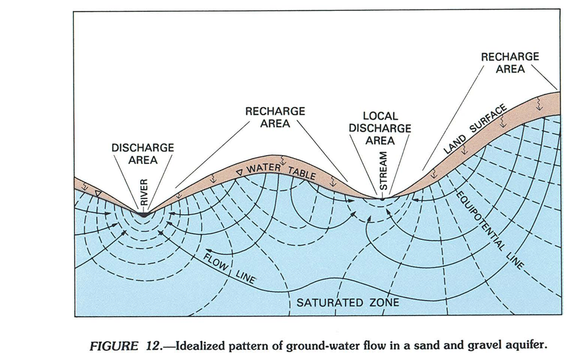

FIGURE 12.—Idealized pattern of ground-water flow in a sand and gravel aquifer.

WATER BALANCE

Annual precipitation, determined by averaging rainfall amounts at 12 sites about the basins from 1951–80, is 47 inches. A water balance (fig. 13) calculated from data collected at Knightville Dam (located immediately upstream from the Westfield River at Knightville gaging station) shows that annual precipitation totals 44.7 inches and annual evapotranspiration equals 23.8 inches (as determined by the method described in Thornthwaite and Mather, 1957). During the period when precipitation exceeds evapotranspiration, a water surplus of 24.0 inches is available for runoff and recharge to the ground-water system. Evapotranspiration exceeds precipitation in June, July, and August creating a water deficiency of 3.1 inches.

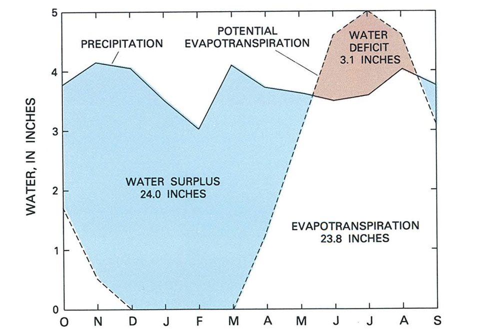

FIGURE 13.—Water balance at Knightville Dam.

SEASONAL CHANGES IN STREAMFLOW AND GROUND-WATER STORAGE

Streamflow and ground-water levels fluctuate as a result of seasonal differences in the amount of water available for runoff and storage. During late fall, winter, and early spring, streamflow and ground-water levels are high because withdrawal to water systems is low, plants are least active, and evapotranspiration rates are low. During the summer months, ground-water levels and streamflow are reduced as water is withdrawn from storage and ground-water contribution to streamflow is reduced because withdrawals from water systems increases and evaporation plus consumptive use (transpiration) by vegetation exceeds replenishment of soil moisture by precipitation. These seasonal changes are shown in figure 14 for two streams and two wells in the basins. The rises and peaks on the hydrographs (fig. 14) occur when the water surplus is greatest (fig. 13) and declines occur when evapotranspiration increases and a water deficit occurs.

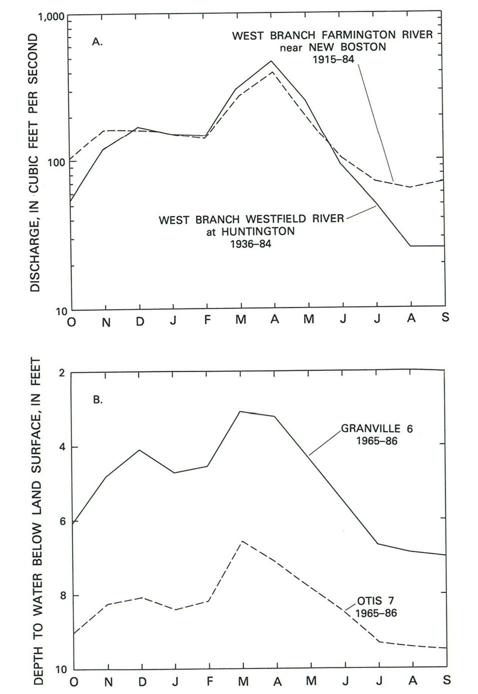

FIGURE 14.—Median monthly hydrographs of streamflow and month-end water water level for:
A. West Branch Westfield River at Huntington and West Branch Farmington River near New Boston
B. Granville 6 well and Otis 7 well

GROUND-WATER LEVEL

Long-Term Ground-Water Level

Long-term trends of water-level decreases or increases are caused by extended periods of drought or above-normal precipitation, respectively. Water levels measured in observation wells GLW 5 (Granville 5), GLW 6 (Granville 6), and OTW 7 (Otis 7) from 1965 to 1986 are shown in figure 15. All three wells have 2-inch-diameter casings with 2-foot-long screens, augered to 67.7 feet, 20.8 feet, and 17.5 feet below land surface, respectively. These are the only wells, unaffected by pumping, with long-term records in the basin.

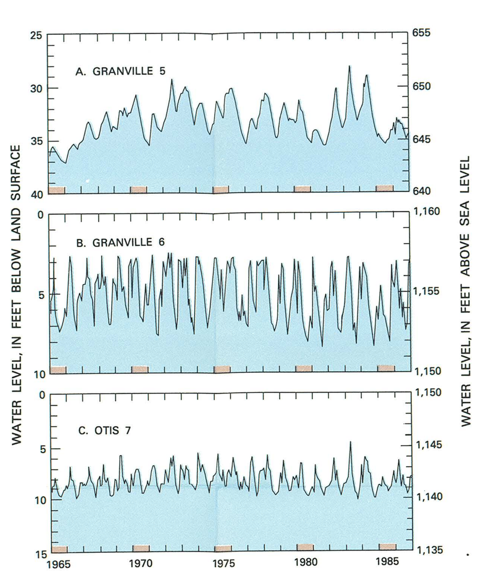

FIGURE 15.—Long-term ground-water level for:
A. Granville 5 well
B. Granville 6 well
C. Otis 7 well

Water-Level Duration

Water-level duration curves of monthly measurements of wells GLW 5, GLW 6, and OTW 7 (fig. 16) show the percentage of time water level was equaled or exceeded for February, March, April, July, August, and September from 1965 to 1986. The curves indicate that the maximum ground-water level in the shallow aquifers generally occurs in March and April. The lowest water level occurs in August and September. However, where depth to the water table from the land surface is greater than 30 feet, the response to recharge is delayed and the maximum water levels can occur as late as July, in spite of the growing season being in progress. Duration curves for months not shown in figure 16 are shaped similar to and fall between the highest and lowest months shown.

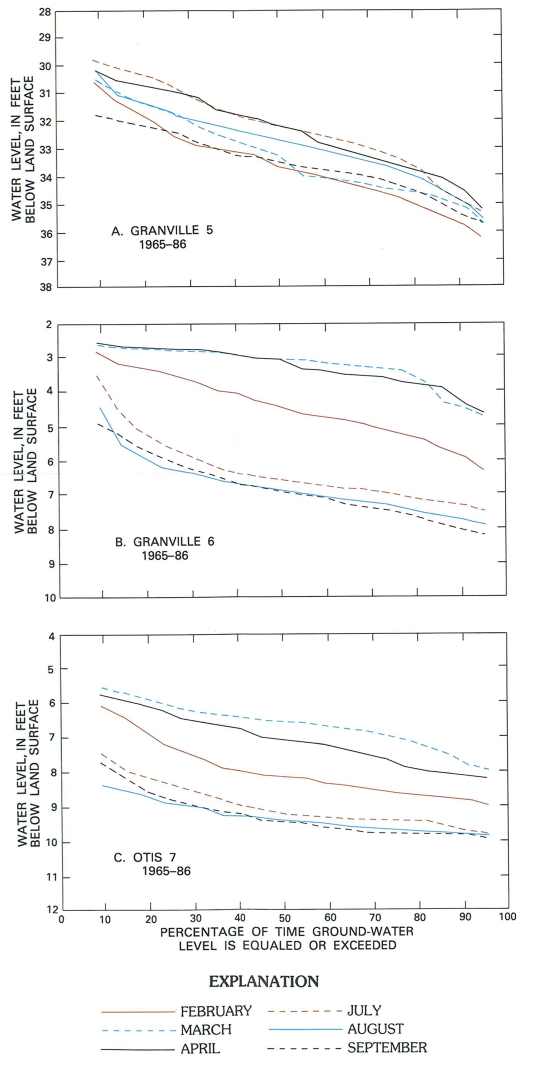

FIGURE 16.—Ground-water-level duration curves for:
A. GLW5
B. GLW6
C. OTW7

Estimate of High Ground-Water Level

Estimates of probable high ground-water level are required by the Commonwealth of Massachusetts, Department of Environmental Quality Engineering for permitting subsurface sanitary sewage-disposal systems. This information commonly is needed at potential building sites or other places that may be adversely affected by high ground-water level. Ground-water level generally reaches its maximum altitude during the early spring; however, measurement at all ground-water observation points during the short period of high level is not always possible. To estimate the high ground-water level for a particular site at any time of year, Frimpter (1981) developed equations that relate the ground-water level at that site to the water level at an observation well measured during the same month. Hydrogeologic and climatic conditions at the site must be similar to those at the observation well. The following equations were derived for use in the Westfield and Farmington River basins. Data from long-term observation wells located about the Westfield and Farmington River basins were applied for sites in different hydrogeologic environments.

For a till site:

$$Sh = Sc - 1.52(WUW - 1.50)$$

For a sand and gravel site on a terrace or hillside:

$$Sh = Sc - 1.69(GLW - 2.49)$$

For a sand and gravel on a valley flat:

$$Sh = Sc - 1.31(WVW - 3.16)$$

where,
Sh is the estimated depth to probable high water level at the site, in feet,
Sc is the measured depth to water at the site, in feet,
WUW is the measured depth to water in observation well West Brookfield 10, in feet (for location of this well, see Krejmas and Maevsky, 1986)
GLW is the measured depth to water in observation well Granville 6, in feet, and
WVW is the measured depth to water in observation well Westfield 152, in feet.

Example: Estimate of the probable high water level for a particular till site where $Sc = 13.61$ feet and $WUW = 9.63$ feet

$$Sh = 13.61 - 1.52(9.63 - 1.50) = 1.25 \text{ feet}$$

The most recent water level for observation wells West Brookfield 10, Granville 6, and Westfield 152 can be obtained from the U.S. Geological Survey report "Current Water Resources Conditions in Central New England", which is issued each month by the New England District office of the U.S. Geological Survey.*

*U.S. Geological Survey, Water Resources Division, New England District, 10 Causeway St., Boston, MA 02222

STREAM DEPLETION BY PUMPED WELLS

Pumping of a municipal well near a stream, such as the municipal wells in Pond Brook and Great Brook aquifers, can result in depletion of nearby streamflow. Streamflow depletion may occur either by infiltration of water from the stream to the pumping well or by reduction of some or all of the ground-water flow that would have been discharged to the stream if it had not been diverted to the pumped well, or both.

Using data on given distances between a well and a stream, and aquifer transmissivity, streamflow depletion can be estimated by using the graph in figure 17, which was adapted by Brackley and Hansen (1977) from Jenkins (1970).

For example: A production well installed in an isotropic homogeneous aquifer, with transmissivity of 4,000 ft^2/d, located 500 feet from a nearby stream, may derive approximately 50 percent of its water from stream depletion after 14 days of pumping. These estimates are based on ideal conditions, and many assumptions, such as the aquifer being isotropic, homogeneous, and semi-infinite in areal extent, are made. Applications, limitations, and additional assumptions made in the use of this method are explained in Jenkins (1970).

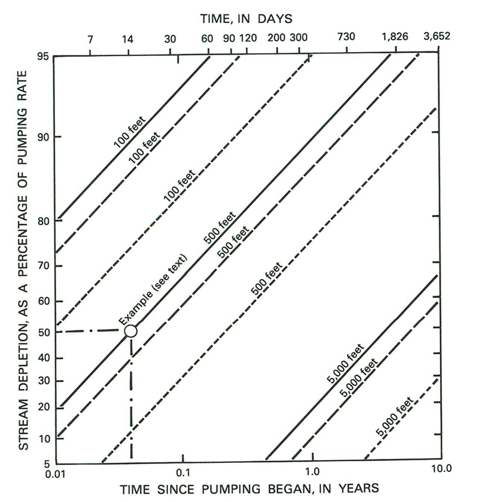

FIGURE 17.—Estimate of stream depletion by pumped well.

GROUND-WATER/ SURFACE-WATER RELATIONS

Induced infiltration from streams and rivers to wells is the principal source of water to most large production wells in the study area. Induced infiltration occurs when the stream stage is greater than the hydraulic head in the aquifer beneath the stream. The rate of induced infiltration depends upon several factors, including vertical hydraulic conductivities of the aquifer and streambed, and the hydraulic gradient that is established between the stream and the well.

To demonstrate ground-water/surface-water relations, observation wells, some of which were equipped with continuous water-level recorders, were installed near the municipal wells in the Pond Brook aquifer (fig. 18). Water-level data obtained from these wells were used to determine the extent of the cone of depression and area of influence, and the rate of induced infiltration from Pond Brook caused by municipal pumping (fig. 19).

The effect on ground-water levels in the aquifer from municipal pumping is shown by water-level fluctuations in the two observation wells, WVW 142 and 143 (Westfield 142 and 143) in figure 20 for April 4–15, 1986. From April 4 until noon on April 7, water levels in these wells remained essentially unchanged because neither Westfield municipal wells 7 or 8 were pumping. From noon on April 7 until noon on April 11, there was intermittent pumping of both municipal wells. From noon on April 11 until April 15, only municipal well no. 8 was pumped.

Observation wells WVW 142 and WVW 143 were installed adjacent to each other 90 feet from the City of Westfield municipal well no. 8 and 920 feet from municipal well no. 7 (fig. 18). The WVW 142 and WVW 143 observation wells are screened from 8 to 18 feet and 126 to 128 feet below land surface, respectively.

Comparison of the water levels in figure 20 indicates that pumping causes greater water-level declines (about 4 ft) in the deep observation well, WVW 143, than in the shallow observation well, WVW 142 (about 2 ft). The greater water-level decline in the deep observation well occurs because the municipal wells are screened at the bottom of the aquifer, and because the aquifer has an estimated 5:1 ratio of horizontal to vertical hydraulic conductivity.

Water-level fluctuations in observation wells WVW 166, 167, and 170 for October 29 to November 5, 1986 are shown in figure 21. Wells WVW 166 and WVW 167 were installed 1,400 feet from Westfield municipal well no. 7 between the municipal well and Pond Brook (fig. 18), and are screened from 105 to 107 feet and 0 to 9 feet below the land surface, respectively. Well WVW 170 was installed in Pond Brook 150 feet from municipal well no. 7 (fig. 18) and is screened 7 to 9 feet beneath the bottom of the brook. The effect of pumping of the municipal wells on the water levels observed in these three observation wells is similar to that observed in wells WVW 142 and 143 (fig. 20). Water levels decline when the municipal wells are being pumped and rise when pumps are shut off. The times when infiltration of water from Pond Brook occurs also can be determined by comparing the water level in WVW 170 to the stage of Pond Brook. When the stage in Pond Brook is higher than the water level in WVW 170, water from the brook is infiltrating down into the Pond Brook aquifer. Conversely, when the stage is lower in the brook than the water level in WVW 170, ground water from the aquifer is discharging into Pond Brook.

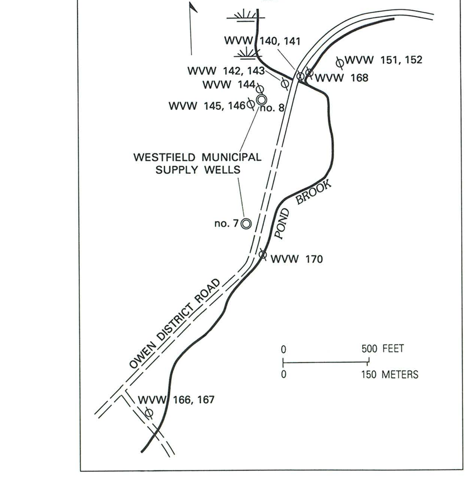

FIGURE 18.—Location of observation wells and municipal supply wells in the Pond Brook aquifer.

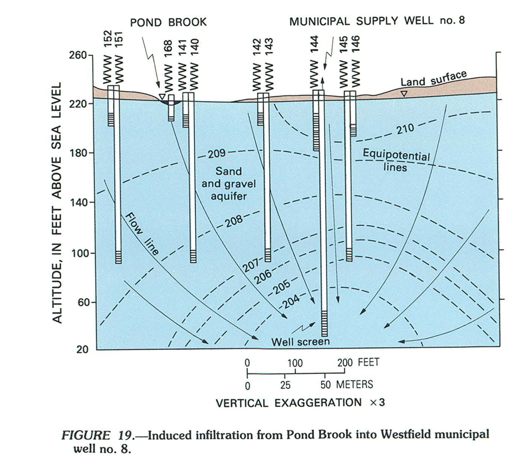

FIGURE 19.—Induced infiltration from Pond Brook into Westfield municipal well no. 8.

WATER QUALITY

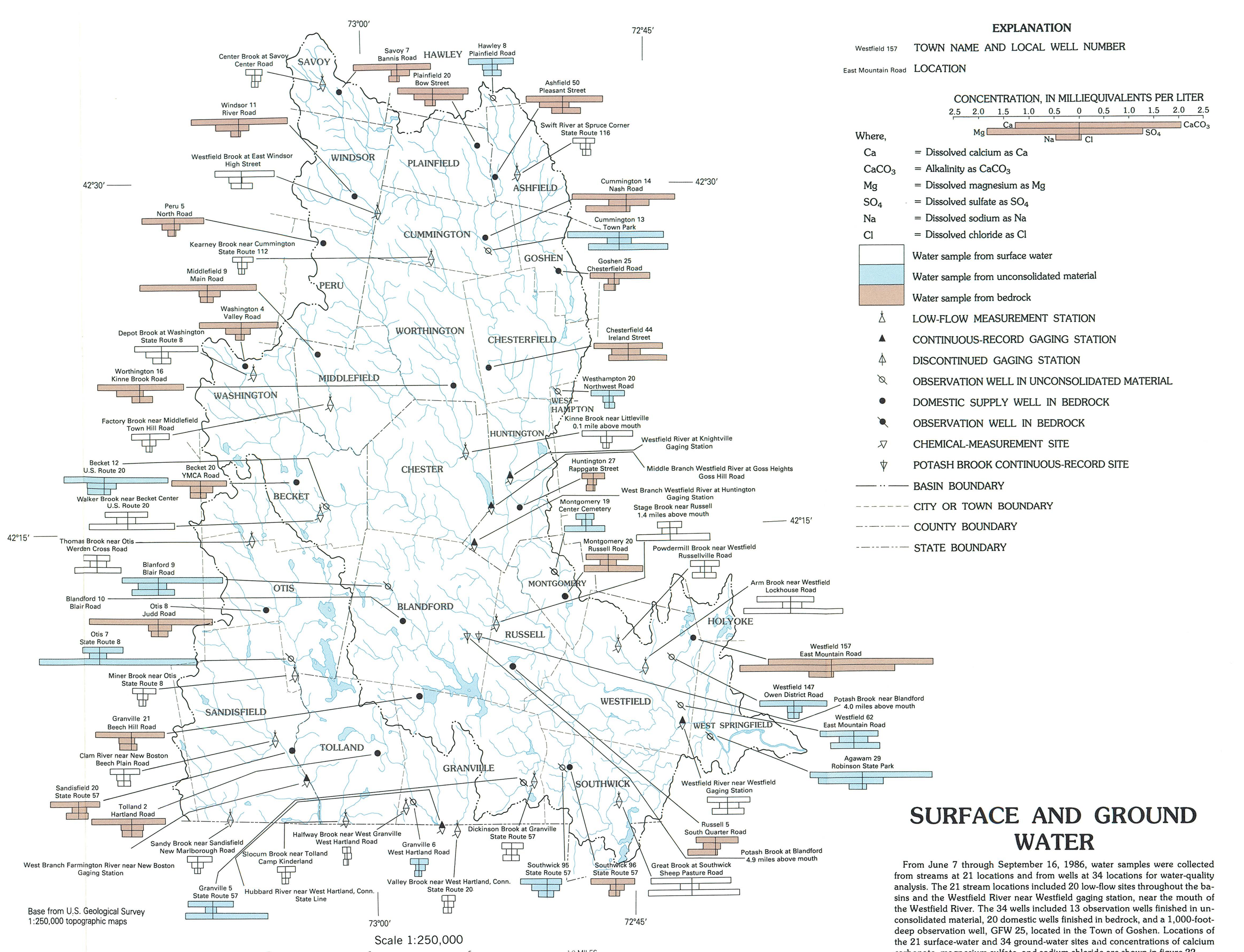

FIGURE 22.—Water-quality sampling sites and common-ion concentration of water samples collected at those sites.

TABLE 3.—Range of field observations of pH and specific conductance for stream waters
[—, insufficient data; µS/cm, microsiemens per centimeter at 25 °Celsius]

Stream and location	Observations: Number	Observations: Water years	pH (standard units): Maximum	pH (standard units): Minimum	Specific conductance (µS/cm): Maximum	Specific conductance (µS/cm): Minimum
Arm Brook at Lockhouse Road near Westfield	6	1984-86	7.3	6.6	550	196
Benton Brook at Otis	5	1984-85	7.6	7.0	93	40
Clam River near New Boston	5	1984-86	7.6	7.0	84	69
Dickinson Brook at Granville	3	1984-86	7.4	6.8	79	70
Dimmock Brook at Otis	5	1984-85	7.1	6.9	126	50
Fall River below Otis Reservoir	29	1977-81	—	—	96	44
Great Brook at Sheep Pasture Road at Southwick	3	1984-86	7.3	7.0	280	130
Great Brook near Westfield	39	1977-82	—	—	255	75
Halfway Brook near West Granville	5	1984-86	6.8	5.6	38	22
Hubbard River near West Hartland, Connecticut	7	1971, 1984, 1986	7.4	5.9	46	16
Johnson Brook near Congamond	3	1984-86	7.3	7.1	144	133
Middle Branch Westfield River at Goss Heights	50	1977-86	—	—	93	36
Miner Brook near Otis	6	1984-86	7.4	6.8	73	38
Powdermill Brook near Westfield	4	1984-86	7.1	6.8	87	78
Sandy Brook near Sandisfield	5	1984-86	7.5	6.7	65	49
Silver Brook near New Boston	4	1984-85	7.5	7.2	80	72
Slocum Brook near Tolland	6	1984-86	7.1	6.3	85	40
Thomas Brook near North Otis	10	1984-86	7.1	6.2	260	83
Thorp Brook near New Boston	5	1984-86	7.3	6.1	35	23
Walker Brook near Becket Center	24	1973, 1975-77 1984	—	—	255	69
West Branch Farmington River near New Boston	37	1977-82, 1984, 1986	—	—	103	43
West Branch Westfield River at Huntington	74	1957, 1971-74 1978-86	—	—	509	44
Westfield River at Knightville	44	1953, 1977-82 1984-86	—	—	154	39
Westfield River near Westfield	68	1952-53, 1957, 1971-74, 1976-86	—	—	246	54
MEDIAN			7.3	6.8	94	50

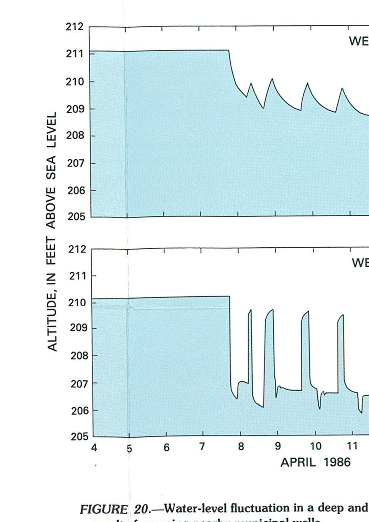

FIGURE 20.—Water-level fluctuation in a deep and shallow observation well as a result of pumping nearby municipal wells.

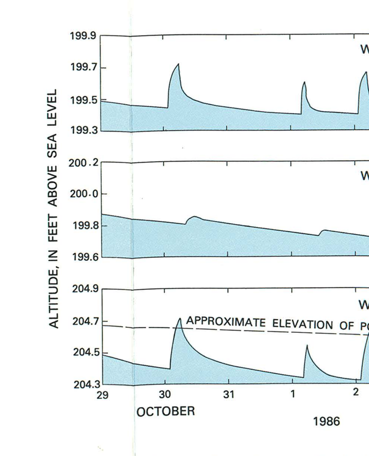

FIGURE 21.—Water-level fluctuation and induced infiltration caused by pumping of nearby municipal supply wells.

SURFACE AND GROUND WATER

From June 7 through September 16, 1986, water samples were collected from streams at 21 locations and from wells at 34 locations for water-quality analysis. The 21 stream locations included 20 low-flow sites throughout the basins and the Westfield River near Westfield gaging station, near the mouth of the Westfield River. The 34 wells included 13 observation wells finished in unconsolidated material, 20 domestic wells finished in bedrock, and a 1,000-foot-deep observation well, GFW 25, located in the Town of Goshen. Locations of the 21 surface-water and 34 ground-water sites and concentrations of calcium carbonate, magnesium sulfate, and sodium chloride are shown in figure 22.

Hardness of water, which generally is associated with effects observed in the use of soap, results from the presence of calcium and magnesium (Hem, 1985). Surface waters in the Westfield and Farmington River basins are soft (hardness concentration less than 60 mg/L (milligrams per liter) as $CaCO_3$) and ground water is soft to moderately hard (hardness concentration less than 120 mg/L as $CaCO_3$) according to the classification system used by Durfor and Becker, 1964. Hardness in water used for ordinary domestic purposes does not become particularly objectionable until it reaches a level of about 100 mg/L as $CaCO_3$ (Hem, 1985, p. 159).

The mean and median concentrations of 12 common constituents in samples from the surface- and ground-water sampling sites, from both unconsolidated material and bedrock, are less than 20 mg/L, except for alkalinity and hardness, which are slightly greater than 20 mg/L (fig. 23). Calcium and carbonate are the dominant ions (fig. 22). The higher concentrations of iron and manganese in water samples collected from surface waters and wells in unconsolidated deposits can result in the staining of laundry and plumbing fixtures (fig. 23).

Median observed field values of maximum and minimum pH were 7.3 and 6.8, respectively, and maximum and minimum specific conductance were 94 and 50 µS/cm (microsiemens per centimeter at 25° Celsius) for some streams in the basins (table 3). A pH of less than 7.0 indicates an acid solution, and if greater than 7.0, an alkaline solution. Specific conductance is a general measure of the ion concentration in a solution. The greater the specific conductance, the greater the ion concentration in solution (Hem, 1985).

According to Hem (1985), elevated aluminum concentrations have been observed in runoff and lake waters in areas affected by precipitation having a low pH. The dissolved aluminum in waters having low pH has a deleterious effect on fish and some other forms of aquatic life (Driscoll and others, 1980). Water samples were collected at the six continuous-record gaging stations (fig. 22) during a spring high-flow event on June 6, and during summer low-flow periods on August 26 and September 16, 1986, to determine concentration of dissolved aluminum. Mean concentration of dissolved aluminum was 78.3 µg/L (micrograms per liter) at high flow and 36.7 µg/L at low flow. The pH of the water samples was in the near-neutral range (6.0 to 7.6) during both periods.

The concentration of dissolved arsenic in water drawn from bedrock wells is of concern in Massachusetts because of the presence of arsenic in well water in central and eastern parts of the State. Ground-water samples from 21 domestic bedrock wells in various bedrock formations, overburden, and topographic settings were collected and analyzed to determine concentrations of dissolved arsenic in the bedrock of the basins. No dissolved-arsenic concentrations exceeded 12 µg/L, which is significantly less than the federal drinking-water standard of 50 µg/L (U.S. Environmental Protection Agency, 1986).

Potential point sources of contaminants in the basins include landfills and septic tanks and dumping grounds near waterways or in areas of high transmissivity. Otis Reservoir, whose shoreline contains a large number of seasonal and year-round homes, is vulnerable to contamination from private septic systems. Shallow wells, driven and dug, also are relatively vulnerable.

Nonpoint sources of contamination include runoff of fertilizers and pesticides from farmland and deicing chemicals and oils from highways. The Pond Brook and Great Brook aquifers are susceptible to contamination from dumping and runoff from farmland and highways because of their high transmissivity. The City of West Springfield has already had to shut down their municipal wells in the Great Brook aquifer because of contamination from the pesticides aldicarb and 1,2-dichloropropane, which had been used for tobacco farming in the area (Ellis, 1986).

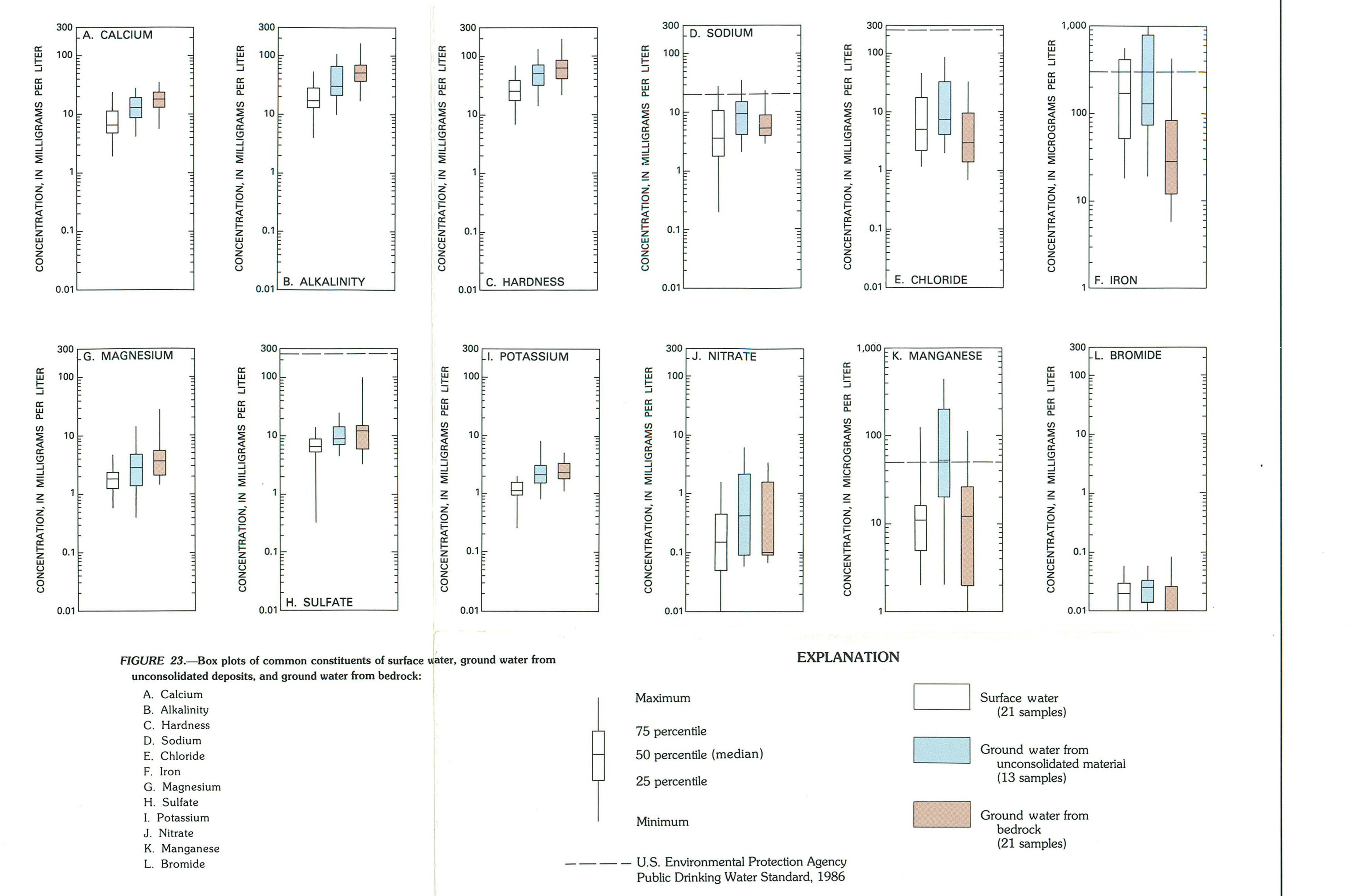

FIGURE 23.—Box plots of common constituents of surface water, ground water from unconsolidated deposits, and ground water from bedrock:
A. Calcium
B. Alkalinity
C. Hardness
D. Sodium
E. Chloride
F. Iron
G. Magnesium
H. Sulfate
I. Potassium
J. Nitrate
K. Manganese
L. Bromide

HIGHWAY RUNOFF

Application of salt to roads and highways is a common winter practice in the basins. During snowmelt, road salt and other contaminants are washed off the roads and enter surface waters as runoff and ground water by infiltration into soils. For example, increased concentrations of sodium chloride have been found in private, domestic-supply wells located along highways and major roads in the communities of Cummington and Goshen (Pioneer Valley Planning Commission, 1986).

Few data are available that describe the rate at which contaminants wash off roadways and are flushed through the local surface-water drainage systems. To assess the rate of road-salt flushing in streams during winter runoff events, pH, specific conductance, and stream temperature were measured during a hard freeze and after the first thaw during January and February 1985 at 23 locations at the upstream and downstream sides of streams that pass under the Massachusetts Turnpike. Continuous recorders were installed along Potash Brook near the Town of Blandford. The recorders were located both upstream (Potash Brook *at* Blandford, fig. 22) and downstream (Potash Brook *near* Blandford, fig. 22) of State Route 23 and the Massachusetts Turnpike from December 1985 to March 1986. The largest runoff event of the winter occured during January 25-26, when 1.4 inches of rain fell. This rainfall, combined with above-freezing temperatures (fig. 24), melted most of the snow cover. No stream-discharge measurements were made during this event. As a result of runoff from this event, the downstream specific conductance rose from a base of 400 µS/cm to 1,850 µS/cm in 3 hours (fig. 24). After a slight decline and subsequent smaller rises, the specific conductance returned to near baseline values of 400 µS/cm within 8 hours of the beginning of the event. The increase in specific conductance indicates the immediate addition of electrically conductive ions, such as dissolved chloride and other dissolved solids, that probably originated from the highways. By comparison, the maximum increase in specific conductance at the upstream site, which drains an area without any highways, was 50 µS/cm during the entire event (fig. 24). The pH of the stream water at both the upstream and downstream sites decreased during the event (fig. 24) because of the addition of meltwater from snow, which had a pH of 4.0 to 4.5.

The rapid rise and short recovery period of specific-conductance values at the downstream site indicates that surface contaminants, such as road salt, were quickly dissolved and moved downstream. The steep slope of the local terrain and low infiltration capacity of the near- surface till and bedrock, enabled rapid flushing in about 11 hours.

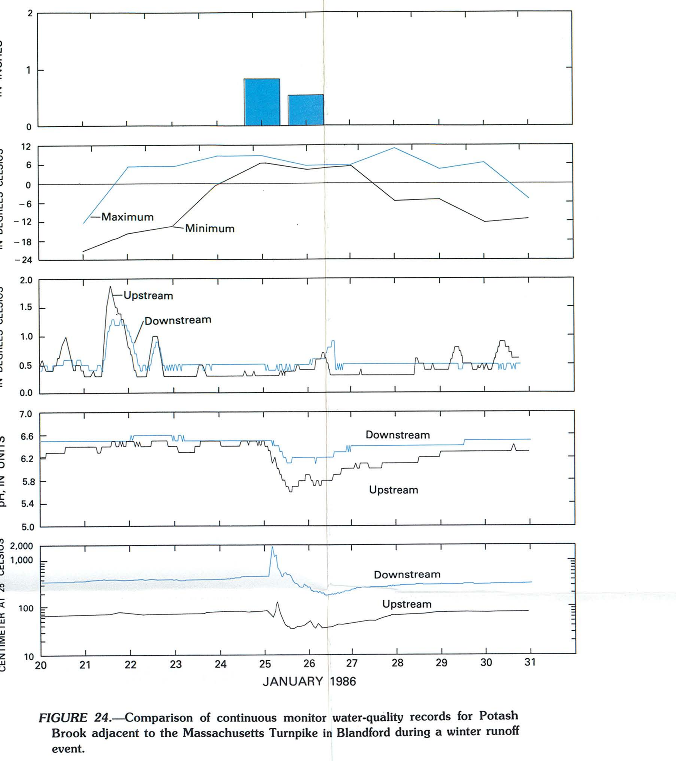

FIGURE 24.—Comparison of continuous monitor water-quality records for Potash Brook adjacent to the Massachusetts Turnpike in Blandford during a winter runoff event.

WATER USE

Water pumped in the study area in 1985 (table 4) from public and private sources was 12.63 Mgal/d, an average 143 gal/d (gallons per day) per inhabitant. About 80 percent of the population is served by public-supply systems, and the remainder by private wells. As a general rule, the public-supply systems rely on surface water and on shallow wells completed in stratified drift. Most private wells are finished in bedrock. Water-use data are not included for the following municipalities because most of their area and source for any public supply in these towns is outside the basin boundary: Agawam, Ashfield, Hawley, Hinsdale, Holyoke, Monterey, New Marlborough, Southampton, Tyringham, Washington, and Westhampton.

TABLE 4.—Municipal water use, 1985

Municipality	Projected population 1985[1]	Percentage of population served by public supply[2]	Water use from public supply[3], in million gallons per day	Self-supplied ground water[4], in million gallons per day	Total water use, in million gallons per day	Gallons per day per capita	Source of supply
Beckett	1,360	0	0	0.10	0.10	75	Onsite self-supplied.
Blandford	1,070	80	0.07	.02	.09	84	Long Pond.
Chester	1,120	65	.09	.03	.12	107	Austin Brook Reservoir, Horn Pond.
Chesterfield	1,080	0	0	.08	.08	75	Onsite self-supplied.
Cummington	680	59	.01	.02	.03	44	Cummington Center well, West Cummington well.
Goshen	690	30	.02	.03	.05	72	Private well.
Granville	1,260	15	.01	.08	.09	71	Four springs, one well.
Huntington	1,850	58	.19	.06	.25	135	Cold Brook Reservoir, two wells.
Middlefield	395	0	0	.03	.03	75	Onsite self-supplied.
Montgomery	665	0	0	.05	.05	75	do.
Otis	980	0	0	.07	.07	75	do.
Peru	695	0	0	.05	.05	75	do.
Plainfield	465	0	0	.03	.03	75	do.
Russell	1,610	77	.35	.03	.38	236	Black Brook Reservoir, one well.
Sandisfield	685	0	0	.05	.05	75	Onsite self-supplied.
Southwick	7,710	50	.42	.29	.71	92	One well, Springfield water system.
Tolland	230	0	0	.02	.02	75	Onsite self-supplied.
West Springfield	27,050	100	3.86	0	3.86	143	Bear Hole Reservoir, Springfield water system.
Westfield	36,890	92	6.22	.22	6.44	175	Eight wells.
Windsor	630	0	0	.05	.05	75	Onsite self-supplied.
Worthington	990	52	.04	.04	.08	81	Three wells, two reservoirs.
TOTAL	88,105	80	11.28	1.35	12.63	143	

[1]Data from Massachusetts Department of Public Health, 1983.
[2]Lower Pioneer Valley Regional Planning Commission, 1983.
[3]Massachusetts Department of Environmental Management, Division of Water Resources and local contacts, includes domestic, commercial, industrial, and agricultural use, 1986.
[4]Estimated on use of 75 gal/d per capita.

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