YIELD AND QUALITY OF GROUND WATER FROM STRATIFIED-DRIFT AQUIFERS, TAUNTON RIVER BASIN, MASSACHUSETTS

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CONVERSION FACTORS AND ABBREVIATIONS

For the convenience of readers who may prefer to use metric (International System) units rather than the inch-pound units used in this report, values may be converted by using the following factors.

Multiply inch-pound unit	By	To obtain metric unit
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.59	square kilometer (km^2)
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile $(ft^3/s)/mi^2$	0.01093	cubic meter per second per square kilometer $(m^3/s)/km^2$
	Other	
foot per day (ft/d)	0.3048	meter per day (m/d)
foot squared per day (ft^2/d)	0.09294	meter squared per day (m^2/d)

Temperature

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows: °C = 5/9 (°F-32).

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A Geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level."

YIELD AND QUALITY OF GROUND WATER FROM STRATIFIED-DRIFT AQUIFERS, TAUNTON RIVER BASIN, SOUTHEASTERN MASSACHUSETTS

BY WAYNE W. LAPHAM

ABSTRACT

Glacial stratified-drift deposits composed primarily of sand and gravel form the major aquifers in the Taunton River basin. In the northern half of the basin, the aquifers are long, narrow, and thin, and saturated thicknesses range from about 20 feet to slightly more than 100 feet. Aquifer widths range from about 0.1 mile to 1.5 miles, and lengths range from about 1 mile to 5 miles.

Aquifer yield from storage, representative of short-term yield during severe drought conditions, were estimated for 26 selected aquifers in the basin. For a 30-day pumping period, 14 aquifers have yields less than 5 ft^3/s (cubic feet per second), 7 have yields of from 5 to 10 ft^3/s; and 5 have yields of from 10 to 15 ft^3/s. Aquifer yields under normal climatic conditions were estimated for the 26 aquifers by considering the cumulative yield from intercepted ground-water discharge, induced infiltration, and storage. These yield estimates are related to the estimated duration of flow of the stream that drains the aquifer. The two highest aquifer yields equal or exceed 11.9 and 11.3 ft^3/s 90 percent of the time, respectively, if minimum stream discharge is maintained at 99.5 percent flow duration. Water for public supply was pumped in 18 of the 26 aquifers during 1983, and all the developed aquifers were pumped at a rate either equal to or greater than 70 percent of the estimated rate of aquifer yield determined in this study.

The pH of the ground water ranges from 5.4 to 7.0, which categorizes the water as mildly corrosive. Hardness of the ground water ranges from 9 to 112 mg/L (milligrams per liter). No concentrations of sulfate or chloride exceeded EPA recommended limits for drinking water. However, concentrations of sodium exceeded the Massachusetts recommended limit for drinking water for those individuals on a sodium-restricted diet of 20 mg/L in 19 of the samples. Natural concentrations of iron and manganese commonly exceed the limits of 0.3 mg/L and 0.05 mg/L recommended for drinking water.

Of 51 analyses for trace metals, including arsenic, barium, cadmium, chromium, copper, cyanide, lead, mercury, selenium, silver, zinc, and nickel, only lead, with a concentration of 60 µg/L (micrograms per liter) exceeded the recommended limit of 50 µg/L at one site. In 13 of 74 analyses for selected organic compounds, one or more of the following compounds were detected: Chloroform; carbon tetrachloride; 1,1 dichloroethane; 1,2 trans-dichloroethylene; tetrachloroethylene; toluene; 1,1,1 trichloroethane; and trichloroethylene. The U.S. Environmental Protection Agency has set Maximum Contaminant Levels (MCLs) for three of these compounds. These three compounds and their MCLs are: Trichloroethylene, 5 µg/L; carbon tetrachloride, 5 µg/L; and 1,1,1-trichloroethane, 200 µg/L. Trichloroethylene was detected in five samples. The concentration of trichloroethylene in one of these five samples exceeded the limit of 5 µg/L. A concentration of carbon tetrachloride of 0.8 µg/L was detected in one sample, which is below the limit of 5 µg/L. Concentrations of 1,1,1 trichloroethane were detected in ten samples, but none exceeded the limit for that compound.

INTRODUCTION

Background

Water shortages are a chronic problem in parts of the Taunton River basin and result from a combination of factors. One factor is that ground-water resources are limited in some parts of the basin because glacial stratified-drift aquifers, which are the only aquifers used for public water supply, are thin, narrow, and discontinuous. A second factor is drought, which causes water levels in aquifers to decline, resulting in mandatory reductions in pumping rates. Water shortages were particularly severe during the drought of the mid-1960's and dry periods of the early 1980's. A third factor is that overall water use in the basin has increased during the past several decades. Finally, and perhaps the most important factor, is conjunctive water use in the basin. Many streams and ponds used for surface-water municipal supply are hydraulically connected to stratified-drift aquifers used for ground-water municipal supply.

Withdrawal of water from surface-water sources can affect the yield from ground-water sources, and vice versa. Regardless of the source, withdrawals can affect yields elsewhere in the basin.

No decrease of water use in this part of the Boston metropolitan area is expected in the next decade, and water shortages are predicted to become more widespread and occur more frequently. Information reported by the Massachusetts Water Resources Commission (1983) indicates that about 50 percent of the cities and towns within and on the perimeter of the basin will have water-supply deficits by 1990 if water-management projects are not pursued during the 1980's.

Purpose and scope

This report presents the results of a study conducted between 1981 and 1984 to determine the yield and quality of ground water from stratified-drift aquifers in the Taunton River basin. The three objectives of the study were to (1) estimate yields of selected stratified-drift aquifers, (2) determine the impact on streamflow and on the ground-water system of alternative aquifer development plans, and (3) characterize the quality of ground water in the stratified-drift aquifers. The study was done cooperatively by the U.S. Geological Survey and the Massachusetts Department of Environmental Management, Division of Water Resources, and is one of a number of studies under Chapter 800 Massachusetts legislation which enables quantitative assessments of regional ground-water resources in the State by the Survey.

Twenty-six stratified-drift aquifers in the northern half of the basin were studied in detail. These aquifers were selected because current and projected 1990 water-supply deficits are greatest in the northern half of the basin, affecting 14 of 19 municipalities, in contrast to predicted deficiencies in only one of nine municipalities in the southern half of the basin (Massachusetts Water Resources Commission, 1983), and use of ground water as the sole source of supply is greatest in the northern half of the basin. Ground water is the sole source of supply in 15 of 19 municipalities. In contrast, only four of nine municipalities in the southern half of the basin use ground water as their sole supply (Massachusetts Water Resources Commission, 1983).

A transmissivity map was used to delineate the stratified-drift aquifers in the basin. The map was drawn by revising the transmissivity map published by Williams and others (1973) using about 500 logs of test borings completed by municipalities from 1968 through 1982. Yields of the 26 stratified-drift aquifers, both during severe drought and during normal climatic conditions, were determined. Yields were determined by estimating the rates of water available to each aquifer from three sources: Aquifer storage, intercepted ground-water discharge, and induced infiltration.

Quality of ground water in the stratified-drift aquifers was characterized using 80 analyses of inorganic chemical constituents, pH, alkalinity, hardness, and specific conductance, 51 analyses of trace metals, and 74 analyses of organic compounds. The inorganic constituents were calcium, magnesium, sodium, potassium, iron, manganese, sulfate, chloride, and nitrate. The trace metals were arsenic, barium, cadmium, chromium, copper, cyanide, lead, mercury, selenium, silver, zinc, and nickel. The organic compounds included chloroform, carbon tetrachloride, 1,1 dichloroethane; 1,2 trans-dichloroethylene; tetrachloroethylene; toluene; 1,1,1 trichloroethane; and trichloroethylene.

Previous Investigations

About 50 reports describing ground-water conditions in municipalities in the basin have been prepared by private consulting firms. Several regional assessments of the water resources of all or parts of the basin have been published (Camp, Dresser, and McKee, 1965; New England River Basins Commission, 1975; Old Colony Planning Council, 1977; Williams, 1968; and Williams and others, 1973). Geohydrologic data in these reports were used in this study. Williams and others (1973) described surface- and ground-water resources and water quality in the basin but did not determine yields or describe in detail the quality of ground water in the stratified-drift aquifers.

Geographic setting

The Taunton River basin covers 530 mi^2 of Bristol, Norfolk, and Plymouth Counties in southeastern Massachusetts (fig. 1). All or parts of the cities of Attleboro, Brockton, Fall River, New Bedford, Taunton, and 36 towns are located in the basin (fig. 2). The basin, which is part of the Seaboard Lowland region of the New England Province (Fenneman, 1938), is drained by the

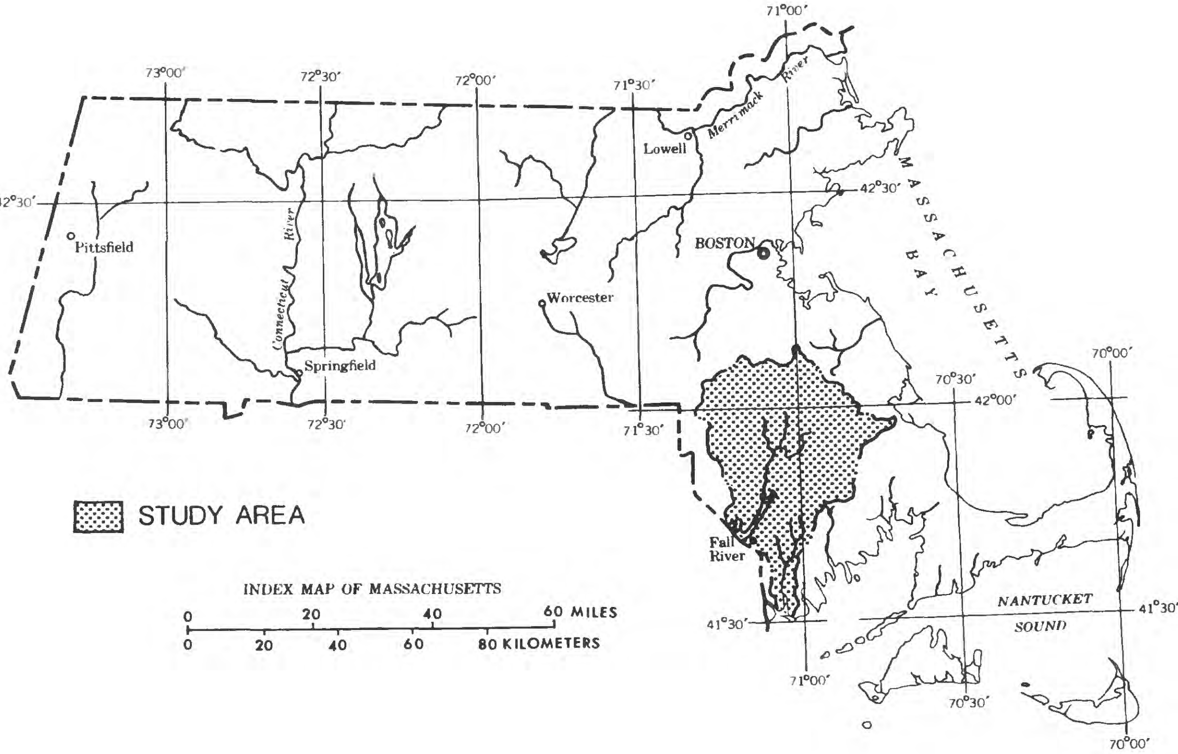


Figure 1.--Location of the Taunton River basin.

Matfield, Town, and Taunton Rivers. Major tributaries of these rivers are the Canoe, Mill, Nemasket, Satucket, Segreganset, Wading, Threemile, and Winnetuxet Rivers (plate 1). Surface-water drainage is generally southward toward Mount Hope Bay, a part of Narragansett Bay at Fall River. Mean annual discharge of the Taunton River at State Farm near Bridgewater is 480 ft^3/s, the discharge equaled or exceeded 90 percent of the time is 66.6 ft^3/s, and the annual minimum 7-day mean discharge for a 10-year recurrence interval is 24.6 ft^3/s (Wandle and Keezer, 1984). Mean annual discharge of the Wading River near Norton is 75.0 ft^3/s, the discharge equaled or exceeded 90 percent of the time is 6.2 ft^3/s, and the annual minimum 7-day mean discharge for a 10-year recurrence interval is 2.2 ft^3/s (Wandle and Keezer, 1984).

Land surface is flat or gently rolling. Land-surface elevations range from sea level to about 450 feet above sea level. The basin contains more than 94 mi^2 of wetlands, including the 11.7 mi^2 Hockomock Swamp, which is the largest wetland in Massachusetts (New England River Basins Commission, 1975). Lakes and ponds occupy about 23 mi^2 of the basin (Williams and others, 1973). Average annual precipitation is approximately 43.5 inches and is distributed fairly evenly over the year (Williams and others, 1973). Land use in the basin consists mostly of cranberry bogs and small farms (New England River Basins Commission, 1975).

Generalized Hydrogeologic Setting

Volcanic and granitic rocks of pre-Carboniferous age underlie both the northern and southern margins of the basin (Williams and Willey, 1973). Sedimentary rocks of Carboniferous age, consisting of sandstone, shale, siltstone, conglomerate, and coal beds, underlie the interior of the basin (Williams and Willey, 1973). The approximate altitude of the bedrock surfaces ranges from about

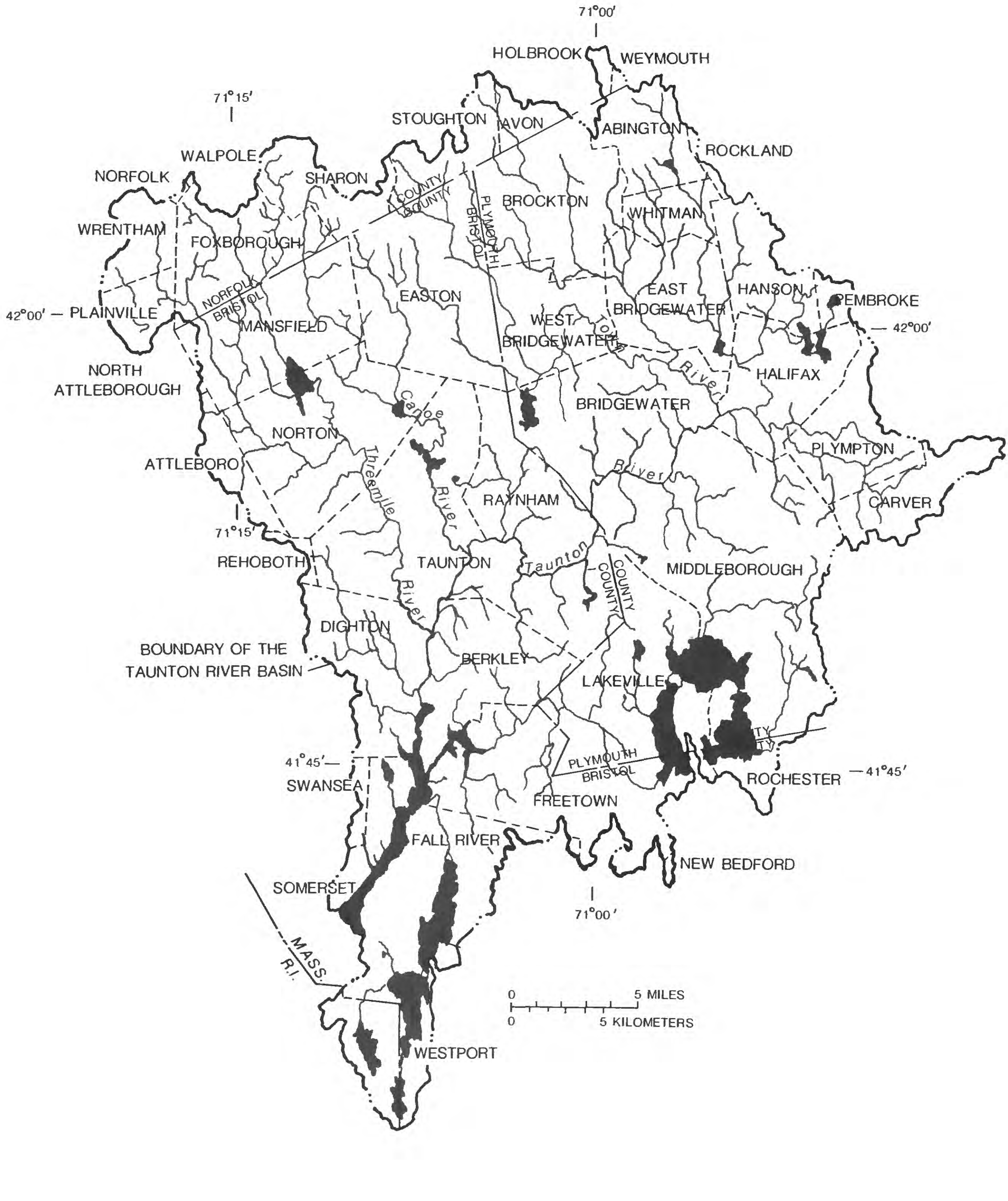


Figure 2.--Physical setting of the study area.

150 feet below sea level in the southwestern part of the basin to about 375 feet above sea level in the northwestern part of the basin (Williams and Willey, 1973). Topographic relief of the bedrock surface is attributable to both preglacial erosion of the bedrock surface by streams and the widening and deepening of these valleys by glacial scour (Frimpter, 1973a; 1973b). The thickness of unconsolidated glacial deposits overlying bedrock ranges from zero to more than 216 feet (Williams and others, 1973).

Bedrock wells generally yield water only at rates sufficient for domestic needs. Although yields of bedrock wells range from about 0.5 to 250 gal/min (gallons per minute), most bedrock wells yield less than 10 gal/min (Williams and others, 1973).

Till of Pleistocene age overlies nearly all the bedrock and is exposed at land surface over about 38 percent of the basin (Williams and others, 1973). The till ranges in thickness from 0 to about 20 feet (Williams and Willey, 1973; Old Colony Planning Council, 1977) and is a poorly sorted mixture of clay, silt, sand, gravel, cobbles, and boulders. Because till is poorly sorted and contains a relatively large fraction of silt and clay, the hydraulic conductivity of till is low. Williams and others (1973) and Old Colony Planning Council (1977) report that wells constructed in till generally yield only a few gallons per minute.

Stratified-drift deposits composed of sand, gravel, cobbles, silt, and clay of Pleistocene and Holocene ages form the only aquifers capable of sustaining public water supplies in the basin. These deposits are exposed at land surface over about 62 percent of the basin (Williams and others, 1973). Stratified-drift deposits are more abundant in the central and southern parts of the basin than in the northern part of the basin. In the northern one-third of the basin, stratified drift fills narrow, north-south trending valleys, which are bounded by till-bedrock uplands.

The stratified-drift deposits are primarily ice contact (kame), outwash, and lake bottom (lacustrine) sediments, which were deposited in preglacial bedrock valleys and in water-filled depressions in the till surface during retreat of the last glacier. Stratified drift ranges in thickness from 0 to about 200 feet in some of the deep preglacial bedrock valleys. The thickest stratified drift are lacustrine deposits composed of fine sand interbedded with silt and clay. Hydraulic conductivities of stratified drift range from near 0 for the fine-grained silts and clays to greater than 300 ft/d (feet per day) for coarse-grained sands and gravels. Yields of wells in the fine-grained stratified drift are usually no more than a few gallons per minute, whereas yields of wells in the coarse-grained stratified drift usually equal or exceed 300 gal/min (Williams and others, 1973).

Plate 1 is a revised transmissivity map of the unconsolidated sand and gravel deposits based on the maps prepared by Williams and others (1973, sheet 2), Williams and Tasker (1974, sheet 2) and Willey and others (1978, sheet 1). Plate 1 was prepared from the original maps by adding data from approximately 500 additional test borings. These borings were completed by municipalities in the basin from 1968 through 1982. Transmissivity at each new test-boring site was calculated using the values of saturated thickness and hydraulic conductivity of the unconsolidated material, according to the method described by Williams and others (1973). Hydraulic-conductivity values for the unconsolidated material were assigned using the relationship between sediment grain size and hydraulic conductivity (J. R. Williams, U.S. Geological Survey, written commun., 1983). Only the locations of the new test-boring sites used to prepare plate 1 are shown. The locations of all other test borings are shown on Williams and others (1973, sheet 2), Williams and Tasker (1974, sheet 2) and Willey and others (1978, sheet 1).

Comparison of the transmissivity contours on sheet 2 of Williams and others, (1973) and plate 1 of this report indicates that the new data do not significantly change the original interpretation of transmissivity. The new data indicate that the areas of stratified drift with transmissivity greater than 1,337 ft^2/d along Hodges Brook near West Mansfield, Rumford River near Mansfield, and Mulberry Brook near the southwestern corner of Easton are somewhat larger than those mapped by Williams and others (1973). The areal extent of stratified drift with transmissivity greater than 1,337 ft^2/d along the Rumford River in Sharon is somewhat smaller than that mapped by Williams and others (1973). An area of stratified drift with transmissivity greater than 1,337 ft^2/d underlying the northwestern edge of Lake Nippentucket in Bridgewater also was identified from the new data. All the test-boring data provide thorough basin-wide coverage for exploration of stratified-drift aquifers for municipal well sites, particularly in the northern half of the basin. Therefore, it is unlikely that there are any large, undiscovered deposits of stratified drift in the basin.

Acknowledgments

The author would like to thank the town engineers and superintendents and employees of municipal water departments in the basin for providing information on ground-water exploration and development in their municipalities. The author also would like to thank personnel at the Southeast Regional Office of the Massachusetts Department of Environmental Quality Engineering in Lakeville, Massachusetts, for their help in compiling water-quality data used in this study.

HYDROGEOLOGIC CHARACTERISTICS OF THE STRATIFIED-DRIFT AQUIFERS

Location, Areal Extent, and Hydraulic Properties

Twenty six stratified-drift aquifers in the northern half of the basin were selected for study (fig. 3; pl. 1). These aquifers were identified as areas of stratified drift with transmissivity equal to or greater than 1,337 ft^2/d (10,000 gal/d/ft). The 26 aquifers underlie or are near major rivers or tributaries to major rivers. Most of the aquifers are thin, narrow, and long, and saturated thicknesses range from about 20 to slightly more than 100 feet, although saturated thicknesses exceed 80 feet in only a few locations. Widths range from about 0.1 to 1.5 miles and lengths range from about 1 to 5 miles.

The stratified-drift aquifers are composed of layers of sand and gravel with some interbedded layers of silt and clay. John R. Williams (U.S. Geological Survey, written commun., 1982) determined that hydraulic conductivity of fine to coarse gravel ranges from about 150 to 500 ft/d, mixed sand and gravel averages about 200 ft/d, and fine to coarse sand ranges from about 25 to 150 ft/d. The transmissivity of the stratified drift is equal to the hydraulic conductivity of the drift times the saturated thickness of the drift. Therefore, equal transmissivities at different locations in an aquifer may be the result of thin deposits of high-conductivity drift or thick deposits of low-conductivity drift. Transmissivity exceeds 4,000 ft^2/d in small areas in nearly all the 26 aquifers. In a few areas, where the stratified drift is thick or has a high hydraulic conductivity, transmissivity exceeds 10,000 ft^2/d.

Water-level fluctuations

Water levels in U.S. Geological Survey observation wells in the basin (figs. 5-6) fluctuate annually from about 4 feet to more than 10 feet (Maevsky, 1976; Frimpter and Maevsky, 1979). Locations of these observation wells are shown in figure 4. According to long-term records, water levels in coarse-grained stratified drift (wells N4W 37, F3W 23, and TAW 337, fig. 5) fluctuate about 4 feet annually; whereas water levels in fine-grained stratified drift (well LKW 14, fig. 5) fluctuate as much as 10 feet annually. The magnitude of water-level fluctuation in the fine-grained stratified drift is similar to that observed in till (well EBW 30, fig. 6). The range of water-level fluctuations in sandstone bedrock is similar to that of fluctuations observed in till and stratified drift (wells HBW 97 and SPW 161, fig. 6). The magnitudes of water-level fluctuation in these two wells is partly attributable to the type of sediments overlying the bedrock. HBW 97 is overlain by stratified drift; whereas SPW 161 is overlain by till. Fluctuations in HBW 97 also are affected somewhat by nearby pumping of domestic wells (Frimpter and Maevsky, 1979).

Ground-Water Discharge

Ground water discharging from a sand and gravel aquifer originates as water directly recharging the aquifer from infiltration of precipitation, water flowing into the aquifer from adjacent low-transmissivity stratified drift, till, bedrock, and from water infiltrating from losing streams. Under natural conditions, this water discharges from aquifers to streams, ponds, lakes, and wetlands. During pumping, some of the ground water is intercepted and withdrawn by wells.

Ground-water discharge was estimated using equations that relate baseflow (ground-water) discharge to percentage of basin covered by stratified drift. Data necessary to adjust field measurements of ground-water discharge for the effect of regulation and diversion of streamflow, and the percentage of pumping in a basin that is consumptive, were not readily available. Also, it was not possible to measure ground-water discharge for each of the 26 aquifers over a wide range of baseflow con-

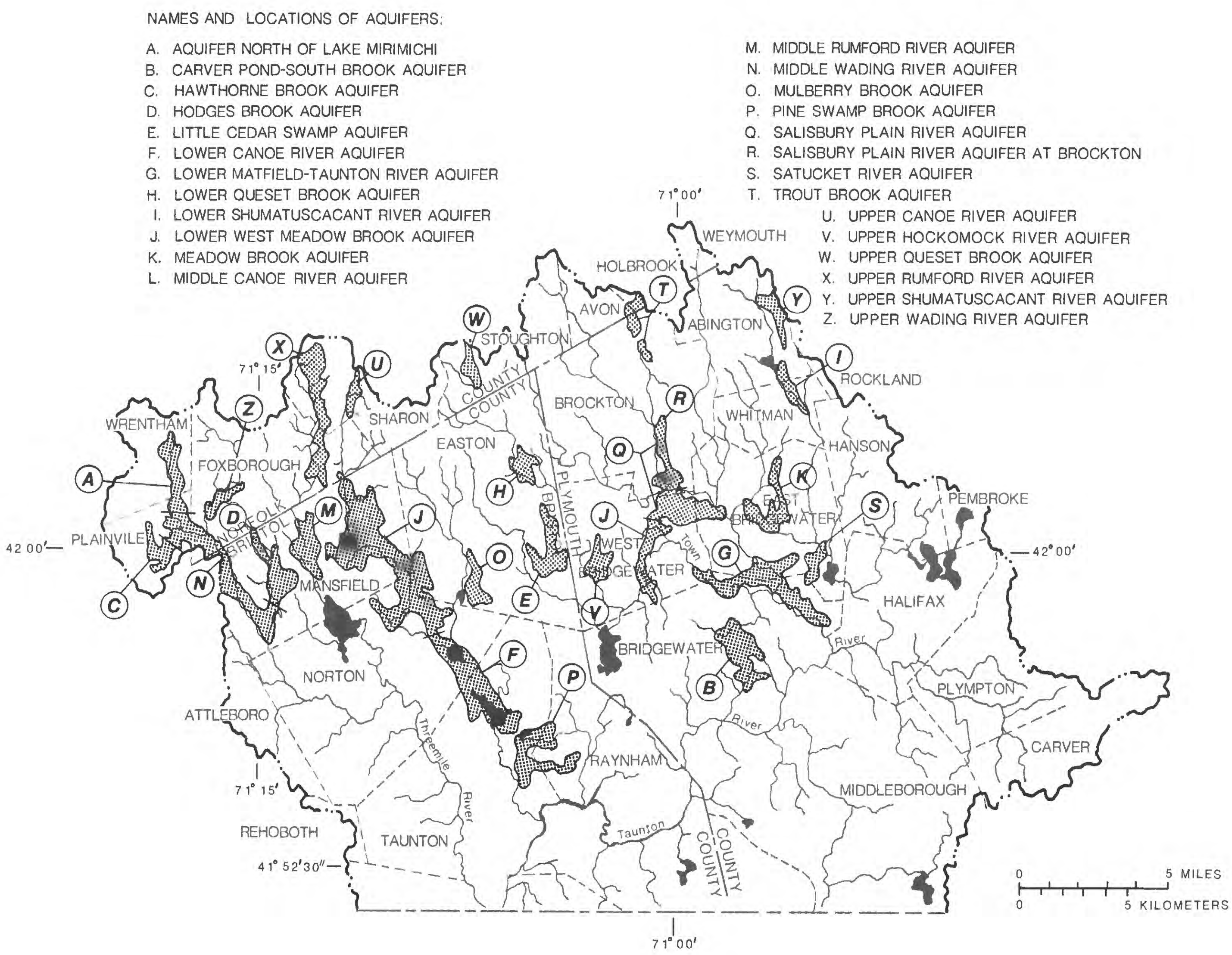


Figure 3.--Names and locations of the stratified-drift aquifers.

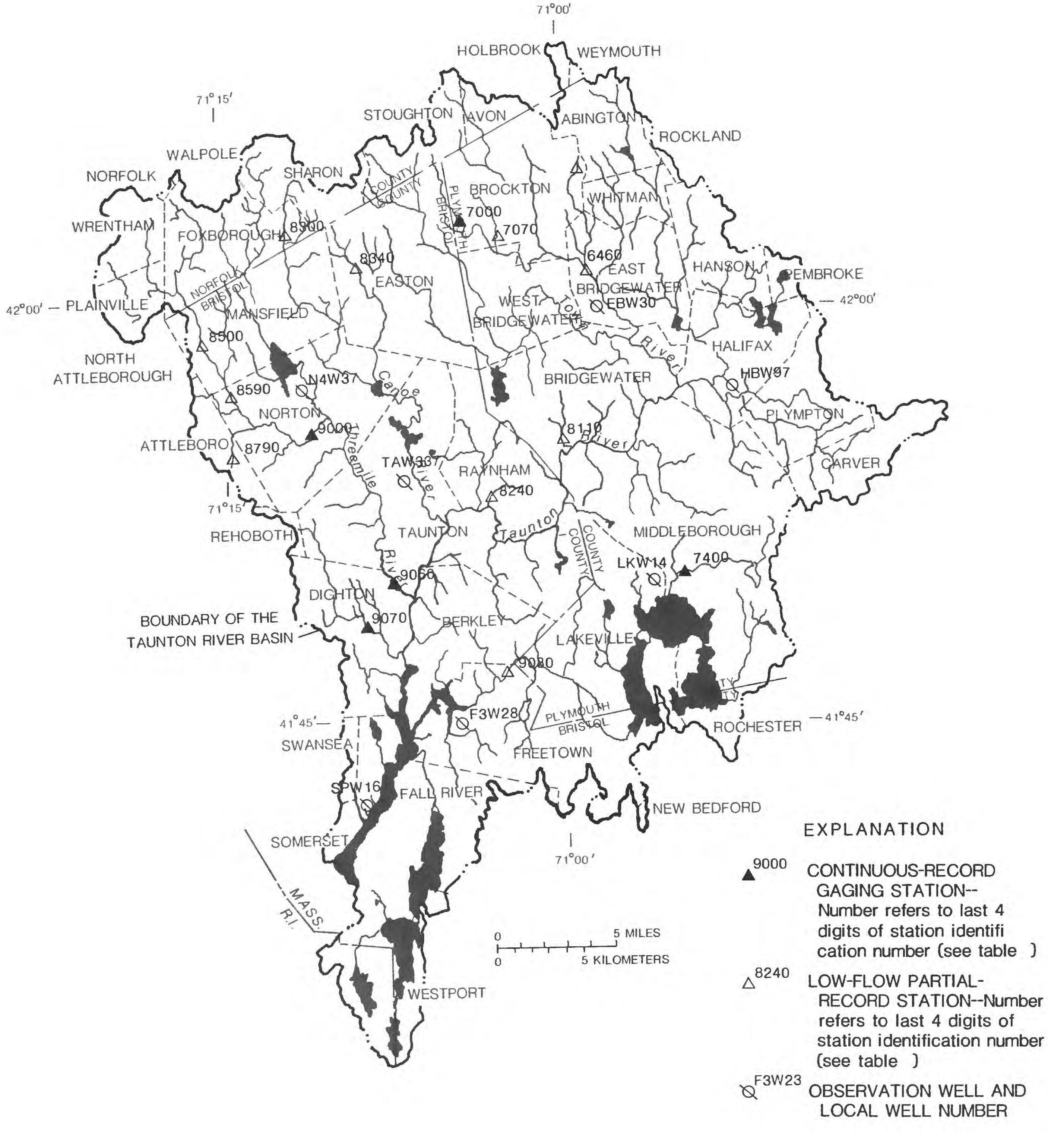


Figure 4.--Locations of streamflow gaging stations, low-flow partial record stations, and observation wells.

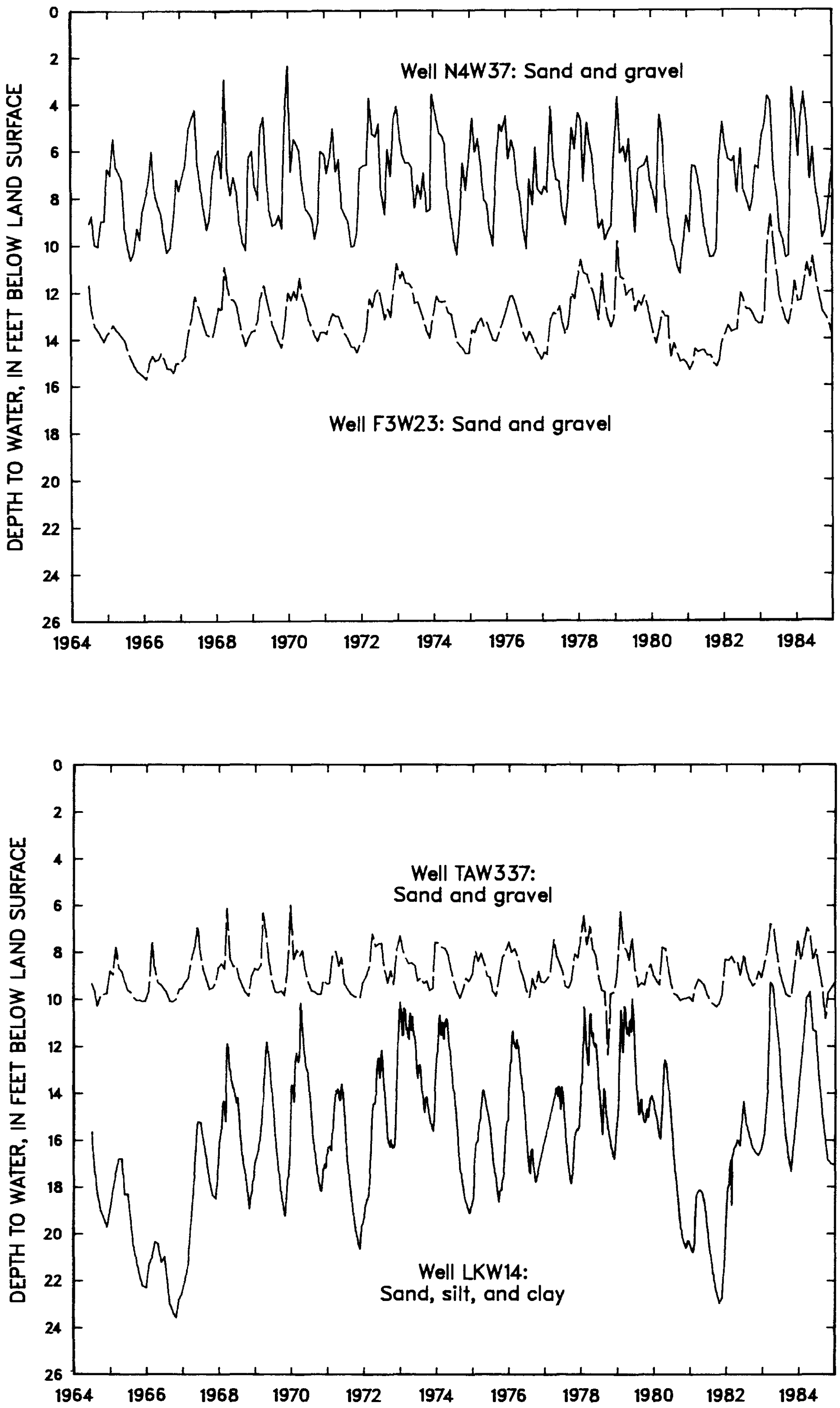
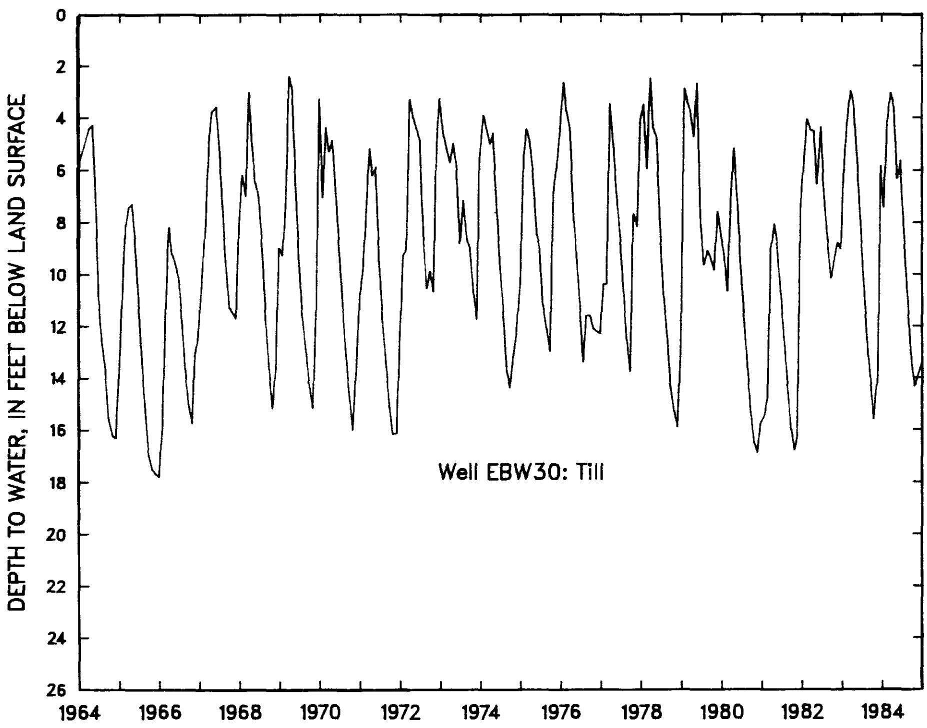


Figure 5.--Water-level fluctuations in stratified-drift.



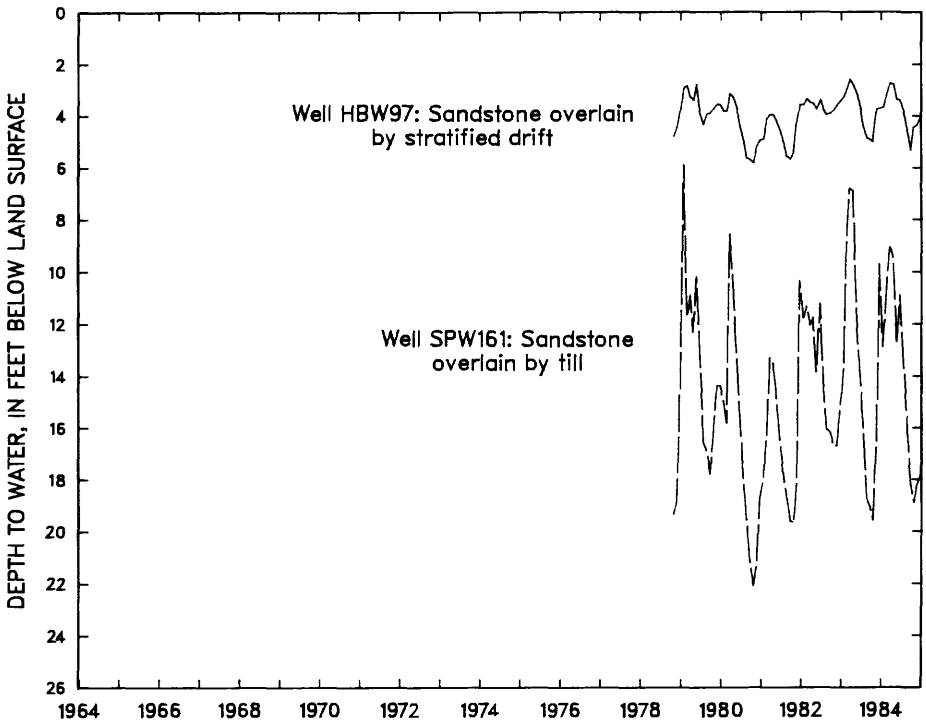


Figure 6.--Water-level fluctuations in till and bedrock.

ditions. Therefore, a regional approach to describing ground-water discharge was followed by using baseflow-duration curves.

Figure 7 shows the streamflow-duration curve for the Wading River at Norton, Massachusetts, for the 1955 through 1981 period of record. During this period, regulation and diversion of the Wading River have remained relatively constant (Wandle, S. W., Jr., U.S. Geological Survey, oral commun., 1983). The Wading River at Norton is considered reasonably representative of unregulated stream discharge in eastern Massachusetts (R. A. Gadoury, U.S. Geological Survey, oral commun., 1983). The streamflow-duration curve has been separated on figure 7 into the overland runoff and baseflow components of streamflow using the technique described by LaSala (1968).

The streamflow duration curve in figure 7 was separated into overload runoff and baseflow by: (1) Determining the estimated maximum rate of baseflow discharge that has occurred from 1955 to 1981 using hydrograph separation, and assuming this maximum rate is equaled or exceeded 0.01 percent of the time. This rate was estimated to equal 120 ft^3/s; (2) assuming all streamflow is baseflow discharge at percent exceedances greater than 90 percent; and (3) drawing smooth curves of overland runoff and baseflow between 0.01 and 90 percent exceedances such that the sum of the rates of baseflow and overland runoff equals the rate of streamflow at each percent duration.

Thirteen stations (fig. 4, table 1) in the basin were selected to develop the relation between ground-water discharge and percentage of stratified drift covering a basin. These 13 stations were selected because there is little regulation or diversion of streamflow and there is no pumping upstream of these stations. Measurements of baseflow discharge at each of the 13 stations and the concurrent baseflow discharge at an index station (the Wading River at Norton--01109000) were used to draw the baseflow-duration curves at each of the 13 stations. This technique is described by Searcy (1959).

After the baseflow-duration curve was drawn for each of the 13 stations, varying percentages of time that the rate of baseflow is equaled or exceeded were determined from each curve for each station. Each of 20 selected discharge rates for each station was then divided by the basin drainage area upstream of the station. The resulting values are the rates of ground-water discharge per square mile that are equaled or exceeded a specified percentage of the time at the station (table 1). The 13 rates of ground-water discharge per square mile, at each percent exceedance, were then plotted against their corresponding percentage of stratified drift. Ground-water discharge per square mile was then regressed against percentage of stratified drift. Graphs of the relations between ground-water discharge per square mile that is equaled or exceeded 0.01, 50, 90, and 99.9 percent of the time and percentage of stratified drift, the linear-regression lines, regression equations, and r^2 (coefficient of determination) values are shown in figures 8a-d, respectively.

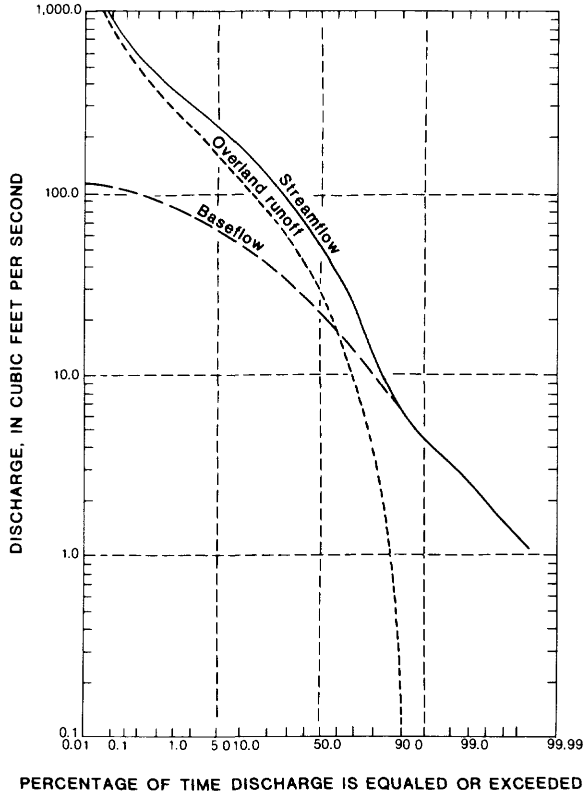


Figure 7.--Streamflow-, overland runoff-, and baseflow-duration curves for the Wading River at Norton, Massachusetts: Station 01109000, 1955-81.

Minimum and maximum r^2 values for the regression equations are 0.28 for 99.9-percent baseflow duration and 0.71 for 50-percent baseflow duration, respectively (fig. 8b and d). The r^2 values indicate that variation in the rate of ground-water discharge cannot be attributed only to variation in percentage of stratified drift. At baseflow durations greater than about 99.5 percent, variables other than percentage of stratified drift become particularly significant in determining rates of

Table 1.--*Ground-water discharge to streams from 13 basins*

Drainage basin and station number[1]	Drainage area, in square miles covering basin	Percentage of stratified drift[2]	Ground-water discharge that is equaled or exceeded at the indicated percentage of time in cubic feet per second per square mile				
			Percentage of time				
			0.01	0.05	0.1	0.5	1
Assonet River upstream of 01109080	16.2	39.0	1.6	1.6	1.5	1.4	1.3
Beaver Brook upstream of 01106455	5.56	5.3	.13	.12	.12	.12	.11
Beaver Brook upstream of 01106460	8.90	20.7	.60	.57	.56	.52	.48
Beaver Brook between 01106455 and 01106460	3.34	46.3	1.4	1.3	1.3	1.2	1.1
Canoe River upstream of 01108300	1.61	44.0	1.6	1.5	1.4	1.3	1.2
Chartley Brook upstream of 01108790	1.40	84.0	2.3	2.2	2.1	1.8	1.7
Dam Lot Brook upstream of 01108240	2.97	49.0	1.6	1.5	1.4	1.3	1.2
Dorchester Brook upstream of 01107000	4.67	19.0	1.8	1.7	1.6	1.4	1.3
Meadow Brook upstream of 01106483	1.50	.8	.19	.18	.18	.17	.16
Poquanticut Brook upstream of 01108340	4.48	42.0	2.2	2.0	2.0	1.7	1.5
Snows Brook upstream of 01108110	2.64	85.0	2.0	1.9	1.8	1.6	1.5
Wading River between 01108590 and 01109000	22.0	59.0	2.6	2.4	2.3	2.1	2.0
West Meadow Brook upstream of 01107070	1.99	31.8	1.4	1.3	1.2	1.1	1.0

ground-water discharge. Other variables that might affect rates of discharge include the geohydrologic characteristics of the stratified drift, till, and bedrock; depth to the water table; area of ponds and wetlands; rate and duration of evapotranspiration; slope of land surface; vegetative type and extent of coverage; and climate. Consideration of these variables in future studies might result in more accurate equations for predicting rates of ground-water discharge. Magnitudes of the rates of discharge per square mile at high baseflow durations are nearly the same regardless of the percentage of stratified drift (fig. 8), and these magnitudes are low when compared to rates at higher durations (fig. 9). Therefore, even though the r^2 values are low, the regression equations probably result in reasonable estimates of ground-water discharge at various flow durations. Figure 9 shows the regression lines relating percentage of stratified drift and ground-water discharge equaled or exceeded 0.01 to 99.9 percent of the time.

The relation between ground-water discharge and percentage of stratified-drift covering was used to calculate ground-water discharge from each of the 26 aquifers in the basin. Estimated rates of ground-water discharge equaled or exceeded 50 to 99.9 percent of the time from each of the aquifers were determined using the drainage area of the aquifer (for example, the drainage area between stations A and B in fig. 10), the percentage of stratified drift covering that drainage area, and the relation between the rate of ground-water discharge per square mile and percentage of stratified drift (fig. 9). Ground-water discharge upstream of station B contributes to streamflow entering the upstream end of the aquifer. The transmissivity map of the aquifers (pl. 1) was used to determine the percentage of each basin covered by stratified drift. The rate of ground-water dis-

Table 1.--*Ground-water discharge to streams from 13 basins* (continued)

Ground-water discharge that is equaled or exceeded at the indicated percentage of time in cubic feet per second per square mile (continued)

Percentage of time (continued)														
5	10	20	30	40	50	60	70	80	90	95	98	99.5	99.8	99.9
1.0	0.89	0.75	0.62	0.54	0.45	0.37	0.31	0.24	0.17	0.13	0.11	0.07	0.06	0.05
.10	.09	.09	.08	.07	.07	.06	.05	.05	.04	.04	.03	.03	.02	.02
.40	.36	.31	.26	.23	.20	.17	.15	.12	.09	.07	.06	.04	.04	.03
.91	.80	.68	.56	.50	.42	.35	.29	.23	.16	.12	.10	.06	.05	.04
.95	.81	.67	.54	.47	.39	.31	.26	.20	.14	.09	.07	.05	.04	.03
1.3	1.0	.82	.63	.53	.42	.32	.26	.18	.12	.08	.06	.04	.03	.02
.94	.80	.66	.53	.46	.38	.30	.25	.19	.13	.09	.07	.04	.03	.03
.94	.77	.61	.46	.38	.30	.23	.18	.12	.08	.05	.04	.02	.02	.01
.14	.12	.11	.10	.09	.08	.07	.06	.05	.04	.04	.03	.02	.02	.02
1.1	.86	.65	.48	.39	.29	.22	.16	.11	.06	.04	.03	.02	.01	.01
1.2	1.1	.91	.75	.66	.55	.46	.38	.30	.21	.16	.13	.09	.08	.07
1.5	1.3	1.1	.85	.74	.60	.48	.39	.29	.19	.13	.10	.06	.05	.04
.81	.70	.58	.46	.40	.33	.27	.22	.17	.12	.08	.07	.04	.04	.03

[1] See figure 4.
[2] Determined using plate 1.

charge from each of the 26 aquifers is given in table 2.

Stream Discharge

Estimates of discharge of streams flowing over the sand and gravel aquifers were made using equations that relate stream discharge at a station to percentage of stratified drift covering the drainage basin above the station. The equations were developed using long-term flow-duration curves of six gaging stations in the basin (fig. 4) and one gaging station near the basin. A regional approach to determining stream discharge was used because it was not possible to make sufficient discharge measurements on every stream considered in this report to establish each stream's flow characteristics independently.

The flow-duration curves of the seven stations are shown in figure 11. For each of the seven stations, the 20 rates of discharge corresponding to the indicated percent-exceedance values in table 3 were divided by the drainage area upstream from that station. For example, for hypothetical station A in figure 10, the drainage area used would be the entire drainage area upstream from station A. The resulting values are the rates of stream discharge per square mile that are equaled or exceeded a specified percentage of the time at each station. These rates for the seven stations are shown in table 3. All seven rates of stream discharge per square mile were then plotted against their corresponding percentage of stratified drift (table 3) for each of the 20-percent exceedance values. The logarithm of stream discharge per square mile was then regressed against percentage of stratified-drift covering. Example plots of the log of stream discharge per square mile as a function of percentage of stratified drift for percent-ex-

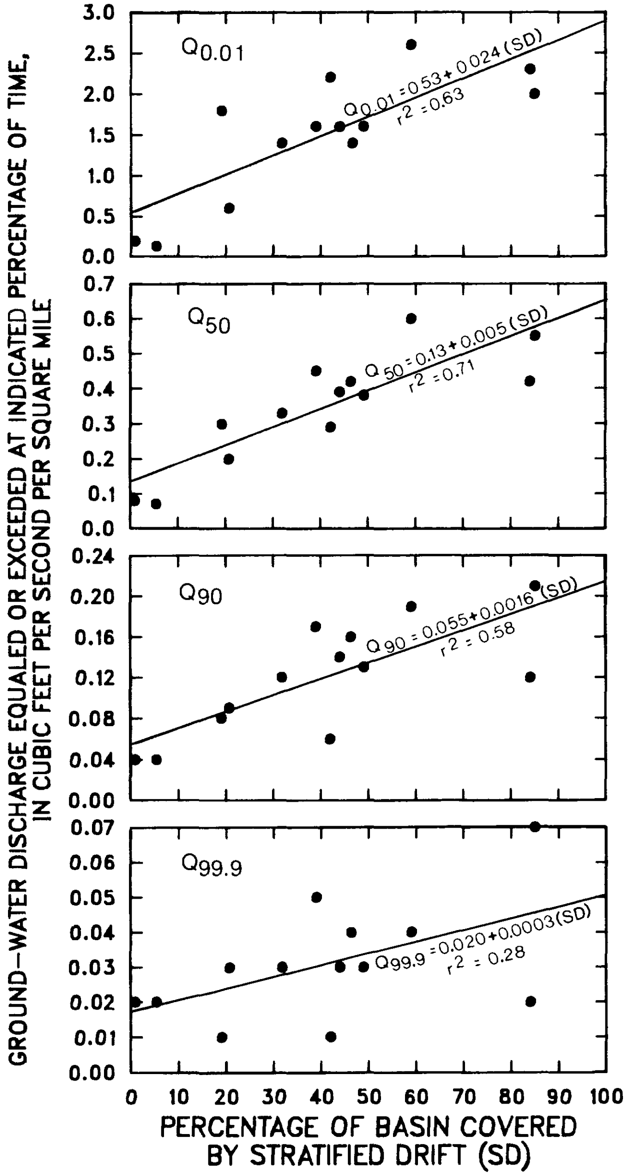


Figure 8.--Linear regressions of ground-water discharge against percentage of basin covered by stratified drift.

ceedance values of 0.1, 30, 90, and 99.9 percent, and the regression lines, the regression equations, and r^2 values of the regressions are shown in figures 12a-d, respectively.

Minimum and maximum r^2 values for the regression equations are 0.06 for 30.0-percent flow duration (fig. 12b) and 0.94 for 98-percent flow duration, respectively. The r^2 value indicates how much variation in the dependent variable (stream discharge per square mile) can be accounted for by the independent variable (percentage of stratified drift). Other variables that might affect rates of discharge include the geohydrologic characteristics of the stratified drift, till, and bedrock; depth to the water table; area of ponds and wetlands; rate and duration of evapotranspiration; slope of land surface; vegetative type and extent of coverage; and climate. Consideration of these variables in future studies might result in more accurate equations for predicting rates of discharge. At flow durations from about 20 to 30 percent, stream discharge is virtually independent of the type of unconsolidated deposits covering a basin, an observation Thomas (1966) noted for streams in Connecticut. Rates of discharge per square mile at low duration percentages are higher than those presented by Thomas (1966). Also, rates of discharge at high duration percentages are lower than those presented by Thomas (1966). Part of the explanation for the lower rates of discharge at high duration percentages may be the shorter period of record, which also includes the mid-1960's drought, used in this study than by Thomas (1966). Further analyses of the relation between discharge and percentage of stratified drift for other streams in eastern Massachusetts are needed before the reasons for these differences can be determined. Even though the r^2 values for several of the regression equations are less than 0.5 (fig. 12a and b), the logs of discharge per square mile at each flow duration for the seven stations vary over a small range of values. For example, at 30-percent flow duration, the log of discharge at the seven stations ranged only from about 0.30 to 0.35 ft^3/s. Therefore, use of the regression equation still provides a reasonable estimate of stream discharge at 30-percent flow duration.

The regression lines relating stream discharge to percentage of stratified drift for percentages of time that discharge is equaled or exceeded are shown in figures 13 and 14. Comparison of the curves in figure 14 indicate that stream discharge per square mile from areas covered mostly by till is greater than that from areas covered mostly by stratified drift during high flow (less than about 40-percent flow duration). As indicated by the crossover point in figure 14, this relationship is reversed during low flows (flows greater than about 40-percent flow duration).

An example of how figure 13 is used is given below. The rate of stream discharge at a site with a drainage area covered by 60 percent stratified drift will equal or exceed 34.5 $(ft^3/s)/mi^2$, for during 0.01 percent of the time; 1.33 $(ft^3/s)/mi^2$, for 50 percent of the time; 0.38 $(ft^3/s)/mi^2$, for 80 percent of the time; and 0.03 $(ft^3/s)/mi^2$, for 99.9 per-

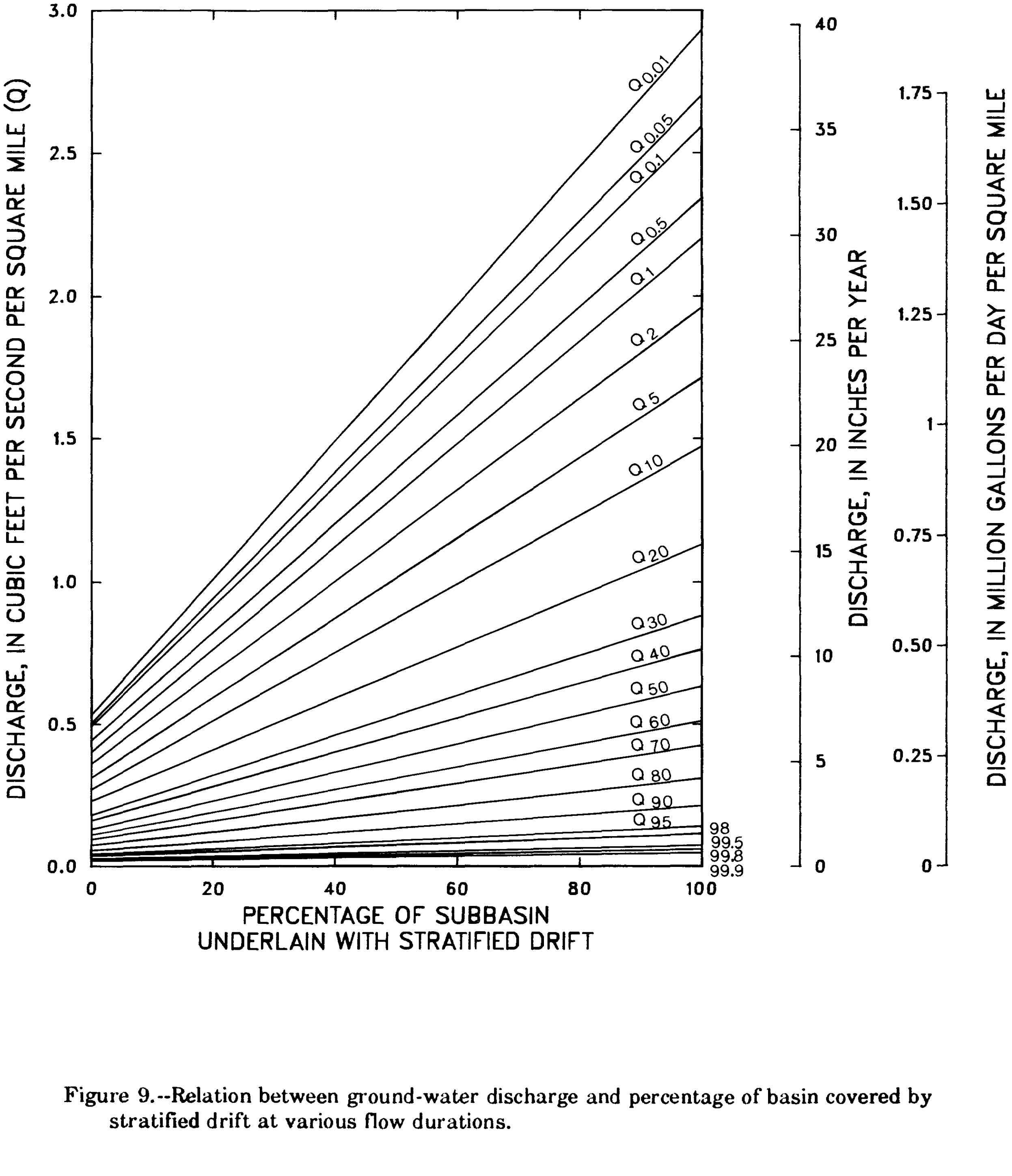
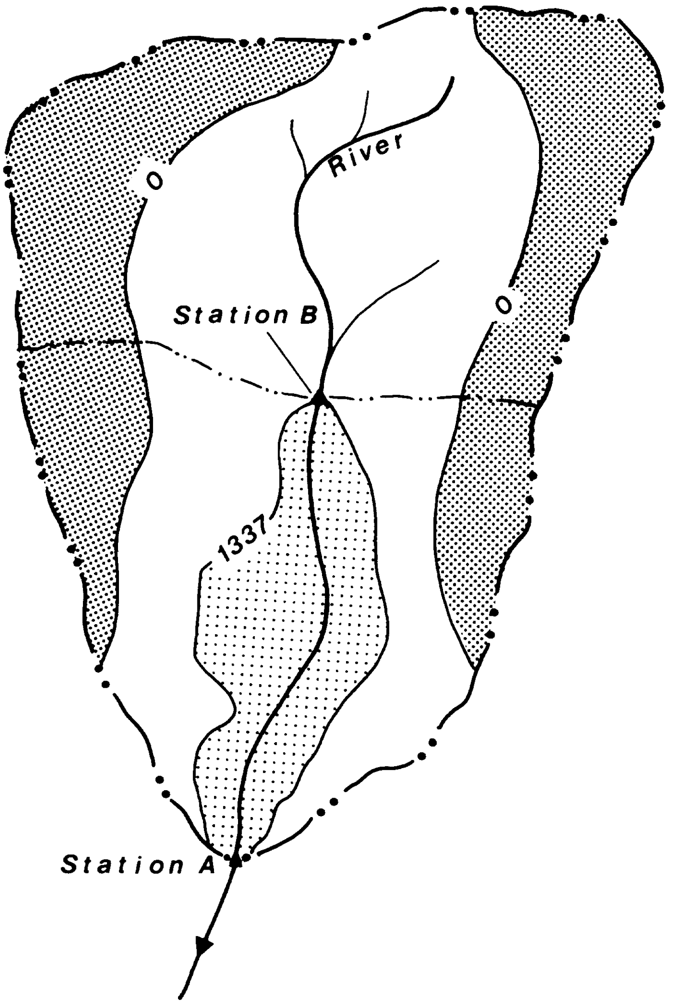


Figure 9.--Relation between ground-water discharge and percentage of basin covered by stratified drift at various flow durations.



EXPLANATION

TILL

STRATIFIED DRIFT--Shows area with transmissivity equal to or less than 1337 feet squared per day

STRATIFIED-DRIFT AQUIFER -- Shows area with transmissivity greater than 1337 feet squared per day

—1337— LINE OF EQUAL TRANSMISSIVITY, IN FEET SQUARED PER DAY

—0— LINE OF ZERO TRANSMISSIVITY

—• •— DRAINAGE BASIN DIVIDE

—· ·— DRAINAGE SUBBASIN DIVIDE

▲ STREAMFLOW GAGING STATION

Figure 10.--Hypothetical basin showing drainage areas contributing to ground-water and surface-water discharge.

Table 2.–*Estimated rates of natural ground-water discharge to streams from the 26 stratified-drift aquifers*

Aquifer system and aquifer name	Approximate contributing drainage area, in square miles	Approximate percentage of stratified drift covering basin	Estimated ground-water discharge that is equaled or exceeded at indicated percentage of the time, in cubic feet per second									
			Percentage of time									
			50	60	70	80	90	95	98	99.5	99.8	99.9
Canoe River aquifer system												
Upper Canoe River	2.22	36.5	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.1	0.08	0.07
Middle Canoe River	12.8	68.0	6.0	4.9	4.1	3.0	2.1	1.4	1.2	.8	.6	.5
Mulberry Brook	2.04	60.0	.9	.7	.6	.4	.3	.2	.2	.1	.09	.08
Lower Canoe River	11.4	82.9	6.2	5.0	4.2	3.1	2.1	1.4	1.2	.8	.6	.5
Hockomock River aquifer system												
Upper Queset Brook	2.04	35.0	.6	.5	.4	.3	.2	.2	.1	.09	.07	.06
Lower Queset Brook	2.10	47.7	.8	.6	.5	.4	.3	.2	.2	.1	.09	.07
Upper Hockomock River	1.76	75.0	.9	.7	.6	.4	.3	.2	.2	.1	.09	.08
Rumford River aquifer system												
Upper Rumford River	6.04	58.4	2.6	2.1	1.7	1.3	.9	.6	.5	.3	.3	.2
Middle Rumford River	2.28	73.7	1.1	.9	.8	.6	.4	.3	.2	.1	.1	.1
Salisbury River aquifer system												
Trout Brook	3.63	34.1	1.1	.9	.8	.6	.4	.3	.2	.2	.1	.1
Salisbury Plain River in Brockton	4.36	54.1	1.8	1.4	1.2	.9	.6	.4	.3	.2	.2	.2
Salisbury Plain River	7.43	69.0	3.5	2.9	2.4	1.8	1.2	.8	.7	.5	.4	.3
Satucket River aquifer system												
Upper Shumatuscacant River	3.60	30.8	1.0	.8	.7	.5	.4	.3	.2	.2	.1	.1
Lower Shumatuscacant River	4.49	26.5	1.2	1.0	.8	.6	.4	.3	.3	.2	.2	.1
Satucket River	1.09	92.0	.6	.5	.4	.3	.2	.2	.1	.08	.06	.05
Wading River aquifer system												
Upper Wading River	2.69	37.2	.8	.7	.6	.4	.3	.2	.2	.1	.1	.08
Aquifer north of Lake Mirimichi	5.84	58.9	2.5	2.0	1.7	1.3	.9	.6	.5	.3	.3	.2
Hawthorne Brook	5.33	44.8	1.9	1.5	1.3	1.0	.7	.5	.4	.3	.2	.2
Middle Wading River	5.22	71.0	2.5	2.1	1.7	1.3	.9	.6	.5	.3	.3	.2
Hodges Brook	3.62	52.8	1.4	1.2	1.0	.7	.5	.3	.3	.2	.2	.1
Other aquifers												
Carver Pond-South Brook	4.78	79.1	2.5	2.0	1.7	1.3	.9	.6	.5	.3	.3	.2
Little Cedar Swamp	3.79	70.3	1.8	1.5	1.2	.9	.6	.4	.4	.2	.2	.2
Lower Matfield-Taunton River	7.50	77.5	3.9	3.2	2.6	2.0	1.3	.9	.7	.5	.4	.3
Lower West Meadow Brook	3.43	58.6	1.4	1.2	1.0	.7	.5	.4	.3	.2	.2	.1
Meadow Brook	3.39	71.1	1.6	1.3	1.1	.8	.6	.4	.3	.2	.2	.1
Pine Swamp Brook	2.70	99.9	1.7	1.4	1.2	.9	.6	.4	.3	.2	.2	.1

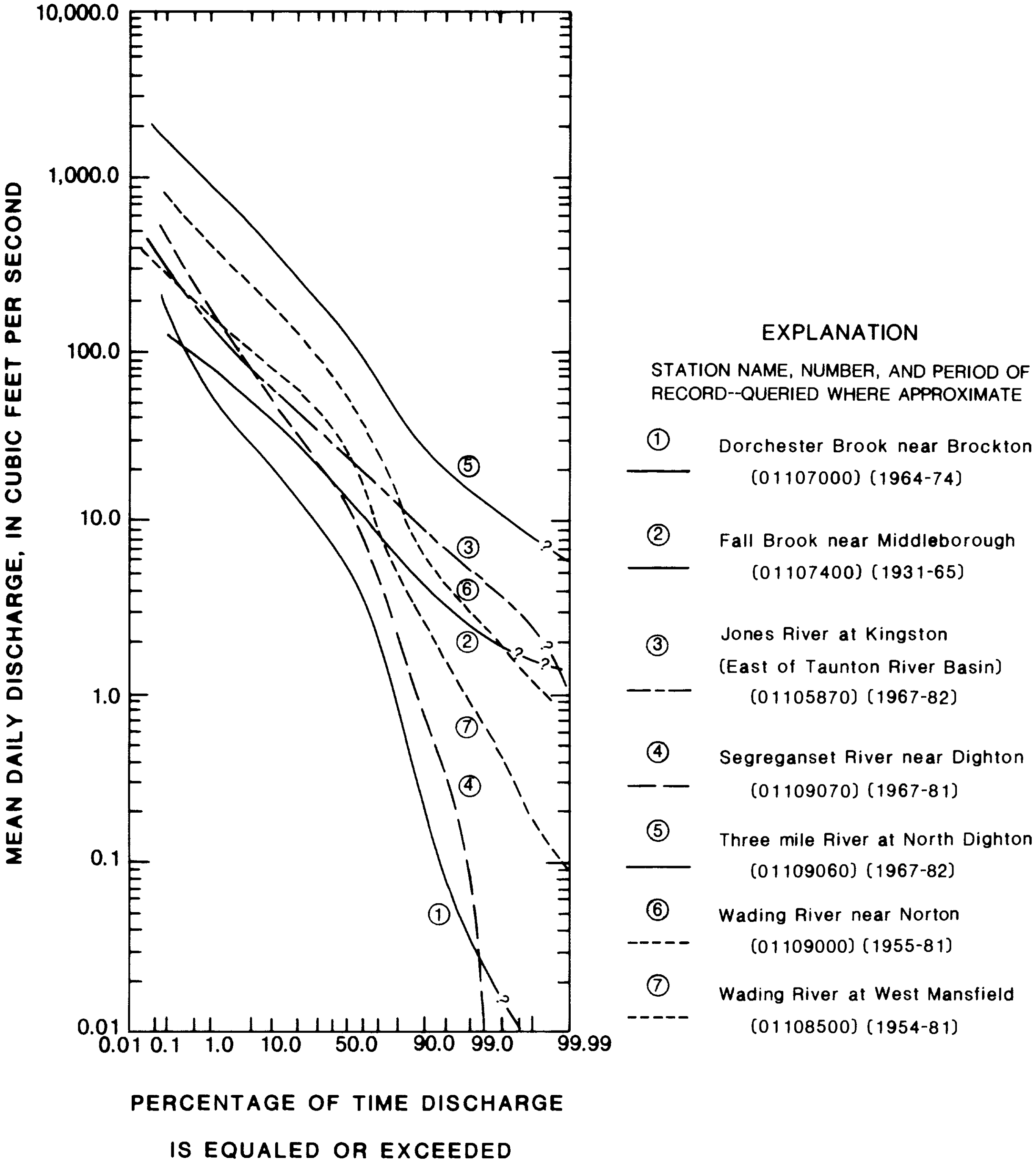


Figure 11.--Flow-duration curves at seven gaging stations.

Table 3.--*Stream discharge at seven gaging stations*

[A dash indicates not determined.]

Station number and name[1] and duration of record	Drainage area, in square miles	Percentage of stratified drift[2]	Average annual flow, in cubic feet per second per square mile	Stream discharge that is equaled or exceeded at indicated percentage of time, in cubic feet per second per square mile				
				Percentage of time				
				0.01	0.05	0.1	0.5	1
01107000. Dorchester Brook near Brockton (1964-74)	4.67	19.0	1.8	--	--	22.5	13.3	10.5
01107400. Fall Brook near Middleborough (adjusted to 1931-65)	9.34	67.0	--	--	--	12.8	9.4	7.9
01105870. Jones River at Kingston (1967-82)	15.8	92.4	1.9	26.6	20.9	18.4	10.4	8.2
01109070. Segregansett River near Dighton (1967-81)	10.6	12.0	2.1	75.5	49.0	40.6	22.6	16.0
01109060. Threemile River at North Dighton (1967-82)	83.3	62.0	2.0	--	20.3	17.9	12.0	10.1
01108500. Wading River at Mansfield (1954-81)	19.5	52.5	1.6	27.7	17.9	13.8	9.1	7.7
01109000. Wading River at Norton (1955-81)	43.3	56.3	1.7	--	19.9	16.2	10.4	8.8

cent of the time. If the basin above this site has a drainage area of 10 mi², then stream discharge at the site will equal or exceed 345 ft³/s for 0.1 percent of the time; discharge will equal or exceed 13.3 ft³/s for 50 percent of the time; discharge will equal or exceed 3.8 ft³/s 80 percent of the time; and discharge will equal or exceed 0.3 ft³/s 99.9 percent of the time.

Estimated rates of stream discharge at the downstream end of each of the 26 aquifers were calculated using the relation between stream discharge per square mile and percentage of stratified drift covering a basin (fig. 13). The transmissivity map (plate 1) was used to determine the percentage of each basin covered by stratified drift above the downstream end of each of the 26 aquifers. The calculated rates that are equaled or exceeded 50 to 99.9 percent of the time are listed in table 4.

Stream discharge at the downstream end of an aquifer should equal or exceed the rate of ground-water discharge from the aquifer to the stream at any specific flow duration. However, in several cases, the calculated stream discharge at the downstream end of an aquifer located in the headwaters of the basin using figure 13 was less than the calculated rate of ground-water discharge to the aquifer using figure 9. This inconsistency occurs because the relation between stream discharge and percentage of stratified drift and ground-water discharge and percentage of stratified drift were developed using limited data. This inconsistency occurred most frequently at high flow durations when virtually all the stream discharge is baseflow. In these cases, stream discharge was set equal to the rate of ground-water discharge calculated using figure 9.

Stream discharge available for infiltration at a given flow duration is not equal to the discharge given in table 4 because the value of stream discharge given in the table includes ground-water

Table 3.--*Stream discharge at seven gaging stations* (continued)

Stream discharge that is equaled or exceeded at indicated percentage of the time, in cubic feet per second per square mile (continued)

Percentage of time (continued)														
5	10	20	30	40	50	60	70	80	90	95	98	99.5	99.8	99.9
5.8	4.1	2.7	2.0	1.6	1.2	0.77	0.36	0.17	0.04	0.02	0.10	0.008	0.002	0.001
4.8	3.7	2.8	2.2	1.8	1.5	1.2	.86	.54	.43	.32	.24	.19	.18	.17
5.0	3.8	2.7	2.2	1.8	1.4	1.3	1.0	.76	.54	.48	.34	.25	.22	.15
6.9	4.8	3.1	2.3	1.6	1.2	.79	.39	.18	.06	.03	.008	--	--	--
6.0	4.5	3.1	2.3	1.8	1.4	1.1	.72	.46	.30	.22	.16	.12	.11	.10
5.0	4.0	2.9	2.3	1.7	1.1	.69	.39	.23	.12	.07	.05	.02	.01	.008
5.5	4.2	2.8	2.1	1.6	1.2	.81	.51	.28	.14	.10	.07	.04	.04	.03

[1] See figure 4.
[2] Determined using plate 1.

discharge to each aquifer and discharge that must be maintained in the stream. Therefore, the rates in table 4 were adjusted to account for these rates. The first adjustment consisted of subtracting the rate of ground-water discharge from each aquifer (table 2).

The second adjustment was made by subtracting the value of stream discharge at either 99.5 or 95 percent exceedance from all rates of stream discharge given in table 4. The effect of this adjustment is to limit stream discharge available for infiltration to that discharge which is in excess of flow at either 99.5- or 95-percent exceedance. Summarizing the data, stream discharge available for infiltration for each of the 26 aquifers' areas, after adjustment for both the rates of ground-water discharge to streams and the minimum stream discharge that might be maintained in the stream, are given in tables 5 and 6.

YIELDS OF THE STRATIFIED-DRIFT AQUIFERS

Methods of Study

During severe drought, ground-water discharge from aquifers is low, streamflow is at a minimum, and there is little surface water stored in wetlands. Consequently, water pumped from most aquifers in New England is derived largely from storage in the aquifers. During more normal climatic conditions, water pumped from an aquifer is derived from storage, intercepted ground-water discharge, and induced infiltration from streams. To account for both drought and normal conditions, two sets of yield estimates were made for each of the 26 stratified-drift aquifers. "Short-term"

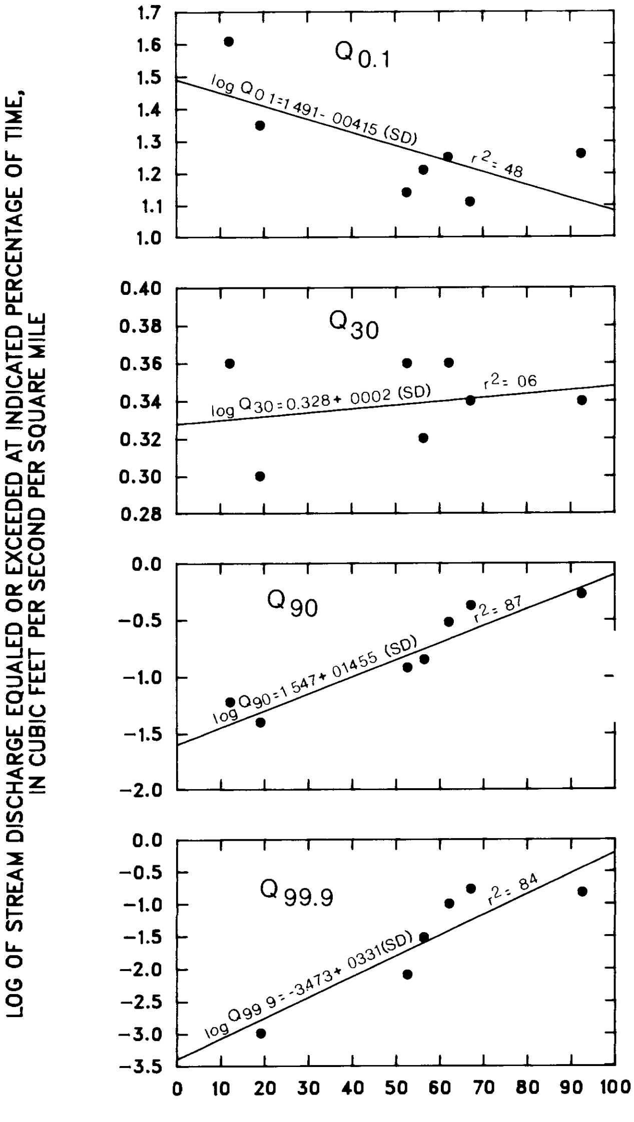


Figure 12.--Regressions of log of stream discharge to percentage of basin covered by stratified drift.

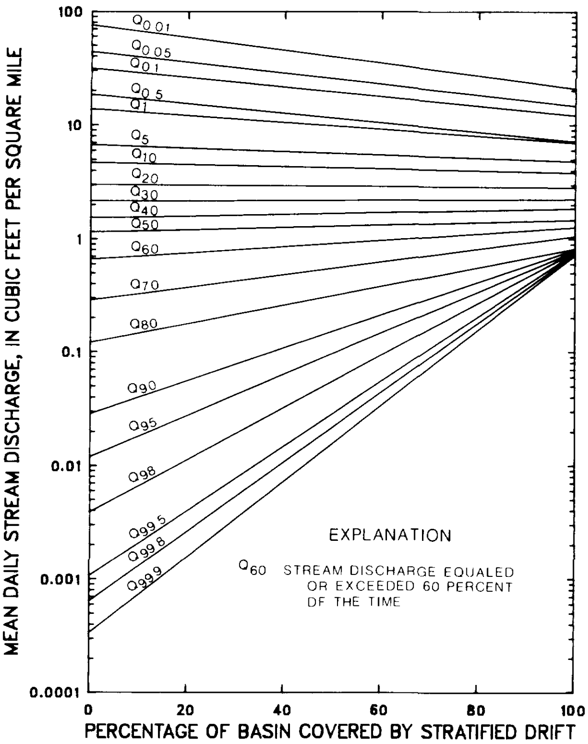


Figure 13.--Relation between stream discharge and percentage of the basin covered by stratified drift for various flow durations.

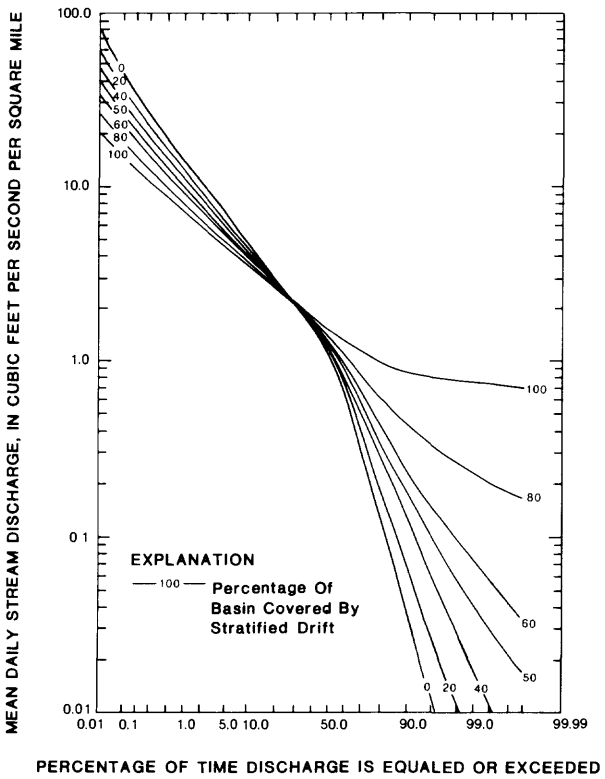


Figure 14.--Relation between stream discharge and percentage of time discharge is equaled or exceeded for various percentages of basin covered by stratified drift.

Table 4.--*Estimated stream discharge at downstream ends of the 26 aquifers*

Aquifer system and aquifer name	Approximate drainage area upstream of downstream end of aquifer, in square miles	Approximate percentage of stratified drift covering drainage area	Estimated stream discharge that is equaled or exceeded at indicated percentage of the time, in cubic feet per second — Percentage of time: 50	60	70	80	90	95	98	99.5	99.8	99.9
Canoe River aquifer system												
Upper Canoe River	2.22	36.5	2.8	1.9	1.0	0.5	0.3	0.2	0.06	0.03	0.02	0.01
Middle Canoe River	15.0	63.3	20.1	14.9	9.8	6.1	3.5	2.5	1.7	1.0	.8	.6
Mulberry Brook	10.4	44.6	13.3	9.2	5.3	2.9	1.3	.8	.4	.2	.2	.1
Lower Canoe River	41.2	64.0	55.2	41.2	27.2	16.9	10.0	7.1	4.8	2.9	2.4	1.9
Hockomock River aquifer system												
Upper Queset Brook	2.04	35.0	2.5	1.7	.9	.5	.2	.1	.05	.02	.01	.01
Lower Queset Brook	9.57	32.1	11.8	7.8	4.2	2.1	.8	.4	.2	.08	.06	.04
Upper Hockomock River	20.4	36.0	25.5	17.0	9.3	4.9	1.9	1.1	.5	.2	.2	.1
Rumford River aquifer system												
Upper Rumford River	6.04	58.4	8.0	5.8	3.7	2.2	1.2	.8	.5	.3	.2	.1
Middle Rumford River	13.1	58.0	17.3	12.6	8.0	4.8	2.6	1.8	1.1	.6	.5	.4
Salisbury River aquifer system												
Trout Brook	3.63	34.1	4.5	2.9	1.6	.8	.4	.2	.1	.04	.03	.02
Salisbury Plain River in Brockton	19.2	30.9	23.7	15.4	8.2	4.2	1.5	.8	.4	.2	.1	.07
Salisbury Plain River	22.3	39.1	28.0	18.9	10.6	5.7	2.4	1.4	.7	.3	.2	.1
Satucket River aquifer system												
Upper Shumatuscacant River	3.60	30.8	4.4	3.0	1.5	.8	.4	.2	.07	.03	.02	.01
Lower Shumatuscacant River	8.09	28.4	9.9	6.4	3.4	1.7	.6	.3	.1	.06	.04	.02
Satucket River	32.2	64.0	43.2	39.2	21.3	13.2	7.8	5.6	3.7	2.3	1.9	1.5
Wading River aquifer system												
Upper Wading River	2.69	37.2	3.4	2.2	1.2	.7	.4	.2	.08	.03	.02	.01
Aquifer north of Lake Mirimichi	5.84	58.9	7.7	5.6	3.6	2.2	1.2	.8	.5	.3	.2	.2
Hawthorne Brook	5.33	44.8	6.8	4.7	2.7	1.5	.7	.4	.2	.1	.08	.06
Middle Wading River	21.3	53.5	27.8	19.9	12.2	7.1	3.6	2.4	1.4	.8	.6	.4
Hodges Brook	3.62	52.8	4.7	3.4	2.1	1.2	.6	.4	.2	.1	.1	.07
Other aquifers												
Carver Pond-South Brook	2.29	90.0	3.3	2.7	2.1	1.6	1.3	1.2	1.0	.9	.8	.8
Little Cedar Swamp	7.33	44.6	9.4	6.4	3.8	2.1	.9	.6	.3	.2	.1	.08
Lower Matfield-Taunton River	120	47.0	154	107	63.4	35.5	16.4	10.2	5.6	2.8	2.1	1.5
Lower West Meadow Brook	55.8	49.0	72.0	50.5	30.3	17.2	8.2	5.2	2.9	1.5	1.1	.8
Meadow Brook	7.70	36.8	9.6	6.4	3.6	1.9	.8	.4	.2	.1	.07	.04
Pine Swamp Brook	2.20	99.9	3.2	2.8	2.3	1.8	1.8	1.7	1.7	1.7	1.6	1.6

Table 5.--*Stream discharge available for induced infiltration to the 26 aquifers assuming minimum streamflow maintained is the discharge equaled or exceeded 99.5 percent of the time*

Aquifer system and aquifer name	Available stream discharge that is equaled or exceeded at indicated percentage of the time, in cubic feet per second							
	Percentage of time							
	50	60	70	80	90	95	98	99.5
Canoe River aquifer system								
Upper Canoe River	2.1	1.3	0.5	0.1	0.0	0.0	0.0	0.0
Middle Canoe River	13.1	9.0	4.7	2.1	.4	.1	.0	.0
Mulberry Brook	12.2	8.3	4.5	2.3	.8	.4	.0	.0
Lower Canoe River	46.1	33.3	20.1	10.9	5.0	2.8	.7	.0
Hockomock River aquifer system								
Upper Queset Brook	1.9	1.2	.5	.2	.0	.0	.0	.0
Lower Queset Brook	10.9	7.1	3.6	1.6	.4	.1	.0	.0
Upper Hockomock River	24.4	16.1	8.5	4.3	1.4	.7	.1	.0
Rumford River aquifer system								
Upper Rumford River	5.1	3.4	1.7	.6	.0	.0	.0	.0
Middle Rumford River	15.6	11.1	6.6	3.6	1.6	.9	.3	.0
Salisbury River aquifer system								
Trout Brook	3.4	2.0	.8	.2	.0	.0	.0	.0
Salisbury Plain River in Brockton	21.7	13.8	6.8	3.1	.7	.2	.0	.0
Salisbury Plain River	24.2	15.7	7.9	3.6	.9	.3	.0	.0
Satucket River aquifer system								
Upper Shumatuscacant River	3.4	2.2	.8	.3	.0	.0	.0	.0
Lower Shumatuscacant River	8.6	5.3	2.5	1.0	.1	.0	.0	.0
Satucket River	40.3	36.4	18.6	10.6	5.3	3.1	1.3	.0
Wading River aquifer system								
Upper Wading River	2.5	1.4	.5	.2	.0	.0	.0	.0
Aquifer north of Lake Mirimichi	4.9	3.3	1.6	.6	.0	.0	.0	.0
Hawthorne Brook	4.8	3.1	1.3	.4	.0	.0	.0	.0
Middle Wading River	24.5	17.0	9.7	5.0	1.9	1.0	.1	.0
Hodges Brook	3.2	2.1	1.0	.4	.0	.0	.0	.0
Other aquifers								
Carver Pond-South Brook	.0	.0	.0	.0	.0	.0	.0	.0
Little Cedar Swamp	7.4	4.7	2.4	1.0	.1	.0	.0	.0
Lower Matfield-Taunton River	147	101	58.0	30.7	12.3	6.5	2.1	.0
Lower West Meadow Brook	69.1	47.8	27.8	15.0	6.2	3.3	1.1	.0
Meadow Brook	7.9	5.0	2.4	1.0	.1	.0	.0	.0
Pine Swamp Brook	.0	.0	.0	.0	.0	.0	.0	.0

Table 6.--*Stream discharge available for induced infiltration to the 26 aquifers assuming minimum streamflow maintained is the discharge equaled or exceeded 95 percent of the time*

Aquifer system and aquifer name	Available stream discharge that is equaled or exceeded at indicated percentage of the time, in cubic feet per second					
	Percentage of time					
	50	60	70	80	90	95
Canoe River aquifer system						
Upper Canoe River	2.0	1.2	0.4	0.0	0.0	0.0
Middle Canoe River	11.6	7.5	3.2	.6	.0	.0
Mulberry Brook	11.6	7.7	3.9	1.7	.2	.0
Lower Canoe River	41.9	29.1	15.9	6.7	.8	.0
Hockomock River aquifer system						
Upper Queset Brook	1.8	1.1	.4	.1	.0	.0
Lower Queset Brook	10.6	6.8	3.3	1.3	.1	.0
Upper Hockomock River	23.5	15.2	7.6	3.4	.6	.0
Rumford River aquifer system						
Upper Rumford River	4.6	2.9	1.2	.1	.0	.0
Middle Rumford River	14.4	9.9	5.4	2.4	.4	.0
Salisbury River aquifer system						
Trout Brook	3.2	1.8	.6	.0	.0	.0
Salisbury Plain River in Brockton	21.1	13.2	6.2	2.5	.1	.0
Salisbury Plain River	23.1	14.6	6.8	2.5	.0	.0
Satucket River aquifer system						
Upper Shumatuscacant River	3.2	2.0	.6	.1	.0	.0
Lower Shumatuscacant River	8.4	5.1	2.2	.8	.0	.0
Satucket River	37.0	33.1	15.3	7.3	2.0	.0
Wading River aquifer system						
Upper Wading River	2.4	1.3	.4	.1	.0	.0
Aquifer north of Lake Mirimichi	4.4	2.8	1.1	.1	.0	.0
Hawthorne Brook	4.5	2.8	1.0	.1	.0	.0
Middle Wading River	22.9	15.4	8.1	3.4	.3	.0
Hodges Brook	2.9	1.8	.7	.1	.0	.0
Other aquifers						
Carver Pond-South Brook	.0	.0	.0	.0	.0	.0
Little Cedar Swamp	7.0	4.3	2.0	.6	.0	.0
Lower Matfield-Taunton River	140	93.6	50.6	23.3	4.9	.0
Lower West Meadow Brook	65.4	44.1	24.1	11.3	2.5	.0
Meadow Brook	7.6	4.7	2.1	.7	.0	.0
Pine Swamp Brook	.0	.0	.0	.0	.0	.0

aquifer yields during drought conditions were determined by considering only water from storage. "Long-term" aquifer yields during normal climatic conditions were determined by considering water available from storage, intercepted ground-water discharge, and induced infiltration.

For the purposes of this study, aquifer yield from storage is defined as the average rate at which an aquifer will yield water from storage given a specified pumping period and a specified drawdown in the aquifer at the end of the pumping period. Aquifer yield from intercepted ground-water discharge, induced infiltration from streams, and storage is defined as the yield equaled or exceeded at a specified percentage of the time from these sources during a 180-day pumping period.

The short- and long-term yields of the aquifers were calculated using ground-water-flow models and the data on ground- and surface-water discharge given in tables 2, 5, and 6. Short-term yields are expressed as single values for several selected pumping periods. The long-term yields are determined according to an approach which utilizes streamflow-duration data; aquifer yields are expressed in terms of percentage of time yield is equaled or exceeded under specified streamflow conditions.

The short- and long-term estimates of aquifer yield described in this section were made assuming that the aquifers were undeveloped. In a later section of the report (Effect of alternative ground-water development plans), the effects of present aquifer development and other alternatives for future aquifer development are described.

Use of Ground-Water-Flow Models

In past ground-water availability studies in southeastern New England (Allen and others, 1966; Rosenshein and others, 1968; Johnston and Dickerman, 1974; Gonthier and others, 1974), yields of aquifers were estimated using analytical (image well) models that were designed to determine rates of combined pumping from wells distributed throughout each aquifer for specified maximum drawdown in each well. In this study, a finite-difference model (McDonald and Harbaugh, 1984) was used in place of an analytical model to aid the determination of aquifer yield, in order to simulate (1) areal variation in saturated thickness and hydraulic conductivity of each aquifer; (2) the actual locations of streams overlying each aquifer and quantify stream characteristics along reaches; and (3) leakage from streams that do not fully penetrate the aquifers.

Figure 15 illustrates the typical hydrogeologic characteristics of a stratified-drift aquifer in the Taunton River basin and the conceptual model of the aquifer used in this study to construct ground-water-flow models. Under typical conditions, ground water flows horizontally and vertically in the aquifers, generally from adjacent uplands and the sides of the valley toward streams, ponds, lakes, and wetlands in the center of the valley. When pumping occurs (fig. 15a), some water that would normally discharge to these surface-water bodies is diverted to pumping wells, and some water also may be induced from nearby surface-water bodies. The conceptual ground-water model was designed to simplify but represent the important hydrogeological characteristics of the ground-water flow in a stratified-drift aquifer (fig. 15b). The conceptual model is based on the following assumptions about the ground-water-flow system:

1. The stratified-drift aquifers are homogeneous and isotropic.

2. Ground-water flow is horizontal.

3. There is no ground-water flow to or from the till and bedrock. No-flow boundaries form the perimeter of each model.

4. Each well field is simulated as a group of interconnected, fully screened, small-diameter wells that are distributed over a large area. Simulated drawdown occurs equally over the entire area of the well field.

5. Areal recharge is not simulated in the models. The water table in each aquifer was simulated as flat prior to pumping.

6. Induced infiltration from streams occurs through a leaky streambed. Streambed thickness is constant, but the vertical hydraulic conductivity of the streambed varies. Stream width also varies along the stream reach. Stage in the stream is set at a constant value throughout the entire stream reach in each model, and does not change with time.

7. Specific yield is constant throughout each aquifer.

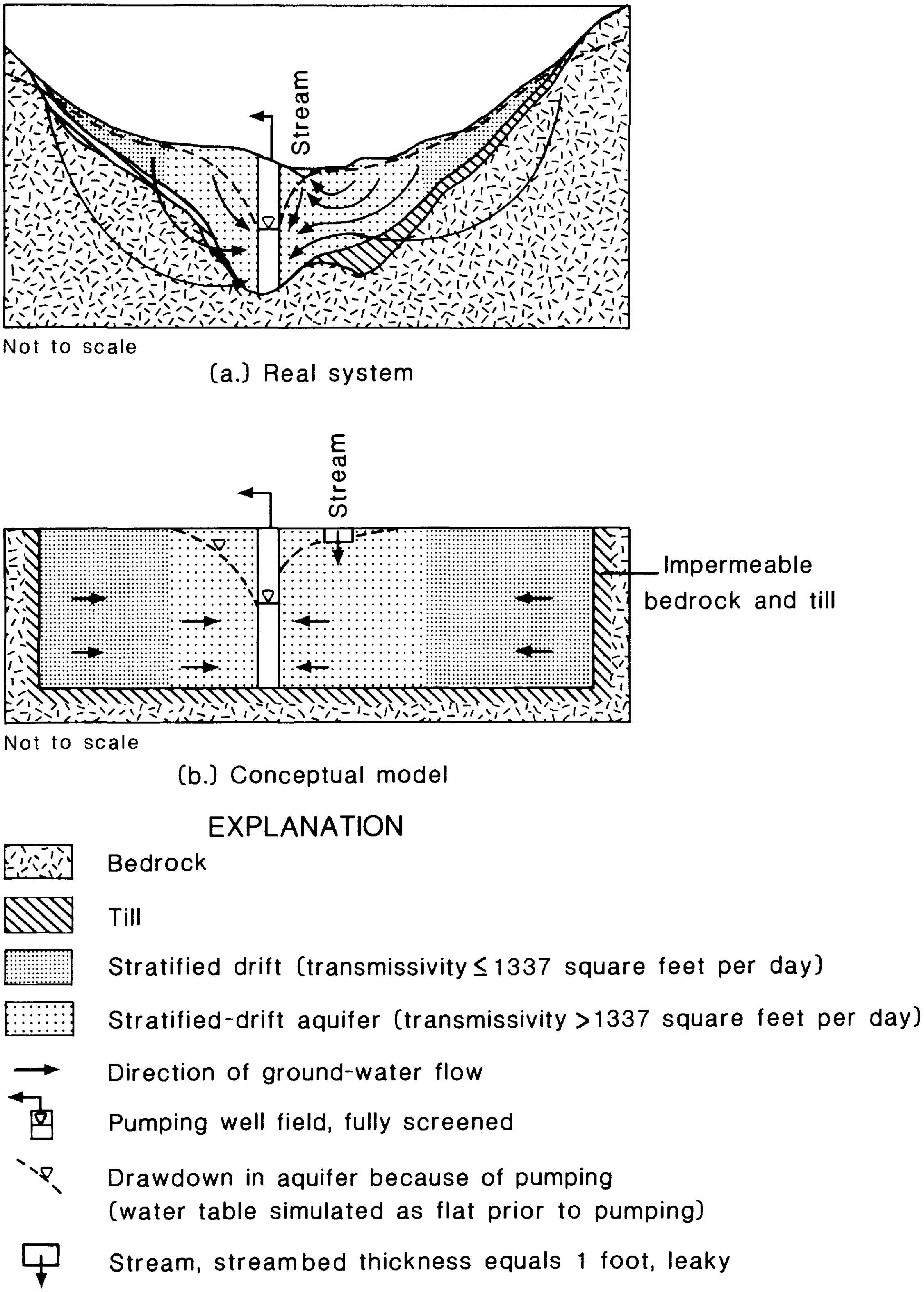


Figure 15.--Representative hydrogeologic section of a stratified-drift aquifer and conceptual model.

Thus, by design, each of the two-dimensional models developed for each aquifer represents a tool used to estimate an aquifer yield with nearly as many limiting assumptions on its use as on an analytical model, rather than a fully calibrated and verified, predictive numerical model. Additional information concerning model construction is available on file at the Survey Office in Boston, Mass.

Model Input

Hydrologic properties of each aquifer for input to the model were determined as follows: Aquifer saturated thickness and hydraulic conductivity were determined from the data used to prepare plate 1, logs of test drilling collected during the study, and data published in Williams and Willey (1967, 1970, and 1973), Williams (1968), Williams and others (1973), Old Colony Planning Council (1977), and consulting reports. Stream width and depth were determined from field investigation. Streambed hydraulic properties were determined from field investigations of streambed lithology and from available information on the relation between lithology and vertical hydraulic conductivity. Lithologic descriptions of streambed material were determined at 28 sites in the basin. At almost all these sites, streambed lithology suggests that the stream flows directly on aquifer material, which consists of sand and mixed sand and gravel. Consequently, with few exceptions, vertical hydraulic conductivity of streambed material was assigned a value of 5 ft/d in the models. A vertical conductivity of 5 ft/d is a reasonable estimate of the conductivity of streambed material composed of sand and mixed sand and gravel in New England (Rosenshein and others, 1968; Gonthier and others, 1974; Haeni, 1978).

Specific yield of aquifer material was not measured in this study. Olimpio and de Lima (1984), in a model study of the Mattapoisett River Valley aquifer located between this study area and Buzzards Bay, found that a value of specific yield of 0.30 most closely represents the lithology of aquifer material where clean, medium grained sand occurs. However, they noted that the value of 0.30 is high for other areas which contain coarser and finer grained sediments. Johnson (1967) summarized results of specific yield determinations of sediments from many studies. He found that the average specific yield of fine sand was 0.21, the average specific yield of coarse sand was 0.27, and the average specific yield of coarse gravel was 0.22. In the models, specific yield of all aquifer material was set equal to 0.20.

Short-Term Yields from Storage

Yields of the 26 aquifers from storage were determined using the ground-water-flow models for pumping periods of 30, 60, 180, and 365 days. Well fields were located throughout areas of highest transmissivity, and simultaneous pumping of all the well fields was simulated. The rate of pumping from each well field was adjusted so that the aquifer beneath each well field was desaturated by 50 percent at the end of the specified pumping period. The specific yields of the aquifers were assigned a value of 0.20. The short-term yield from storage for each aquifer then was calculated as the sum of the rates of pumping from all the well fields simulated in the aquifer.

Results of these simulations are shown in table 7. For a 30-day pumping period, yields range from 2.6 ft^3/s (1 ft^3/s = 0.646 Mgal/d) from the Lower West Meadow Brook aquifer to 15.0 ft^3/s from the Lower Canoe River aquifer. Fourteen of the 26 aquifers have yields that are less than 5 ft^3/s, seven have yields between five and 10 ft^3/s, and 5 have yields between 10 and 15 ft^3/s. For a 180-day pumping period, yields range from 1.6 ft^3/s from the Upper Canoe and Upper Wading River aquifers to 10.5 ft^3/s from the Lower Canoe River aquifer. Nineteen of the 26 aquifers have yields that are less than 5 ft^3/s, 6 have yields between 5 and 10 ft^3/s, and one has a yield of 10.5 ft^3/s.

Long-Term Yields from Ground-Water Discharge, Induced Infiltration, and Storage

The long-term yield of each aquifer was determined by summing rates of water derived from storage, infiltration, and ground-water discharge from the aquifer (table 2). Rates of actual induced infiltration were unavailable for this study. Therefore, the models used to calculate short-term aquifer yield from storage were modified to simulate streams, and the model-calculated average rate of infiltration occurring over a 180-day pumping period was used to derive the maximum rate of induced infiltration. The actual induced infiltration rate then was determined from the smaller of either the calculated maximum rate

Table 7.–*Aquifer yields only from storage from the 26 aquifers*

Aquifer system and aquifer name	Aquifer yield, in cubic feet per second[1], for indicated pumping period, in days			
	Pumping period			
	30	60	180	365
Canoe River aquifer system				
Upper Canoe River	3.4	2.7	1.6	1.0
Middle Canoe River	10.1	9.2	7.2	5.7
Mulberry Brook	3.8	3.2	2.2	1.6
Lower Canoe River	15.0	13.7	10.5	8.3
Hockomock River aquifer system				
Upper Queset Brook	3.4	2.8	1.8	1.2
Lower Queset Brook	3.9	3.3	2.2	1.5
Upper Hocomock River	4.6	4.1	3.0	2.2
Rumford River aquifer system				
Upper Rumford River	5.7	5.0	3.5	2.6
Middle Rumford River	3.7	3.1	2.0	1.4
Salisbury River aquifer system				
Trout Brook	7.1	5.6	3.4	2.2
Salisbury Plain River in Brockton	3.7	3.4	2.7	2.2
Salisbury Plain River	9.8	8.8	6.6	5.1
Satucket River aquifer system				
Upper Shumatuscacant River	3.4	2.8	1.8	1.8
Lower Shumatuscacant River	4.6	3.6	2.3	1.5
Satucket River	3.0	2.7	2.1	1.7
Wading River aquifer system				
Upper Wading River	3.6	2.7	1.6	1.1
Aquifer north of Lake Mirimichi	5.3	4.3	2.9	2.0
Hawthorne Brook	2.8	2.5	1.8	1.3
Middle Wading River	11.2	9.2	6.1	4.3
Hodges Brook	3.5	2.9	2.0	1.5
Other aquifers				
Carver Pond-South Brook	10.7	9.4	6.9	5.3
Little Cedar Swamp	5.8	5.2	4.1	3.2
Lower Matfield-Taunton River	13.4	12.1	8.8	6.7
Lower West Meadow Brook	2.6	2.4	1.9	1.5
Meadow Brook	5.4	4.8	3.4	2.6
Pine Swamp Brook	9.0	8.0	6.0	4.6

[1] 1 ft^3/s = 0.646 Mgal/d

from the model or the rate of streamflow available for infiltration.

Simulated Yields from Induced Infiltration and Storage

Figure 16 shows results of model simulation of pumping from the Middle Rumford River aquifer, as an example of the use of the ground-water model to estimate maximum rates of infiltration. In this model, the streambed hydraulic conductivity was set equal to 5 ft/d, the duration of simulated pumping periods ranged from 0 to 360 days. The rates of water derived from storage, from induced infiltration from the Rumford River, and the sum of these two rates are those that will result in the Middle Rumford River aquifer being desaturated by 50 percent beneath all simulated well fields. For example, for a pumping period of 180 days, the rate is about 2.8 ft^3/s. Of this total rate, 2.0 ft^3/s is derived from induced infiltration and 0.8 ft^3/s is derived from aquifer storage. Figure 16 also shows that, as the duration of the pumping period increases, the total rate decreases. This relation between increasing duration of the pumping period and decreasing total rate occurs because a finite quantity of water is obtained from storage for any particular pumping rate. In addition, figure 16 shows that the average rate at which water is derived from infiltration increases over about the first 180 days. After 180 days, the average infiltration rate does not change very much. Therefore, the infiltration rate of 2.0 ft^3/s that occurs for a 180-day pumping period was chosen as a reasonable estimate of the maximum rate at which water can be induced to the Middle Rumford River aquifer from overlying streams. Model-derived maximum rates of induced infiltration at 180 days for the 26 aquifers are listed in table 8.

Table 8 also lists the maximum rate of water derived from storage when induced infiltration is simulated. Under real conditions, less water is required from storage when pumping induces infiltration of water from nearby streams. Therefore, the rate at which water is derived from storage depends, in part, on the rate of induced infiltration (fig. 17). If sufficient stream discharge is available, then infiltration can occur at a maximum rate. If stream discharge available for infiltration is less than a maximum rate of infiltration, then pumping from the aquifer must be decreased to a rate that does not cause infiltration to exceed stream discharge.

For the Middle Rumford River aquifer, the rates from infiltration and storage, and the total rate, are 2.0, 0.8, and 2.8 ft^3/s, respectively, for 50 percent desaturation of the aquifer beneath simulated well fields after a 180-day pumping period (fig. 17). These rates are available from the Middle Rumford River aquifer if there is at least 2.0 ft^3/s of excess stream discharge available for infiltration. If available streamflow for infiltration in the Middle Rumford River aquifer equals only 1.0 ft^3/s, pumping must be reduced so that infiltration is limited to 1.0 ft^3/s. If infiltration is limited to a rate of 1.0 ft^3/s, desaturation of the aquifer beneath simulated well fields must be less than 50 percent and water derived from storage must be less than 0.8 ft^3/s. As indicated in figure 17, for a rate of infiltration of 1.0 ft^3/s, aquifer desaturation beneath simulated well fields is equal to about 21 percent and the corresponding rate at which water is derived from storage is about 0.4 ft^3/s.

Using the results of model simulations, a graph, similar to figure 17, of the relation between yields from infiltration and storage and percentage of desaturation of the aquifer beneath well fields, was drawn for each of the 26 aquifers. These curves were used to determine the percentage of desaturation of an aquifer beneath simulated well fields and the corresponding rate at which water is derived from storage when stream discharge available for infiltration was equal to or less than the model-derived maximum rate of infiltration.

Estimated Yields from Ground-Water Discharge, Induced Infiltration, and Storage

Two sets of estimates of long-term aquifer yields for each of the 26 aquifers from intercepted ground-water discharge, induced infiltration, and storage were made. The two sets of estimates were made by limiting water available for infiltration to the rate that is in excess of the stream discharge at flow durations of either 99.5 and 95 percent.

The yield of each aquifer equaled or exceeded at various percentages of the time for each duration was determined by summing rates of ground-water discharge from the aquifer (table 2), actual induced infiltration (the smaller of either the maximum rate of induced infiltration (table 8) or the rate of streamflow available for infiltration (tables 5 or 6), and water derived from storage as

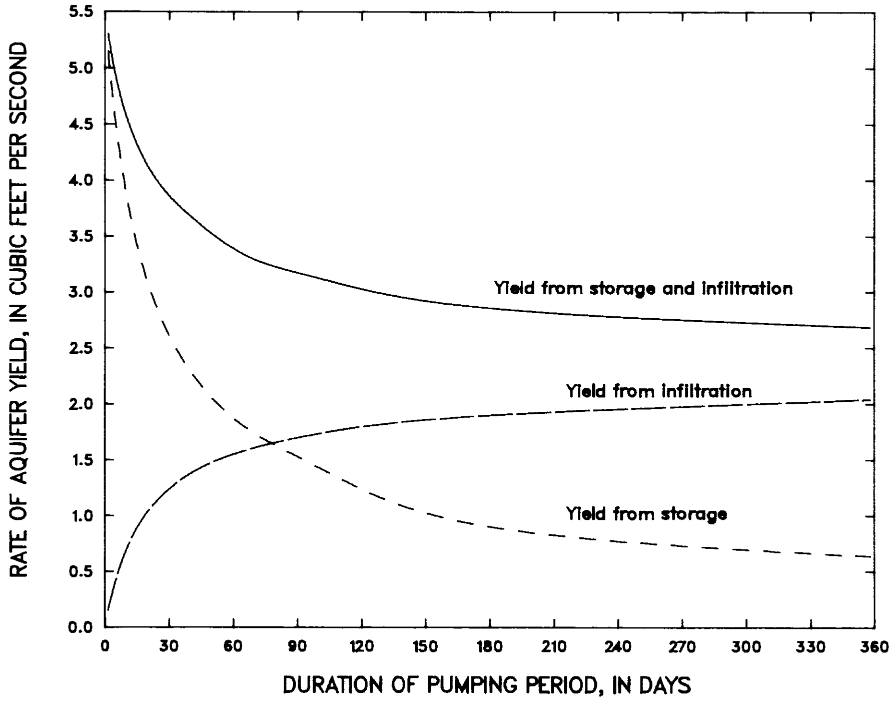


Figure 16.--Relation between sources of yield and duration of pumping period for the Middle Rumford River aquifer.

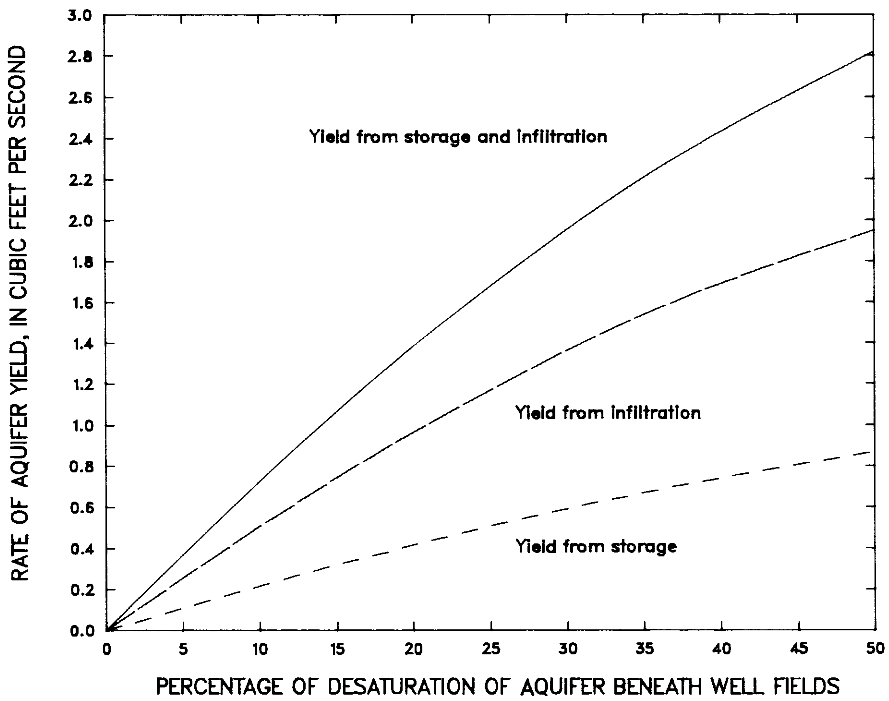


Figure 17--Relation between yield from infiltration, yield from storage, and percentage of desaturation of aquifer beneath well fields, for a 180-day pumping period for the Middle Rumford River aquifer.

Table 8.--*Model-derived maximum rates of water from induced infiltration and storage for the 26 aquifers after a 180-day pumping period*

Aquifer system and aquifer name	Rate, in cubic feet per second		
	Infiltration	Storage	Total rate
Canoe River aquifer system			
Upper Canoe River	0.4	0.9	1.3
Middle Canoe River	4.3	3.6	7.9
Mulberry Brook	2.1	1.1	3.2
Lower Canoe River	6.3	5.5	11.8
Hockomock River aquifer system			
Upper Queset Brook	.5	1.4	1.9
Lower Queset Brook	2.6	.9	3.5
Upper Hocomock River	1.5	1.7	3.2
Rumford River aquifer system			
Upper Rumford River	1.3	2.3	3.6
Middle Rumford River	2.0	.8	2.8
Salisbury River aquifer system			
Trout Brook	2.2	1.9	4.1
Salisbury Plain River in Brockton	1.8	1.4	3.2
Salisbury Plain River	2.7	4.3	7.0
Satucket River aquifer system			
Upper Shumatuscacant River	1.7	.9	2.6
Lower Shumatuscacant River	2.6	.8	3.4
Satucket River	1.3	1.1	2.4
Wading River aquifer system			
Upper Wading River	1.9	.7	2.6
Aquifer north of Lake Mirimichi	.9	1.9	2.8
Hawthorne Brook	1.0	1.0	2.0
Middle Wading River	8.2	2.1	10.3
Hodges Brook	.5	1.4	1.9
Other aquifers			
Carver Pond-South Brook	2.0	5.0	7.0
Little Cedar Swamp	2.6	2.1	4.7
Lower Matfield-Taunton River	6.2	4.4	10.6
Lower West Meadow Brook	.9	1.1	2.0
Meadow Brook	.7	2.5	3.2
Pine Swamp Brook	1.9	4.2	6.1

calculated with consideration of the effect of infiltration (using data similar to those in figure 17).

An example of these calculations is shown in table 9 for the Middle Rumford River aquifer. At the limiting stream discharge of 99.5-percent exceedance, intercepted ground-water discharge, induced infiltration, and water derived from storage must all be equal to zero because all water from these sources is needed to maintain stream discharge at that flow duration. During times when there is no stream discharge available for infiltration, the aquifer yield is equal to the rate of ground-water discharge minus the minimum streamflow to be maintained.

Two sets of calculations similar to those shown in table 9 were made for all 26 aquifers and then graphed as curves of aquifer yield versus percentage of time yield is equaled or exceeded (figs. 18-27). Figures 18-22 illustrate aquifer yields when the minimum stream discharge to be maintained is the discharge equaled or exceeded 99.5 percent of the time. Figures 23-27 illustrate aquifer yields when the minimum stream discharge to be maintained is the discharge equaled or exceeded 95 percent of the time.

For example, for a minimum discharge maintained at the 99.5-percent duration, the yield available from the Middle Rumford River aquifer will equal or exceed about 4.0 ft^3/s for 50 percent of the time, 2.6 ft^3/s for 90 percent of the time, 1.5 ft^3/s for 95 percent of the time, and 0.7 ft^3/s for 98 percent of the time. However, for a minimum discharge maintained at the 95-percent duration, the yield available from the Middle Rumford River aquifer will equal or exceed 4.0 ft^3/s for 50 percent of the time, 1.0 ft^3/s for 90 percent of the time, and 0 ft^3/s for durations equal to or greater than 95 percent of the time.

The Lower Matfield-Taunton River aquifer and the Lower Canoe River aquifer have the highest yields of the 26 aquifers. Yields of these two aquifers equal or exceed 11.9 and 11.3 ft^3/s for 90 percent of the time, respectively (fig. 22), if minimum stream discharge is to be maintained at 99.5-percent flow duration. The remaining 24 aquifers have yields that equal or exceed only 4 ft^3/s or less for 90 percent of the time. The yields of the Lower Matfield-Taunton River and Lower Canoe River aquifers are high compared to the other aquifers because their rates of ground-water discharge (table 2), rates of water derived from storage, and rates if infiltration are high (table 8). The rates of ground-water discharge from these two aquifers are high because their drainage areas are large and a large percentage of the drainage areas are covered by stratified drift. Rates of water from storage and infiltration are high because the aquifers cover large areas and have larger areas of high transmissivity compared to most of the other aquifers. Also, these aquifers underlie rivers that are further downstream in the basin (pl. 1) and, consequently, have large quantities of streamflow discharge available for infiltration (tables 5 and 6).

Several of the aquifers are small but have high yields because of the large quantities of streamflow available for infiltration. An example of one of these aquifers is the Upper Hockomock River aquifer. Streamflow available for infiltration to this aquifer equals or exceeds 5.3 ft^3/s for 90 percent of the time. For some aquifers, such as the Satucket River aquifer and the Lower West Meadow Brook aquifer, streamflow available for infiltration at nearly all flow durations exceeds the maximum infiltration rate (tables 5 and 8). Many of the aquifers, especially those in the headwaters of the basin, have little or no streamflow available for infiltration for durations greater than about 90 percent. For these aquifers, the only source of water contributing to aquifer yield is ground-water discharge (table 2).

Effect of Alternative Ground-Water Development Plans

Comparison of Aquifer Yields and 1983 Pumping Rates

Average daily pumping rates from 18 of the 26 aquifers during 1983 for public water supply are shown in table 10. There was no pumping from eight aquifers in 1983 for public water supply. The appropriate graph of yield of each aquifer (figs. 18-27) was used to determine the approximate percentage of the time the estimated yield of that aquifer equals or exceeds the 1983 pumping rate. For example, the average 1983 pumping rate from the Lower Canoe River aquifer was 1.9 ft^3/s (table 10). For minimum stream discharge maintained at the 99.5 percent duration, the yield of the Lower Canoe River aquifer equals or exceeds 1.9 ft^3/s for 98.5 percent of the time. Therefore, the Lower Canoe River aquifer can support the 1983 pumping about 98.5 percent of the time. However, for minimum stream discharge main-

Table 9.--*Sample calculation of yield of the Middle Rumford River aquifer assuming minimum streamflow to be maintained is the discharge that is equaled or exceeded 99.5 percent of the time*

Sources of water	Rate that is equaled or exceeded indicated percentage of the time, in cubic feet per second							
	Percentage of time							
	50	60	70	80	90	95	98	99.5
1. Intercepted ground-water discharge from aquifer available for capture by wells[1]	1.1	0.9	0.8	0.6	0.4	0.3	0.2	0.0
2. Rate of induced infiltration[2]	2.0	2.0	2.0	2.0	1.6	.9	.3	.0
3. Model-derived rate of water from aquifer storage during infiltration[3]	.8	.8	.8	.8	.6	.4	.2	.0
(percentage of desaturation of aquifer beneath well fields[3])	(50)	(50)	(50)	(50)	(36)	(18)	(2)	(0)
4. Yield	3.9	3.7	3.6	3.4	2.6	1.6	7	.0

[1] From table 2, except for rate at 99.5 percent (see text).
[2] The smaller of either the maximum infiltration rate (table 8) or streamflow available for infiltration (table 5).
[3] From figure 17, depending on infiltration rate.

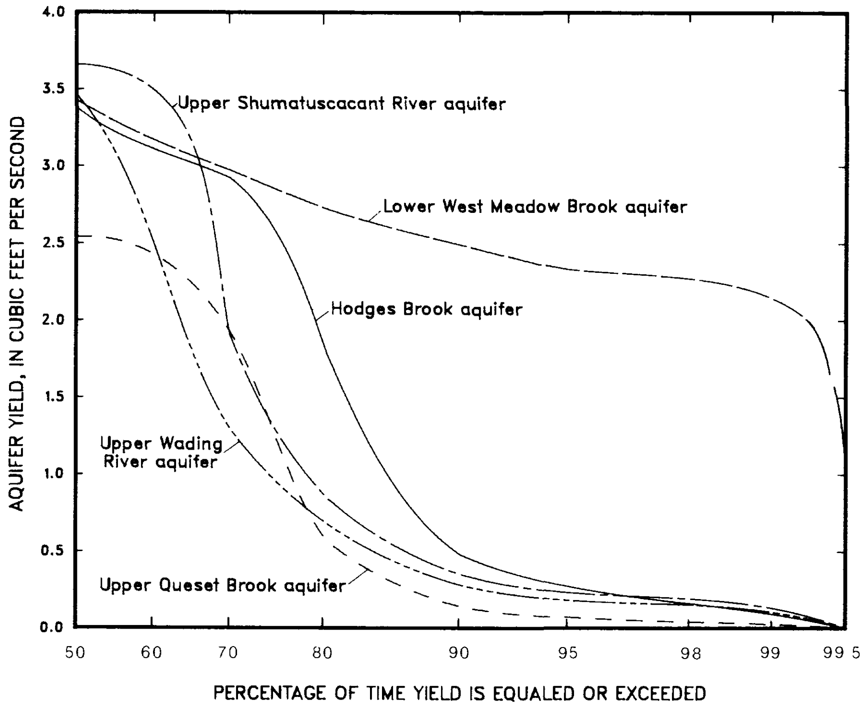


Figure 18.--Relation between aquifer yield and percentage of time yield is equaled or exceeded if minimum stream discharge is maintained at 99.5-percent duration for Hodges Brook, Lower West Meadow Brook, Upper Queset Brook, Upper Shumatuscacant River, and Upper Wading River aquifers.

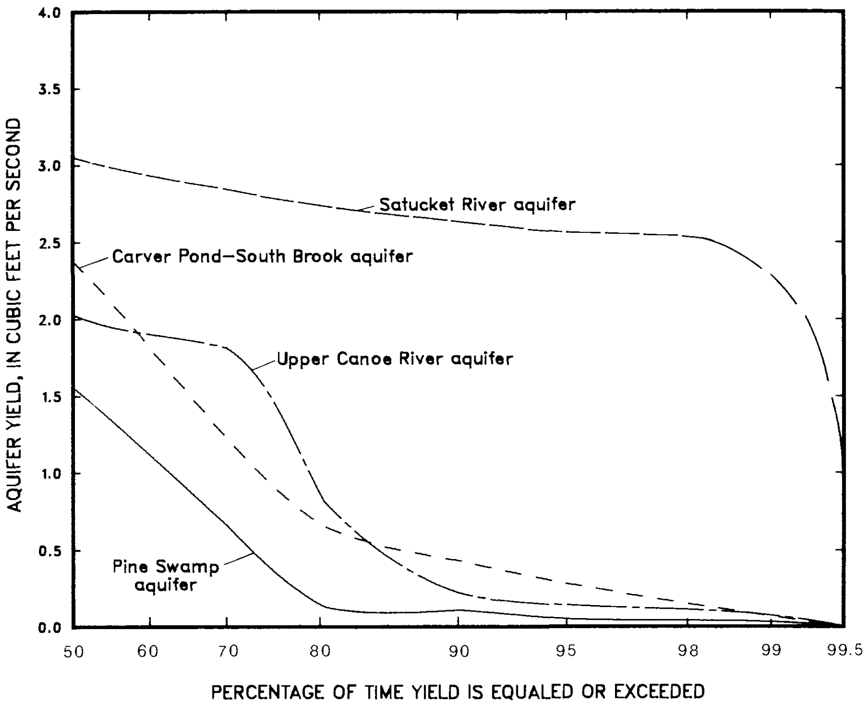


Figure 19.--Relation between aquifer yield and percentage of time yield is equaled or exceeded if minimum stream discharge is maintained at 99.5-percent duration for Carver Pond-South Brook, Pine Swamp Brook, Satucket River, and Upper Canoe River aquifers.

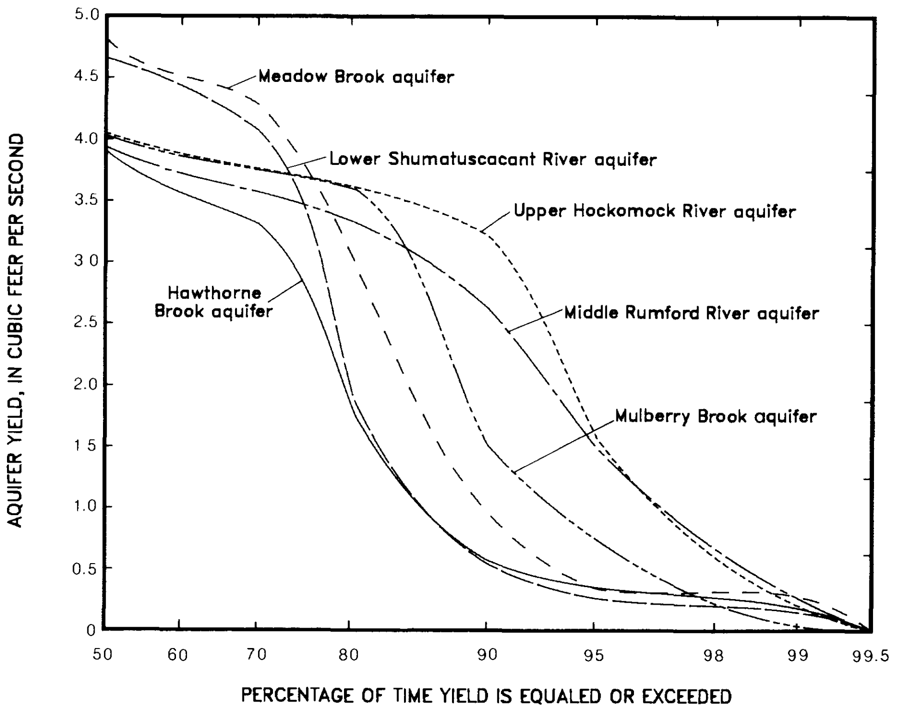


Figure 20.--Relation between aquifer yield and percentage of time yield is equaled or exceeded if minimum stream discharge is maintained at 99.5-percent duration for Hawthorne Brook, Lower Shumatuscacant River, Meadow Brook, Middle Rumford River, Mulberry Brook, and Upper Hockomock River aquifers.

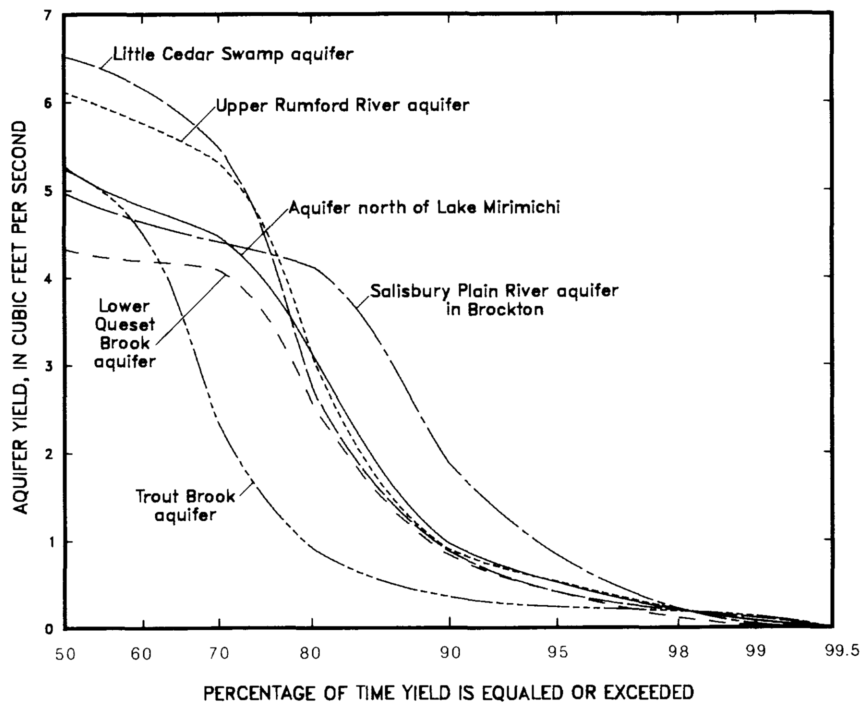


Figure 21.--Relation between aquifer yield and percentage of time yield is equaled or exceeded if minimum stream discharge is maintained at 99.5-percent duration for the aquifer north of Lake Mirimichi, Salisbury Plain River aquifer in Brockton, and Little Cedar Swamp, Lower Queset Brook, Trout Brook, and Upper Rumford River aquifers.

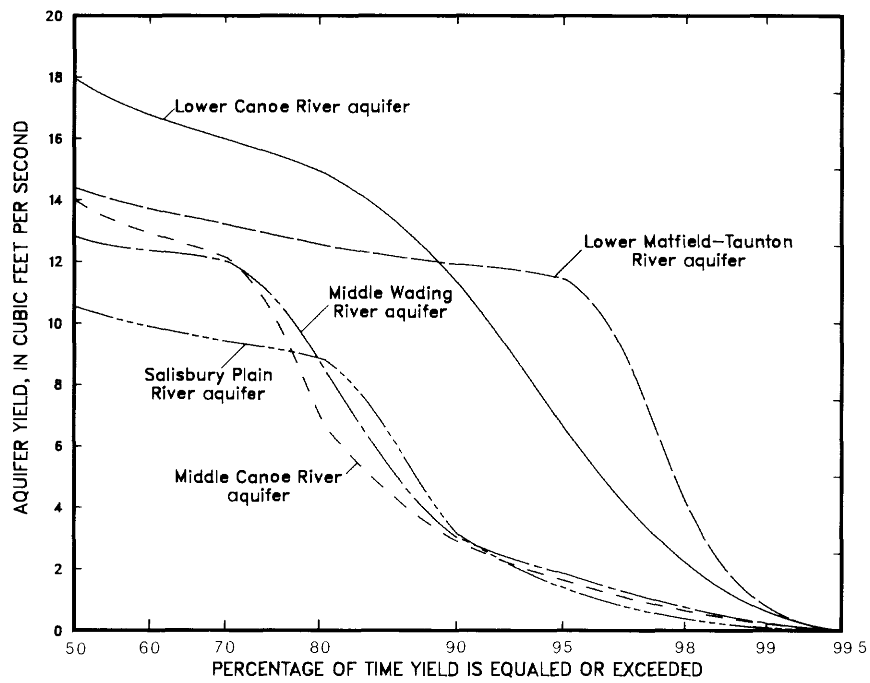


Figure 22.--Relation between aquifer yield and percentage of time yield is equaled or exceeded if minimum stream discharge is maintained at 99.5-percent duration for Lower Canoe River, Lower Matfield-Taunton River, Middle Canoe River, Middle Wading River, and Salisbury Plain River aquifers.

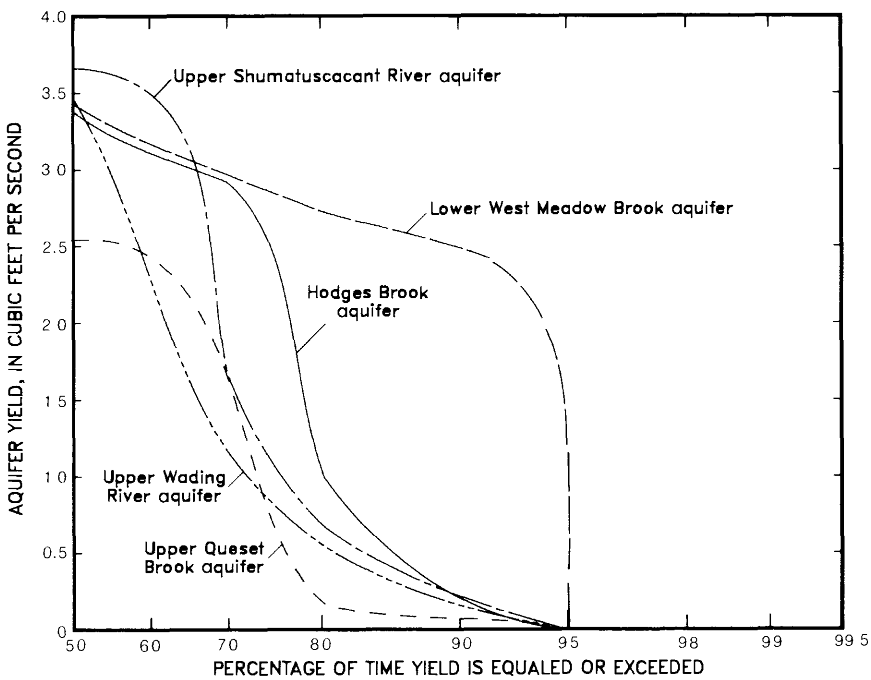


Figure 23.--Relation between aquifer yield and percentage of time yield is equaled or exceeded if minimum stream discharge is maintained at 95-percent duration for Hodges Brook, Lower West Meadow Brook, Upper Queset Brook, Upper Shumatuscacant River, and Upper Wading River aquifers.

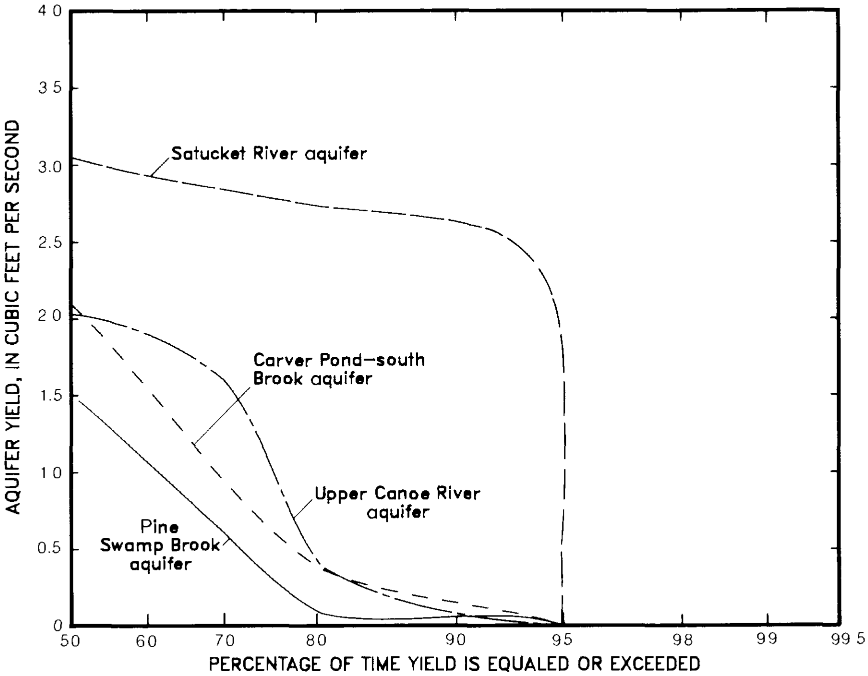


Figure 24.--Relation between aquifer yield and percentage of time yield is equaled or exceeded if minimum stream discharge is maintained at 95-percent duration for Carver Pond-South Brook, Pine Swamp Brook, Satucket River, and Upper Canoe River aquifers.

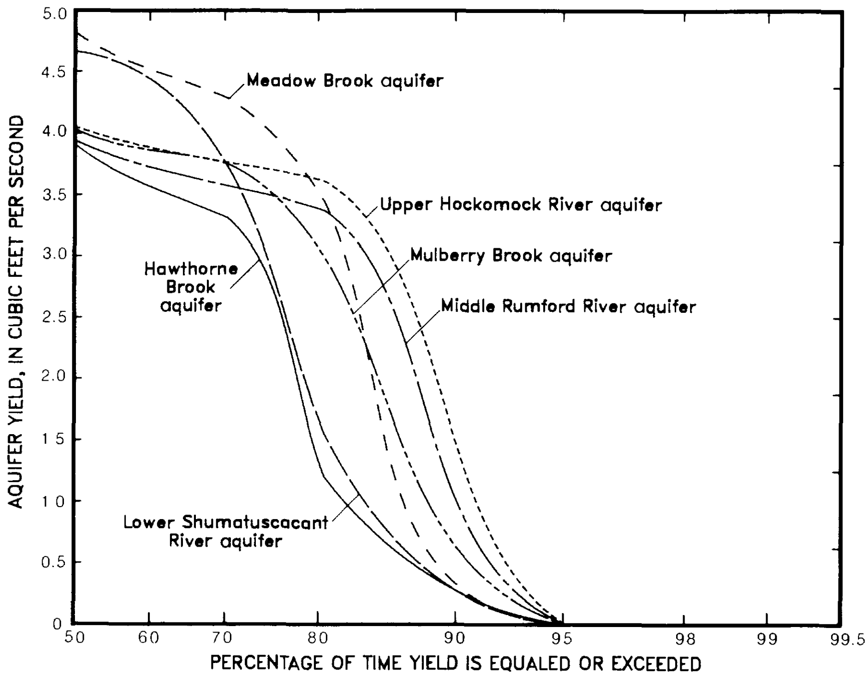


Figure 25.--Relation between aquifer yield and percentage of time yield is equaled or exceeded if minimum stream discharge is maintained at 95-percent duration for Hawthorne Brook, Lower Shumatuscacant River, Meadow Brook, Middle Rumford River, Mulberry Brook, and Upper Hockomock River aquifers.

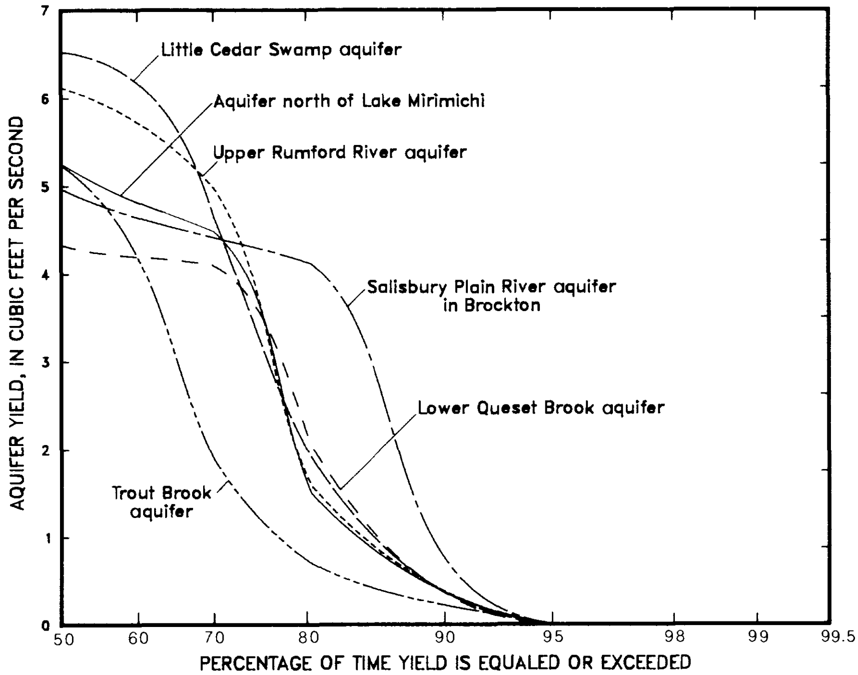


Figure 26.--Relation between aquifer yield and percentage of time yield is equaled or exceeded if minimum stream discharge is maintained at 95-percent duration for the aquifer north of Lake Mirimichi, Salisbury Plain River aquifer at Brockton, Little Cedar Swamp, Lower Queset Brook, Trout Brook, and Upper Rumford River aquifers.

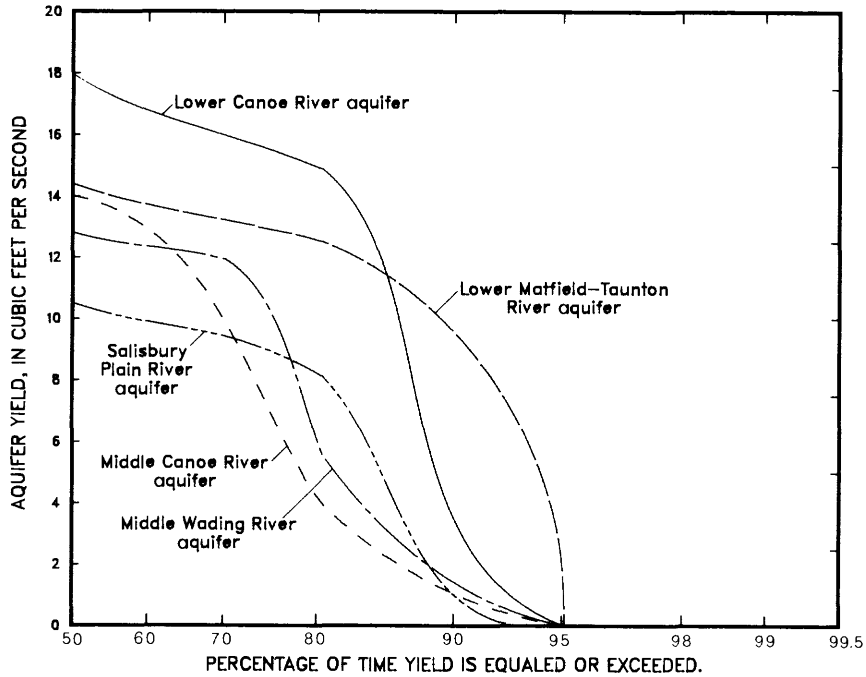


Figure 27.--Relation between aquifer yield and percentage of time yield is equaled or exceeded if minimum stream discharge is maintained at 95-percent duration for Lower Canoe River, Lower Matfield-Taunton River, Middle Canoe River, Middle Wading River, and Salisbury Plain River aquifers.

Table 10.--*Approximate percentage of the time aquifer yield equals or exceeds 1983 pumping rate, assuming all pumping is consumptive and that minimum streamflow maintained is the discharge equaled or exceeded indicated percentage of the time*

Aquifer name	1983 pumping rate, in		Percentage of time yield is equaled or exceeded if streamflow limit is to be maintained at:	
	Million gallons per day	Cubic feet per second[1]	95-percent flow duration	99.5-percent flow duration
			Percentage of time	
Aquifer north of Lake Mirimichi	0.45	0.7	87	93
Carver Pond-South Brook	0.3	0.5	78	86
Hawthorne Brook	.48	.07	84	87
Lower Canoe River	1.2	1.9	92	98.6
Lower Matfield-Taunton River	.53	.8	95	99
Lower Queset Brook	.72	1.1	85	87
Lower Shumatuscacant River	.37	.6	87	89
Middle Canoe River	2.5	3.9	81	87
Middle Wading River	1.2	1.9	89	94
Pine Swamp	.25	.4	74	74
Salisbury Plain River	.53	.8	90	96
Salisbury Plain River in Brockton	.11	.2	92	98
Trout Brook	.37	.6	80	83
Upper Canoe River	.21	.3	82	88
Upper Hocomock River	.30	.5	93	98.2
Upper Queset Brook	1.2	1.9	68	70
Upper Rumford River	1.8	2.8	78	81
Upper Wading River	.14	.2	88	95

[1] Rounded to nearest tenth.

tained at the 95-percent duration, the yield of the Lower Canoe River aquifer equals or exceeds 1.9 ft^3/s about 92 percent of the time.

Of the 18 aquifers pumped in 1983, the Upper Queset Brook aquifer was pumped at the highest rate relative to its yield. The Upper Queset Brook aquifer was pumped at a rate of 1.9 ft^3/s and could sustain this pumping rate about 70 percent of the time if minimum stream discharge is maintained at the 99.5-percent duration. The Lower Matfield-Taunton River aquifer, Lower Canoe River aquifer and Upper Hockomock River aquifer, were pumped at the lowest rates relative to their yields. All three of these aquifers could sustain their 1983 pumping rate at least 98 percent of the time. The overall results of the aquifer yield determinations listed in table 10 show that the 1983 pumping rate of each of the 18 aquifers could be sustained at least 70 percent of the time if minimum streamflow is maintained at the 99.5-percent flow duration.

Assessment of Potential of Aquifers to Support New Development

Figures 18-27 can be used to assess the potential of an aquifer to support historical, current, or new development under the conditions that aquifer development is limited to a rate that does not cause streamflow to decrease below the discharge equaled or exceeded either 95 or 99.5 percent of the time. For example, the Middle Rumford River aquifer can sustain development of 2.6 ft^3/s about 90 percent of the time (fig. 20) if stream discharge is maintained at the 99.5-percent duration, but can sustain that development only 85 percent of the time if stream discharge is maintained at the 95 percent duration (fig. 25). Similarly, the data listed in table 10 and illustrated in figures 18-27 can be used to estimate the percentage of time any selected amount of yield may be available from one of the 26 aquifers.

Effect of Simultaneous Development of Aquifers on Yield Estimates

Up to this point, the yields of the 26 aquifers in the study area were determined based on the assumption that each aquifer was independent of all others. From a geologic, hydrologic, and hydraulic point of view, this assumption generally is not valid. Sand and gravel deposits large enough to support aquifer development often are interconnected by thin, narrow glacial deposits, or are drained by the same stream. Therefore, it is important to understand, particularly from a basin-wide water-management perspective, that the development of one aquifer may affect the potential yield of adjacent or downstream aquifers. Decreases in yield because of simultaneous aquifer development usually result from either well interference effects caused by pumpage in adjacent aquifers or by reductions in stream discharge available for infiltration caused by pumpage of upstream aquifers. The ground-water-flow models were used to demonstrate how multiple-aquifer development affects individual aquifer yields.

Effect of Well Interference During Simultaneous Pumping of Aquifers

Several model simulations were made to determine the effect of well interference on aquifer yield during simultaneous pumping of upstream and downstream aquifers. The yields of the Middle Wading River aquifer and the Lower Canoe River aquifer from storage under isolated development were compared with the yields of these two aquifers during simultaneous development of them and nearby aquifers for pumping periods ranging from 1 to 365 days. The nearby aquifers when simulating development of the Middle Wading River aquifer were the Hawthorne Brook aquifer, the Hodges Brook aquifer, the Upper Wading River aquifer, and the aquifer north of Lake Mirimichi. The nearby aquifer was the Middle Canoe River aquifer when simulating development of the Lower Canoe River aquifer. In both cases, the aquifers were pumped at rates such that each simulated well field was desaturated by 50 percent at the end of the pumping period. Well-field locations were the same as those used in previous simulations. The results of these simulations indicate that well interference between aquifers does not appreciably decrease individual aquifer yield.

The effect of interference between aquifers located in adjacent subbasins was not investigated because, in the north part of the basin, till-bedrock highlands commonly separate the subbasins. The transmissivity of the till and bedrock is low. Therefore, most aquifers probably would not be greatly affected by pumping in aquifers located in adjacent subbasins. In the central and southern parts of the basin, however, some subbasins are separated by areally extensive stratified drift rather than till-bedrock. It is possible that an aquifer in these parts of the basin could be affected by pumping in aquifers located in adjacent subbasins.

Effect of Reduced Stream Discharge Available for Induced Infiltration

Modeling results indicate that reduction in stream discharge available for infiltration to a downstream aquifer, because of simultaneous development of aquifers upstream, may significantly decrease the yield of the downstream aquifer. As an example of how this effect was determined, yield calculations for the Middle Rumford River aquifer during simultaneous development of the Upper Rumford River aquifer are listed in table 11. Ground-water discharge from the Upper Rumford River aquifer equals or exceeds 2.6 ft^3/s 50 percent of the time (table 2), and the maximum rate of infiltration to the Upper Rumford River aquifer after a 180-day pumping period is 1.3 ft^3/s (table 8) for a total of 3.9 ft^3/s. If the Upper Rumford River aquifer is fully developed, the estimated stream discharge available for infiltration to the Middle Rumford River aquifer (table 5) must be decreased by 3.9 ft^3/s for all stream-discharge values ranging from 50- to 99.9-percent exceedance. Yield calculations for the Middle Rumford River aquifer with full development of the Upper Rumford River aquifer are listed in table 11. Comparison of yields in tables 9 and 11 show the effect of this simultaneous aquifer development. For example, for isolated development of the Middle Rumford River aquifer, yield equaled or exceeded 90 percent of the time is 2.6 ft^3/s (table 9). With full development of the Upper Rumford River aquifer, the estimated yield decreases to 1.4 ft^3/s (table 11) or about one-half of the yield of the aquifer under isolated development.

The estimated yields of seven selected aquifers, where full development of upstream aquifers may take place, are shown in figures 28 and 29. Yields shown in these two figures can be compared to yields of the same aquifers shown in figures 18-27 to assess the effect of full development of upstream aquifers on the yields of these seven aquifers.

The effects of development of upstream aquifers on yields, equaled or exceeded 90 percent of the time, for those seven aquifers, are summarized in table 12. The reason that the yield of the Middle Canoe River aquifer does not change when minimum streamflow to be maintained is at the 95-percent flow duration is because the yield available from the Upper Canoe River aquifer under these conditions is nearly equal to zero (fig. 24).

Appraisal of Aquifer-Yield Estimates

Tables 13-16 summarize the yields of the 26 aquifers for four alternate management options. There are many other possible options; these four were selected for illustrative purposes and are intended to show the wide range in estimated yield which result from a wide range of maintained minimum streamflows. The yields listed in table 13 are the highest of the four estimates because minimum stream discharge is set at the lowest of the two flows and the percentage of time the yield is available is 70 percent. Conversely, the yields listed in table 16 are the lowest of the four estimates because minimum stream discharge is set at the highest of the two flows and the percentage of time the yield is available is 90 percent.

Comparison of the available yield of an aquifer and the 1983 pumping rate indicates that aquifers such as the Upper Hockomock River aquifer have sufficient yields available to satisfy the 1983 pumping rate under all selected flow conditions. However, other aquifers, such as the Upper Queset Brook aquifer, were pumped at rates that exceeded the estimated yields available under the three most restrictive flow conditions. This discrepancy illustrates that the actual rate of pumpage of aquifers in the basin may differ significantly from the estimated yields determined in this study. The principal reason why actual and estimated yields may differ is that real field conditions and pumping conditions may invalidate one or more of the assumptions upon which the estimates are based. The following discussion summarizes the most important factors to consider when using the estimated aquifer-yield results.

Yields of aquifers are estimated based on all available information about the geometry and hydraulic properties of the aquifers. The yield estimates were made assuming conditions that existed prior to any aquifer development. Actual yields may differ from the estimated yields because of specific limitations in well-field design or well performance: (1) It may not be possible to install a well field in the exact location where it was simulated in the model. A different location may be necessary if poor quality ground water exists at the modeled well-field location, or if it is physically

Table 11.--*Estimated yield of the Middle Rumford River aquifer for full development of the Upper Rumford River aquifer*

Sources of water	Rate that is equaled or exceeded indicated percentage of the time, in cubic feet per second							
	Percentage of time							
	50	60	70	80	90	95	98	99.5
1. Intercepted ground-water discharge from aquifer[1]	1.1	0.9	0.8	0.6	0.4	0.3	0.2	0.0
2. Rate of induced infiltration[2]	2.0	2.0	2.0	1.7	.7	.4	.0	.0
3. Model-derived rate of water from aquifer storage during infiltration[3]	.8	.8	.8	.7	.3	.1	.0	.0
(Percentage of desaturation of aquifer associated with infiltration rate[3])	(50)	(50)	(50)	(38)	(14)	(7)	(0)	(0)
4. Yield	3.9	3.7	3.6	3.0	1.4	.8	.2	.0

[1] From table 2.
[2] The smaller of either the maximum infiltration rate (table 8); or streamflow available for infiltration (table 5) minus upstream loss of stream discharge because of simultaneous development of the Upper Rumford River aquifer.
[3] From figure 17 depending on infiltration rate.

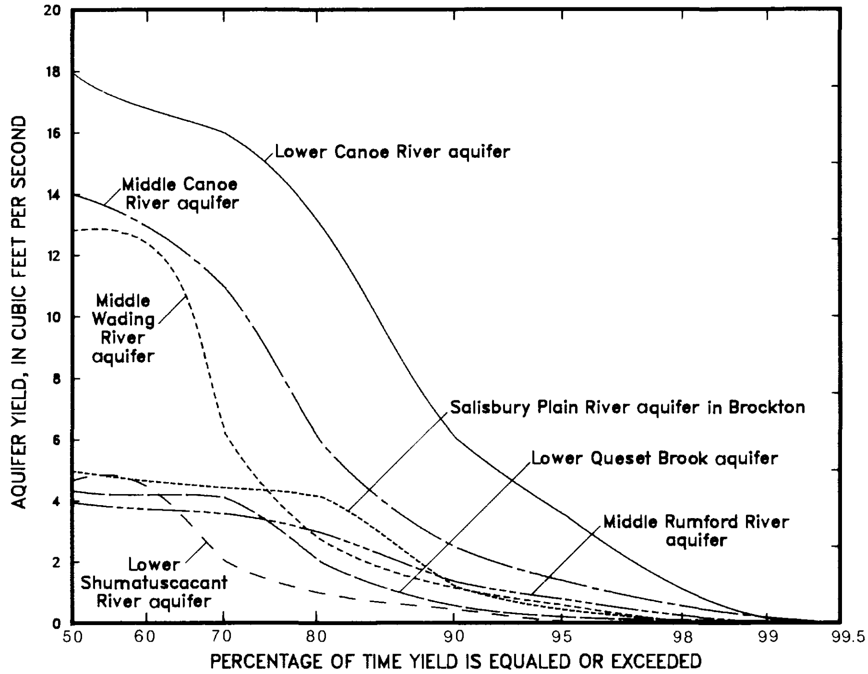


Figure 28.--Relation between aquifer yield and percentage of time yield is equaled or exceeded for simultaneous development of upstream aquifers and minimum streamflow equal to the discharge that is equaled or exceeded 99.5 percent of the time.

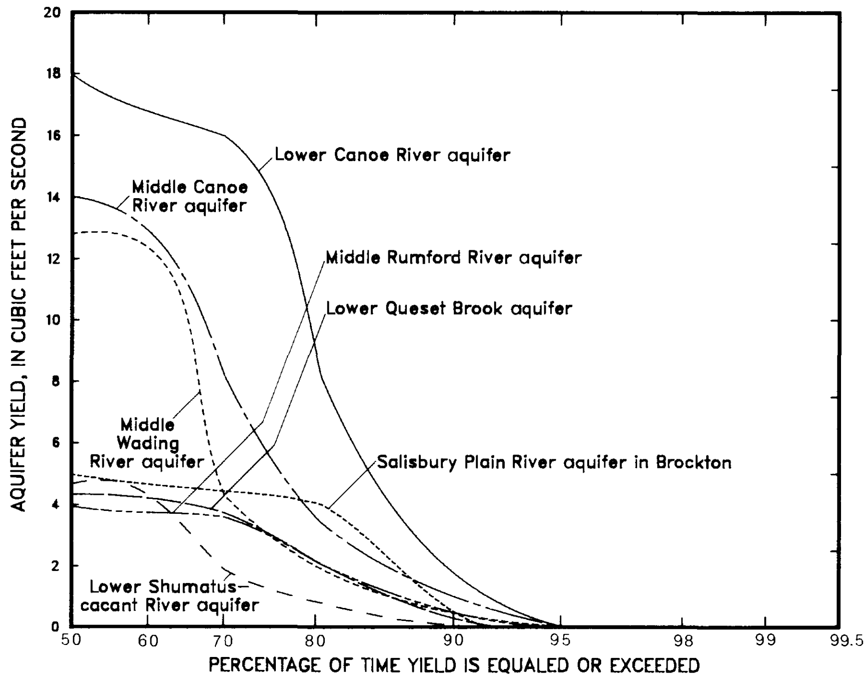


Figure 29.--Relation between aquifer yield and percentage of time yield is equaled or exceeded for simultaneous development of upstream aquifers and minimum streamflow equal to the discharge that is equaled or exceeded 95 percent of the time.

Table 12.--*Aquifer yield equaled or exceeded 90 percent of the time, for no development (figs. 18-27) and full development (figs. 28 and 29) of upstream aquifers*

Aquifer (fig. 3 and pl. 1)	Upstream aquifers fully developed (fig. 3 and pl. 1)	Aquifer yield, in cubic feet per second, if streamflow limit to be maintained is: 95 percent	99.5 percent
Lower Canoe River	none	3.4	11.3
Lower Canoe River	Upper and Middle Canoe River	1.8	6.0
Lower Queset Brook	none	.4	.8
Lower Queset Brook	Upper Queset Brook	.3	.6
Lower Shumatuscacant River	none	.3	.5
Lower Shumatuscacant River	Upper Shumatuscacant River	<.1	.2
Middle Canoe River	none	1.0	2.8
Middle Canoe River	Upper Canoe River	1.0	2.4
Middle Rumford River	none	1.0	2.6
Middle Rumford River	Upper Rumford River	.5	1.4
Middle Wading River	none	1.4	3.2
Middle Wading River	Upper Wading, Hawthorne Brook, and aquifer north of Lake Mirimichi	.4	1.1
Salisbury Plain River in Brockton	none	.8	1.8
Salisbury Plain River in Brockton	Trout Brook	.5	1.2

Table 13.–*Aquifer yields equaled or exceeded 70 percent of the time for minimum streamflow maintained at 99.5-percent flow duration, in cubic feet per second*

[The number to left of slash is the rate with no development of upstream aquifers; and the number following slash is the rate with full development of upstream aquifers.]

Aquifer system and aquifer name	Basin discharge[1]	Minimum stream discharge maintained[2]	Sources of water contributing to aquifer yield: Intercepted ground-water discharge[3]	Induced infiltration[4]	Storage[5]	Aquifer yield[6]	1983 pumping rate[7]
Canoe River aquifer system							
Upper Canoe River	1.0	0.03	0.5	0.4	0.9	1.8	0.3
Middle Canoe River	9.8	1.0	4.1/4.1	4.3/3.7	3.6/3.0	12.0/10.8	3.9
Mulberry Brook	5.3	.2	.6	2.1	1.1	3.8	.0
Lower Canoe River	27.2	2.9	4.2/4.2	6.3/6.3	5.5/5.5	16.0/16.0	1.9
Hockomock River aquifer system							
Upper Queset Brook	.9	.02	.4	.5	1.1	2.0	1.9
Lower Queset Brook	4.2	.08	.5/.5	2.6/2.6	.9/.9	4.0/4.0	1.1
Upper Hockomock River	9.3	.2	.6	1.5	1.7	3.8	.5
Rumford River aquifer system							
Upper Rumford River	3.7	.3	1.7	1.3	2.4	5.4	2.8
Middle Rumford River	8.0	.6	.8/.8	2.0/2.0	.8/.8	3.6/3.6	.0
Salisbury River aquifer system							
Trout Brook	1.6	.04	.8	.8	.6	2.2	.6
Salisbury Plain River in Brockton	8.2	.2	1.2/1.2	1.8/1.8	1.4/1.4	4.4/4.4	.2
Salisbury Plain River	10.6	.3	2.4	2.7	4.3	9.4	.8
Satucket River aquifer system							
Upper Shumatuscacant River	1.5	.03	.7	.8	.4	1.9	.0
Lower Shumatuscacant River	3.4	.06	.8/.8	2.5/1.0	.8/.2	4.1/2.0	.6
Satucket River	21.3	2.3	.4	1.3	1.1	2.8	.0
Wading River aquifer system							
Upper Wading River	1.2	.03	.6	.5	.1	1.2	.2
Aquifer north of Lake Mirimichi	3.6	.3	1.7	.9	1.9	4.5	.7
Hawthorne Brook	2.7	.1	1.3	1.0	1.0	3.3	.7
Middle Wading River	12.2	.8	1.7/1.7	8.2/3.6	2.1/.9	12.0/6.2	1.9
Hodges Brook	2.1	.1	1.0	.5	1.4	2.9	.0
Other aquifers							
Carver Pond-South Brook	2.1	.9	1.2	.0	.0	1.2	.5
Little Cedar Swamp	3.8	.2	1.2	2.4	1.9	5.5	.0
Lower Matfield-Taunton River	63.4	2.8	2.6	6.2	4.4	13.2	.8
Lower West Meadow Brook	30.3	1.5	1.0	.9	1.1	3.0	.0
Meadow Brook	3.6	.1	1.1	.7	2.5	4.3	.0
Pine Swamp Brook	2.3	1.7	.6	.0	.0	.6	.4

[1] From table 4 at 70-percent flow duration.
[2] From table 4 at 99.5-percent flow duration.
[3] Ground-water discharge at 70-percent flow duration available for capture by wells. For number to the left of the slash: From table 2 (if there is infiltration) or the basin discharge minus the minimum stream discharge to be maintained (if there is no infiltration). Number to the right of the slash includes the effect of upstream development on the rates of ground-water discharge, infiltration, and storage. See example calculation in table 11.
[4] Infiltration rate after 180-days of pumping. For number to the left of the slash: the smaller of either the maximum rate of infiltration (table 8) or stream discharge available for infiltration (table 5) at 70-percent flow duration. Number to the right of the slash includes the effect of upstream development on the rates of ground-water discharge, infiltration, and storage. See example calculation in table 11.
[5] Water derived from aquifer storage during infiltration (from figures similiar to figure 17).
[6] Aquifer yield equaled or exceeded 70 percent of the time (the sum of columns 3 + 4 + 5). See figures 18-22.
[7] From table 10.

Table 14.--*Aquifer yields equaled or exceeded 70 percent of the time for minimum streamflow maintained at 95-percent flow duration, in cubic feet per second*

[The number to left of slash is the rate with no development of upstream aquifers; the number following slash is the rate with full development of upstream aquifers.]

Aquifer system and aquifer name	Basin discharge[1]	Minimum stream discharge maintained[2]	Sources of water contributing to aquifer yield: Intercepted ground-water discharge[3]	Induced infiltration[4]	Storage[5]	Aquifer yield[6]	1983 pumping rate[7]
Canoe River aquifer system							
Upper Canoe River	1.0	0.2	0.5	0.4	0.8	1.7	**0.3**
Middle Canoe River	9.8	2.5	4.1/4.1	3.2/2.3	2.6/1.8	9.9/8.2	**3.9**
Mulberry Brook	5.3	.8	.6	2.1	1.1	3.8	**0**
Lower Canoe River	27.2	7.1	4.2/4.2	6.3/6.3	5.5/5.5	16.0/16.0	**1.9**
Hockomock River aquifer system							
Upper Queset Brook	.9	.1	.4	.4	.9	1.7	**1.9**
Lower Queset Brook	4.2	.4	.5/.5	2.6/2.4	.9/.8	4.0/3.7	**1.1**
Upper Hockomock River	9.3	1.1	.6	1.5	1.7	3.8	**.5**
Rumford River aquifer system							
Upper Rumford River	3.7	.8	1.7	1.2	2.1	5.0	**2.8**
Middle Rumford River	8.0	1.8	.8/.8	2.0/2.0	.8/.8	3.6/3.6	**.0**
Salisbury River aquifer system							
Trout Brook	1.6	.2	.8	.6	.5	1.9	**.6**
Salisbury Plain River in Brockton	8.2	.8	1.2/1.2	1.8/1.8	1.4/1.4	4.4/4.4	**.2**
Salisbury Plain River	10.6	1.4	2.4	2.7	4.3	9.4	**.8**
Satucket River aquifer system							
Upper Shumatuscacant River	1.5	.2	.7	.6	.3	1.6	**.0**
Lower Shumatuscacant River	3.4	.3	.8/.8	2.2/.8	.7/.2	3.7/1.8	**.6**
Satucket River	21.3	5.6	.4	1.3	1.1	2.8	**.0**
Wading River aquifer system							
Upper Wading River	1.2	.2	.6	.4	.1	1.1	**.2**
Aquifer north of Lake Mirimichi	3.6	.8	1.7	.9	1.9	4.5	**.7**
Hawthorne Brook	2.7	.4	1.3	1.0	1.0	3.3	**.7**
Middle Wading River	12.2	2.4	1.7/1.7	8.1/2.1	2.1/.5	11.9/4.3	**1.9**
Hodges Brook	2.1	.4	1.0	.5	1.4	2.9	**.0**
Other aquifers							
Carver Pond-South Brook	2.1	1.2	.9	.0	.0	.9	**.5**
Little Cedar Swamp	3.8	.6	1.2	2.0	1.4	4.6	**.0**
Lower Matfield-Taunton River	63.4	10.2	2.6	6.2	4.4	13.2	**.8**
Lower West Meadow Brook	30.3	5.2	1.0	.9	1.1	3.0	**.0**
Meadow Brook	3.6	.4	1.1	.7	2.5	4.3	**.0**
Pine Swamp Brook	2.3	1.7	.6	.0	.0	.6	**.4**

[1] From table 4 at 70-percent flow duration.
[2] From table 4 at 95-percent flow duration.
[3] Ground-water discharge at 70-percent flow duration available for capture by wells. For number to the left of the slash: From table 2 (if there is infiltration) or the basin discharge minus the minimum stream discharge to be maintained (if there is no infiltration). Number to the right of the slash includes the effect of upstream development on the rates of ground-water discharge, infiltration, and storage. See example calculation in table 11.
[4] Infiltration rate after 180-days of pumping: For number to the left of the slash: the smaller of either the maximum rate of infiltration (table 8) or stream discharge available for infiltration (table 6) at 70-percent flow duration. Number to the right of the slash includes the effect of upstream development on the rates of ground-water discharge, infiltration, and storage. See example calculation in table 11.
[5] Water derived from aquifer storage during infiltration (from figures similiar to figure 17).
[6] Aquifer yield equaled or exceeded 70 percent of the time (the sum of columns 3 + 4 + 5). See figures 23-27.
[7] From table 10.

Table 15.–*Aquifer yields equaled or exceeded 90 percent of the time for minimum streamflow maintained at 99.5-percent flow duration, in cubic feet per second*

[The number to left of slash is the rate with no development of upstream aquifers; and the number following slash is the rate with full development of upstream aquifers.]

Aquifer system and aquifer name	Basin discharge[1]	Minimum stream discharge maintained[2]	Sources of water contributing to aquifer yeild: Intercepted ground-water discharge[3]	Induced infiltration[4]	Storage[5]	Aquifer yield[6]	1983 pumping rate[7]
Canoe River aquifer system							
Upper Canoe River	0.3	0.03	0.3	0.0	0.0	0.3	0.3
Middle Canoe River	3.5	1.0	2.1/2.1	.4/.2	.3/.1	2.8/2.4	3.9
Mulberry Brook	1.3	.2	.3	.8	.4	1.5	0
Lower Canoe River	10.0	2.9	2.1/2.1	5.0/2.1	4.2/1.8	11.3/6.0	1.9
Hockomock River aquifer system							
Upper Queset Brook	.2	.02	.2	.0	.0	.2	1.9
Lower Queset Brook	.8	.08	.3/.3	.4/.3	.1/.0	.8/.6	1.1
Upper Hockomock River	1.9	.2	.3	1.4	1.5	3.2	.5
Rumford River aquifer system							
Upper Rumford River	1.2	.3	.9	.0	.0	.9	2.8
Middle Rumford River[8]	2.6	.6	.4/.4	1.6/.7	.6/.3	2.6/1.4	.0
Salisbury River aquifer system							
Trout Brook	.4	.04	.4	.0	.0	.4	.6
Salisbury Plain River in Brockton	1.5	.2	.6/.6	.7/.4	.5/.2	1.8/1.2	.2
Salisbury Plain River	2.4	.3	1.2	.9	1.1	3.2	.8
Satucket River aquifer system							
Upper Shumatuscacant River	.3	.03	.3	.0	.0	.3	.0
Lower Shumatuscacant River	.6	.06	.4/.2	1/.0	.0/.0	.5/.2	.6
Satucket River	7.8	2.3	.2	1.3	1.1	2.6	.0
Wading River aquifer system							
Upper Wading River	.4	.03	.4	.0	.0	.4	.2
Aquifer north of Lake Mirimichi	1.2	.3	.9	.0	.0	.9	.7
Hawthorne Brook	.7	.1	.6	.0	.0	.6	.7
Middle Wading River	3.6	.8	.9/.9	1.9/.2	.4/.0	3.2/1.1	1.9
Hodges Brook	.6	.1	.5	.0	.0	.5	.0
Other aquifers							
Carver Pond-South Brook	1.3	.9	.4	.0	.0	.4	.5
Little Cedar Swamp	.9	.2	.6	.1	.1	.8	.0
Lower Matfield-Taunton River	16.4	2.8	1.3	6.2	4.4	11.9	.8
Lower West Meadow Brook	8.2	1.5	.5	.9	1.1	2.5	.0
Meadow Brook	.8	.1	.6	.1	.3	1.0	.0
Pine Swamp Brook	1.8	1.7	.1	.0	.0	.1	.4

[1] From table 4 at 90-percent flow duration (if rate in table 4 is less than rate in table 2, rate in table 2 is used).
[2] From table 4 at 99.5-percent flow duration.
[3] Ground-water discharge at 90-percent flow duration available for capture by wells. For number to the left of the slash: From table 2 (if there is infiltration) or the basin discharge minus the minimum stream discharge to be maintained (if there is no infiltration). Number to the right of the slash includes the effect of upstream development on the rates of ground-water discharge, infiltration, and storage. See example calculation in table 11.
[4] Infiltration rate after 180-days of pumping: For number to the left of the slash: the smaller of either the maximum rate of infiltration (table 8) or stream discharge available for infiltration (table 5) at 90-percent flow duration. Number to the right of the slash includes the effect of upstream development on the rates of ground-water discharge, infiltration, and storage. See example calculation in table 11.
[5] Water derived from aquifer storage during infiltration (from figures similiar to figure 17).
[6] Aquifer yield equaled or exceeded 90 percent of the time (the sum of columns 3 + 4 + 5). See figures 18-22.
[7] From table 10.
[8] Also see tables 9 and 11 at 90-percent flow duration.

Table 16.--*Aquifer yields equaled or exceeded 90 percent of the time for minimum streamflow maintained at 95-percent flow duration, in cubic feet per second*

[The number to left of slash is the rate with no development of upstream aquifers; and the number following slash is the rate with full development of upstream aquifers.]

Aquifer system and aquifer name	Basin discharge[1]	Minimum stream discharge maintained[2]	Sources of water contributing to aquifer yeild: Intercepted ground-water discharge[3]	Induced Infiltration[4]	Storage[5]	Aquifer yield[6]	1983 pumping rate[7]
Canoe River aquifer system							
Upper Canoe River	0.3	0.2	0.1	0.0	0.0	0.1	0.3
Middle Canoe River	3.5	2.5	1.0/1.0	.0/.0	.0/.0	1.0/1.0	3.9
Mulberry Brook	1.3	.8	.3	.2	.1	.6	.0
Lower Canoe River	10.0	7.1	2.1/1.8	.8/.0	.5/.0	3.4/1.8	1.9
Hockomock River aquifer system							
Upper Queset Brook	.2	.1	.1	.0	.0	.1	.1.9
Lower Queset Brook	.8	.4	.3/.3	.1/.0	.0/.0	.4/.3	.1.1
Upper Hockomock River	1.9	1.1	.3	.6	.6	1.4	.5
Rumford River aquifer system							
Upper Rumford River	1.2	.8	.4	.0	.0	.4	2.8
Middle Rumford River	2.6	1.8	.4/.4	.4/.1	.2/.0	1.0/.5	.0
Salisbury River aquifer system							
Trout Brook	.4	.2	.2	.0	.0	.2	.6
Salisbury Plain River in Brockton	1.5	.8	.6/.5	.1/.0	.1/.0	.8/.5	.2
Salisbury Plain River	2.4	1.4	1.0	.0	.0	1.0	.8
Satucket River aquifer system							
Upper Shumatuscacant River	.3	.2	.2	.0	.0	.2	.0
Lower Shumatuscacant River	.6	.3	.3/.1	.0/.0	.0/.0	.3/.1	.6
Satucket River	7.8	5.6	.2	1.3	1.1	2.6	.0
Wading River aquifer system							
Upper Wading River	.4	.2	.2	.0	.0	.2	.2
Aquifer north of Lake Mirimichi	1.2	.8	.4	.0	.0	.4	.7
Hawthorne Brook	.7	.4	.3	.0	.0	.3	.7
Middle Wading River	3.6	2.4	.9/.4	.3/.0	.1/.0	1.4/.4	1.9
Hodges Brook	.6	.4	.2	.0	.0	.2	.0
Other aquifers							
Carver Pond-South Brook	1.3	1.2	.1	.0	.0	.1	.5
Little Cedar Swamp	.9	.6	.3	.0	.0	.3	.0
Lower Matfield-Taunton River	16.4	10.2	1.3	4.9	3.3	9.5	.8
Lower West Meadow Brook	8.2	5.2	.5	.9	1.1	2.5	.0
Meadow Brook	.8	.4	.4	.0	.0	.4	.0
Pine Swamp Brook	1.8	1.7	.1	.0	.0	.1	.4

[1] From table 4 at 90-percent flow duration (if rate in table 4 is less than rate in table 2, rate in table 2 is used).
[2] From table 4 at 95-percent flow duration.
[3] Ground-water discharge at 90-percent flow duration available for capture by wells. For number to the left of the slash: From table 2 (if there is infiltration) or the basin discharge minus the minimum stream discharge to be maintained (if there is no infiltration). Number to the right of the slash includes the effect of upstream development on the rates of ground-water discharge, infiltration, and storage. See example calculation in table 11.
[4] Infiltration rate after 180-days of pumping. For number to the left of the slash: the smaller of either the maximum rate of infiltration (table 8) or stream discharge available for infiltration (table 6) at 90-percent flow duration. Number to the right of the slash includes the effect of upstream development on the rates of ground-water discharge, infiltration, and storage. See example calculation in table 11.
[5] Water derived from aquifer storage during infiltration (from figures similiar to figure 17).
[6] Aquifer yield equaled or exceeded 90-percent of the time (the sum of columns 3 + 4 + 5). See figs. 23-27.
[7] From table 10.

or economically more feasible to locate a well field elsewhere; (2) well efficiency is not 100 percent, as is assumed in the models; and (3) it is probably not possible to capture 100 percent of the ground-water discharge from the aquifer by pumping. Only a fraction of the basin ground-water discharge may be captured by the wells. Actual yields also may differ from the estimated yields because the value of specific yield of an aquifer differs from the value of 0.2 assigned in the models. Sensitivity tests of the effect of variation in specific yield from 0.1 to 0.3 for several aquifers indicate that yields from storage might differ by as much as 0.6 to 1.5 times the yield predicted by the model when using the assigned value of 0.2. Also, streams were assumed to be well connected to the underlying aquifers on the basis of field investigation of streambed lithology. However, there may be low-conductivity layers of stratified drift at depth beneath the stream. In these situations, actual infiltration rates would be less than the rates predicted by the models. Estimated rates of ground-water discharge to streams also could vary by as much as 50 percent from actual rates of discharge.

Estimates of yields from intercepted ground-water discharge, induced infiltration, and storage and the resulting analysis of the impact of developing the aquifers were made assuming that water is derived only from these three sources. However, there are other sources that may increase yield. Four additional sources of water are: (1) Ground-water discharge from the aquifer across subbasin boundaries as underflow, which could be captured prior to discharging; (2) water captured by lowering the water table, which reduces evapotranspiration of ground water; (3) return flow from wastewater discharge; and (4) water available from storage for conditions when there is no stream discharge available for induced infiltration. Under these conditions, ground-water discharge to the aquifer was assumed to be the only source of water contributing to the aquifer yield. Underflow was not considered a source of water for the yield estimates because rates of underflow probably are small compared to rates available from the three sources considered in this study. Water captured by reducing evapotranspiration and return flow from wastewater discharge were not included as sources of water during pumping because accurate determination of the rates of contribution from these sources would require extensive data collection and analysis that was beyond the scope of this report. Some water also is derived from storage during pumping to capture ground-water discharge. Because the areal extents and thicknesses of the 26 aquifers considered in this study are small, the additional water derived from storage during pumping to capture ground-water discharge would probably be small.

The estimates of yields from aquifer storage are applicable during severe drought. Because water is derived primarily from aquifer storage, steady-state conditions may never be achieved, and continued pumping will cause water levels to continue to decline.

The models constructed in this study were used to assess aquifer yields from a regional perspective. They were not designed to investigate the effect of local aquifer development on ground-water levels and ground-water flow patterns, or to determine optimum locations of well fields. Development of models designed to address the effect of local aquifer development requires intensive, site-specific field study, and model design, development, and calibration, which were beyond the scope of this study.

Regional relationships between stream discharge and percentage of stratified drift (fig. 13) and ground-water discharge and percentage of stratified drift (fig. 9) were developed; however, the use of these relations is not intended to replace direct field measurement of stream discharge and ground-water discharge. These relations provide estimates of discharge when measurement sites are inaccessible or where field measurements would be inaccurate and unrepresentative.

The r^2 values of the regression lines describing stream discharge and ground-water discharge in terms of percentage of stratified drift covering a basin indicate how much variation in discharge can be accounted for by the percentage of drift. The r^2 values indicate that other variables in addition to percentage of stratified drift contribute to variation in ground-water and stream discharge among basins under certain flow conditions. These other factors probably include the geohydrologic characteristics of the stratified drift, till, and bedrock; depth to the water table; area of ponds and wetlands; the rate and duration of evapotranspiration; slope of land surface; vegetative type and extent of coverage; and climate of the basins. Consideration of these factors in future studies might result in more accurate equations for predicting rates of ground-water and stream discharge.

The yield estimates presented in this report should prove useful in (1) assessing the potential of an aquifer to sustain current or future withdrawal during normal and drought conditions; (2) planning and managing the regional development of the water resources for all uses in the basin; and (3) assessing the need for and effects of interbasin and intrabasin transfer of water.

QUALITY OF GROUND WATER IN THE STRATIFIED-DRIFT AQUIFERS

Eighty analyses of physical properties and concentrations of common constituents, 51 analyses of selected trace metals, and 74 analyses of selected volatile organic compounds were used to characterize quality of ground water in the stratified-drift aquifers. Most samples were collected by local water department personnel from public-supply and test wells and were analyzed by the Massachusetts Department of Environmental Quality Engineering. Results of these analyses were obtained from the Southeast Regional Office of the Massachusetts Department of Environmental Quality Engineering in Lakeville, Mass. Several of the samples were collected by homeowners from their domestic wells and were analyzed by a private water-quality laboratory. The Survey collected 35 samples from public-supply and test wells, domestic wells, and industrial-supply wells for analysis at the Survey's Laboratory, Atlanta, Ga. Of these samples, 3 were analyzed for common constituents, 27 for trace metals, and 5 for volatile organic compounds. The Survey sampling sites were located in areas where water-quality data from other sources were not available.

Physical Properties and Major Chemical Constituents

Selected physical properties and concentrations of major constituents in ground water from stratified-drift aquifers at 80 sampling sites throughout the basin are listed in tables 17 and 18, and are illustrated in figure 30 and plate 2. Three of the 80 samples were collected and analyzed by the Survey (table 18).

No concentrations of sulfate or chloride exceeded limits recommended for drinking water. However, concentrations of sodium exceeded the Massachusetts limit recommended for drinking water for those on sodium-restricted diets of 20 mg/L (Mass. DEQE, 1982) in 19 of the 80 samples (tables 17 and 18).

Ph

The pH of ground water ranges from 5.4 to 7.0. PH of ground water was less than 6.0 at one-half of the sites, and less than 6.5 at 90 percent of the sites. PH exceeded 6.9 at only one site. Ground water is mildly corrosive to metal pipes and may result in the dissolution of lead, copper, zinc, and cadmium from metal plumbing systems. Elevated concentrations of copper may cause an astringent metallic taste and blue staining of plumbing fixtures. Lead in concentrations above the 50 micrograms per liter level may not be detectable by taste and will not cause stains but is considered highly toxic.

Hardness

Hardness of the ground water ranged from 9 to 97 mg/L, and the mean hardness of water from all samples was 37 mg/L. Hardness was less than 34 mg/L at one-half of the sites and hardness was less than 69 mg/L at 90 percent of the sites. Hardness of ground water in most areas of stratified drift is less than or equal to 60 mg/L, which classifies the ground water as soft (Durfor and Becker, 1964). The hardness of ground water in all other areas ranged between 60 and 120 mg/L, which classifies water at these sites as moderately hard.

Specific Conductance

Specific conductance of ground water ranged from 38 to 410 microsiemens per centimeter at 25°C (tables 17 and 18). The specific conductance of water is frequently used as an indirect measure of the concentration of total dissolved solids in water (Williams and other, 1973, sheet 3, fig. 8). Consequently, specific conductance can be used as a general indication of the quality of water. Also, changes in specific conductance at a site over time frequently can be used to detect changes in ground-water quality over time. Increasing concentrations of sodium and chloride in ground water from continued use of road salts, for example, might be detected by observing an increase in specific conductance of the ground water over time.

The two ionic species that contribute most to high specific conductance are sodium and chloride. This conclusion is based on comparison of the frequency distributions of major cations and anions

Table 17.--*Statistical summary of selected chemical constituent data in ground water in stratified-drift aquifers*

[Data are in milligrams per liter except as indicated; NL = no recommended limit.]

Constituents and properties	Number of analyses	Concentration						
		Recommended limit[1]	Minimum value	Mean	Maximum value	Values in 50 percent of analyses are less than those shown	Values in 90 percent of analyses are less than those shown	Number of samples exceeding recommended limit
pH (units)	79	NL	5.4	--	7.0	6.0	6.5	--
Alkalinity (as $CaCO_3$)	80	NL	4.0	16.5	41.0	14.5	27.0	--
Hardness (Ca + Mg as $CaCO_3$)	77	NL[2]	9.0	37.3	97.0	34.5	69.2	0
Calcium	80	NL	1.6	10.0	25.0	9.1	17.0	--
Magnesium	80	NL	.9	3.1	21.0	2.3	5.9	--
Sodium	80	[3]20	2.0	15.7	54.0	11.3	30.0	19
Potassium	80	NL	.3	1.4	8.6	1.0	2.3	--
Iron	80	.3	.0	.6	19.0	.02	.57	12
Manganese	80	.05	.0	.2	2.1	.02	.62	37
Sulfate	80	250	2.0	16.7	44.0	14.9	33.0	0
Chloride	80	250	4.0	23.6	87.0	18.5	55.0	0
Nitrate (as N)	80	10	.0	1.4	16.0	.82	2.7	2
Specific conductance (microsiemens per centimeter at 25°C)	80	NL	38.0	161	410	142	280	--

[1] Recommended limits for drinking water, U.S. Environmental Protection Agency (1975; 1977; 1980).
[2] Soft water is commonly considered to have hardness concentrations between 0 and 60 mg/L (Durfor and Becker, 1964).
[3] Recommended limit for drinking water for those individuals on sodium-restricted diets (MDEQE, 1982).

Table 18.–*Concentrations of selected chemical constituents in ground water in stratified-drift aquifers*

[Analyses are in milligrams per liter except as noted; NM = no measurement.]

Samples with 15-digit station numbers ending in "OL" are domestic wells for which water quality was analyzed by Oliveira Labs, Bridgewater, Mass.; samples with 15-digit station numbers ending in "01" were collected and analyzed by the U.S. Geological Survey; and samples with 8-digit station numbers were analyzed by the DEQE (Massachusetts Department of Environmental Quality Engineering). The number following the 2-letter town or water-district prefix is the sample number assigned by the DEQE during water-quality analysis.

For U.S. Geological Survey analyses, the concentrations of calcium, magnesium, sodium, potassium, sulfate, chloride, nitrogen, iron, and manganese are dissolved fractions; whereas for DEQE and Oliveira analysis, concentrations are totals (suspended plus dissolved).

U.S. Environmental Protection Agency (1975; 1977; 1980) recommended drinking water limit for sulfate and chloride is 250 mg/L, for sodium is 20 mg/L, for nitrate is 10 mg/L, for iron is 0.3 mg/L, and for manganese is .05 mg/L. There are no recommended limits for other constituents listed.

Station number	Date of sample	Specific conductance (μs/cm)	PH (standard units)	Calcium (as Ca)	Magnesium (as Mg)	Sodium (as Na)	Potassium (as K)	Alkalinity lab (as $CaCO_3$)	Sulfate (as SO_4)	Chloride (as Cl)	Nitrogen, nitrate (as N)	Iron (as Fe)	Manganese (as Mn)
					Avon								
AV559594	01-18-82	410	6.2	23	7.2	48	2.3	41	24	75	3.99	0.02	0.1
AV559596	01-18-82	370	6.1	21	5.6	39	2.8	27	29	70	1.9	0	.14
AV559597	01-18-82	270	6.3	18	3.9	28	1.3	37	21	46	.70	0	.7
					Berkley								
415036071062501	08-22-83	55	5.9	2.9	1.2	4.6	.4	4.0	11	5.3	<.10	.19	.01
415048071050101	08-22-83	150	5.9	12	1.4	15	1.2	20	16	22	.42	.17	.01
					Bridgewater								
BR559397	11-12-81	70	6.0	5.2	1.3	4.8	.3	16	10.5	4.0	.10	1.7	.1
BR563206	02- -83	320	6.5	18	6.9	23	8.6	18	23	35	14.8	.02	.62
BR563207	02- -83	170	7.0	8.6	3.2	19	2.3	29	2.0	22	.30	.02	.22
BR563208	02- -83	310	6.3	16	6.9	22	8.4	17	21	34	16.0	0	.63
BR563209	02- -83	130	6.2	5.8	2.3	12	.5	12	18	19	.20	.48	.14
MC553586	02-05-80	170	6.2	9.0	3.3	16	1.0	17	14	29	.70	.02	.04
MC553587	02-05-80	150	6.6	17	2.6	8.0	.8	39	33	9.0	.00	1.7	.63
					Brockton								
BO559806	02-03-82	190	5.9	10	3.8	16	1.5	11	34	23	.30	0	.03
					Dighton								
DH563179	02-07-83	150	6.0	8.8	1.6	12	1.4	13	16	19	.90	.1	.08
DH563180	02-07-83	170	6.1	8.7	1.8	15	1.9	14	15	25	1.3	0	0
					East Bridgewater								
EB559855	02-08-82	140	5.9	5.8	2.7	13	1.4	11	16	21	.80	.23	.06
EB559856	02-08-82	170	6.3	14	3.8	8.2	1.4	15	35	13	.80	.2	.08
EB559857	02-08-82	130	6.0	8.1	3.9	7.7	.7	15	30	8.0	.01	.36	.09
EB561493	06-30-82	86	6.6	2.7	2.0	8.1	.6	18	7.5	9.0	.10	.03	0
					Easton								
EA557085	03-09-81	160	5.8	10	2.9	12	1.4	10	23	19	1.8	0	0
EA557086	03-09-81	185	5.9	9.5	2.1	19	2.1	12	23	24	4.0	0	.22
EA557087	03-09-81	115	5.9	7.4	2.3	8.7	1.1	15	16	10	.60	0	.25
EA559764	02-01-82	235	5.9	10	2.8	30	1.0	17	21	35	3.7	.04	0
EA561860	09-07-82	70	6.3	7.3	1.2	6.0	.5	15	8.0	6.0	.40	0	0
					Foxborough								
FO557164	03-11-81	140	6.0	8.2	1.8	11	.9	15	14	17	1.3	.02	.01
FO557165	03-11-81	106	5.9	6.4	1.6	8.5	1.0	12	14	12	.50	.08	.16
FO557167	03-11-81	150	6.0	14	2.7	19	1.0	18	20	22	1.6	.02	.08
FO557168	03-11-81	150	6.2	11	2.2	13	.9	18	9.0	21	1.0	.02	.01
FO557170	03-11-81	160	5.9	11	2.3	15	.9	10	2.0	26	.90	0	.05
FO561071	05-05-82	140	6.2	11	2.5	11	.4	18	10.5	18	1.9	0	0
					Halifax								
HA532573	06-19-75	70	6.3	3.7	1.6	7.0	.6	22	2.0	8.0	.00	.03	.01
HA539943	09-29-76	38	6.6	2.0	.9	5.0	.4	9.0	4.0	4.0	.10	0	0
HA559936	02-16-82	165	6.3	10	4.3	12	1.1	19	23	21	.10	.7	.52
HA559937	02-16-82	195	6.5	15	5.9	11	1.2	25	35	22	.00	.57	1.6
					Hanson								
HN555684	09-26-80	57	6.3	3.0	1.2	5.8	.4	7.0	5.0	7.0	.10	0	0
HN559554	01-08-82	210	6.2	19	8.0	15	2.8	27	44	27	.50	.05	.03

Table 18.--*Concentrations of selected chemical constituents in ground water in stratified-drift aquifers (continued)*

Station number	Date of sample	Specific conductance (µs/cm)	PH (standard units)	Calcium (as Ca)	Magnesium (as Mg)	Sodium (as Na)	Potassium (as K)	Alkalinity lab (as $CaCO_3$)	Sulfate (as SO_4)	Chloride (as Cl)	Nitrogen, nitrate (as N)	Iron (as Fe)	Manganese (as MN)
					Lakeville								
414847070551601	08-23-83	123	NM	8.3	1.5	6.0	2.6	14	12	5.8	2.70	.23	<.01
4149310705536OL	07-07-83	260	5.8	1.6	3.9	37.5	1.4	11	17	70	1.56	.30	<.01
4151400705628OL	08-05-83	44	5.8	2.0	1.5	<2.0	.6	4.0	4.0	8.0	<.10	.25	<.01
					Mansfield								
MN556463	12-02-80	59	5.9	3.4	1.1	7.4	1.7	15	12	7.0	.00	.02	.03
MN557437	04-01-81	96	6.2	6.0	1.4	8.6	.8	9.0	12	11	.60	.01	0
MN559585	01-11-82	120	6.0	10	2.7	5.7	.5	10	16	9.0	4.6	.05	0
MN560114	02-23-82	115	6.3	6.3	2.2	11	1.2	11	15	14	.80	.02	0
MN561298	06-03-82	115	6.0	9.1	2.4	8.4	1.1	12	12.3	10	4.7	.05	0
					Middleborough								
MI555870	10-14-80	120	6.5	13	2.0	7.0	.8	22	3.0	20	.30	.07	.05
MI560240	03-02-82	150	6.1	13	3.5	8.3	1.9	13	32	13	.80	.17	.1
MI560241	03-02-82	270	6.1	9.1	3.4	49	1.3	9.0	11	68	1.3	0	.01
MI560242	03-02-82	330	5.9	9.3	3.3	54	1.7	7.0	11	87	1.2	.02	.03
MI560244	03-02-82	310	6.9	16	3.9	39	2.0	20	17	67	1.3	.02	0
MI560245	03-02-82	140	5.7	5.0	1.9	16	1.3	13	8.0	27	.40	.18	.68
MI560247	03-02-82	140	6.0	5.2	2.0	17	1.5	10	8.0	27	1.5	0	.01
MI560248	03-02-82	180	6.0	7.1	2.2	22	1.2	11	9.0	39	.80	0	.01
MI561457	06-24-82	86	6.6	7.5	1.5	6.2	.4	16	5.8	10	.60	.03	.01
					Norton								
NT560135	02-25-82	73	6.3	5.8	1.8	6.1	.6	13	9.0	7.0	.10	.03	.2
NT560136	02-25-82	74	6.2	5.8	1.8	5.6	.5	13	12	8.0	.10	.04	.2
NT560137	02-25-82	85	6.1	6.5	1.7	8.1	.5	11	2.0	10	.90	.02	.01
NT560138	02-25-82	105	6.2	8.3	2.5	9.5	1.0	17	3.0	8.0	.70	.13	.49
NT560139	02-25-82	68	6.5	5.3	1.9	5.4	.3	16	10	6.0	.10	.01	.02
					Plainville								
PL560974	04-27-82	260	5.7	13	2.5	39	1.8	10	16	61	4.0	.03	.13
PL560975	04-27-82	195	5.6	8.7	21	26	.8	9.0	14.8	42	1.9	.09	.27
					Raynham								
RC560523	03-23-82	100	5.7	4.4	1.6	11	.9	6.0	10.5	13	.90	.73	.54
RN560775	04- -82	90	5.8	6.6	1.8	7.6	.6	9.0	13	9.0	1.4	.01	.08
RN560776	04- -82	230	5.4	13	3.0	25	2.0	6.0	35	32	2.4	.1	.81
					Sharon								
SH556982	03-02-81	76	5.9	6.5	1.4	6.7	.6	12	3.0	15	.00	.1	.02
SH557863	04-28-81	160	6.5	11	2.9	9.4	.7	28	12	15	.80	0	0
SH560610	03-30-82	140	6.0	12	2.9	10	.9	15	22.5	15	.80	0	0
					Somerset								
SM560692	04-05-82	120	6.9	6.6	1.4	11	1.0	36	15.8	6.0	.80	.04	.06
					Stoughton								
ST560717	04-05-82	125	6.3	10	3.3	7.0	.8	25	15	9.0	.80	.05	.57
ST560718	04-05-82	105	6.2	9.0	2.2	7.0	.7	17	16	10	.40	.02	.02
ST560719	04-05-82	160	6.4	9.2	2.3	13	1.1	37	13	13	.01	.01	.01
ST561995	10-01-82	200	5.9	15	3.8	21	2.9	16	12	38	2.5	.03	.01
					Taunton								
TN560757	04-13-82	90	6.0	10	2.1	4.9	.5	20	16	5.0	.70	.01	.01
TN560759	04-13-82	140	6.5	11	1.8	14	2.0	21	25	11	1.3	.17	.03
					West Bridgewater								
WB560696	04-06-82	175	5.9	11	3.2	17	2.0	13	30	22	1.5	.32	.33
WB560697	04-06-82	195	5.9	11	3.2	23	1.5	6.0	35	30	1.4	.62	.22
WB560698	04-06-82	310	6.3	21	4.7	45	1.4	22	32.5	59	.30	.27	1.3
					Whitman								
WH555882	10-08-80	250	6.0	16	7.2	17	1.2	22	25	37	.40	.67	.42
WH558809	07-29-81	280	6.1	25	8.5	25	4.0	37	34	39	.00	15	2.1
WH559491	12-13-81	300	5.7	19	7.3	29	3.2	18	36.3	55	.10	19	1.3
					Wrentham								
WR560945	04-21-82	170	6.4	12	2.1	17	.8	15	15	29	.90	.02	0

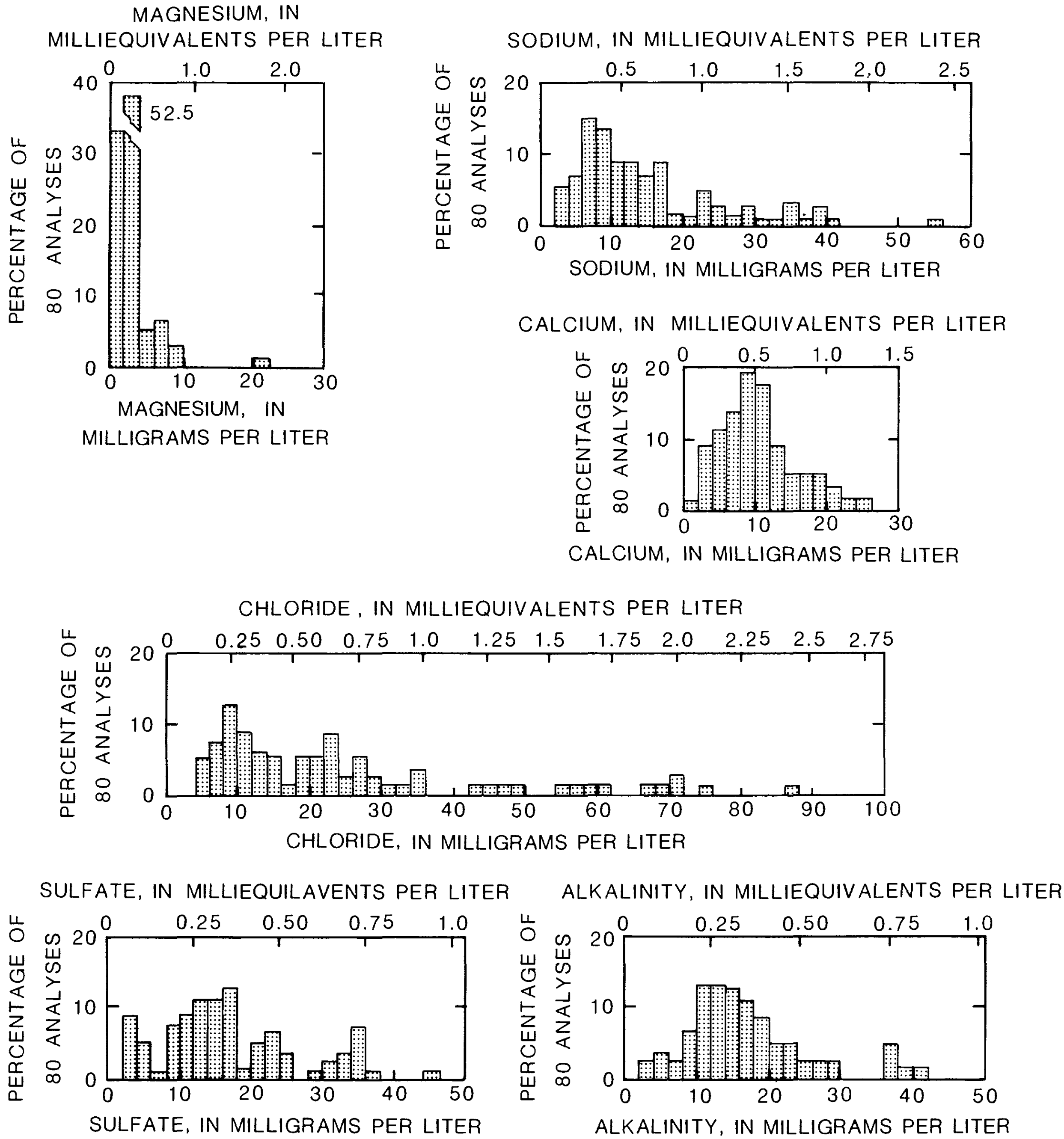


Figure 30.--Frequency distributions of major cations and anions in ground water in the stratified-drift aquifers.

illustrated in figure 30, which shows frequency distributions of concentrations of calcium, magnesium, sodium, alkalinity, sulfate, and chloride in the 80 ground-water samples used in this study. The bar graphs show the variability in concentration of each constituent among the 80 sites. For example, concentrations of calcium range from 0 to 25 mg/L with almost 50 percent of the concentrations between 8 and 12 mg/L, whereas concentrations of chloride are widely distributed between 4 and 87 mg/L. Comparison of the bar graphs in figure 30 using the milliequivalents per liter scale indicates that at relatively high concentrations (greater than or equal to 1 milliequivalent per liter), the cations and anions that contribute most to high specific conductance in the ground water are sodium and chloride, respectively. This conclusion that the high specific conductance is mostly attributable to the presence of sodium and chloride is further supported by comparing the concentrations of selected ions in the sample from station AV559594 (table 18). The concentrations of calcium, sodium, sulfate, and chloride in water from that station are 1.15, 2.09, 0.5, and 2.11 milliequivalents per liter, respectively. Comparison of these concentrations shows that there are only about one-half as many calcium and one-quarter as many sulfate equivalents in the ground water at this site as there are sodium and chloride equivalents.

Chloride

The temporal variation of chloride concentrations in ground water from five wells in the basin is shown in figure 31 and 32. These five wells are illustrated because the concentrations of chloride in these wells were among the highest shown in table 18, and because historical measurements of chloride concentrations in these wells were readily available. The three wells shown in figure 31 are located within several hundred feet of each other in the Lower Matfield-Taunton River aquifer (fig. 4) in Bridgewater, Mass. The two wells shown in figure 32 are located near major interstate highways. West Bridgewater well 3 is located near the intersection of Interstate 24 and Route 106 in the Upper Hockomock River aquifer (pl. 1, fig. 3). Middleborough Rock Road 1 is located just south of Interstate 25 in an unnamed stratified-drift aquifer.

Chloride concentrations in the two wells near the interstate highways (fig. 32) increased from 1964 to 1984, except for the decrease in the early 1980's in Middleborough Rock Road 1. The increasing chloride concentration in ground water in these two wells since the early 1960's coincides with an increase in deicing salts applied on State highways in Massachusetts from 1955 to about 1973 (Pollock and Toler, 1973; Frimpter and Gay, 1979). Chloride concentrations seem to have remained relatively constant at about 10 mg/L from the early 1950's to about 1964 in the three Bridgewater wells. After 1964, chloride concentrations gradually increased to about 30-40 mg/L in the early 1980's. The increase in chloride concentration in ground water from the three wells shown in figure 31 also might be attributable to application of deicing salts on town highways.

Iron and Manganese

Twelve of the 80 samples analyzed for iron and 37 of the 80 sites analyzed for manganese had concentrations that exceeded the recommended limits (table 17). Concentrations of these two metals that exceed the limits of 0.3 mg/L for iron and 0.05 mg/L for manganese recommended for drinking water are a common occurrence in stratified-drift aquifers in New England. These limits have been recommended primarily for aesthetic reasons. High concentrations of iron and manganese affect the taste of water and can stain both plumbing fixtures and laundered clothing. Ground water in the basin pumped for public supplies is generally treated for reduction or removal of iron and manganese before distribution if concentrations of the two metals exceed their recommended limits.

Nitrate

Nitrate concentrations were below the recommended limit of 10 mg/L (tables 17 and 18) in all but two of the 80 samples. The two samples that had nitrate concentrations that exceeded the recommended limit are from two adjacent High Street wells in the Lower Matfield-Taunton River aquifer in the Town of Bridgewater. Water from these two wells presently receives treatment for removal of nitrate prior to distribution. High nitrate concentrations are usually attributable to man's activities and the most common sources include farm-animal waste, leaching from septic tanks and

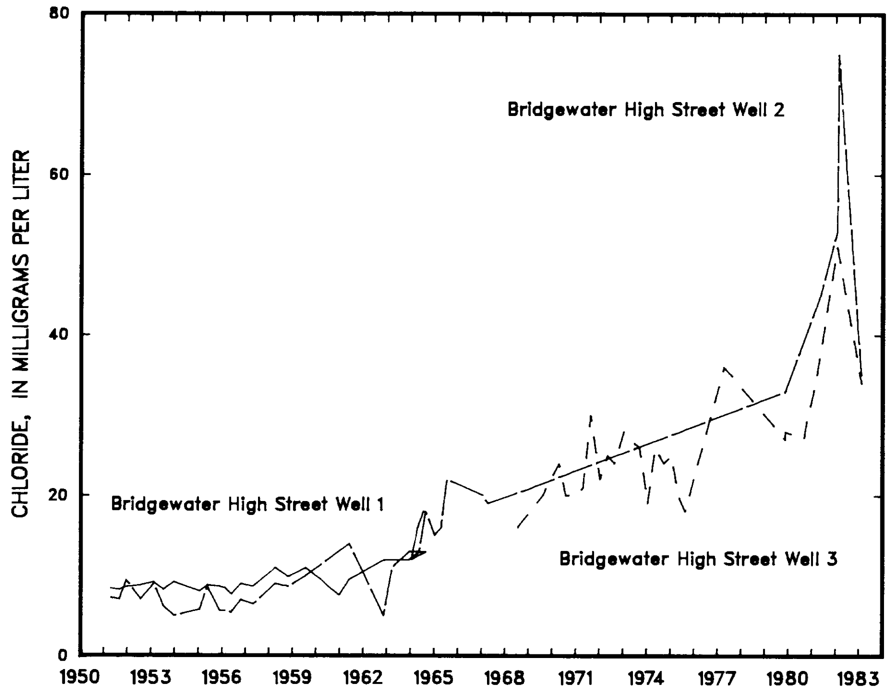


Figure 31--Temporal variation in chloride concentration in water from selected wells in the Lower Matfield-Taunton River Aquifer.

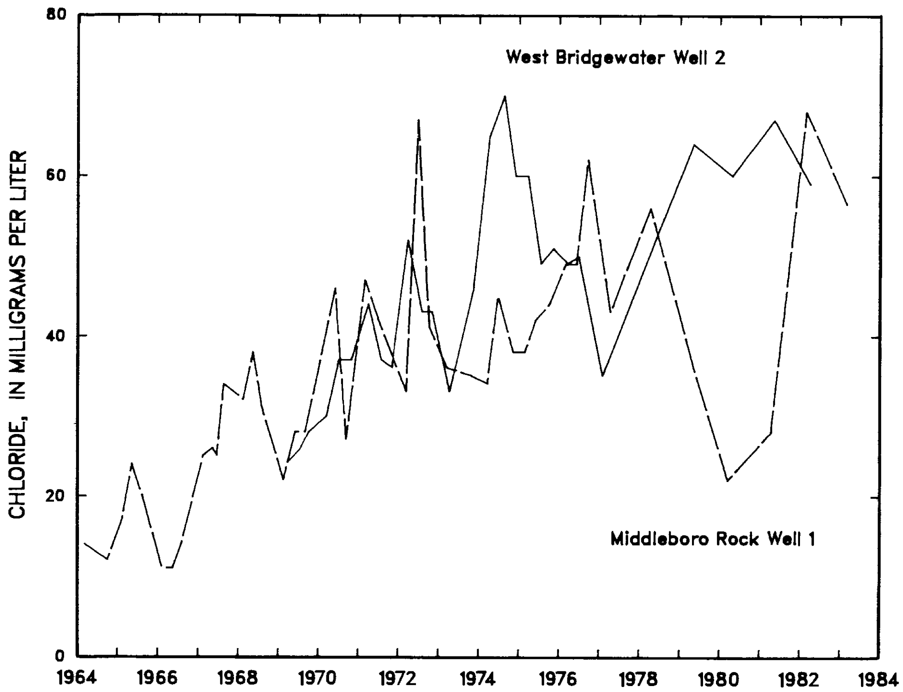


Figure 32--Temporal variation in chloride concentration in water from wells in two stratified-drift aquifers.

landfills, and runoff from fertilized agricultural land.

Temporal variation in nitrate concentration in ground water from the High Street wells in Bridgewater are shown in figure 33. Although the historical data are sparse, nitrate concentrations suddenly increased about 1965 in High Street well 2, and seems to have remained high through 1983. Nitrate concentrations were even higher in High Street well 3 during this period. The source of the nitrates to these wells has not been positively identified, and it also is not known why the concentration of nitrate in High Street well 3 is higher than that in High Street well 2, even though both wells are within several hundred feet of each other and are about 60 feet deep.

Regional Ground-Water Quality

Plate 2, which shows the locations of the 80 sampling sites in the basin, also shows the concentrations of selected major constituents in the ground water at each site using a Stiff diagram. The constituents shown on each diagram are: sodium plus potassium, chloride, calcium, alkalinity as $CaCO_3$, magnesium, sulfate, iron, and nitrate. The milliequivalents per liter of each of the eight constituents is represented by the length of the line from the vertical axis. The general chemical character of the ground water at each site at the time of sampling can be determined from the Stiff diagram. For example, relatively elevated concentrations of sodium and chloride occur in the ground water in the north part of the basin in the Towns of Avon, Sharon, and Whitman, near Route 24 in West Bridgewater, and near Route 25 in Middleborough. These relatively elevated concentrations are evident from the Stiff diagrams because of the relatively long sodium-chloride axis as compared to the length of the sodium-chloride axis on the other Stiff patterns. Elevated nitrate concentrations are evident in the two wells near High Street in Bridgewater.

Areal variation in water quality within and among stratified-drift aquifers in the basin also can be determined by comparing the variation in size and shape of the diagrams. For this comparison, it is assumed that there is no significant variation in ground-water quality over the several years the water-quality data were collected.

For example, the same shapes and sizes of the diagrams throughout the Trout Brook aquifer (pl. 1, fig. 3) indicate that the quality of the ground water is the same throughout this aquifer. All three Stiff patterns of ground-water quality in

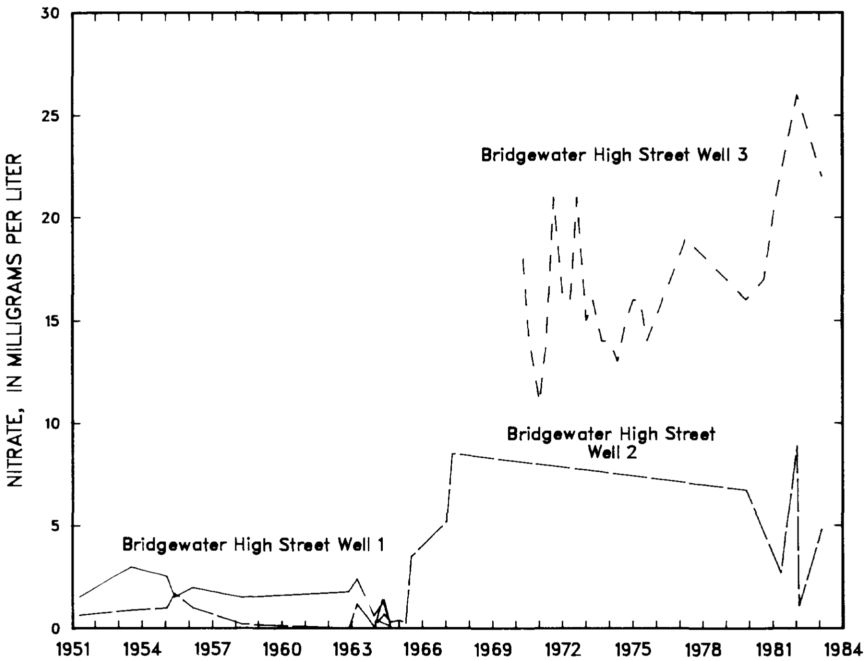


Figure 33--Temporal variation in nitrate concentration in water from selected wells in the Lower Matfield-Taunton River aquifer.

this aquifer show similar, elevated concentrations of sodium, chloride, calcium, and alkalinity. The same observations regarding the sizes and shapes of diagrams throughout the Middle Canoe River aquifer, Lower Canoe River aquifer, and Salisbury Plain River aquifer suggest that the quality of ground water is the same throughout each of these aquifers.

Comparison of diagrams among aquifers suggests that the quality of ground water in the Trout Brook and Salisbury Plain River aquifers is similar, that the quality of ground water in the Middle and Lower Canoe River Aquifers is similar, but that the quality of ground water in the Middle and Lower Canoe River aquifers is different from that in the Trout Brook and Salisbury Plain River aquifers. The concentrations of common constituents in ground water in both the Trout Brook and Salisbury Plain River aquifers are relatively elevated compared to the concentrations of these same constituents in the Middle and Lower Canoe River aquifers.

Selected Trace Metals

Fifty-one analyses (table 19) of selected trace metals in ground-water samples from stratified-drift aquifers throughout the basin were used to characterize trace metal concentrations in the ground water. The trace metals were arsenic, barium, cadmium, chromium, copper, cyanide, lead, mercury, selenium, silver, zinc, and nickel. Twenty-seven of these samples were collected and analyzed by the Survey. For the 10 constituents in table 19 that have U.S. Environmental Protection Agency (1975 and 1977) recommended drinking water limits, only lead at one sampling site had a concentration that exceeded the recommended limit of 50 μg/L (micrograms per liter). A concentration of 60 μg/L was detected in MI561193.

Summary statistics of nine of the trace metals are shown in table 20. Minimum, mean, and maximum values of the concentrations of the trace metals in table 20 provide an indication of the background concentrations of these constituents in ground water in stratified-drift aquifers in the basin.

Selected Volatile Organic Compounds

Analyses of selected organic compounds in ground water in the stratified-drift aquifers at 74 locations revealed that 13 of the samples contained one or more of the following: Chloroform; carbon tetrachloride; 1,1 dich-loroethane; 1,2 trans-dichloroethylene; tetrachloroethylene; toluene; 1,1,1 trichloroethane; and trichloroethylene (table 21).

The U.S. Environmental Protection Agency has set Maximum Contaminant Levels (MCLs) for community water systems for 8 synthetic organic compounds (U.S. Environmental Protection Agency, 1985). These eight compounds and their MCLs are: Trichloroethylene, 5 μg/L; carbon tetrachloride, 5 μg/L; vinyl chloride, 1 μg/L; 1,2-dichloroethane, 5 μg/L; benzene, 5 μg/L; 1,1-dichloroethylene, 7 μg/L; 1,1,1-trichloroethane, 200 μg/L; and p-dichlorobenzene, 750 μg/L. As noted above, three of these compounds were detected. Trichloroethylene was detected in five samples. The concentration of trichloroethylene in one of these five samples exceeded the limit of 5 μg/L. A concentration of carbon tetrachloride of 0.8 μg/L was detected in one sample, which is below the MCL of 5 μg/L. Concentrations of 1,1,1 trichloroethane were detected in ten samples, but none exceeded the MCL for that compound.

SUMMARY AND CONCLUSIONS

This report presents estimated yields for 26 selected aquifers located in the northern half of the Taunton River basin and describes the quality of ground water in stratified drift in the basin.

Glacial stratified-drift deposits form the major aquifers in the basin. These aquifers are long, narrow, and thin; their saturated thicknesses range from about 20 feet to somewhat more than 100. Aquifer widths range from about 0.1 to 1.5 miles, and lengths range from about 1 to 5 miles. These aquifers are composed of layers of sand and gravel with some interbedded layers of silt and clay.

Estimates of yields available from aquifer storage for the 26 aquifers were made to determine yields available during severe drought. For a 30-day pumping period, yields range from 2.6 ft^3/s from the Lower West Meadow Brook aquifer to 15.0 ft^3/s from the Lower Canoe River aquifer. Fourteen of the 26 aquifers have yields that are less than 5 ft^3/s, seven have yields of from 5 to 10 ft^3/s,

Table 19.--*Concentrations of selected trace metals in ground water in stratified-drift aquifers*

[Analyses are in micrograms per liter except as noted; <0.01 = concentration of trace metal is less than analysis detection limit of 0.01 mg/L; NM = not measured.]

Samples with 15-digit station numbers were collected and analyzed by the U.S. Geological Survey; samples with 8-digit station numbers were analyzed by the DEQE (Massachusetts Department of Environmental Quality Engineering). The number following the two-letter town prefix is the sample number assigned by DEQE during water-quality analysis.

U.S. Environmental Protection Agency (1975; 1977) recommended limit for drinking water for mercury is 2 ug/L; for selenium and cadmium is 10 ug/L; for arsenic, chromium, lead, and silver is 50 ug/L; for barium and copper is 1000 ug/L; and for zinc is 5000 ug/L. There are no recommended drinking water limits for cyanide, nickel, tin.

Station number	Date of sample	Arsenic total (As)	Barium total recoverable (Ba)	Cadmium total recoverable (Cd)	Chromium total Recoverable (Cr)	Copper total recoverable (Cu)	Cyanide total (mg/l Cn)	Lead total (Pb)	Mercury total (Hg)	Selenium total (Se)	Silver total (Ag)	Zinc total recoverable (Zn)	Nickel (Ni)	Tin (Sn)
						Avon								
AV527766	10-18-74	NM	NM	NM	0	0	NM	NM	NM	NM	NM	50	0	NM
AV527767	10-18-74	NM	NM	NM	0	250	NM	NM	NM	NM	NM	0	0	NM
AV527768	10-18-74	NM	NM	NM	0	20	NM	NM	NM	NM	NM	50	200	NM
AV527769	10-18-74	NM	NM	NM	0	0	NM	NM	NM	NM	NM	0	0	NM
AV547130	09-13-78	NM	NM	NM	0	NM	NM	0	NM	NM	NM	0	0	<0.10
AV547131	09-13-78	NM	NM	NM	0	NM	NM	0	NM	NM	NM	0	0	<.10
						Berkely								
415036071062501	08-22-83	1	100	1	10	58	<0.01	NM	NM	<1	NM	120	NM	NM
415048071050101	08-22-83	1	100	1	10	220	<.01	NM	NM	<1	NM	10	NM	NM
						Bridgewater								
BR559419	11-16-81	2	10	0	0	NM	NM	0	0.2	0	0	NM	NM	NM
415831070580501	08-16-83	1	100	1	10	51	<.01	NM	NM	<1	NM	10	NM	NM
415953070561601	08-16-83	2	<100	<1	20	31	<.01	NM	NM	<1	NM	20	NM	NM
						Brockton								
BO558870	07-30-81	3	<100	0	0	NM	NM	0	.1	3	0	NM	NM	NM
						East Bridgewater								
EB561489	06-30-82	NM	NM	0	0	10	NM	0	NM	NM	NM	10	0	NM
EB561493	06-30-82	NM	NM	0	0	0	NM	0	NM	NM	NM	20	0	NM
420104070540701	08-18-83	1	100	1	10	90	<.01	NM	NM	<1	NM	20	NM	NM
420121070541501	08-18-83	1	100	1	10	64	<.01	NM	NM	<1	NM	20	NM	NM
420144070541301	08-18-83	1	100	<1	10	96	<.01	NM	NM	<1	NM	10	NM	NM
						Easton								
EA561860	09-07-82	0	50	0	0	NM	NM	0	0	0	0	NM	NM	NM
420301071054701	08-15-83	1	100	1	10	43	<.01	NM	NM	<1	NM	20	NM	NM
420326071053101	08-15-83	1	100	<1	10	32	<.01	NM	NM	<1	NM	10	NM	NM
						Foxborough								
420477071123601	08-22-83	1	100	1	<10	55	<.01	NM	NM	<1	NM	100	NM	NM
						Halifax								
415941070501301	08-16-83	2	100	1	10	62	<.01	NM	NM	<1	NM	30	NM	NM
420011070521801	08-16-83	2	<100	1	<10	63	<.01	NM	NM	<1	NM	110	NM	NM
						Hanson								
HN558799	07-28-81	10	<100	0	0	NM	NM	0	.2	2	0	NM	NM	NM
						Lakeville								
414847070551601	08-23-83	1	100	1	20	110	<.01	NM	NM	<1	NM	20	NM	NM
415140070562801	08-23-83	1	100	1	10	87	<.01	NM	NM	<1	NM	100	NM	NM

Table 19.--*Concentrations of selected trace metals in ground water in stratified-drift aquifers (continued)*

Station number	Date of sample	Arsenic total (As)	Barium total recoverable (Ba)	Cadmium total recoverable (Cd)	Chromium total recoverable (Cr)	Copper total recoverable (Cu)	Cyanide total (mg/l (Cn)	Lead total (Pb)	Mercury total (Hg)	Selenium total (Se)	Silver total (Ag)	Zinc total recoverable (Zn)	Nickel (Ni)	Tin (Sn)
						Mansfield								
MN555535	09-03-80	5	0	0	0	NM	NM	0	0	0	0	NM	NM	NM
MN556463	12-02-80	0	140	0	0	NM	NM	0	.1	2	0	NM	NM	NM
MN561298	06-03-82	0	0	0	0	NM	NM	0	0	0	0	NM	NM	NM
MN565030	07-18-83	0	50	0	1	NM	NM	1	0	0	0	NM	NM	NM
420015071162501	08-18-83	1	100	1	10	48	<.01	NM	NM	<1	NM	20	NM	NM
420058071101701	08-18-83	1	<100	1	10	100	<.01	NM	NM	<1	NM	40	NM	NM
						Middleborough								
MI555870	10-16-80	NM	10	NM	NM	NM	NM	NM	NM	4	NM	NM	NM	NM
MI561193	05-21-82	NM	NM	0	0	430	NM	60	NM	NM	NM	60	0	NM
MI561490	06-29-82	3	0	0	2	NM	NM	2	0	0	4	NM	NM	NM
415047070513101	08-17-83	1	<100	1	10	110	<.01	NM	NM	<1	NM	40	NM	NM
415124070512501	08-17-83	1	<100	1	10	61	<.01	NM	NM	<1	NM	30	NM	NM
415256070543301	08-15-83	2	200	1	10	30	<.0to1	NM	NM	<1	NM	30	NM	NM
						Norton								
415718071094001	08-17-83	1	100	1	10	58	<.01	NM	NM	<1	NM	50	NM	NM
415825071082701	08-17-83	1	<100	<1	<10	50	<.01	NM	NM	<1	NM	10	NM	NM
415936071093501	08-17-83	1	100	1	20	53	<.01	NM	NM	<1	NM	20	NM	NM
						Plainville								
420036071184301	08-19-83	2	200	1	10	50	<.01	NM	NM	<1	NM	20	NM	NM
						Raynham								
RN560543	03-29-82	0	<10	0	4	NM	NM	0	.1	0	0	NM	NM	NM
						Sharon								
420515071113601	08-14-83	1	100	1	10	36	<.01	NM	NM	<1	NM	20	NM	NM
420523071125301	08-19-83	2	<100	1	<10	49	<.01	NM	NM	<1	NM	30	NM	NM
						West Bridgewater								
WB556019	11-03-80	0	100	0	0	NM	NM	0	.4	0	0	NM	NM	NM
WB562694	11-23-82	0	0	0	4	NM	NM	0	0	0	0	NM	NM	NM
420202071000801	08-15-83	1	100	1	10	69	<.01	NM	NM	<1	NM	30	NM	NM
420212070595001	08-23-83	1	100	1	10	48	<.01	NM	NM	<1	NM	10	NM	NM
						Whitman								
WH555332	10-08-80	0	10	0	0	NM	NM	0	0	9	0	NM	NM	NM
WH559498	12-15-81	2	80	10	0	NM	NM	0	0	0	0	NM	NM	NM

Table 20.--*Statistical summary of selected trace metal concentrationdata in ground water in stratified-drift aquifers*

[Data are in micrograms per liter except as indicated; NL = no recommended limit.]

Constituent	Number of analyses	Concentration				
		Recom-mended limit[1]	Minimum value	Mean	Maximum value	Number of samples exceeding recommended limit
Arsenic	41	50	0	1.4	10.0	0
Barium	42	1,000	0	63.1	200	0
Cadmium	44	10	0	.8	10.0	0
Chromium	50	50	0	5.4	20.0	0
Copper	34	1,000	0	74.5	430	0
Cyanide	27	NL	0	.0	.0	--
Lead	19	50	0	3.3	60.0	1
Mercury	14	2.0	0	.1	.4	0
Selenium	42	10	0	.5	9.0	0
Silver	14	50	0	.3	4.0	0
Zinc	36	5,000	0	31.7	120	0
Nickel	9	NL	0	22.2	200	--

[1]Recommended limits for drinking water (U.S. Environmental Protection Agency, 1975; 1977).

Table 21.--*Concentrations of selected volatile organic compounds in ground water in stratified-drift aquifers*

[Analyses are in micrograms per liter; <0.1 = concentration of compound is less than analysis detection limit of 0.1 µg/L; NM = not measured; ND = not detected.]

Samples with 15-digit station numbers were collected and analyzed by the U.S. Geological Survey; samples with 8-digit sample numbers were analyzed by the DEQE (Massachusetts Department of environmental Quality Engineering).The number following the two-letter town prefix is the sample number assigned by the DEQE during water-quality analysis.

Station number	Date of sample	Benzene total	Bromoform total	Carbon-tetrachloride total	Chlorobenzene total	Chlorodibromomethane total	Chloroethane total	2-Chloroethylvinyl-ether total	Chloroform total	Dichlorobromomethane total	Dichlorodifluoromethane total	1,1-Dichloroethane total	1,2-Dichloroethane total
						Avon							
AV001907	07-15-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
AV001908	07-15-80	NM	ND	ND	NM	ND	NM	NM	0.2	ND	NM	1.0	ND
AV001909	07-15-80	NM	ND	ND	NM	ND	NM	NM	.1	ND	NM	1.0	ND
AV001910	07-15-80	NM	ND	ND	NM	ND	NM	NM	.4	ND	NM	1.6	ND
						Berkley							
415036071062501	08-22-83	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
415048071050101	08-22-83	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
						Bridgewater							
BR000190	02-13-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
BR000191	02-13-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
BR000192	02-13-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
BR000193	02-13-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
BR001626	06-30-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
BR005589	11-23-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
MC000194	02-20-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
MC000195	02-20-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
						Brockton							
BO004909	08-05-81	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
						Dighton							
DH004221	05-11-81	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
						East Bridgewater							
EB001430	06-02-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
EB001431	06-02-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
EB001432	06-02-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
EB006877	07-30-82	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
EB006878	07-30-82	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
						Easton							
EA000378	03-10-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
EA000379	03-10-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
EA000380	03-10-80	NM	ND	.8	NM	ND	NM	NM	ND	ND	NM	NM	ND
EA000381	03-10-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
EA007271	09-15-82	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
EA007656	10-26-82	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
						Foxborough							
FO003224	12-17-81	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
FO003225	12-17-81	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
FO003785	04-03-81	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
FO003786	04-03-81	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
						Halifax							
HA003356	01-23-81	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
HA003357	01-23-81	NM	ND	ND	NM	ND	NM	NM	0.4	ND	NM	ND	ND
420011070521801	08-16-83	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
						Hanson							
HN003099	12-08-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
HN003100	12-08-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
						Lakeville							
414847070551601	08-23-83	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
415140070562801	08-23-83	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0

Table 21.–*Concentration of selected volatile organic compounds in ground water in stratified-drift aquifers (continued)*

1,1-Dichloroethylene total	1,2 Transdichloroethylene total	1,2-Dichloropropane total	1,3-Dichloropropane total	Ethylbenzene total	Methylbromide total	Methylene chloride total	1,1,2,2 Tetrachloroethane total	Tetrachloroethylene total	Toluene total	1,1,1-Trichloroethane total	1,1,2-Trichloroethane total	Trichloroethylene total	Trichlorofluoromethane total	Vinyl chloride total
Avon														
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	2.0	NM	0.5	NM	NM
ND	0.2	NM	NM	NM	NM	ND	NM	ND	NM	.2	NM	.1	NM	NM
ND	.2	NM	NM	NM	NM	ND	NM	4.9	NM	.3	NM	.6	NM	NM
ND	1.4	NM	NM	NM	NM	ND	NM	.6	1.6	5.9	NM	6.7	NM	NM
Berkley														
<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Bridgewater														
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
Brockton														
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
Dighton														
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
East Bridgewater														
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
Easton														
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	.7	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
Foxborough														
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
Halifax														
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Hanson														
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
Lakeville														
<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0

Table 21.--*Concentrations of selected volatile organic compounds in ground water in stratified-drift aquifers (continued)*

Station number	Date of sample	Ben-zene total	Bromo-form total	Carbon-tetra-chlo-ride total	Chlor-oben-zene total	Chloro-dibromo-methane total	Chloro-ethane total	2-Chlo-roethyl-vinyl-ether total	Chlor-oform total	Di-Chloro-bromo-methane total	Dichlo-ro-di-fluoro-methane total	1,1-Di-chloro-ethane total	1,2-Di-chloro-ethane total
						Mansfield							
MN001198	05-13-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
MN001199	05-13-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
MN001201	05-13-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
MN002268	09-05-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
MN003098	12-08-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
MN004328	05-13-81	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
MN006734	06-22-82	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
						Middleborough							
MI000184	02-19-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
MI000185	02-19-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
MI000186	02-20-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
MI000187	02-20-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
MI000188	02-20-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
MI000189	02-20-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
MI001904	07-22-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
MI001905	07-22-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
MI002674	10-22-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
MI006870	07-30-82	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
						Norton							
NT000563	04-14-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
NT000564	04-14-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
NT000565	04-15-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
NT000566	04-14-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
						Plainville							
PL001195	05-08-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
PL001196	05-08-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
						Raynham							
RC000386	03-14-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
RN006233	04-06-82	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
						Sharon							
SH003783	03-11-81	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
SH003784	03-11-81	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
						Somerset							
SM001900	07-21-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
						Stoughton							
ST003228	12-17-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
ST003229	12-17-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
ST003230	12-17-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
						West Bridgewater							
WB000382	03-12-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
WB000383	03-12-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
WB000384	03-12-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND
						Whitman							
WH005742	12-13-81	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	ND	ND
						Wrentham							
WR000562	04-14-80	NM	ND	ND	NM	ND	NM	NM	ND	ND	NM	NM	ND

Table 21.–*Concentration of selected volatile organic compounds in ground water in stratified-drift aquifers (continued)*

1,1-Dichloroethylene total	1,2 Transdichloroethylene total	1,2-Dichloropropane total	1,3-Dichloropropane total	Ethylbenzene total	Methylbromide total	Methylene chloride total	1,1,2,2 Tetrachloroethane total	Tetrachloroethylene total	Toluene total	1,1,1-Trichloroethane total	1,1,2-Trichloroethane total	Trichloroethylene total	Trichlorofluoromethane total	Vinyl chloride total
							Mansfield							
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	9.5	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
							Middleborough							
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
							Norton							
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
							Plainville							
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	22.4	NM	ND	NM	MN
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	7.8	NM	ND	NM	NM
							Raynham							
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
							Sharon							
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	.1	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
							Somerset							
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
							Stoughton							
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	1.2	NM	ND	NM	NM
							West Bridgewater							
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM
							Whitman							
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	.6	NM	NM
							Wrentham							
ND	ND	NM	NM	NM	NM	ND	NM	ND	NM	ND	NM	ND	NM	NM

and five have yields of from 10 to 15 ft^3/s. For a 180-day pumping period, yields range from 1.6 ft^3/s from the Upper Canoe and Upper Wading River aquifers to 10.5 ft^3/s from the Lower Canoe River aquifer. Nineteen of the 26 aquifers have yields that are less than 5 ft^3/s, six have yields of from 5 to 10 ft^3/s, and one has a yield of 10.5 ft^3/s.

Estimates of yields available from intercepted ground-water discharge, induced infiltration, and storage for the 26 aquifers were made to determine yields available under normal climatic conditions. Two sets of estimates of yields were made for each of the aquifers. For the first set of estimates, aquifer yields were calculated for the condition where stream discharge does not decrease below the discharge that is equaled or exceeded 99.5 percent of the time. For the second set of estimates, aquifer yields were calculated for the condition where stream discharge does not decrease below the discharge that is equaled or exceeded 95 percent of the time.

The Lower Matfield-Taunton River aquifer and the Lower Canoe River aquifer have the highest yields of the 26 aquifers. Yields of these two aquifers equal or exceed 11.9 and 11.3 ft^3/s for 90 percent of the time, respectively, if minimum stream discharge is maintained at 99.5-percent flow duration.

Pumping for public water supply occurred in 18 of the 26 aquifers during 1983. Of these 18 aquifers, the Upper Queset Brook aquifer was pumped at the highest rate relative to its yield. The Upper Queset Brook aquifer was pumped at a rate of 1.9 ft^3/s and could sustain this pumping rate for about 70 percent of the time if the discharge is maintained at 99.5-percent flow duration. The Lower Matfield-Taunton River aquifer, Lower Canoe River aquifer, and Upper Hockomock River aquifer, were pumped at the lowest rates relative to their yields. All four of these aquifers could sustain their 1983 pumping rate for at least 98 percent of the time if the discharge is maintained at 99.5-percent flow duration.

Well interference between aquifers in the northern part of the basin during simultaneous pumping does not appreciably decrease individual aquifer yield. This occurs because most of the aquifers are separated by relatively low-transmissivity deposits, which isolates them hydraulically from nearby aquifers. However, development of upstream aquifers can affect the yield of downstream aquifers because of reduced stream discharge available for infiltration.

The aquifer yields estimated in this study were based on simplified geometric and hydraulic properties of the aquifers. The yield estimates were made assuming conditions that existed prior to any aquifer development. The ground-water-flow models constructed in this study were used to assess aquifer yields on a regional basis. The models were used in place of image well models, and were not designed to investigate the effect of local aquifer development on ground-water levels and ground-water-flow patterns or to determine optimum locations of well fields. The models were used as tools with which to test and estimate certain factors contributing to aquifer yield, rather than as fully tested and calibrated predictive simulators.

The yield estimates presented in this report may prove useful in (1) assessing the potential of an aquifer to sustain current or future withdrawals during normal and drought conditions; (2) planning and managing the regional development of the water resources for all uses in the basin; and (3) assessing the need for and effects of interbasin and intrabasin transfer of water.

Selected physical properties and concentrations of major constituents in ground water from the stratified-drift aquifers at 80 sampling sites were used to characterize general ground-water quality in the stratified-drift aquifers.

The pH of the ground water ranged from 5.4 to 7.0. At half of the sites, pH was less than 6.0, and at 90 percent of the sites, pH was less than 6.5. Hardness of the ground water ranged from 9 to 112 mg/L. Mean hardness was 37 mg/L. Hardness at half of the sites was less than 34 mg/L, and hardness at 90 percent of the sites was less than 69 mg/L. At 86 percent of the sites, the ground water had hardness concentrations less than or equal to 60 mg/L, which classifies the ground water at these sites as soft. At the remaining 14 percent of the sites, hardness ranged between 60 and 120 mg/L, which classifies water at these sites as moderately hard.

No concentrations of sulfate or chloride that exceeded recommended limits for drinking water (U.S. EPA, 1975, 1977, 1980) were found in the ground water. However, concentrations of sodium exceeded the Massachusetts recommended limit for drinking water for those individuals on a sodium-restricted diet of 20 mg/L in 19 of the samples.

Elevated natural concentrations of iron and manganese in ground water in the stratified-drift aquifers exist locally throughout the basin. Natural concentrations of these two metals commonly exceed the limits of 0.3 mg/L for iron and 0.05 mg/L for manganese recommended for drinking water. Twelve of the 80 samples analyzed for iron and 37 of the 80 samples analyzed for manganese had concentrations that exceeded the recommended limits.

Fifty-one analyses of selected trace metals in ground-water samples from stratified-drift aquifers throughout the basin were used to characterize trace metal concentrations in the ground water. The trace metals were arsenic, barium, cadmium, chromium, copper, cyanide, lead, mercury, selenium, silver, zinc, and nickel. For the 10 constituents sampled that have U.S. Environmental Protection Agency recommended drinking water limits, only lead had a concentration (60 µg/L) that exceeded the recommended limit of (50 µg/L) at one site.

Analyses of selected organic compounds in ground water in the stratified-drift aquifers at 74 sites throughout the basin were used to investigate the presence of organic compounds. In 13 of the analyses, one or more of the following compounds were detected: Chloroform; carbon tetrachloride; 1,1 dichloroethane; 1,2 transdichloroethylene; tetrachloroethylene; toluene; 1,1,1 trichloroethane; and trichloroethylene. None of the samples in which organic compounds were detected had concentrations of these compounds that exceeded the MCLs proposed by the U.S. Environmental Protection Agency.

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