Streamflow, Ground-Water Recharge and Discharge, and Characteristics of Surficial Deposits in Buzzards Bay Basin, Southeastern Massachusetts

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Abstract

Streamflow measurements at 14 low-flow partial-record stations and two discontinued streamflow-gaging stations were related to concurrent streamflows at six long-term streamflow-gaging stations to estimate streamflows at selected flow durations from 50 to 99 percent for water years 1967-91. At low flows, stream discharge per square mile generally increased with increasing percentage of subbasin underlain by stratified-drift deposits. At the 70-, 90-, and 99-percent flow durations, subbasins underlain primarily by stratified-drift deposits had stream discharges per square mile at least 2, 4, and 8 times greater, respectively, than subbasins underlain primarily by till and bedrock deposits. Streamflow measured three times at the Paskamanset River showed that streamflows downstream of municipal pumped wells increased at a lower rate per unit drainage area than streamflows upstream of the pumped wells. When pumpage from wells near the river was added to measured streamflow at the most downstream station, the sum was similar to the potential streamflow at the station if its streamflow per unit area was the same as that upstream from the pumped wells.

Mean ground-water recharge and discharge rates were computed from continuous records of daily mean discharge during water years 1967-91 for six streamflow-gaging stations in southeastern Massachusetts and Rhode Island. Estimates of mean ground-water recharge were 19.7 to 22.6 inches per year for stations with drainage areas primarily underlain by till and bedrock deposits, and 23.8 to 25.2 inches per year for stations with drainage areas primarily underlain by stratified-drift deposits. During drought years, annual ground-water recharge can be less than 50 percent of the mean ground-water recharge rate for water years 1967-91. Estimates of ground-water discharge rates generally were 1 to 4 inches per year less than estimates of ground-water recharge rates.

Ground-water discharge-duration curves were calculated from hydrograph separation of streamflow records at the six continuous streamflow-gaging stations for water years 1967-91. When streamflows were less than the median streamflow (50-percent duration), ground-water discharges averaged 85.7 percent of the total streamflow at the six streamflow-gaging stations. Ground-water discharges were estimated at the 14 low-flow partial-record stations and two discontinued streamflow-gaging stations by multiplying streamflows at the selected flow durations from 50 to 99 percent for water years 1967-91 by 85.7 percent.

Data on surficial deposits in the basin were obtained by drilling 10 wells, by conducting 12 seismic-refraction surveys, and by collecting well log data for 313 wells from consulting firms and the Massachusetts Department of Environmental Management. These data indicated that a few minor corrections could be made to existing saturated thickness maps for stratified-drift deposits in Buzzards Bay Basin. Few well logs were detailed enough to estimate transmissivities; thus existing transmissivity maps were not updated for stratified-drift deposits in the basin.

INTRODUCTION

Buzzards Bay Basin in southeastern Massachusetts is drained by several rivers discharging into Buzzards Bay and Rhode Island Sound. The 374 mi^2 basin extends west from the Cape Cod canal to the Massachusetts-Rhode Island border (fig. 1).

Only 10 of the 14 towns and 2 cities that are partly or completely in Buzzards Bay Basin had public water-supply systems in 1992. Seven municipalities had ground-water-supply wells completed in stratified-drift deposits within the basin's boundaries, and three municipalities relied entirely on surface-water supplies. Residents in areas without public water-supply systems depend primarily on private wells completed in bedrock. Water-supply sources were adequate to meet demands in 1992; however, water shortages have occurred in Buzzards Bay Basin during droughts in the mid-1960's and early 1980's. If the population in Buzzards Bay Basin increases, some municipalities may need to consider development of additional ground-water resources in the basin.

This hydrologic study of the Buzzards Bay Basin began in April 1991 and was done by the U.S. Geological Survey (USGS), in cooperation with the Massachusetts Department of Environmental Management, Division of Resource Conservation, Office of Water Resources. This study of basin hydrology is one of several under the Massachusetts Chapter 800 legislation of 1979, which provides quantitative assessments of ground-water resources and related hydrologic studies in basins of the State.

The purpose of this report is to (1) provide estimates of streamflows for streams in Buzzards Bay Basin, (2) provide estimates of ground-water recharge and discharge in the basin, and (3) update previously described characteristics of surficial deposits in the basin. This report is based on hydrologic and geologic data collected during 1991-92, data in existing USGS data bases, and data compiled from other water-resources studies.

Streamflows were estimated for selected streams draining Buzzards Bay Basin. In addition, the relation of streamflow to surficial deposits and the effects of ground-water withdrawals on streamflow were evaluated. Ground-water recharge rates for the basin were estimated through analysis of hydrographs at continuous streamflow-gaging stations in southeastern Massachusetts and Rhode Island. Ground-water discharges were estimated for selected streams draining the basin. Information on saturated thickness and (or) lateral extent of stratified-drift deposits in the basin were updated where possible. Hydrogeologic information was not collected for the previously studied Mattapoisett River subbasin and Plymouth-Carver aquifer area described by Olimpio and de Lima (1984) and Hansen and Lapham (1992).

Information in this report will be useful for water managers in understanding characteristics of streamflows and ground-water discharge to streams in the basin, evaluating the effect of ground-water pumping on streamflows, determining the contributing areas to wells for various climatic conditions, determining response of ground-water levels to climatic variations, identifying potential sources of ground water for public supply, and predicting yield for individual wells and well fields.

Water resources in Buzzards Bay Basin have been described in several USGS reports published in the last 20 years. Ground-water resources, streamflow, and water quality for the basin were described by Williams and Tasker (1974), Willey and others (1978), and Williams and Tasker (1978). These three reports presented saturated thickness and transmissivity maps, and other water-resources information for the basin. Ground-water, surface-water, and water-quality data were presented by Williams and others (1977), Williams and others (1980), and Willey and others (1983).

The reports for basin hydrology studies done during the 1980's under the Massachusetts Chapter 800 legislation provide detailed hydrologic and geologic information for the Mattapoisett River subbasin (Olimpio and de Lima, 1984) and for the Plymouth-Carver aquifer area (Hansen and Lapham, 1992). These reports also describe models used to demonstrate the effects of ground-water withdrawals on ground-water and surface-water resources within their areas of study. Additional reports for basin hydrology studies done under the Massachusetts Chapter 800 legislation by the USGS provide information on ground-water resources in the nearby Taunton River Basin (Lapham, 1988) and the Southeast Coastal Basin (Persky, 1993).

Tasker (1972), Wandle and Keezer (1984), and Wandle and Morgan (1984) provide hydrologic characteristics of the streams in Buzzards Bay Basin. Additional information regarding the ground-water resources of the basin, including lithologic logs,

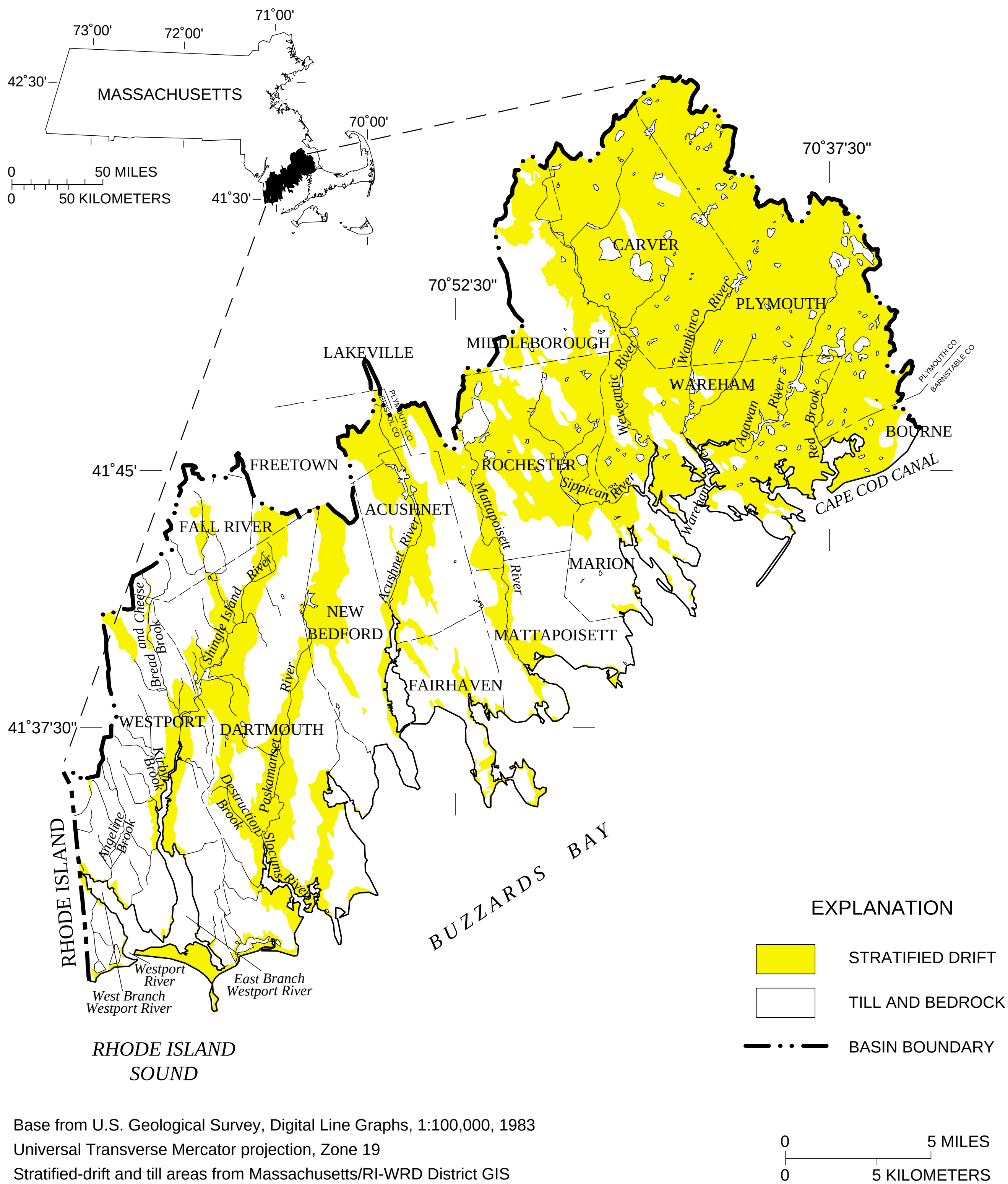


Figure 1. Location of study area, and stratified-drift and till and bedrock deposits in Buzzards Bay Basin, southeastern Massachusetts.

seismic-refraction surveys, and location maps were provided by consulting firms. These hydrologic and geologic studies were done to locate additional ground-water sources for municipalities, to describe sites for future landfills, and to describe contaminated sites for remediation that are currently on the National Priority List of the U.S. Environmental Protection Agency.

The author thanks the many private individuals and consulting firms, and public officials and agencies, who provided assistance and information during this study. Valuable hydrologic and geologic data were provided by the Massachusetts Department of Environmental Management, Division of Resource Conservation, Office of Water Resources, and the Massachusetts Department of Environmental Protection, Office of Watershed Management. Precipitation data were provided by the Cranberry Experiment Station in Wareham, New Bedford Water Treatment Plant in Rochester, New Bedford Engineering Department, and Dartmouth Water Department. Finally, special thanks and appreciation is due to municipalities and private landowners, who granted permission to the USGS to install and monitor observation wells and to conduct seismic-refraction surveys on their property.

DESCRIPTION OF STUDY AREA

Buzzards Bay Basin is located in southeastern Massachusetts in parts of Barnstable, Bristol, and Plymouth Counties (fig. 1). A large part of the basin is rural, with sparsely settled woodlands, brushland, agricultural lands, and wetlands. Urban and suburban areas are in and adjacent to the cities of New Bedford and Fall River. Population in the rural areas has increased since the 1970’s with the completion of a major highway that transects the study area and provides residents access to major cities in an hour or less. Rural areas of the basin are farmed, primarily for cranberries. Cranberry bogs are primarily in the eastern part of the basin in the Sippican, Weweantic, Wankinco, and Agawam River subbasins.

Topographic Setting

Buzzards Bay Basin lies within the Lowlands Physiographic Province of New England. From the Sippican River subbasin eastward, the land is flat or gently rolling. The land west of the Sippican River subbasin consists primarily of low relief valley and ridge landforms following the several south-flowing rivers. Land-surface altitudes range from sea level to more than 350 ft above sea level in the western part of the basin.

The basin is drained by several rivers (Wareham, Weweantic, Mattapoisett, Acushnet, Slocums, and Westport) that flow towards the south and discharge into Buzzards Bay and Rhode Island Sound. The Wareham, Weweantic, Slocums, and Westport River subbasins are drained by Agawam and Wankinco Rivers; Weweantic and Sippican Rivers; Destruction Brook and Paskamanset River; and East Branch Westport (Bread and Cheese Brook, Kirby Brook, and Shingle Island River) and West Branch Westport Rivers (Adamsville and Angeline Brooks), respectively (fig. 1).

Geologic Setting

Buzzards Bay Basin is underlain primarily by granitic and metamorphic rocks. The depth to bedrock ranges from land surface to about 100 ft below land surface at headwaters (northern part of basin) of several of the rivers draining the basin (Willey and others, 1978, sheet 1; Williams and Tasker, 1978, sheet 1) and from land surface to about 200 ft below land surface in one area of the Plymouth-Carver aquifer area (Hansen and Lapham, 1992, p. 15, 16, and pl. 2).

The surficial deposits overlie most of the bedrock in the basin and were deposited during the last glacial period. The retreat of the glacial ice sheet, which covered the basin, began about 15,000 years ago, and southeastern Massachusetts was ice free within 1,000 years (Larson, 1982, p. 111). Most of the glacial landforms are the result of events that occurred during the retreat of the glacial ice sheet (Hansen and Lapham, 1992, p. 7).

Surficial deposits in the basin are primarily till and stratified-drift deposits. Till, an unsorted, unstratified mixture of clay, silt, sand, gravel, cobbles, and boulders, was deposited by glaciers on bedrock throughout much of the basin. The till is overlain by stratified drift in large parts of the basin. Melvin and others (1992, p. 5, 6) report that tills in southern New England (Connecticut, Massachusetts, and Rhode Island), which they refer to as “surface till,” are relatively sandy. Thickness of till generally is less than 10 ft in areas overlain by stratified drift, and 10 to 30 ft in areas where it is exposed at the land surface (Melvin and others, 1992, p. 8). Till is more prevalent at land surface in the western part of the basin (fig. 1), where it is exposed on the north-south trending ridges (Willey and others, 1978, sheet 1; Williams and Tasker, 1978, sheet 1). Till deposits exposed at land surface generally are small and discontinuous in extent from the Sippican River subbasin eastward (Williams and Tasker, 1974, sheet 2).

Stratified drift is a common term for sorted and layered glaciofluvial and glaciolacustrine deposits. Glaciofluvial deposits are materials of all grain sizes (clay, silt, sand, gravel, and cobbles) deposited by glacial meltwater streams in outwash plains and valleys (Stone and Peper, 1982, p. 153). Glaciolacustrine deposits generally consist of clay, silt, and fine sand, deposited in temporary lakes that were present for short periods after the retreat of the glacial ice sheet from the area (Hansen and Lapham, 1992, p. 8). Stratified-drift deposits are widespread in the eastern part of the basin (fig. 1) (Williams and Tasker, 1974, sheet 2; Hansen and Lapham, 1992, p. 6). Stratified-drift deposits from the Mattapoisett River subbasin and westward mainly follow north-south trending river valleys (Willey and others, 1978, sheet 1; Williams and Tasker, 1978, sheet 1). The stratified-drift deposits range in thickness from 0 to about 200 ft in the basin.

Moraine deposits can be classified and mapped as either till or stratified drift depending on the composition of the deposits. Moraines in this area generally are composed of stratified sand and gravel with interfingered till and covered by a thin layer of till (Hansen and Lapham, 1992, p. 7). The moraine deposits were formed at the ice contact at times when the retreat of the glacial ice sheet paused for a period of time. Stone and Peper (1982, p. 149-151) and Hansen and Lapham (1992, p. 7) report evidence of moraine deposits at three ice-margin retreatal positions, which trend southwest to northeast from the western to the eastern part of the basin.

Climate

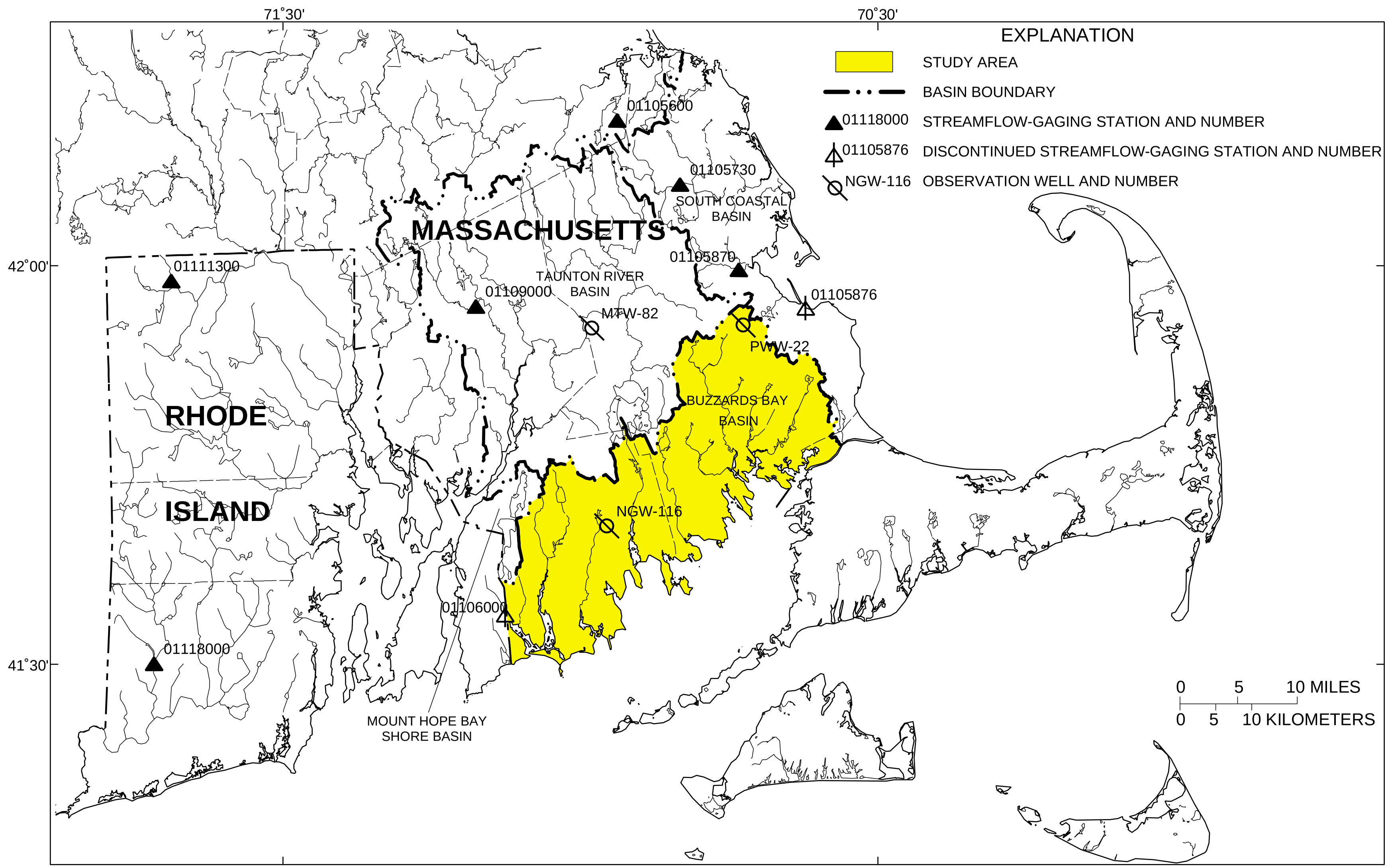
Three National Weather Service climatological stations are in the basin, at East Wareham, Rochester, and New Bedford, Mass. Average annual temperature ranges from 48.8 to 52.3˚F based on data from 1951 to 1980 (National Oceanic and Atmospheric Administration, 1989, p. 16). The lowest mean monthly temperature ranges from 26.9 to 31.6˚F during January, and highest mean monthly temperature ranges from 70.8 to 73.9˚F during July.

Average annual (1951-80) precipitation ranges from 43.9 to 48.6 in. at the three climatological stations in the basin (National Oceanic and Atmospheric Administration, 1989, p. 9). Precipitation is fairly uniformly distributed throughout the year. June and July are the driest months, when precipitation generally is less than 3 in.; December is the wettest month, when precipitation is about 5 in. Average annual snowfall is about 36 in. (U.S. Department of Agriculture-Soil Conservation Service, 1981, p. 78).

Ground-Water Level Fluctuations

Ground-water levels in southeastern Massachusetts generally rise from October through March or April due to recharge from precipitation. Ground-water levels generally decline from May through September when evapotranspiration exceeds precipitation. Long-term water-level fluctuations (changes in ground-water storage) in Buzzards Bay Basin are represented by three USGS observation wells in or near the basin (fig. 2). Observation wells used to monitor ground-water levels in stratified drift in the basin are NGW-116 and PWW-22. There are no observation wells completed in till in the basin, therefore, well MTW-82 (10 mi north of the basin) is shown to represent water-level fluctuations in till. Although these long-term water-level records adequately represent expected water-level fluctuations for stratified drift and till in Buzzards Bay Basin, water-level fluctuations in the basin may vary spatially.

Seasonal variations are the primary component of water-level fluctuations in the three wells; trends over the long-term record are not apparent (fig. 3). Water levels in observation well NGW-116 (stratified drift) fluctuate less than 3 ft annually. The maximum annual water-level fluctuation in observation well PWW-22 (stratified drift) was about 7 ft. The water-level record for observation well PWW-22 reflects the drought periods, such as the ones in 1964-66 and 1980-81. Water-level fluctuations in observation well MTW-82 (till) can be greater than 15 ft annually (fig. 3). Fluctuations of this magnitude are common in till because of their low storage properties relative to stratified drift.



Base from U.S. Geological Survey, Digital Line Graphs, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 19

Figure 2. Location of streamflow-gaging stations and observation wells in and near Buzzards Bay Basin, southeastern Massachusetts.

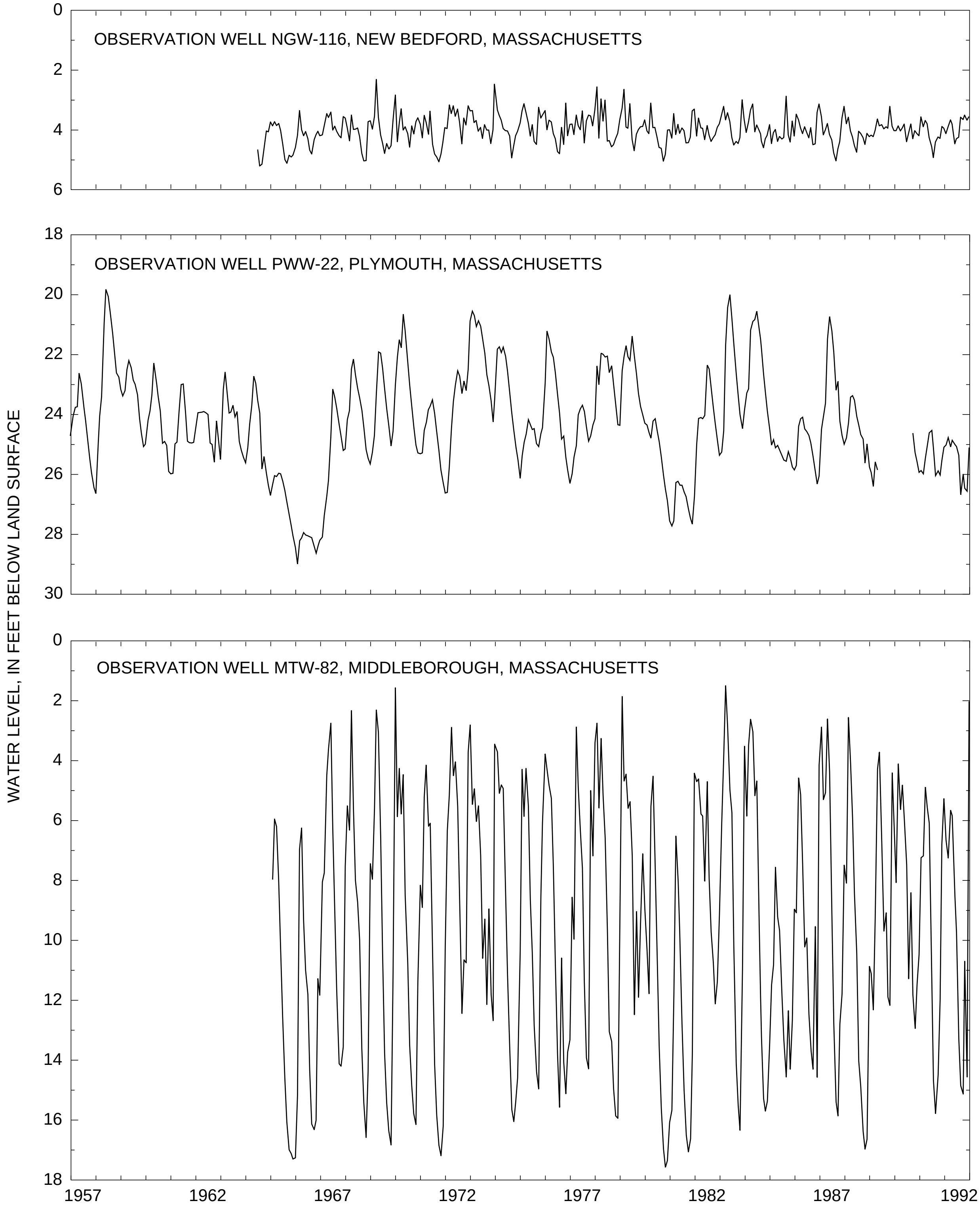


Figure 3. Water-level fluctuations for selected observation wells in and near Buzzards Bay Basin, southeastern Massachusetts, 1957-92.

Water Use

In 1986, eight municipalities had public water-supply systems in Buzzards Bay Basin (table 1). Middleborough, Plymouth, Fall River, and New Bedford had public-water supplies outside of the basin. Within the basin, 26 wells completed in stratified-drift deposits and 2 surface-water sources were used for public supplies (Bratton, 1991, p. 83). Surface water comprised 57 percent of the total water withdrawn (Bratton, 1991, p. 83). Surface water was transferred from the Mount Hope Bay Shore Basin to Fall River, and from the Taunton River Basin to New Bedford. New Bedford then supplied water to Acushnet and Dartmouth.

In 1992, 35 wells completed in stratified-drift deposits and 2 surface-water sources were used for public-water supplies in the basin by the same eight municipalities as in 1986 (fig. 4 and table 1). New Bedford also supplied water to Acushnet, Dartmouth, and Freetown. Fall River also supplied water to Freetown and several other municipalities outside of Buzzards Bay Basin. Several large apartment complexes and other large housing developments have their own water-supply well(s).

In 1991, a total of 11.85 Mgal/d of water was used for municipal supplies in Buzzards Bay Basin, of which 7.09 Mgal/d (60 percent) was derived from ground water and 4.76 Mgal/d (40 percent) was derived from surface water. In 1992, 7.33 Mgal/d (58 percent) and 5.41 Mgal/d (42 percent) came from ground-water and surface-water sources, respectively, for a total average of 12.74 Mgal/d. Total water used in the basin was calculated from table 1 and does not include values of unavailable data or water that came from outside of the basin boundaries.

Ground-water pumpage is highest in the Mattapoisett and Paskamanset River subbasins. In 1992, total average pumpage was 2.28 Mgal/d from six municipal wells in the Mattapoisett River subbasin (wells GW-16 and 17 for Fairhaven; well GW-22 for Marion; and wells GW-23, 24, and 25 for Mattapoisett) (fig. 4 and table 1). Total average pumpage was 1.89 Mgal/d from seven municipal wells in the Paskamanset River subbasin (wells GW-7, 8, 9, 10, 11, 12, and 13 for Dartmouth) (fig. 4 and table 1). Pumpage from municipal wells in the Mattapoisett and Paskamanset River subbasins was 57 percent of the ground water used in the basin during 1992.

Private supplies for domestic use primarily are derived from bedrock wells. Industrial water uses in the basin are small, and only the SEMASS Partnership in Rochester reported pumpage of 0.15 Mgal/d in 1992. Cranberry growers use large amounts of water for frost protection, irrigation, cooling, and harvesting. Most water used by cranberry growers is returned to the basin with small amounts lost through evapotranspiration during the summer months. Hansen and Lapham (1992, p. 9) reported that 84 percent of the water supplied for use on cranberry bogs is from ponds and reservoirs. The greatest area of cranberry bogs is in the Wareham (includes Agawam and Wankico Rivers), Weweantic, and Sippican River subbasins of Buzzards Bay Basin.

STREAMFLOW

Streamflow characteristics were determined through flow-duration analyses for 16 stations in Buzzards Bay Basin. Factors affecting streamflow characteristics of the 16 stations were hypothesized by comparing differences in streamflow of the 16 stations on a per square mile basis.

Flow-Duration Analysis

Streamflow variations at a station can be characterized by constructing flow-duration curves, which represent the percentage of time streamflows were equaled or exceeded during a selected period (Searcy, 1959). Flow-duration curves vary depending on the time period selected due to short- and long-term changes in climate. The longer the period selected for the flow-duration analysis, the more representative the flow-duration curve will be of long-term conditions at the station.

Streamflow-Gaging Stations

No streamflow-gaging stations were operated during the study in Buzzards Bay Basin. Therefore, six streamflow-gaging stations (fig. 2 and table 2) outside but near the basin in southeastern Massachusetts and Rhode Island were used for analyses of streamflow. These six gaging stations were selected as index stations because they have at least 10 years of record, the least amount of regulation at streamflow-gaging stations in the area, and because their drainage-area size, precipitation, and geology are similar to subbasins in Buzzards Bay Basin. Flow-duration curves were computed for a base period of water years 1967-91[1] at the six streamflow-gaging stations and are shown in figure 5.

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[1]A water year is the 12-month period beginning October 1 and ending September 30. It is designated by the calendar year in which it ends.

Table 1. Water use for municipalities in Buzzards Bay Basin, southeastern Massachusetts, 1986, 1991, and 1992

[Municipality: Location shown in figure 4, unless otherwise noted. Site type and No.: GW, ground water; SW, surface water. Average water use: 1986 data are from Bratton, 1991. Mgal/d, million gallons per day; --, no data; *, not operating]

Municipality and water supplier	Site type and No.	Average water use (Mgal/d)		
		1986	1991	1992
ACUSHNET				
Acushnet Water Department				
New Bedford Water Department[1]				
Little Quittacas Pond	SW-1	--	0.48	0.51
BOURNE				
Buzzards Bay Water District				
Head of the Bay Road Well Station 2	GW-1	0.14	.11	.17
Bournedale Road Well Station 1	GW-2	.22	.08	.05
Bournedale Road Well Station 3	GW-3	--	.22	.15
Bournedale Road Well Station 4	GW-4	--	.14	.09
CARVER				
Cranberry Village	GW-5	--	--	--
South Meadow Village				
Tubular Well Field	GW-6	--	--	.18
DARTMOUTH				
Dartmouth Water Division				
Chase Road Well A	GW-7	.25	.23	.14
Chase Road Well B	GW-8	.24	.40	.42
Chase Road Well C	GW-9	.24	.24	.21
Chase Road Well D	GW-10	(*)	.28	.38
Old Westport Road Well V-1	GW-11	.42	.35	.27
Old Westport Road Well V-2	GW-12	(*)	(*)	.19
Old Westport Road Well V-3	GW-13	(*)	(*)	.28
New Bedford Water Department[1]				
Little Quittacas Pond (Faunce Corner)	SW-1	--	.61	.19
FAIRHAVEN				
Fairhaven Board of Public Health				
Mill Road Well Field	GW-14	.26	(*)	(*)
River Road Well Field	GW-15	.26	.09	(*)
Tinkham Lane Well	GW-16	(*)	1.15	1.26
Wolf Island Wells	GW-17	.89	.11	.11
FALL RIVER				
Fall River Water Department				
Copicut Reservoir	SW-2	7.00	4.54	5.18
Fall River Water Department[2]				
North Watuppa Pond	SW-3	7.00	14.23	14.60
FREETOWN				
Freetown Water Commission				
Fall River Water Department[2]				
North Watuppa Pond	SW-3	--	.05	.06
New Bedford Water Department[1]				
Little Quittacas Pond	SW-1	--	.03	.04
LAKEVILLE				
No Public Water Supply				
MARION				
Marion Water Department				
Main Water Station	GW-18	.03	.10	.10
Mary's Pond Station	GW-19	.12	.02	.003
Rochester East Well	GW-20	.03	(*)	(*)
Rochester West Well	GW-21	.04	.005	(*)
Wolf Island Wells	GW-22	.36	.56	.43

Table 1. Water use for municipalities in Buzzards Bay Basin, southeastern Massachusetts, 1986, 1991, and 1992—*Continued*

Municipality and water supplier	Site type and No.	Average water use (Mgal/d)		
		1986	1991	1992
MATTAPOISETT				
Mattapoisett Water Department				
Acushnet Road Well 2	GW-23	0.01	0.005	0.004
Hereford Hill Road Well 3	GW-24	.15	.16	.21
Hereford Hill Road Well 4	GW-25	.32	.38	.27
MIDDLEBOROUGH				
Middleborough Water Department[3]				
East Grove Street Well	GW-26	.11	.05	.06
Tispaquin Well 1	GW-27	.16	.09	.07
Tispaquin Well 2	GW-28	.00	.07	.08
Miller Street Well	GW-29	.42	.47	.45
Rock Well 1	GW-30	.20	.16	.16
Rock Well 2	GW-31	.22	.20	.20
East Main Well 1	GW-32	.17	.13	.12
East Main Well 2	GW-33	.07	.13	.14
Plympton Street Well	GW-34	.10	.10	.10
Cross Street Well	GW-35	.29	.26	.24
Spruce Street Well	GW-36	.00	.12	.14
NEW BEDFORD				
New Bedford Water Department[1]				
Little Quittacas Pond	SW-1	17.09	17.91	13.70
PLYMOUTH				
Plymouth Water Department				
Federal Furnace Well	GW-37	.33	.45	.47
Darby Pond Well	GW-38	(*)	.13	.21
Plymouth Water Department[4]				
Lout Pond Well	GW-39	.28	.05	.005
Wannos Pond Well	GW-40	.23	.26	.44
Ship Pond Well	GW-41	.22	.29	.28
Bradford Well	GW-42	.56	.89	1.03
Ellisville Well	GW-43	.30	.56	.50
North Plymouth Well	GW-44	.99	.75	.66
Little South Pond (Great South Pond)	SW-4	.87	1.14	1.03
ROCHESTER				
No Public Water Supply				
WAREHAM				
Onset Fire District				
Red Brook Road Well 3	GW-45	.13	.22	.17
Red Brook Road Well 4	GW-46	.10	.15	.15
Sand Pond	SW-5	.29	.22	.23
Wareham Fire District				
Maple Spring Well 1	GW-47	.16	.31	.26
Maple Spring Well 2	GW-48	.45	.35	.28
Maple Spring Well 3	GW-49	.15	.08	.26
Maple Spring Well 4	GW-50	.15	.21	.23
Seawood Spring Well 6	GW-51	.50	.16	.11
Seawood Spring Well 7	GW-52	(*)	.40	.28
WESTPORT				
No Public Water Supply				

[1] Little Quittacas Pond used by the New Bedford Water Department is in the Taunton River Basin. Also, Little Quittacas Pond is connected to Assawompset, Great Quittacas, and Long Ponds. (Not shown in fig. 4.)

[2] North Wattuppa Pond used by the Fall River Water Department is in Mount Hope Bay Shore Basin.

[3] All wells used by the Middleborough Water Department are in the Taunton River Basin. (Not shown in fig. 4.)

[4] All wells used by the Plymouth Water Department are in the South Coastal (South Coastal Shore) Basin, excluding the Federal Furnace and Darby Pond wells, which are in Buzzards Bay Basin. Also, Great South Pond is connected to Little South Pond. (Not shown in fig. 4.)

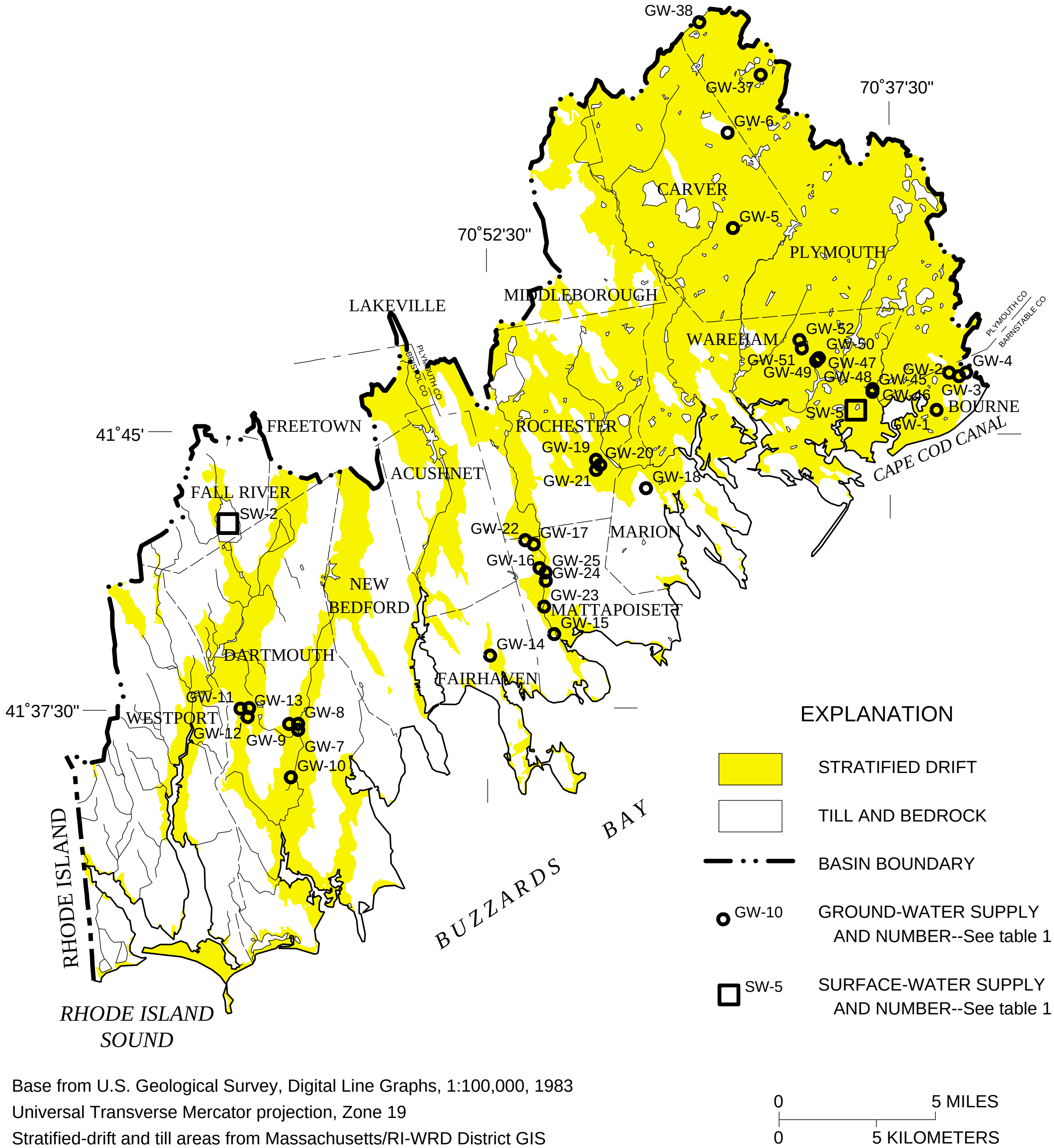


Figure 4. Location of ground-water and surface-water sources used for public-water supplies in Buzzards Bay Basin, southeastern Massachusetts, 1992.

Table 2. Descriptions of streamflow-gaging stations in southeastern Massachusetts and Rhode Island used in flow-duration and ground-water recharge and discharge analysis

[USGS station No.: Locations shown in figure 2. Latitude and longitude are given in degrees, minutes, seconds. Stratified-drift area measured with geographic information technology and therefore may differ slightly from, and does not supersede, previously published figures. mi^2, square mile]

USGS station No.	Station name	Latitude ° ′ ″	Longitude ° ′ ″	Period of record	Drainage area (mi^2)	Stratified-drift area (percent)	Remarks
01105600	Old Swamp River near South Weymouth, Mass.	421125	705643	1966-present	4.50	26.4	--
01105730	Indian Head River at Hanover, Mass.	420602	704923	1966-present	30.3	68.3	Some regulation by mills and dams upstream[1]
01105870	Jones River at Kingston, Mass.	415927	704403	1966-present	15.7	82.8	Flow regulated by dams upstream[1]
01106000	Adamsville Brook at Adamsville, R.I.	413330	710747	1941-78, 1987	7.91	9.36	--
01109000	Wading River near Norton, Mass.	415651	711038	1925-present	43.3	58.7	Flow regulated by dams and diversions upstream[1]
01111300	Nipmuc River near Harrisville, R.I.	415852	714111	1964-1991, 1994-present	16.0	28.1	--

[1] From Gadoury and others (1989).

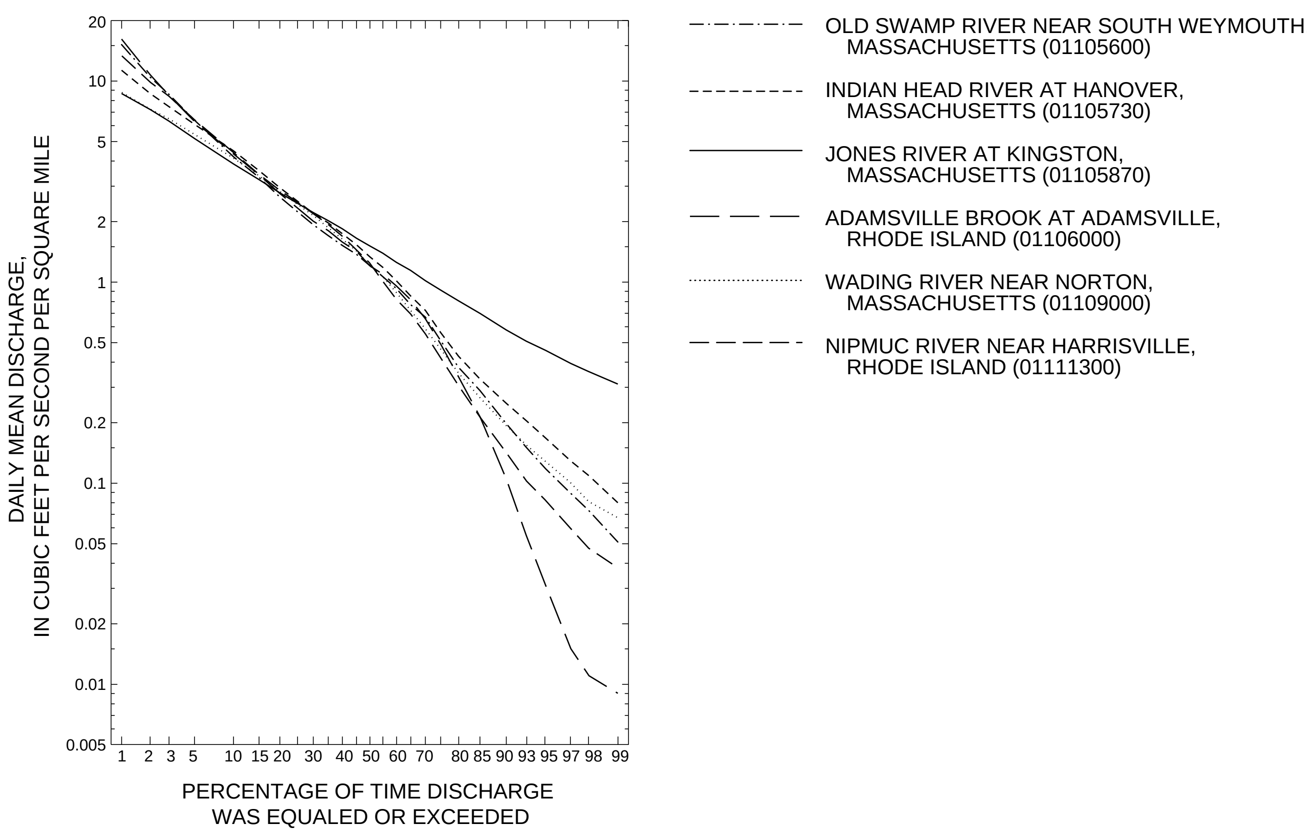


Figure 5. Flow-duration curves of daily mean discharge per square mile at six streamflow-gaging stations in southeastern Massachusetts and Rhode Island, water years 1967-91.

Daily mean discharges for the Adamsville Brook streamflow-gaging station (01106000) were available only for water years 1967-78. A record-extension technique was used to determine duration discharges for Adamsville Brook for water years 1967-91. The record-extension technique involved plotting selected duration discharges for the period of record at Adamsville Brook with concurrent duration discharges at other nearby gaging stations to establish curves of relation between the stations and Adamsville Brook. The gaging stations used were five of the six streamflow-gaging stations (table 2) excluding Jones River (01105870), and Wood River at Hope Valley, Rhode Island (01118000) (fig. 2) and Sevenmile River near Spencer, Massachusetts (01175670), located 25 mi northwest of the Nipmuc River (01111300). Selected duration discharges for water years 1967-91 at the six gaging stations were then entered into their respective relation curves with Adamsville Brook to estimate the selected duration discharges for water years 1967-91 at Adamsville Brook. The average of the six discharges estimated for each selected duration were used as the duration discharges for water years 1967-91 at Adamsville Brook.

Flow-duration curves of daily mean discharge per square mile for the six index stations are shown in figure 5. Duration discharges for the base period at each of the six index stations were standardized by dividing them by their drainage areas. This procedure allows a comparison of the streamflow characteristics among the index stations. Variations in discharges per square mile primarily are due to differences in surficial deposits, although other factors can affect the distribution of streamflows.

Discharge per square mile from 1- to 10-percent flow duration was higher at Adamsville Brook (01106000), Nipmuc River (01111300), and Old Swamp River (01105600) than the other stations (fig. 5). This is assumed to be caused by infiltration rates of till and bedrock, which are lower than stratified-drift deposits and underlie more than 75 percent of these basins (table 2). During heavy rains, these basins have higher runoff rates than the three basins underlain by more than 58 percent stratified drift and consequently higher stream discharges per square mile. Discharge per square mile from 90- to 99-percent flow duration was higher at Jones (01105870), Indian Head (01105730), and Wading (01109000) Rivers than at the other stations. These basins are underlain by more than 50 percent stratified drift (table 2), which allows for greater amounts of precipitation to infiltrate into the ground water and discharge during low-flow periods.

Low-Flow Partial-Record and Discontinued Streamflow-Gaging Stations

Discharges were estimated for 14 low-flow partial-record stations and two discontinued streamflow-gaging stations (fig. 6 and table 3) for the selected durations ranging from the 50 to 99 percentiles for the base period of water years 1967-91. The 50 to 99 percentiles were selected because streamflows that are primarily from ground-water discharge are more prevalent at the higher percentiles, which correspond to lower streamflows. Streamflows that are exceeded 90 to 99 percent of the time are usually all ground-water discharge.

Baseflow measurements (appendix A, table A1) at 14 low-flow partial-record stations in the basin (fig. 5 and table 3) were correlated with the concurrent daily mean discharges at each of the six nearby streamflow-gaging (index) stations. Scatterplots of log-transformed baseflow measurements at the 14 partial-record stations and same day log-transformed daily mean discharges at the six index stations were made to determine the nature and quality of the relations between the stations. When any of the plots indicated a log-linear relation, the maintenance of variance extension, type 1 (MOVE.1) technique (Hirsch, 1982) was used to provide an equation that relates baseflow at the low-flow partial-record station to that at the gaging station. The discharges at the index station for the selected durations (water years 1967-91) were substituted into the equation to obtain the corresponding duration discharges for the low-flow partial-record station. When the plots of concurrent log-transformed discharge data indicated a curved (nonlinear) relation, a graphical technique (Searcy, 1959) was used to fit a smooth curve through each plot of the untransformed data points by visual inspection. Duration discharges at the low-flow partial-record stations were determined with these curves and the corresponding duration discharges at the index stations for water years 1967-91. Detailed description of the MOVE.1 and graphical techniques as applied to low-flow analyses are discussed in Ries (1994, p. 22-24).

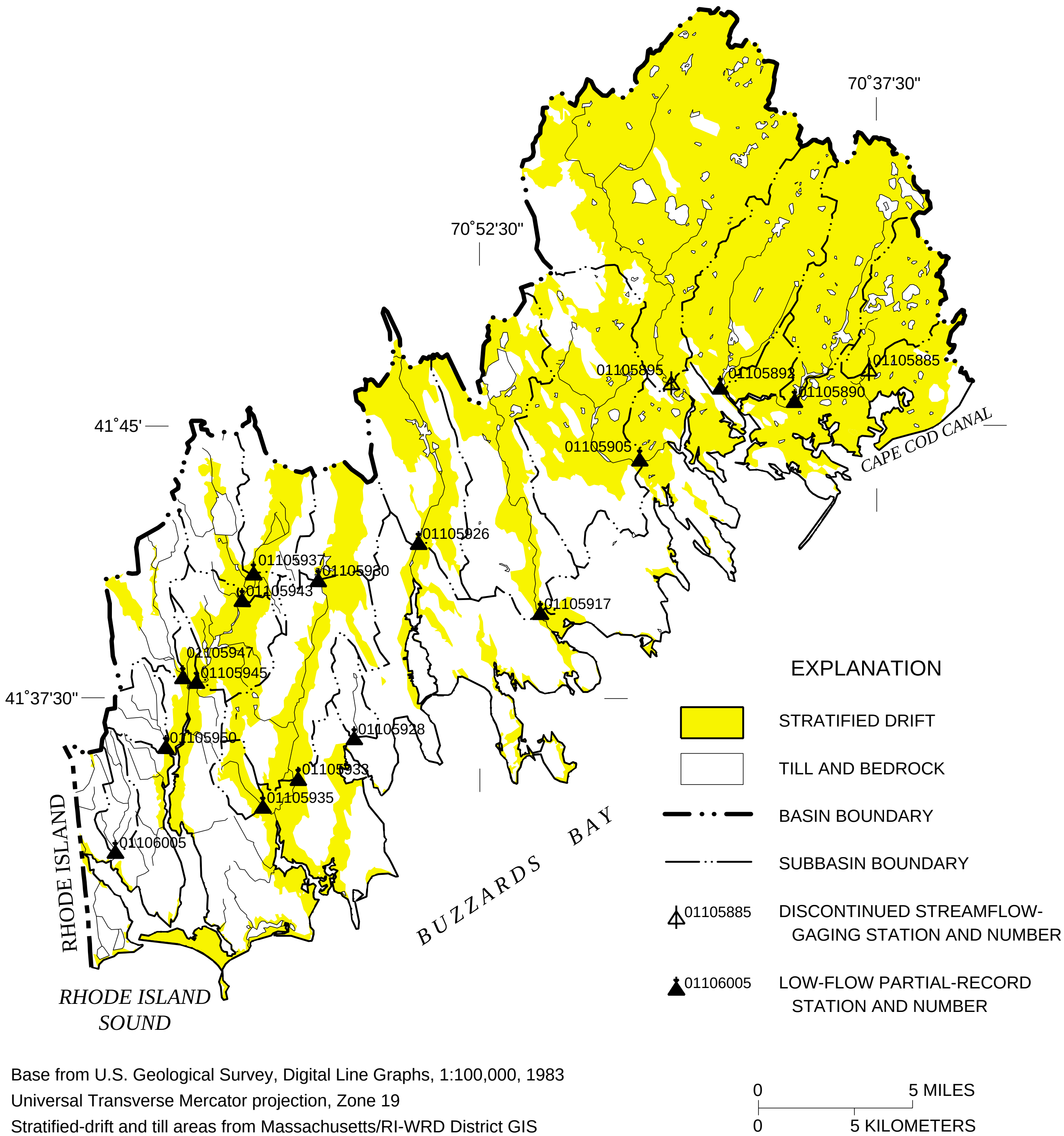


Figure 6. Location of low-flow partial-record stations and discontinued streamflow-gaging stations in Buzzards Bay Basin, southeastern Massachusetts.

Table 3. Descriptions of low-flow partial-record stations and discontinued streamflow-gaging stations in Buzzards Bay Basin, southeastern Massachusetts for which stream discharge estimates are provided

[USGS station No.: Locations shown in figure 6. Listed in order of increasing USGS station No. Latitude and longitude given in degrees, minutes, seconds. Stratified-drift areas were measured by geographic information systems technology and therefore may differ slightly from, and do not supersede, previously published figures. mi^2, square mile; ft, foot]

USGS station No.	Station name and location	Latitude ° ′ ″	Longitude ° ′ ″	Drainage area (mi^2)	Stratified-drift (percent)	Remarks
01105885[1]	Red Brook near Buzzards Bay at bridge on State Highway 25	41∞∞4632	70∞∞3751	9.14	100	Cranberry bogs and associated reservoirs and regulation for fish purposes
01105890	Agawam River at East Wareham at culvert 800 ft below Mill Pond	41∞4540	70∞4040	17.1	100	Cranberry bogs and associated reservoirs and municipal supply wells
01105895[2]	Weweantic River near South Wareham at bridge on Fearing Hill Road	41∞4612	70∞4518	56.1	87.9	Cranberry bogs and associated reservoirs and a hydroelectric dam
01105905	Sippican River near Marion at bridge on County Road	41∞4403	70∞4631	28.1	59.1	Cranberry bogs and associated reservoirs and municipal supply wells
01105917	Mattapoisett River near Mattapoisett 0.4 mi above bridge on U.S. Highway 6	41∞3945	70∞5020	24.0	45.8	Municipal supply wells of which 87 percent of the water leaves the basin and a few cranberry bogs
01105926	Acushnet River at Acushnet at bridge on Hamlin Road	41∞4145	70∞5452	16.4	53.5	A few cranberry bogs and associated reservoirs, and a emergency municipal supply reservoir
01105928	Buttonwood Brook near South Dartmouth at bridge on Russells Mills Road	41∞3615	70∞5720	2.93	.00	Municipal sewer system
01105930	Paskamanset River near New Bedford at bridge on Old Plainville Road	41∞4043	70∞5839	8.12	44.4	--
01105933	Paskamanset River near South Dartmouth at bridge on Russells Mills Road	41∞3507	70∞5927	26.2	43.9	Municipal supply wells and municipal sewer system
01105935	Destruction Brook near South Dartmouth at bridge on Slades Corner Road	41∞3420	71∞0047	2.64	54.5	--
01105937	Shingle Island River near North Dartmouth at bridge on Old Fall River Road	41∞4055	71∞0105	8.59	36.3	A few cranberry bogs and associated reservoirs
01105943	Shingle Island River near North Dartmouth at bridge on Hixville Road	41∞4010	71∞0132	18.8	33.8	A few cranberry bogs and associated reservoirs, and a municipal supply reservoir
01105945	East Branch Westport River at Head of Westport at bridge on Forge Road	41∞3752	71∞0315	28.2	43.3	A few cranberry bogs and associated reservoirs, a municipal supply reservoir, and a emergency supply reservoir
01105947	Bread and Cheese Brook at Head of Westport at culvert on State Highway 177	41∞3800	71∞0346	8.70	13.7	--
01105950	Kirby Brook near Head of Westport at culvert on Drift Road	41∞3602	71∞0425	3.69	.54	--
01106005	Angeline Brook near Westport Point at culvert on Cornell Road	41∞3305	71∞0620	3.22	.00	--

[1] Streamflow-gaging station during water years 1981-86.

[2] Streamflow-gaging station during water years 1970-71.

Information on the flow-duration analysis for each of the stations is presented in table 4, including the method of analysis, gaging stations and number of measurements used in the relations, correlation coefficients, and root mean square errors of estimate. Correlation coefficients, which measure the strength of the linear relation between the partial-record station and index station, were supplied when the MOVE.1 method was used. The root mean square error, an indication of the variation that can be expected in estimates obtained from the relations, is provided for both estimation methods. About two-thirds of the estimates obtained from the relations will have errors that are less than the values presented in the table.

Correlation coefficients and root mean squared errors were used to determine which of the six index stations would be used to obtain the estimated duration discharges for each partial-record station. Index stations with lower correlation coefficients and higher root mean square errors in relation to the other index stations were not used in the analyses. When more than one index station was used in the analyses, the average of each calculated duration discharge was used for the final estimate.

Two discontinued streamflow-gaging stations, Red Brook (01105885) and Weweantic River (01105895) (fig. 6 and table 3), were operated during water years 1981-86 and 1970-71, respectively, in Buzzards Bay Basin. Record extension was used to determine duration discharges for Red Brook and Weweantic River for water years 1967-91. This was done by plotting selected duration discharges for the period of record at the two discontinued gaging stations against concurrent duration discharges for the six index stations to establish relation curves between the stations. Selected duration discharges for water years 1967-91 at the six index stations were then entered into their respective relation curves with Red Brook and Weweantic River to estimate the selected duration discharges for water years 1967-91 at the two discontinued gaging stations. Estimates of duration discharges at Red Brook were based solely on the relation to Jones River, because it was the only index station that had a sufficient relation to Red Brook.

Estimates of stream discharge are not provided for the Wankico River (01105892) subbasin. The Wankico River subbasin is between the Agawam River (01105890) and the Weweantic River (01105895) subbasins in the eastern part of the basin (fig. 6). Baseflow

Table 4. Summary of flow-duration analysis for low-flow partial-record stations and discontinued streamflow-gaging stations in Buzzards Bay Basin, southeastern Massachusetts, water years 1967-91

[USGS station No.: Locations shown in figure 6 and are described in table 3. Gaging stations used in relations: Locations shown in figure 2 and described in table 3. --, not applicable]

USGS station No.	Method of analysis	Gaging stations used in relation	Number of measurements used in relation	Correlation coefficient	Root mean square error of estimate (percent)
01105885[1]	Record extension	Jones River	1,617	--	2.78
01105890	MOVE.1	Nipmuc River	7	0.92	5.76
		Old Swamp River	7	.95	4.34
					average 5.05
01105895[2]	Record extension	Wading River	658	--	7.94
	MOVE.1	Indian Head River	656	.91	39.6
		Jones River	656	.89	43.6
		Nipmuc River	658	.90	41.2
					average 33.1
01105905	MOVE.1	Wading River	14	.99	13.2
01105917	MOVE.1	Indian Head River	12	.98	27.8
01105926	MOVE.1	Adamsville Brook	14	.96	34.6
		Wading River	16	.93	36.6
					average 35.6

Table 4. Summary of flow-duration analysis for low-flow partial-record stations and discontinued streamflow-gaging stations in Buzzards Bay Basin, southeastern Massachusetts, water years 1967-91—*Continued*

USGS station No.	Method of analysis	Gaging stations used in relation	Number of measurements used in relation	Correlation coefficient	Root mean square error of estimate (percent)
01105928	Graphical	Adamsville Brook	8	--	31.0
		Indian Head River	7	--	29.1
		Nipmuc River	7	--	35.5
		Old Swamp River	8	--	62.0
		Wading River	8	--	69.8
				average	45.5
01105930	MOVE.1	Old Swamp River	17	0.95	37.6
01105933	MOVE.1	Adamsville Brook	16	.97	26.1
		Old Swamp River	19	.98	19.0
				average	22.6
01105935	MOVE.1	Indian Head River	15	.96	20.0
		Old Swamp River	19	.95	20.3
				average	20.2
01105937	Graphical	Adamsville Brook	18	--	50.6
		Indian Head River	16	--	44.6
		Nipmuc River	14	--	[3]51.8
		Old Swamp River	19	--	[3]70.4
		Wading River	17	--	[3]60.2
				average	55.5
01105943	MOVE.1	Indian Head River	16	.96	24.4
		Nipmuc River	14	.95	31.0
		Wading River	17	.94	29.8
				average	28.4
01105945	MOVE.1	Adamsville Brook	6	.99	11.2
		Indian Head River	4	.99	18.4
		Nipmuc River	5	.98	23.8
		Old Swamp River	6	.99	11.0
				average	16.1
01105947	MOVE.1	Adamsville Brook	11	.96	35.6
		Indian Head River	8	.95	30.7
		Nipmuc River	10	.94	48.7
		Old Swamp River	9	.94	34.9
		Wading River	9	.94	30.7
				average	36.1
01105950	MOVE.1	Adamsville Brook	9	.95	53.8
		Indian Head River	7	.96	48.6
				average	51.2
01106005	MOVE.1	Adamsville Brook	10	.93	39.3
		Indian Head River	8	.94	44.6
				average	42.0

[1] Streamflow-gaging station during water years 1981-86.

[2] Streamflow-gaging station during water years 1970-71.

[3] One streamflow measurement used in analysis was not used in calculation of root mean square error of estimate because estimated streamflow was less than zero.

measurements were not collected in the Wankico River subbasin during this study, and attempts to estimate stream discharges for the subbasin using measurements from previous studies were unsuccessful because data were insufficient.

Estimates of stream discharge at the selected durations for the 16 (14 low-flow partial-record stations and 2 discontinued streamflow-gaging stations) for water years 1967-91 are presented in table 5. Streamflows at 11 of the 16 stations are affected by upstream dams, by diversions of water for municipal, industrial, or agricultural uses that may not be returned to the subbasin, and (or) by urban storm sewers (table 3). Estimates of stream discharges provided for these stations do not reflect natural flow conditions.

Factors Affecting Streamflow

Estimated discharges for water years 1967-91 from table 5 were divided by the drainage areas of their respective subbasins to compare differences in discharge characteristics among the 16 stations. Values of duration discharges per square mile between the 50 and 99 percentiles for the 16 stations for water years 1967-91 are in table 6. Differences in discharge per square mile can be attributed to many factors including: (1) ground-water drainage boundaries that are not coincident with surface-water drainage boundaries determined from topographic maps; (2) differences in surficial deposits; (3) differences in areas of wetlands and water bodies; (4) human influences, such as irrigation, diversions, dam regulations, and ground-water pumpage; (5) potential ground-water underflow; and (6) differences in other physical features of the subbasins, such as basin shape, slope, aspect, and length of streams. The combination of these factors affects the overall streamflow regime of a basin.

Differences in Surface-Water and Ground-Water Drainage Boundaries

The Red Brook (01105885), Agawam River (01105890), and Weweantic River (01105895) subbasins are within 7 mi of each other in the eastern part of Buzzards Bay Basin (fig. 6). These three subbasins are part of the Plymouth-Carver aquifer area (Hansen and Lapham, 1992), where stratified-drift deposits are more extensive than in the western half of the basin. Differences in stream discharge per square mile are evident among the three subbasins (table 6), even though they are each almost entirely underlain by stratified drift (table 3). Estimated stream discharges per square mile at the 99-percent flow duration for Red Brook (01105885), Agawam River (01105890) and Weweantic River (01105895) subbasins are 0.156, 1.46, and 0.234 $(ft^3/s)/mi^2$, respectively, and at the 50-percent flow duration the values are 0.402, 2.56, and 1.45 $(ft^3/s)/mi^2$, respectively (table 6). The values for the Agawam River are the highest of the 16 stations in the basin (table 6), whereas the values at Red Brook are much lower than those for other stations with drainage areas where stratified-drift deposits underlie more than 50 percent of their total area.

Ground-water drainage boundaries from the Weweantic River subbasin eastward in the basin (Plymouth-Carver aquifer area) are not coincident with surface-water drainage boundaries determined from topographic maps. Differences were found between the surface-water boundaries drawn from topographic maps for the Weweantic River (01105895), Agawam River (01105890), and Red Brook (01105885), and the ground-water boundaries determined from the water-table map for the Plymouth-Carver aquifer area done by Hansen and Lapham (1992, pl. 1). These differences partly explain the differences in discharge per square mile between the stations. The surface-water drainage areas of the Weweantic River (01105895) and Agawam River (01105890) subbasins, and Red Brook (01105885) subbasin are 56.1, 17.0, and 9.14 mi^2, respectively, whereas their ground-water drainage areas are 50.9, 23.4, and 3.89 mi^2, respectively. This should cause duration discharges per square mile calculated from surface-water drainage areas to appear smaller than expected in the Weweantic River and Red Brook subbasins, and larger than expected in the Agawam River subbasin.

Surficial Deposits

Previous studies in New England have found that stations with greater percentages of stratified-drift area generally have higher stream discharge per unit area at low flows and lower stream discharges per unit area at high flows than stations with smaller percentages of stratified-drift area (Thomas, 1966; Tasker, 1972; Cervione, 1982, p. 16-18; Lapham, 1988, p. 13-14; and de Lima, 1991, p. 22-23). In Buzzards Bay Basin, stream discharges per square mile at the 50-, 70-, 90-, and 99-percent flow durations for water years 1967-91 (fig. 5 and table 6) were related by simple linear regression analysis to percentage of basin underlain by stratified drift for the six streamflow-gaging (index) stations and for 14 of the 16 stations used in the study (fig. 7).

Table 5. Estimated stream discharge at selected flow durations for low-flow partial-record stations and discontinued streamflow-gaging stations in Buzzards Bay Basin, southeastern Massachusetts, water years 1967-91

[USGS station No.: Locations shown in figure 6 and described in table 3]

USGS station No.	Stream discharge equaled or exceeded at indicated percentage of time, in cubic feet per second													
	50	55	60	65	70	75	80	85	90	93	95	97	98	99
01105885[1]	3.67	3.49	3.28	3.12	2.92	2.71	2.60	2.37	2.14	2.01	1.80	1.76	1.68	1.43
01105890	43.7	42.4	41.2	40.0	38.5	37.0	35.1	33.2	31.1	29.6	28.5	27.1	26.4	25.0
01105895[2]	81.6	73.5	65.6	59.1	52.5	45.8	40.2	34.0	28.4	24.7	21.9	18.4	16.4	13.1
01105905	44.6	39.8	34.0	28.8	24.2	20.2	16.0	12.6	9.78	8.19	7.06	5.89	5.11	4.19
01105917	32.5	26.9	21.6	16.6	13.0	8.90	6.00	4.08	2.72	2.02	1.51	1.02	.798	.509
01105926	21.9	19.5	16.6	14.1	11.7	9.41	7.16	5.26	3.50	2.50	1.88	1.34	1.10	.879
01105928	1.55	1.44	1.30	1.17	1.04	.892	.728	.585	.413	.300	.227	.161	.129	.090
01105930	17.0	14.5	12.5	10.1	7.79	6.21	4.38	3.21	2.07	1.52	1.14	.821	.657	.433
01105933	27.6	24.7	22.0	18.9	15.7	12.9	9.83	7.43	4.91	3.50	2.58	1.81	1.49	1.14
01105935	4.18	3.76	3.37	2.92	2.51	2.10	1.68	1.37	1.06	.882	.742	.599	.521	.402
01105937	8.82	7.74	6.89	6.00	5.06	3.98	2.77	1.83	1.03	.634	.416	.221	.125	.025
01105943	23.7	20.4	17.2	14.4	11.9	9.40	7.14	5.35	3.94	3.13	2.61	2.04	1.75	1.35
01105945	32.2	28.4	24.8	21.5	18.1	14.7	11.4	8.66	6.13	4.68	3.72	2.79	2.37	1.82
01105947	11.1	9.32	7.67	6.23	4.90	3.70	2.62	1.83	1.18	.837	.629	.443	.357	.257
01105950	5.20	3.82	2.66	1.76	1.12	.588	.282	.123	.041	.017	.008	.003	.002	.001
01106005	3.63	2.98	2.37	1.83	1.39	.935	.601	.369	.193	.113	.070	.039	.028	.018

[1] Streamflow-gaging station during water years 1981-86.

[2] Streamflow-gaging station during water years 1970-71.

Table 6. Estimated stream discharge per square mile at selected flow durations for low-flow partial-record stations and discontinued streamflow-gaging stations in Buzzards Bay Basin, southeastern Massachusetts, water years 1967-91

[USGS station No.: Locations shown in figure 6 and described in table 3]

USGS station No.	Stream discharge per unit area equaled or exceeded at indicated percentage of time, in cubic feet per second per square mile													
	50	60	55	65	70	75	80	85	90	93	95	97	98	99
01105885[1]	0.402	0.382	0.359	0.341	0.319	0.296	0.284	0.259	0.234	0.220	0.197	0.193	0.184	0.156
01105890	2.56	2.48	2.41	2.34	2.25	2.16	2.05	1.94	1.82	1.73	1.67	1.58	1.54	1.46
01105895[2]	1.45	1.31	1.17	1.05	.936	.816	.717	.606	.506	.440	.390	.328	.292	.234
01105905	1.59	1.42	1.21	1.02	.861	.719	.569	.448	.348	.291	.251	.210	.182	.149
01105917	1.35	1.12	.900	.692	.542	.371	.250	.170	.113	.084	.063	.043	.033	.021
01105926	1.34	1.19	1.01	.860	.713	.574	.437	.321	.213	.152	.115	.082	.067	.054
01105928	.529	.491	.444	.399	.355	.304	.248	.200	.141	.102	.077	.055	.044	.031
01105930	2.09	1.79	1.54	1.24	.959	.765	.539	.395	.255	.187	.140	.101	.081	.053
01105933	1.05	.943	.840	.721	.599	.492	.375	.284	.187	.134	.098	.069	.057	.044
01105935	1.58	1.42	1.28	1.11	.951	.795	.636	.519	.402	.334	.281	.227	.197	.152
01105937	1.03	.901	.802	.698	.589	.463	.322	.213	.120	.074	.048	.026	.015	.003
01105943	1.26	1.09	.915	.766	.633	.500	.380	.285	.210	.166	.139	.109	.093	.072
01105945	1.14	1.01	.879	.762	.642	.521	.404	.307	.217	.166	.132	.099	.084	.065
01105947	1.28	1.07	.882	.716	.563	.425	.301	.210	.136	.096	.072	.051	.041	.030
01105950	1.41	1.04	.721	.477	.304	.159	.076	.033	.011	.005	.002	.001	.001	.000
01106005	1.13	.925	.736	.568	.432	.290	.187	.115	.060	.035	.022	.012	.009	.006

[1] Streamflow-gaging station during water years 1981-86.
[2] Streamflow-gaging station during water years 1970-71.

Red Brook (01105885) and Agawam River (01105890) were excluded from the regression analysis used to develop the relations because stream discharges per square mile at these two stations do not conform to the values and (or) trends of the other stations, probably because their surface-water drainage boundaries do not correspond to their ground-water drainage boundaries, and both streams are regulated.

Coefficient of determination (R^2 values), which measure the proportion of variation in stream discharge that is explained by the percentage of basin underlain by stratified drift, were 0.21, 0.63, 0.69, and 0.61 at the 50-, 70-, 90-, and 99-percent flow durations, respectively. The R^2 values and slopes of the regression lines in figure 7 show that the percentage of the basin underlain by stratified drift strongly influences stream discharges per square mile at low flows (high flow duration), and that the relation is weak at the median flow (50-percent flow duration). These results compare well to those for stations in the Taunton River Basin (Lapham, 1988, p. 13-14, 21), which is adjacent and directly to the north of Buzzards Bay Basin (fig. 2).

Flow durations at the 70, 90, and 99 percentiles in subbasins primarily underlain by stratified drift (Jones River, 01105870; and Weweantic River, 01105895) were at least 2, 4, and 8 times greater respectively, than subbasins primarily underlain by till and bedrock (Buttonwood Brook, 01105928; Kirby Brook, 01105950; and Angeline Brook, 01106005) (fig. 7 and table 6). These results are similar to the findings of Wandle and Randall (1994, p. 44), who determined that contributions from stratified-drift areas to low flows were 4 to 8 times greater than contributions from till and bedrock areas in Central New England (including stations in southeastern Massachusetts).

Wetlands and Water Bodies

Wandle and Randall (1994, p. 6, 33) found that the areal extent of lakes and swamps in basins throughout central New England (including stations in southeastern Massachusetts and Rhode Island) correlates negatively with low flows, and suggested that lakes, ponds, and (or) swamps can be expected to reduce low flows because the water table is at or near the land surface in these areas. This results in (1) more surface runoff during precipitation and (2) more evaporation or evapotranspiration during the summer months and growing season. Both of these mechanisms decrease ground-water discharge. Large areas of wetlands and water bodies were apparent in all subbasins based on visual inspection of topographic maps, except Buttonwood Brook (01105928), Kirby Brook, (01105950), and Angeline Brook (01106005). In addition, there are ponds with no outlets and many cranberry bogs that have associated reservoirs and water tables near land surface in the Sippican River (01105905), Weweantic River (01105895), Agawam River (01105890), and Red Brook (01105885) subbasins.

Ground-Water Withdrawals

Ground-water withdrawals can affect streamflow in two ways: (1) Ground water that would discharge into the stream under nonpumping conditions is intercepted by the pumping of a well, and (2) The pumping of a well can induce streamflow to infiltrate through the streambed into the aquifer, and then move through the aquifer to the well. During all periods, and especially during the drier summer months, pumping of wells can decrease streamflow below minimum levels necessary to maintain stream ecology, fisheries, wildlife, aesthetics, and recreation. Olimpio and de Lima (1984, p. 56-78) modeled the effects of well pumpage on streamflow in the Mattapoisett River subbasin of Buzzards Bay Basin. They found that all pumping alternatives simulated would decrease streamflow during dry and severely dry conditions.

Streamflow from the Mattapoisett River (01105917) and Paskamanset River (01105933) subbasins (table 6) could be affected by municipal wells. Average ground-water pumpage in the Mattapoisett and Paskamanset River subbasins is 2.24 and 1.51 Mgal/d, respectively. Average ground-water pumpage was calculated using 1986, 1991, and 1992 water-use data from wells GW-15, 16, and 17 for Fairhaven; well GW-22 for Marion; and GW-23, 24, and 25 for Mattapoisett in the Mattapoisett River subbasin and from wells GW-7, 8, 9, 10, 11, 12, and 13 for Dartmouth in the Paskamanset River subbasin (table 1). These average pumping rates correspond to 0.146 and 0.089 $(ft^3/s)/mi^2$ for the Mattapoisett and Paskamanset River subbasins, respectively, and are a significant percentage of the total discharge of their respective subbasins at low flows (table 6). About 78 percent of the ground water pumped in the Mattapoisett River subbasin is transferred out of the subbasin to Fairhaven and Marion. In the Paskamanset River subbasin, water pumped from municipal wells owned by Dartmouth is discharged as treated wastewater into Buzzards Bay. If 78 and 100 percent of the average pumping rates (0.146 and 0.089 $(ft^3/s)/mi^2$) in the Mattapoisett and Paskamanset River subbasins,

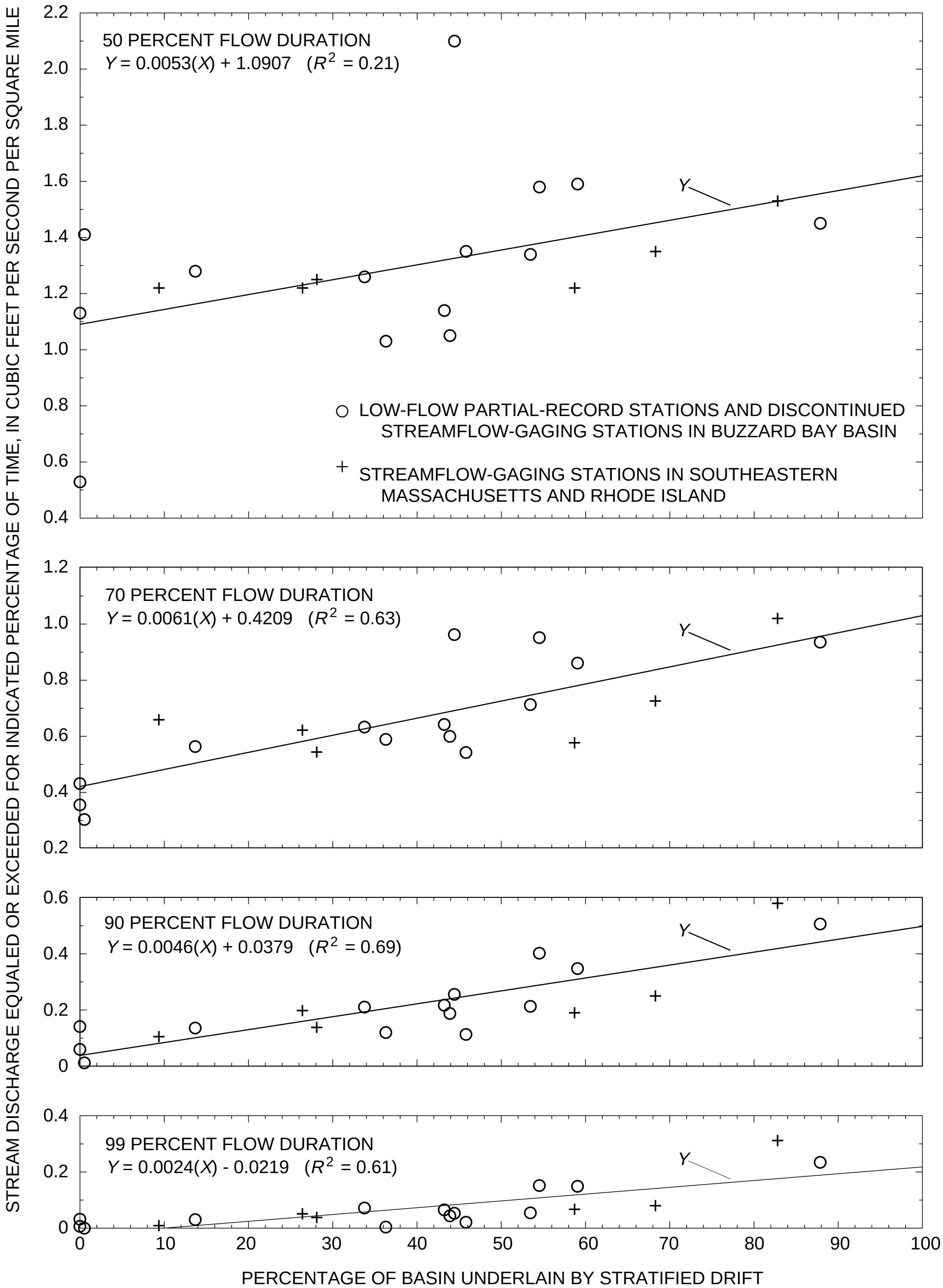


Figure 7. Stream discharge per square mile equaled or exceeded 50, 70, 90, and 99 percent of the time in relation to percentage of basin underlain by stratified drift in southeastern Massachusetts and Rhode Island, water years 1967-91.

respectively, were added to their stream discharge per square mile, these adjusted values would be similar to those of other subbasins in the study area (fig. 7 and table 6).

The effects of ground-water withdrawals from public water-supply wells on streamflow were studied further in the Paskamanset River subbasin. Streamflows were measured upstream and downstream from the pumped wells during baseflow conditions to determine reductions caused by pumping. Streamflow was measured along the Paskamanset River and at several tributaries from stations 01105930 to 01105933 (fig. 8) on September 18, 1991, and July 28 and September 16, 1992. Streamflow at stations 01105930 and 01105933 on the three dates (table 7) relate to about the 93-, 91-, and 80-percent flow durations, respectively, using table 5. Municipal well pumpage reported by the Dartmouth Water Department (Len Boyce, Dartmouth Water Department, written commun., 1993) on the three dates are listed in table 7. Downstream changes in streamflow from stations 01105930 to 01105933 for the three dates are shown in figure 9.

Streamflows increased with increasing drainage area between station 01105930 and station 011059315 (fig. 9 and table 7). Below station 011059315, streamflows increased little or did not increase with increasing drainage area. Uniform increases in streamflow would be expected because the percentage of stratified drift does not vary much within the measured reach (table 7). The potential effects of well pumpage on streamflows were demonstrated two ways. First, the line of relation of streamflows to drainage area between stations 01105930 and 011059315 in figure 9 was extended at the same slope through the drainage area for station 01105933 to show potential streamflows without ground-water pumpage. Second, pumpage by four wells (wells A, B, C, and D) near the Paskamanset River (fig. 8, table 7) and for all seven wells in the subbasin were summed separately and then added to the measured streamflow at the last station (01105933), and then the two totals were plotted at station 01105933 (fig. 9). This was done to simulate possible streamflows at station 01105933 without the ground-water pumpage by the four wells near the river and all seven wells in the subbasin, assuming that the reduction in streamflow is equivalent to the pumping rate. At station 01105933, the rate of increase in streamflow by drainage area was most similar to the measured streamflow plus well pumpage at the four wells near the river (fig. 9). Although effects of ground-water pumpage on streamflows during baseflow periods from the three wells (wells V-1, V-2, and V-3) in the headwaters of a tributary to the Paskamanset River are not apparent, there still will be some minor effect on streamflows during periods of the year because the pumpage is removing ground water that would eventually discharge to the river.

Ground-Water Underflow

Discharge from a basin could be underestimated if ground water flows through stratified-drift deposits and bypasses the measuring point (continuous streamflow-gaging station or low-flow partial record station) (Jacob, 1938; Randall and others, 1988, p. 24, 25; and Dickerman and Bell, 1993, p. 9). In Buzzards Bay Basin, ground-water underflow at the three till and bedrock stations, Buttonwood Brook (01105928), Kirby Brook (01105950), and Angeline Brook (01106005), is negligible because ground-water flow through till and bedrock is small relative to streamflow. At the Bread and Cheese Brook (01105947), East Branch Westport River (01105945), Shingle Island River (01105943), Destruction Brook (01105935), Paskamanset River (01105930 and 01105933), Acushnet River (01105926), and Sippican River (01105905) stations, ground-water underflow may occur because the stratified drift is laterally extensive at the measuring points, although the saturated thickness of the stratified drift is 25 ft or less (Willey and others, 1978, sheet 1; and Williams and Tasker, 1978, sheet 1). At the Shingle Island River (01105937), Mattapoisett River (01105928), Weweantic River (01105895), Agawam River (01105890), and Red Brook (01105885) stations, ground-water underflow may be significant because the saturated thickness of the stratified drift at these stations is 50 to 75 ft, 25 to 50 ft, 0 to 50 ft, 0 to 50 ft, and 0 to 100 ft, respectively, and the stratified drift is laterally extensive at the measuring points (Willey and others, 1978, sheet 1; Williams and Tasker, 1974, sheet 2; and Williams and Tasker, 1978, sheet 1). At all the stations, excluding the till and bedrock stations, Buttonwood Brook (01105928), Kirby Brook (01105950), and Angeline Brook (01106005), the amount of underflow also depends on the water-transmitting properties of the stratified-drift deposits at the measuring point and the water-table gradient.

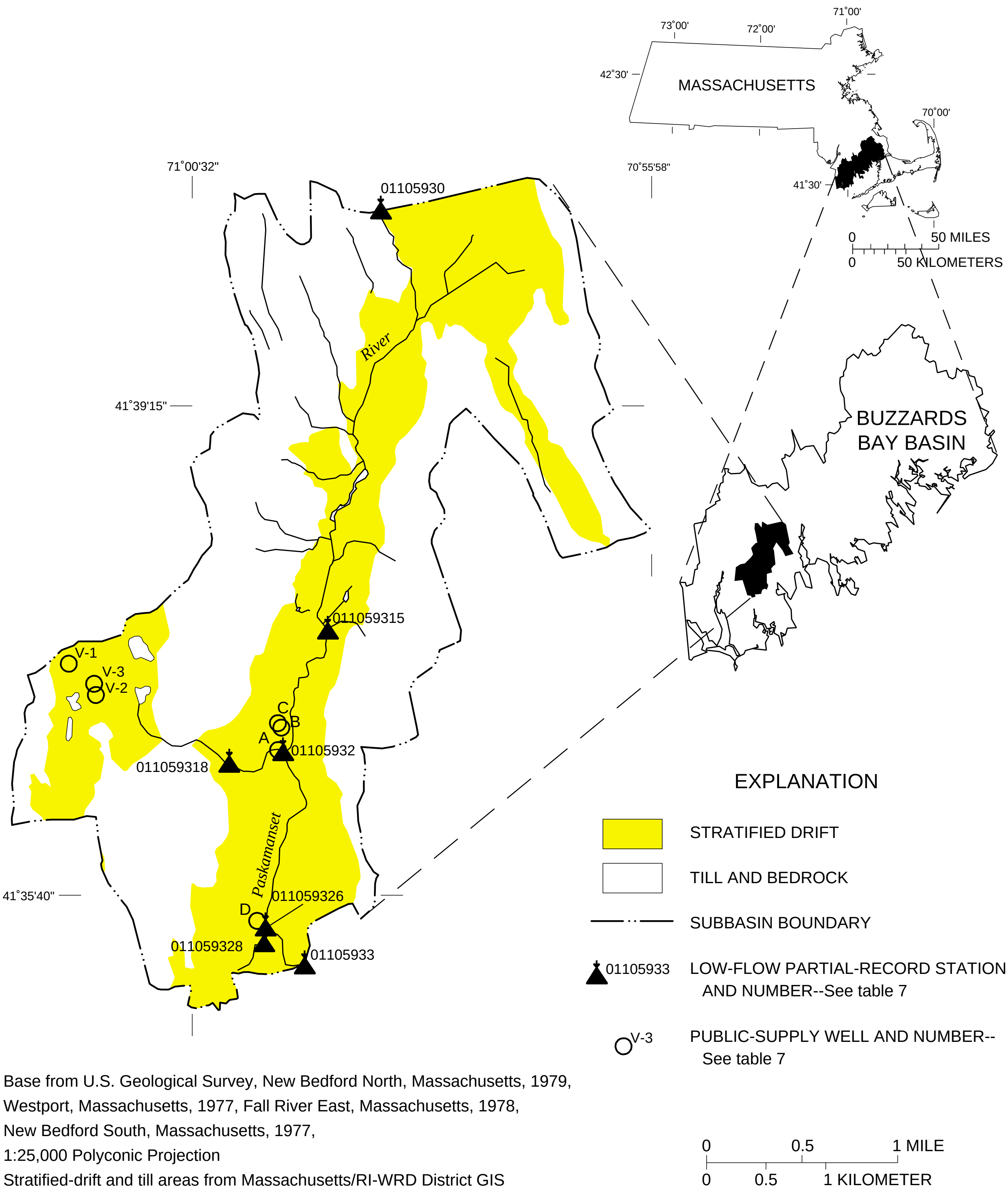


Figure 8. Location of low-flow partial-record stations and public-supply wells along the Paskamanset River and selected tributaries, southeastern Massachusetts.

Table 7. Streamflow and well pumpage on the Paskamanset River, southeastern Massachusetts, and on selected tributaries to the Paskamanset River on September 18, 1991, and on July 28 and September 16, 1992

[USGS station No. or town well No.: Locations shown in figure 8. Latitude and longitude are given in degrees, minutes, seconds. Stratified-drift areas were measured by geographic information systems technology and therefore may differ slightly from, and do not supersede, previously published figures. mi^2, square mile; ft^3/s, cubic foot per second. --, not applicable]

USGS station No. or town well No.	Station name	Latitude ° ′ ″	Longitude ° ′ ″	River mile	Drainage area (mi^2)	Stratified-drift area (percent)	Streamflow or well pumpage (ft^3/s)		
							9-18-91	7-28-92	9-16-92
01105930	Paskamanset River at Turner Pond outlet	414043	705839	0.00	8.12	44.4	1.40[3]	1.72	4.28
011059315	Paskamanset River at Friends Academy	413736	705912	4.18	18.1	40.1	3.63	3.95	8.17
Well V-1[1]	--	413746	710146	[2]	--	--	.509	.486	.472
Well V-2[1]	--	413756	710130	[2]	--	--	.000	.572	.614
Well V-3[1]	--	413713	710131	[2]	--	--	.000	.353	.387
011059318	Unnamed tributary at Chase Road	413637	710011	5.45	2.58	49.2	.182	.133	.629
Well A[1]	--	413643	705942	5.46	--	--	.393	.309	.000
Well B[1]	--	413655	705942	5.46	--	--	.569	.633	.608
Well C[1]	--	413653	705940	5.46	--	--	.306	.377	.000
01105932	Paskamanset River below unnamed tributary and east of well A	413642	705939	5.47	22.9	41.3	3.50	4.28	9.70
Well D[1]	--	413527	705955	7.12	--	--	.665	.718	.699
011059326	Paskamanset River below well D	413524	705950	7.13	25.8	43.2	3.32	4.68	9.98
011059328	Unnamed tributary on gravel road below well D	413517	705951	7.19	.25	99.6	.000	.000	.054
01105933	Paskamanset River at Russells Mills Road	413507	705927	7.73	26.2	44.1	3.76	4.31	10.0

[1]Wells A, B, C, D, V-1, V-2, and V-3 are wells GW-7 to GW-13, respectively, in table 1 and figure 2.

[2]Wells V-1, V-2, and V-3 are in the headwaters of Paskamanset unnamed tributary (011059318) (fig. 7), which flows into the Paskamanset River at river mile 5.45.

[3] Streamflow on September 18, 1991, for station 01105930 was estimated based on relation of streamflow measurements between stations 01105930 and 01105933.

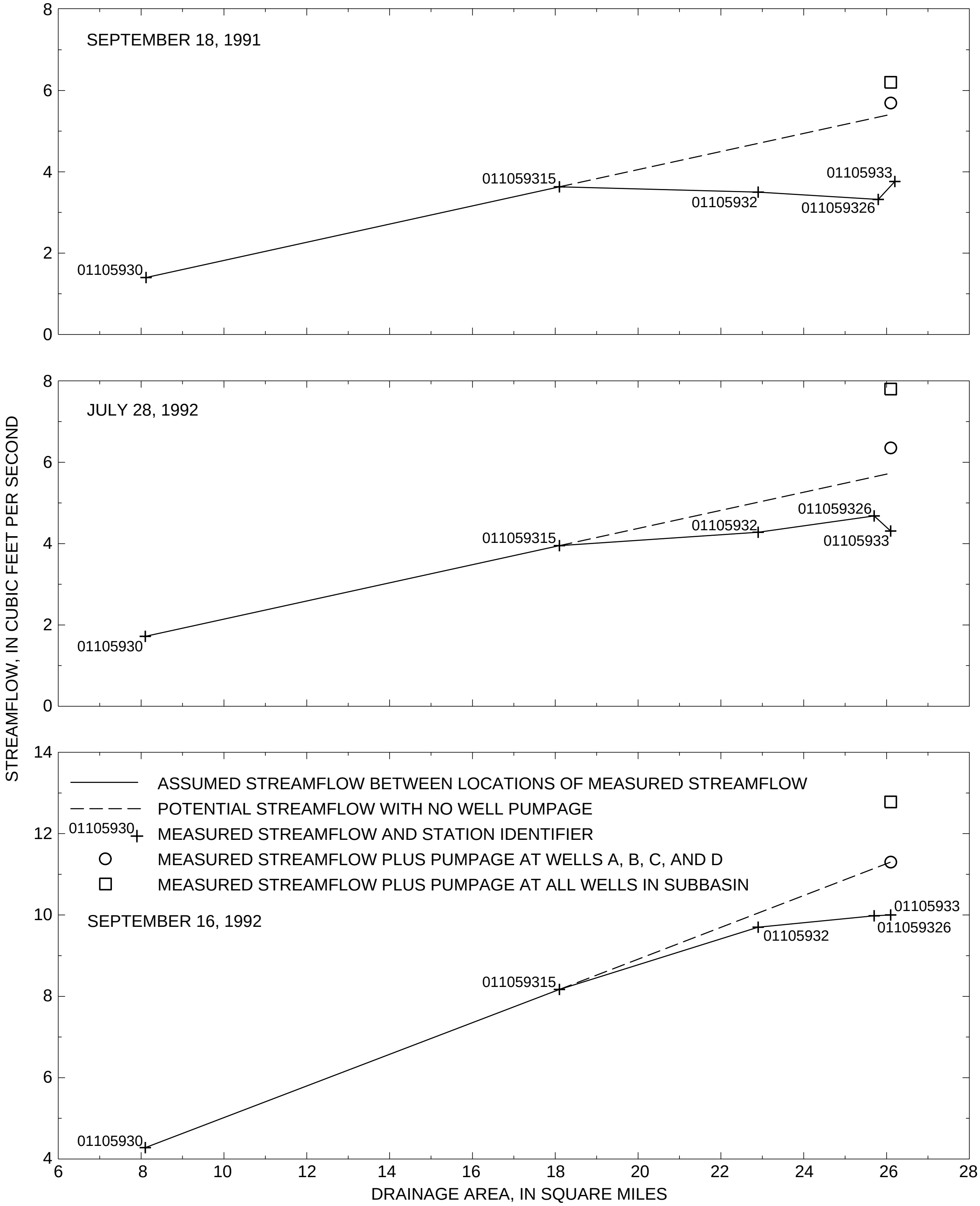


Figure 9. Paskamanset River streamflow by drainage area from stations 01105930 to 01105933 on September 18, 1991, and on July 28 and September 16, 1992.

GROUND-WATER RECHARGE AND DISCHARGE

Ground-water recharge is the amount of precipitation that infiltrates through the land surface and reaches the water table. Ground-water discharge is that part of streamflow which is ground water that has discharged from the aquifer to the stream channel upstream of the measuring point. Ground water discharges continuously to streams and is typically the principal component of streamflow 3 to 7 days after a peak in streamflow caused by precipitation or snowmelt, depending on antecedent conditions. Estimates of annual ground-water recharge and discharge rates are useful in assessing potential water supplies. During most years, ground-water levels and ground-water discharge decrease during the growing season. During drought periods, extended periods of no ground-water recharge to aquifer may occur. Annual recharge and discharge rates can vary significantly with variations in annual precipitation.

Because there were no active streamflow-gaging stations in Buzzards Bay Basin during the study, streamflow records for six nearby gaging (index) stations in southeastern Massachusetts and Rhode Island (fig. 2 and table 2) were analyzed to assess potential ground-water recharge and discharge rates and responses to climatic variations. Data for water years 1967-91 were analyzed for five of the stations. Data for Adamsville Brook (01106000) were not available after 1978, so only data for water years 1967-78 were analyzed at that location.

Recharge

The computer program RORA was used to estimate mean ground-water recharge rates. RORA uses the recession-curve-displacement method to estimate ground-water recharge for each peak in streamflow during the period of record, and is described by Rutledge (1993, p. 4, 20-29). The recession-curve-displacement method uses the pre-peak and post-peak recession periods to extrapolate the change in the total potential ground-water discharge as estimated at critical time after the peak (Rutledge, 1993, p. 4, 20-29). Total potential ground-water discharge to the stream at critical time after a peak in streamflow, approximately when the streamflow hydrograph becomes log-linear again, is about one-half of the total volume of water that recharged the ground-water system during the peak (Rutledge, 1993, p. 22). The method applies in flow systems that are driven by areally diffuse recharge events that can be considered to be roughly concurrent with peaks in streamflow (Rutledge, 1993, p. 3).

Ground-water recharge to stratified-drift areas is typically expected to be greater than ground-water recharge to till and bedrock areas, because of lower infiltration rates in till and bedrock areas. Results in table 8 show mean ground-water recharge rates ranged from 19.7 to 25.2 in/yr at the six index stations during water years 1967-91. Percentage of stratified drift (82.8 percent) and estimated mean ground-water recharge rate (25.2 in/yr) were highest at Jones River (01105870). Percentages of stratified drift (9.36, 28.1, and 26.4 percent) and mean ground-water recharge rates (22.6, 22.3, and 19.7 in/yr) were lowest at Adamsville Brook (01106000), Nipmuc River (01111300), and Old Swamp River (01105600) (table 8).

Estimates of ground-water recharge rates for this study are similar to those reported for other studies in and near the Buzzards Bay Basin. Hansen and Lapham (1992, p. 22, 23) estimated a ground-water recharge rate of 26.9 in/yr in the Eel River Basin (01105876) in Plymouth, Mass., which is underlain 100 percent by stratified-drift deposits, and is adjacent to the Buzzards

Table 8. Estimates of minimum, maximum, and mean ground-water recharge and discharge rates during water years 1967-91 at six streamflow-gaging stations in southeastern Massachusetts and Rhode Island derived from the computer programs RORA and HYSEP

[USGS station No.: Station locations shown in figure 2 and described in table 2. Ground-water recharge and discharge are in inches per year]

USGS station No.	Water year	Minimum	Water year	Maximum	Mean	Standard deviation
Annual ground-water recharge derived by RORA						
01105600	1985	9.82	1984	28.0	19.7	4.42
01105730	1981	10.4	1984	35.0	23.8	5.90
01105870	1981	11.7	1984	44.9	25.2	7.88
01106000[1]	1975	17.1	1973	30.2	22.6	4.14
01109000	1981	9.05	1984	36.9	23.8	7.07
01111300	1985	13.6	1978	30.8	22.3	4.96
Annual ground-water discharge derived by HYSEP (fixed interval technique)						
01105600	1985	8.78	1984	26.9	18.4	4.25
01105730	1981	9.77	1984	32.2	21.4	5.31
01105870	1981	11.4	1984	41.9	23.4	7.06
01106000[1]	1975	16.2	1973	26.9	20.3	3.18
01109000	1981	7.42	1984	29.1	19.1	5.45
01111300	1985	11.9	1984	28.4	20.1	4.64

[1] Values for Adamsville Brook (01106000) are based on water years 1967-78, because the station was discontinued after 1978.

Bay Basin (fig. 2). Barlow and Hess (1993, p. 17, 18) estimated a ground-water recharge rate of 22.9 in/yr using climatological data from the East Wareham Climatological Station in Wareham, Mass., which is in the Buzzards Bay Basin. Estimated ground-water recharge rates at Indian Head River (01105730), Jones River (01105870), and Wading River (01109000) Basins (table 8), which are greater than 58 percent stratified drift, were most similar to rates reported by Hansen and Lapham (1992, p. 22, 23) and Barlow and Hess (1993, p. 17, 18).

Estimates of ground-water recharge rates at Adamsville Brook (01106000), Nipmuc River (01111300), and Old Swamp River (01105600) Basins, where till and bedrock deposits underlie 71 percent or more of their basins, are greater than rates commonly assumed for till and bedrock deposits. An estimate of 6.8 in/yr for till and bedrock deposits was used in ground-water models in the Mattapoisett River study (Olimpio and deLima, 1984) and the Plymouth-Carver aquifer study (Hansen and Lapham, 1992), both areas are in Buzzards Bay Basin. The ground-water recharge rate of 6.8 in/yr for till and bedrock deposits was first reported by Morrissey (1983, p. 14-16). Morrissey (1983, p. 14-16) used a manual method of sketching a curve below the streamflow hydrograph, which would produce a different result than an analysis using the computer program RORA. Other reasons for different results at stations for this study are that the stations are underlain by less than 100 percent till and bedrock deposits and that Morrissey (1983, p. 15) analyzed only one water year (1981) of streamflow record, when total runoff was 6 in. less than the long-term average annual runoff.

Estimates of annual ground-water recharge rates for water years 1967-91 showed that during drought years, such as 1981 and 1985, annual ground-water recharge could be less than one-half of the mean rates for water years 1967-91 (table 8). Water levels in USGS observation well PWW-22 (fig. 3) show similar results as water levels rose only slightly in 1981 following a decline in 1980. Water levels in 1985 also show only small rises in water levels. Maximum estimated annual recharge rates generally occurred in 1984, when recharge rates were 50 percent or more than the mean rates for water years 1967-91 (table 8). Water levels in well PWW-22 (fig. 3) show a high water level in 1984, which followed a high water level in 1983.

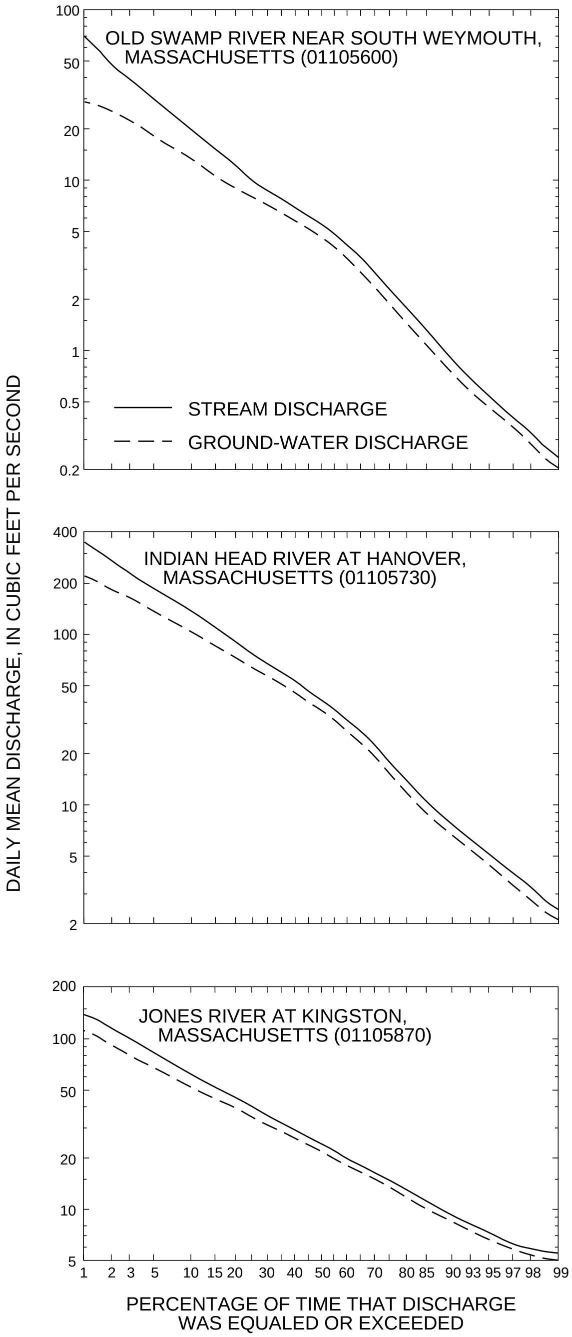
Discharge

Hydrograph separation was used to determine ground-water discharge from the six streamflow-gaging (index) stations (table 2). A choice of three hydrograph-separation methods are available in the computer program HYSEP (White and Sloto, 1990, p. 3-11 and Sloto, 1991, p. 101-110) to estimate mean daily ground-water discharges from streamflow records. The fixed interval method in HYSEP was used in this study, with a 3-day interval. Mean daily ground-water discharges were computed for water years 1967-91 for five of the gaging stations, and for water years 1967-78 for Adamsville Brook.

When results from the computer program HYSEP were compared to the estimates of mean ground-water recharge computed by RORA, mean ground-water discharge rates were 1 to 4 in/yr less than mean ground-water recharge rates (table 8). Minimum and maximum ground-water discharge rates for water years 1967-91 generally were 1 to 4 in/yr less than mean ground-water recharge rates (table 8). These results show that annual and mean ground-water discharge rates could be used as low estimates of annual and mean ground-water recharge rates. Rutledge (1993), who developed the computer program RORA, found mean ground-water discharge to be 1 to 2 in/yr less than mean ground-water recharge in the Appalachian Valley and Ridge, Piedmont, and Blue Ridge physiographic provinces of the United States. Rutledge attributed this difference between mean ground-water recharge and discharge to the loss of water to riparian evapotranspiration. Riparian evapotranspiration was defined as the loss of water in stream channels to evaporation and the loss of water in the saturated zone near the stream to evapotranspiration by Rutledge (1993, p. 40).

For the six streamflow-gaging stations, hydrograph-separation and flow-duration analysis were combined to compute ground-water discharge-duration curves. These curves indicated the percentages of time that ground water of various magnitudes is discharged from the basin upstream from the station.

Ground-water-discharge duration curves were constructed from the estimated daily mean ground-water discharges, derived from the fixed interval method in the hydrograph separation program HYSEP (fig. 10). Comparison of stream discharge and ground-water discharge-duration curves at each of the six gaging stations showed that ground-water discharge averaged 85.7 percent of stream discharge between the 50- and 99-percent flow durations and ranged from 74.2 to 93.9 percent of stream discharge (table 9).



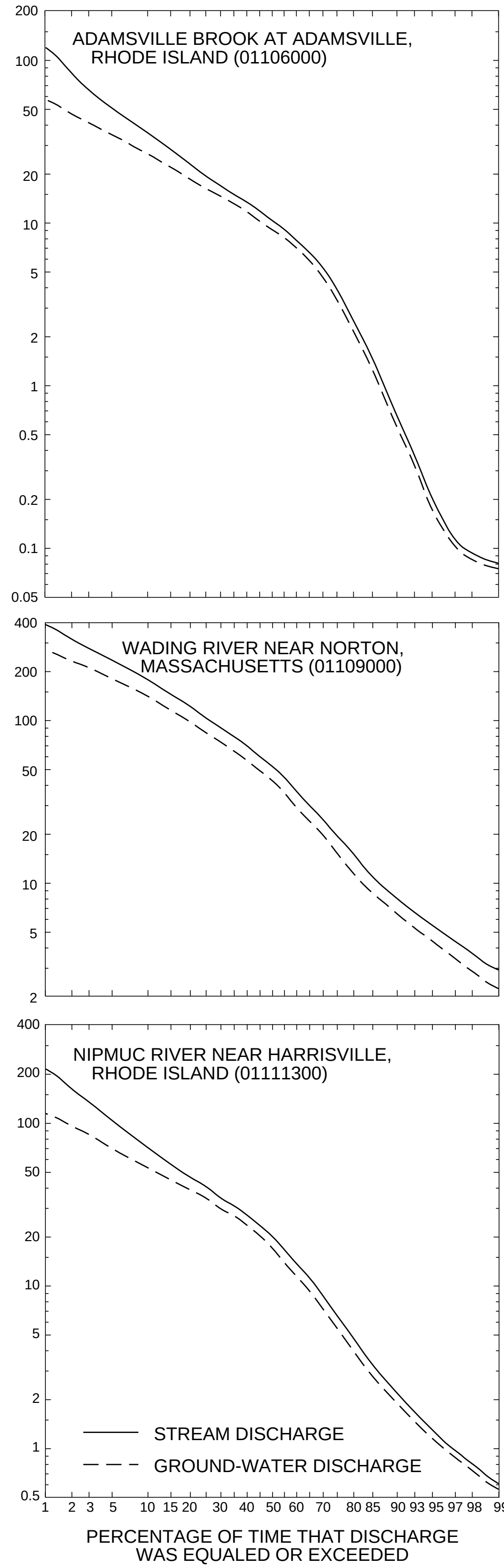


Figure 10. Flow-duration curves for stream discharge and ground-water discharge at six streamflow-gaging stations in southeastern Massachusetts and Rhode Island, water years 1967-91. (Flow-duration curves for Adamsville Brook (01106000) are based on water years 1967-78 because the station was discontinued after 1978.)

Table 9. Streamflow, ground-water discharge, and ratio of ground-water discharge to streamflow at selected flow durations at six streamflow-gaging stations in southeastern Massachusetts and Rhode Island, water years 1967-91

[USGS station No.: Locations shown in figure 2 and described in table 2.]

USGS station No.	Equaled or exceeded at indicated percentage of time														
	50	55	60	65	70	75	80	85	90	93	95	97	98	99	
Streamflow, in cubic feet per second															
01105600	5.56	4.88	4.21	3.57	2.87	2.30	1.80	1.33	0.891	0.681	0.544	0.404	0.335	0.236	
01105730	41.4	36.6	31.7	26.9	22.2	17.8	14.1	10.4	7.72	6.26	5.17	3.98	3.34	2.43	
01105870	24.2	22.1	19.8	18.1	16.3	14.8	13.1	11.3	9.19	8.18	7.31	6.28	5.87	5.05	
01106000[1]	10.5	9.25	8.01	6.82	5.57	4.08	2.62	1.54	.685	.371	.215	.117	.098	.081	
01109000	53.9	46.2	38.2	31.2	25.2	20.3	15.9	11.2	8.20	6.62	5.55	4.46	3.75	2.93	
01111300	20.3	16.9	13.7	11.2	8.75	6.64	4.89	3.34	2.23	1.68	1.32	.956	.836	.610	
Ground-Water Discharge, in cubic feet per second															
01105600	4.66	4.09	3.53	2.89	2.36	1.89	1.46	1.08	0.742	0.572	0.466	0.359	0.285	0.205	
01105730	36.1	31.8	27.3	22.9	19.0	15.3	11.9	8.85	6.68	5.44	4.48	3.38	2.78	2.12	
01105870	21.9	19.7	18.1	16.5	15.0	13.5	11.8	10.1	8.47	7.46	6.61	5.90	5.37	4.56	
01106000[1]	9.21	8.21	7.21	6.12	4.87	3.50	2.26	1.31	.580	.324	.180	.107	.089	.075	
01109000	44.2	37.3	30.2	25.0	20.3	16.1	11.8	8.90	6.72	5.23	4.52	3.62	2.95	2.25	
01111300	17.2	14.0	11.5	9.29	7.25	5.57	4.06	2.83	1.93	1.47	1.16	.884	.747	.563	
Ratio of Ground-Water Discharge to Streamflow															**Mean**
01105600	0.838	0.838	0.838	0.810	0.822	0.822	0.811	0.812	0.833	0.840	0.857	0.889	0.851	0.869	0.838
01105730	.872	.869	.861	.851	.856	.860	.844	.851	.865	.869	.867	.849	.832	.872	.858
01105870	.905	.891	.914	.912	.920	.912	.901	.894	.922	.912	.904	.939	.915	.903	.910
01106000[1]	.877	.888	.900	.897	.874	.858	.863	.851	.847	.873	.837	.915	.908	.926	.880
01109000	.820	.807	.791	.801	.806	.793	.742	.795	.820	.790	.814	.812	.787	.768	.796
01111300	.847	.828	.839	.829	.829	.839	.830	.847	.865	.875	.879	.925	.894	.923	.861
Mean	.860	.854	.857	.850	.851	.847	.832	.842	.859	.860	.860	.888	.864	.876	.857

[1]Values for Adamsville Brook (01106000) are based on water years 1967-78 because the station was discontinued after 1978.

Table 10. Estimated ground-water discharges at selected flow durations for low-flow partial-record stations and discontinued streamflow-gaging stations in Buzzards Bay Basin, southeastern Massachusetts, water years 1967-91

[USGS station No.: Locations shown in figure 6 and described in table 3. Values obtained by multiplying values in table 5 by mean ratio of ground-water discharge to streamflow (0.857) in table 9]

USGS station No.	Ground-water discharge equaled or exceeded at indicated percentage of time, in cubic feet per second													
	50	55	60	65	70	75	80	85	90	93	95	97	98	99
01105885[1]	3.15	2.99	2.81	2.67	2.50	2.32	2.23	2.03	1.83	1.72	1.54	1.51	1.44	1.23
01105890	37.5	36.3	35.3	34.3	33.0	31.7	30.1	28.5	26.7	25.4	24.4	23.2	22.6	21.4
01105895[2]	69.9	63.0	56.2	50.6	45.0	39.3	34.5	29.1	24.3	21.2	18.8	15.8	14.1	11.2
01105905	38.2	34.1	29.1	24.7	20.7	17.3	13.7	10.8	8.38	7.02	6.05	5.05	4.38	3.59
01105917	27.9	23.1	18.5	14.2	11.1	7.63	5.14	3.50	2.33	1.73	1.29	.874	.684	.436
01105926	18.8	16.7	14.2	12.1	10.0	8.06	6.14	4.51	3.00	2.14	1.61	1.15	.943	.753
01105928	1.33	1.23	1.11	1.00	.891	.764	.624	.501	.354	.257	.195	.138	.111	.077
01105930	14.6	12.4	10.7	8.66	6.68	5.32	3.75	2.75	1.77	1.30	.977	.704	.563	.371
01105933	23.7	21.2	18.9	16.2	13.5	11.1	8.42	6.37	4.21	3.00	2.21	1.55	1.28	.977
01105935	3.58	3.22	2.89	2.50	2.15	1.80	1.44	1.17	.908	.756	.636	.513	.446	.345
01105937	7.56	6.63	5.90	5.14	4.34	3.41	2.37	1.57	.883	.543	.357	.189	.107	.021
01105943	20.3	17.5	14.7	12.3	10.2	8.06	6.12	4.58	3.38	2.68	2.24	1.75	1.50	1.16
01105945	27.6	24.3	21.3	18.4	15.5	12.6	9.77	7.42	5.25	4.01	3.19	2.39	2.03	1.56
01105947	9.51	7.99	6.57	5.34	4.20	3.17	2.25	1.57	1.01	.717	.539	.380	.306	.220
01105950	4.46	3.27	2.28	1.51	.960	.504	.242	.105	.035	.015	.007	.003	.002	.001
01106005	3.11	2.55	2.03	1.57	1.19	.801	.515	.316	.165	.097	.060	.033	.024	.015

[1] Streamflow-gaging station during water years 1981-86.
[2] Streamflow-gaging station during water years 1970-71.

The ground-water component of streamflow is larger at durations greater than 50 percent than at durations less than 50 percent. As streamflows approach the 99-percent flow duration, they generally are the result of periods of no rainfall during the summer, and are usually entirely ground-water discharge; however, even flows between the 90- and 99-percent flow durations can at times contain surface runoff. For example, a rainstorm that occurs when streamflows are at the 98-percent duration could cause streamflow to increase to the 93-percent flow duration through added surface runoff. Thus, in this example, the streamflow at the 93-percent flow duration would not be entirely ground-water discharge.

Measured streamflows at the 16 stations in Buzzards Bay Basin were related to daily mean streamflow on the same days at nearby gaging (index) stations to estimate duration discharges between the 50 and 99 percentiles for the partial-record stations, as described previously. Ground-water duration discharges were then determined by multiplying the streamflow duration discharges by 85.7 percent (table 10), the average proportion of the streamflow duration discharge that is ground-water discharge. Estimates of ground-water discharge could be underestimated if ground-water underflow occurs in the subbasin, and overestimated or underestimated slightly because an average was used.

CHARACTERISTICS OF SURFICIAL DEPOSITS

Characteristics of the surficial deposits in Buzzards Bay Basin were investigated through the collection of water-level, test-drilling, aquifer-test, and seismic-refraction data from Federal, State, and local agencies. Several studies of characteristics of surficial deposits in the basin have been done previously by the USGS and consulting firms.

This study almost exclusively collected information on characteristics of stratified-drift deposits, because they are the most productive water source in Buzzards Bay Basin. Yield from wells in stratified-drift deposits in the basin can range from 0 gal/min for fine-grained silts and clays to greater than 300 gal/min for coarse-grained sands and gravels (Williams and Tasker, 1978, sheet 1). Wells in till generally yield only a few gallons per minute (de Lima, 1991, p. 4). Bedrock wells can yield from 1 to 150 gal/min and average about 8 gal/min (Simcox, 1992, p. 49).

Twelve seismic-refraction surveys (appendix B, table B1 and fig. B1) and 10 test drillings (appendix C, tables C1 and C2) were done in selected areas of stratified-drift deposits where the potential for high transmissivities had been mapped (Willey and others, 1978, sheet 1; and Williams and Tasker, 1978, sheet 1) but no detailed data existed. Transmissivity of an aquifer is defined as the saturated thickness of the aquifer multiplied by the horizontal hydraulic conductivity of the aquifer. The saturated thickness of the aquifer is the distance from the water table to the bedrock surface. The horizontal hydraulic conductivity of the aquifer is a measure of the ability of the aquifer material to transmit water in a horizontal direction. Seismic-refraction surveys providing information on depths to water table and bedrock and on lateral boundaries of the deposits were collected and interpreted using methods described by Haeni (1988). Test drilling was done to determine the depth to the water table and bedrock and lithology.

Information on 323 wells was compiled, including 10 test wells installed by the USGS, 72 wells installed by consulting firms, and 241 private wells in and near stratified-drift deposits. The information was entered into the USGS Ground-Water Site Inventory (GWSI) data base. Well logs from the 10 test wells installed by USGS and many of the 72 wells installed by consultants contained sufficient lithologic detail that hydraulic conductivity of the deposits could be estimated. Well information for the 241 private wells were collected from records at the Massachusetts Department of Environmental Management, Division of Resource Conservation, Office of Water Resources. All 241 wells were located in the field to determine latitude and longitude locations so that they could be entered into the USGS GWSI data base. The well logs for the 241 privately drilled wells provided information on the depth to bedrock, depth to water table, and general information on the lithology. The lithologic information was not detailed enough to estimate hydraulic conductivities, and consequently transmissivities could not be estimated for stratified-drift deposits. In many cases, the depth to the water table for private bedrock wells was estimated because the reported water level was measured after the well had been pumped and had not fully recovered or was a measurement of the hydraulic head of the bedrock unit not the stratified-drift or till unit.

Red Brook, Agawam River, Wankico River, and Weweantic River Subbasins (all are part of Plymouth-Carver aquifer area)

During this study, no new data were collected on surficial deposits in this area of the basin. Detailed information on characteristics of surficial deposits in this area are provided by Williams and Tasker (1974) and more recently by Hansen and Lapham (1992). Hansen and Lapham (1992, p. 16, pls. 1, 2) provide maps showing the water table, depth to bedrock, and saturated thickness. The subbasins in the Plymouth-Carver aquifer area are primarily stratified-drift deposits (table 3), with the Weweantic River subbasin having the most amount of its basin underlain by stratified drift (87.9 percent). Saturated thickness in the Red Brook subbasin generally range from 100 to 200 ft and increases towards its headwaters (Hansen and Lapham, 1992, p. 16). Saturated thickness in the Agawam and Wankinco River subbasins generally ranges from 50 to 200 ft and 0 to 200 ft, respectively, and increases towards their headwaters. Saturated thickness in the Weweantic River subbasin generally ranges from 0 to 150 ft and increases towards its headwaters (Hansen and Lapham, 1992, p. 16). Transmissivity maps for the Plymouth-Carver aquifer area are not available.

Sippican River Subbasin

Stratified-drift deposits underlie 59.1 percent of the subbasin (table 3). Saturated thickness of the stratified drift ranges from 0 to greater than 50 ft, and can exceed 75 ft thick locally (Williams and Tasker, 1978, sheet 1). Transmissivities for these deposits are classified as less than 1,400 ft^2/d and from 1,400 to 4,000 ft^2/d. Several small discontinuous units of stratified drift have transmissivities classified as greater than 4,000 ft^2/d (Williams and Tasker, 1978, sheet 1).

Four wells (appendix C, tables C1 and C2) were installed and four seismic-refraction surveys (appendix B, table B1 and fig. B1) were conducted by the USGS. Consulting firm reports provided information on seven additional test wells (Ralph Preble, Camp Dresser & McKee, Inc., written commun., 1991; and Thomas Tansey, SEMASS Partnership, written commun., 1991). Information on 51 private wells in the subbasin was obtained. Additional interpretation of the aquifer transmissivities presented by Williams and Tasker (1978, sheet 1) was not done because of a lack of data.

Well logs indicated significant changes in saturated thickness in two areas and in the lithology of one of those areas in the Sippican River subbasin. Saturated thicknesses greater than 75 ft were previously shown for Area 1 (fig. 11 and table 11) by Williams and Tasker (1978, sheet 1), however, recent well logs indicated saturated thicknesses less than 25 ft (Manuel Repoza, landowner, personal commun., 1991). Area 2 (fig. 11 and table 11), previously had been classified as a till and bedrock area (Williams and Tasker, 1978, sheet 1); however, nine well logs indicated that stratified-drift deposits are present with saturated thicknesses ranging from 0 to 36 ft. Saturated thicknesses were consistent with those mapped by Williams and Tasker (1978, sheet 1) for the locations of seismic-refraction survey lines 1-4 (appendix B, table B1 and fig. B1).

Mattapoisett River Subbasin

During this study, no new data were collected on surficial deposits in this area of the basin. Detailed information on characteristics of surficial deposits in this area are provided by Williams and Tasker (1978) and more recently by Olimpio and de Lima (1984, p. 10-13, 16-17), who provided water table, depth to bedrock, and saturated thickness maps for the subbasin. They reported saturated thicknesses from 0 to greater than 75 ft. Stratified-drift deposits generally were limited to the valley bottom along the river, and saturated thickness of the deposits ranged from 0 to less than 75 ft (Olimpio and de Lima, 1984, p. 16-17). Transmissivities range from less than 1,400 to greater than 4,000 ft^2/d for the stratified-drift deposits along the river (Williams and Tasker, 1978, sheet 1). The units of transmissivities classified as greater than 4,000 ft^2/d were small and discontinuous.

Acushnet River Subbasin

Surficial deposits in the Acushnet River subbasin were previously mapped by Williams and Tasker (1978). Stratified-drift deposits primarily follow the valley bottom, and the uplands are primarily till and bedrock. Saturated thickness of the stratified-drift deposits range from 0 to less than 75 ft, with a small area greater than 75 ft in the headwaters of the subbasin (Williams and Tasker, 1978, sheet 1). Transmissivities are primarily classified as less than 1,400 ft^2/d and from 1,400 to 4,000 ft^2/d, with two small areas classified as greater than 4,000 ft^2/d in the headwaters of the subbasin (Williams and Tasker, 1978, sheet 1).

One well (appendix C, tables C1 and C2) was installed and two seismic-refraction surveys (appendix B, table B1 and fig. B1) were conducted by the USGS. Because of sparse data, aquifer transmissivities were not interpreted. The best estimates of aquifer transmissivities in the subbasin are those presented by Williams and Tasker (1978, sheet 1).

Saturated thicknesses, based on well logs in the Acushnet River subbasin, were primarily unchanged from those described by Williams and Tasker (1978, sheet 1). Stratified drift with saturated thicknesses that ranged from 50 to 75 ft was identified from three well logs in Area 3 (fig. 11 and table 11). This area was previously mapped as till and bedrock. Seismic-refraction survey line 6 (appendix B, table B1 and fig. B1) and several observed bedrock outcrops in Area 4 (fig. 11 and table 11), which was previously mapped with a saturated thickness of 25 to 50 ft, showed saturated thicknesses primarily to be less than 25 ft. Saturated thicknesses determined from seismic-refraction survey line 5 (appendix B, table B1 and fig. B1) were similar to those previously mapped by Williams and Tasker (1978, sheet 1) for that area.

Slocums River Subbasin (includes Destruction Brook and Paskamanset River Subbasins)

Williams and Tasker (1978, sheet 1) mapped stratified-drift deposits primarily in the valley bottoms along the river and till and bedrock deposits in the upland areas of the Destruction Brook and Paskamanset

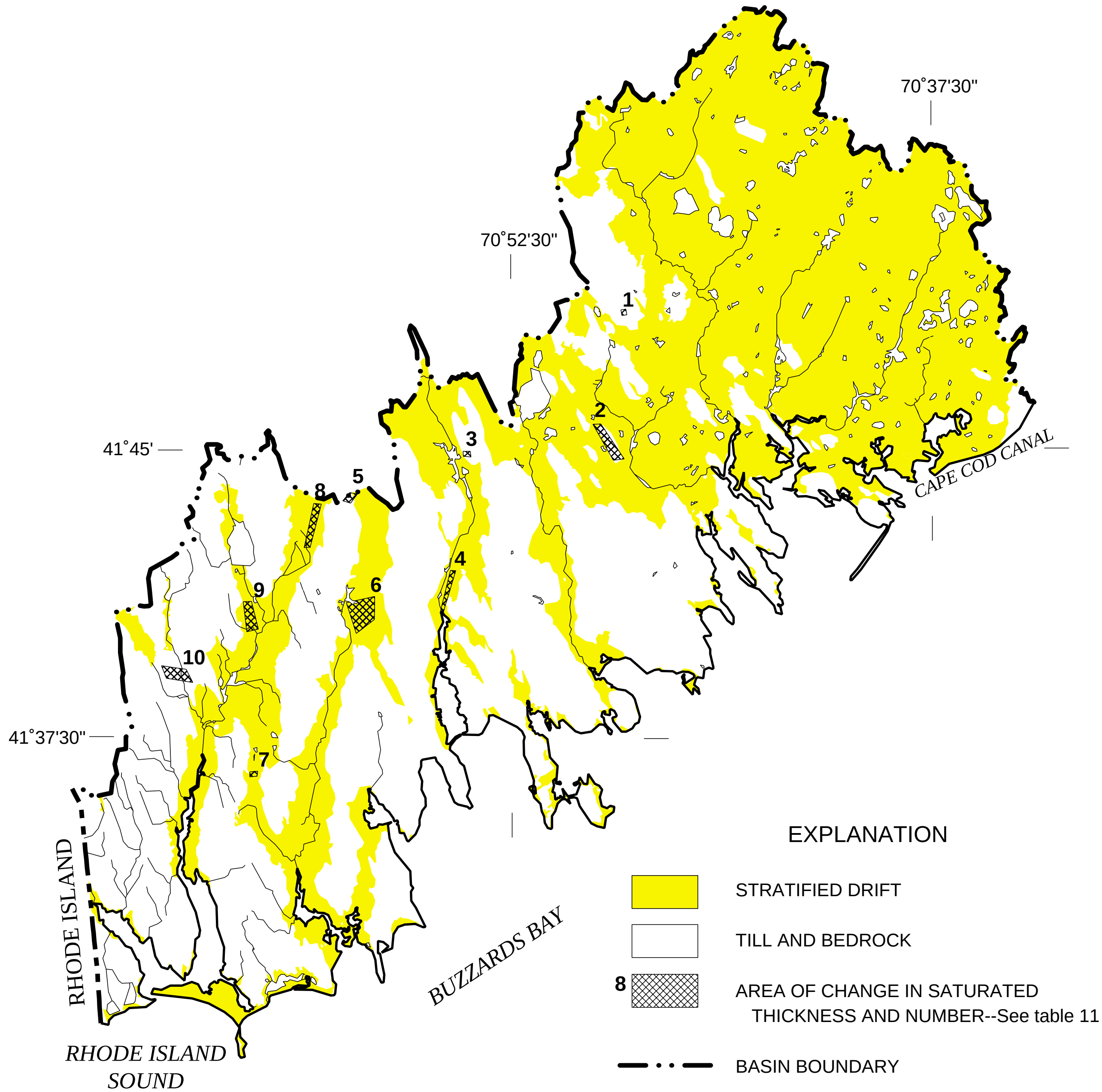


Figure 11. Locations of areas of changes in saturated thickness of the stratified-drift deposits in Buzzards Bay Basin, southeastern Massachusetts.

River subbasins. Saturated thicknesses of all stratified-drift deposits in the Destruction Brook subbasin were less than 25 ft and transmissivities were less than 1,400 ft^2/d. Saturated thicknesses of stratified-drift deposits in the Paskamanset River subbasin ranged from 0 to less than 100 ft (Williams and Tasker, 1978, sheet 1). Saturated thickness for a large area of stratified drift in the upper part of the subbasin to its headwaters was

Table 11. Descriptions of locations for areas of changes in characteristics of surficial deposits in Buzzards Bay Basin, southeastern Massachusetts

[Area of change No.: Locations of areas of change shown in figure 11. Saturated thickness refers to stratified-drift deposits. Latitude and longitude given in degrees, minutes, seconds. ft, foot]

Area of change No.	Subbasin	Corner points of area of change		Change that was determined
		Latitude ° ′ ″	Longitude ° ′ ″	
1	Sippican River	414844 414845 414836 414835	704837 704827 704825 704835	Area mapped with saturated thicknesses greater than 75 ft (Williams and Tasker, 1978, sheet 1), but well logs indicated saturated thicknesses less than 25 ft.
2	Sippican River	414542 414542 414446 414444	704939 704922 704833 704856	Area mapped as till and bedrock (Williams and Tasker, 1978, sheet 1), but well logs indicated that the area is stratified drift with saturated thicknesses ranging from 0 to 36 ft.
3	Acushnet River	414500 414500 414451 414453	705417 705401 705400 705416	Area mapped as till and bedrock (Williams and Tasker, 1978, sheet 1), but well logs indicated that the area is stratified drift with saturated thicknesses ranging from 50 to 75 ft.
4	Acushnet River	414151 414149 414043 414042	705446 705435 705501 705509	Area mapped with saturated thicknesses from 25 to 50 ft (Williams and Tasker, 1978, sheet 1), but a seismic-refraction survey and observed bedrock outcrops indicated saturated thicknesses primarily less than 25 ft.
5	Paskamanset River	414355 414354 414342 414342	705819 705812 705826 705834	Area mapped with saturated thicknesses less than 25 ft and as till and bedrock (Williams and Tasker, 1978, sheet 1), but well logs indicated that the area is all stratified drift with saturated thicknesses ranging from 37 to 62 ft.
6	Paskamanset River	414059 414109 414032 414010	705828 705727 705728 705807	Area mapped with saturated thicknesses from 0 to 75 ft, but primarily greater than 75 ft (Williams and Tasker, 1978, sheet 1). Seismic-refraction survey identified saturated thicknesses less than 65 ft and well logs indicated saturated thicknesses ranging from 23 to 37 ft.
7	Destruction Brook	413630 413631 413623 413622	710156 710139 710140 710156	Area mapped with saturated thicknesses less than 25 ft (Williams and Tasker, 1978, sheet 1), but seismic-refraction survey identified saturated thicknesses ranging from 0 to 50 ft.
8	Shingle Island River	414338 414337 414228 414229	705937 705921 705944 705957	Area mapped with saturated thicknesses from 50 ft to greater than 100 ft (Willey and others, 1978, sheet 1), but well logs indicated saturated thicknesses may only slightly exceed 50 ft.
9	Shingle Island River	414102 414103 414018 414015	710208 710150 710136 710200	Area mapped with saturated thicknesses greater than 25 ft (Willey and others, 1978, sheet 1), but well logs and an observed bedrock outcrop indicated saturated thicknesses less than 25 ft.
10	Bread and Cheese Brook	413920 413914 413853 413900	700503 710410 710356 710453	Area mapped as till and bedrock (Willey and others, 1978, sheet 1), but well logs indicated that the area is stratified drift with saturated thicknesses less than 25 ft.

greater than 75 ft but less than 100 ft. Transmissivities of the stratified-drift deposits ranged from less than 1,400 ft^2/d to 4,000 ft^2/d. Transmissivities were greater than 4,000 ft^2/d for two small areas in the lower and upper parts of the Paskamanset River subbasin.

Three wells (appendix C, tables C1 and C2) were installed and three seismic-refraction surveys (appendix B, table B1 and fig. B1) were conducted by the USGS in the Slocums River subbasin. Detailed well logs for an additional 40 wells and seismic-refraction surveys were obtained from consulting firms (Len Boyce, Dartmouth Water Department, written commun., 1991; Michael O'Reilly, Dartmouth Conservation Commission, written commun., 1991; Scott Alfonse, New Bedford Environmental Department, written commun., 1991; Michael Kostur, Camp Dresser & McKee, Inc., written commun., 1991; John Krawczk, Fay, Spofford, and Thorndike, Inc., written commun., 1991; and Charles Race, Woodard and Curran, Inc., written commun., 1992) (Dr. James Skehan, Boston College, written commun., 1991; and Charles Race, Woodard and Curran, Inc., written commun., 1992) (Weston Geophysical Engineers, Inc., 1967). Of the 40 detailed well logs, 23 wells were primarily in areas of till or in areas around municipal wells in the subbasin, where transmissivities were already accurately described, so transmissivity maps for the subbasin were not updated.

Additional data from 14 private well reports and seismic-refraction data from consulting reports indicated significant changes in saturated thickness at a few locations. In area 5 (fig. 11 and table 11), three well logs indicated that saturated thickness ranged from 37 to 62 ft in an area that was previously mapped by Williams and Tasker (1978, sheet 1) as stratified drift with saturated thickness less than 25 ft, and as till and bedrock. In area 6 (fig. 11 and table 11), Williams and Tasker (1978, sheet 1) mapped a large area of saturated thicknesses from 0 to greater than 75 ft, with most of the area shown as having saturated thicknesses greater than 75 ft. Seismic-refraction survey line 7 (appendix B, table B1 and fig. B1) done in this area identified saturated thicknesses less than 65 ft, and two well logs (appendix C, table C1) indicated that saturated thicknesses ranged from 23 to 37 ft. In Area 7 (fig. 11 and table 11), seismic-refraction survey line 8 (appendix B, table B1 and fig. B1) identified saturated thicknesses ranging from 0 to 50 ft. This area was previously mapped as less than 25 ft of saturated thickness.

East Branch Westport River Subbasin (includes Bread and Cheese Brook and Shingle Island River Subbasins)

Surficial deposits mapped by Willey and others (1978) show stratified-drift deposits located in the valley bottoms along Bread and Cheese Brook and Shingle Island River, and till and bedrock deposits situated in the upland areas. Saturated thicknesses range from 0 to more than 100 ft in one area of the headwaters of the Shingle Island River subbasin (Willey and others, 1978, sheet 1). Transmissivities of the stratified-drift deposits ranged from less than 1,400 to greater than 4,000 ft^2/d.

Two wells (appendix C, tables C1 and C2) were installed and three seismic-refraction surveys (appendix B, table B1 and fig. B1) were conducted by the USGS in the East Branch Westport River subbasin, which includes the Shingle Island River and Bread and Cheese Brook subbasins. An additional 25 logs from test wells (Len Boyce, Dartmouth Water Department, written commun., 1991; Michael O'Reilly, Dartmouth Conservation Commission, written commun., 1991; and Gerald Blaze, Fall River Water Department, written commun., 1991) and seismic-refraction survey data (Dr. James Skehan, Boston College, written commun., 1991) (Weston Geophysical Engineers, Inc., 1967) and 75 private well reports were collected. Aquifer transmissivities were determined for 22 wells. Transmissivities of wells in stratified drift were consistent with previously mapped values by Willey and others (1978, sheet 1).

Data obtained by this study mostly confirmed saturated thicknesses mapped by Willey and others (1978, sheet 1) in the East Branch Westport River subbasin, except for three areas (fig. 11 and table 11). In area 8 (fig. 11 and table 11), saturated thicknesses ranged from 50 ft to greater than 100 ft, but several well logs show that saturated thickness may only slightly exceed 50 ft. In area 9 (fig. 11 and table 11), saturated thicknesses were greater than 25 ft, but three well logs and an observed bedrock outcrop indicated that saturated thicknesses are less than 25 ft. In area 10 (fig. 11 and table 11), seven well logs indicated the extent of stratified drift with a saturated thickness of less than 25 ft was far more extensive than shown on their map. Some of this area was previously mapped as till and bedrock. Saturated thicknesses in the East Branch Westport River subbasin were consistent with those mapped by Willey and others (1978, sheet 1) for the locations of seismic-refraction lines 10-12 (appendix B, table B1 and fig. B1).

SUMMARY

Buzzards Bay Basin covers 374 mi^2 in southeastern Massachusetts and is drained by several brooks and rivers, which discharge into Buzzards Bay. In 1992, water supplies were sufficient in the basin, but water shortages have been experienced by some municipalities during previous drought periods. If the basin population increases, some municipalities may need to consider development of additional ground-water resources. This report (1) provides estimates of streamflow for streams in Buzzards Bay Basin, (2) provides estimates of ground-water recharge and discharge in the basin, and (3) updates previously described characteristics of surficial deposits in the basin.

In 1992, a total of 12.74 Mgal/d of water was used for municipal supplies in Buzzards Bay Basin. About 58 percent of the total municipal water supply came from ground-water pumpage, of which municipal wells in the Mattapoisett and Paskamanset River subbasins accounted for about 57 percent of the total ground-water pumpage. There are only two surface-water supplies in the entire basin. Several municipalities obtain their water supplies from sources outside the basin, and several municipalities do not have public water-supply systems.

Buzzards Bay Basin has two distinct landforms, which are reflected in differences in coverage of stratified-drift deposits. From the Sippican River subbasin eastward, the landform is flat or gently rolling, and stratified-drift deposits cover from 60 to 100 percent of individual river subbasins in this area. West of the Sippican River subbasin, the landform is low-relief valley and ridge. Stratified-drift deposits in this area generally are confined to valley bottoms along the south-flowing rivers, and cover from 0 to 53 percent of individual river subbasins.

Estimates of stream discharges at selected durations between the 50 and 99 percentiles for water years 1967-91 were determined for 14 low-flow partial-record stations and two discontinued streamflow-gaging stations in Buzzards Bay Basin. Estimated stream discharges determined for 11 of the 16 stations do not reflect natural flow conditions. Streamflows at the 11 stations are affected by man-made influences, such as municipal, industrial, or agricultural uses that may cause water to be diverted to or from the subbasin, and (or) by urban storm sewers. At the 16 stations, stream discharges were divided by their drainage area to evaluate factors affecting streamflows. At low flows, stream discharge per square mile at stations in the basin and at the six gaging stations generally increased with increasing percentage of basin underlain by stratified drift. At the 70-, 90-, and 99-percent flow durations, streamflows from subbasins underlain primarily by stratified drift were at least 2, 4, and 8 times greater, respectively, than subbasins underlain primarily by till and bedrock.

About 87 and 100 percent of the ground water withdrawn from the Mattapoisett and Paskamanset River subbasins is not returned to the subbasin. Stream discharge per square mile of these subbasins are lower than those for subbasins with little or no ground-water pumpage. When the percentage of average daily pumpage leaving the Mattapoisett and Paskamanset River subbasins was added to their stream discharge per square mile, the adjusted values were similar to those of the other river subbasins in Buzzards Bay Basin. Streamflow were measured on the Paskamanset River three times during baseflow conditions to further assess the effect of ground-water pumpage on streamflows. Plots of streamflow by drainage area for stations along the Paskamanset River showed the slope of the relation to increase at a lower rate downstream from the municipal pumped wells. A line showing the rate of increase in streamflows by drainage area for the two stations upstream of any influence of well pumpage was extended to the most downstream station for the three measurement dates. At the most downstream station, these lines were similar to data points of measured streamflow plus well pumpage for only the four wells near the Paskamanset River.

Ground-water recharge rates were estimated for Buzzards Bay Basin by analyzing streamflow records for water years 1967-91 at six nearby gaging stations in southeastern Massachusetts and Rhode Island using a USGS computer program RORA. Estimates of mean ground-water recharge rates at the six gaging stations showed that recharge in the basin probably ranges from 19.7 to 25.2 in/yr depending on the percentage of the basin underlain by stratified-drift deposits. Mean ground-water recharge rates for basins underlain primarily by till and bedrock deposits (less than 25-percent stratified-drift deposits) were from 19.7 to

22.6 in/yr. These rates are much higher than the rate of 6.8 in/yr used in southeastern Massachusetts for previous studies. Estimates of annual ground-water recharge rates indicated that during drought years ground-water recharge could be less than one-half of the mean ground-water recharge rate for water years 1967-91. Estimates of mean, minimum, and maximum ground-water discharge rates, calculated by the USGS computer program HYSEP, generally were 1 to 4 in/yr less than estimates of mean, minimum, and maximum ground-water recharge rates during water years 1967-91. Ground-water discharge rates could be used as a low estimate of ground-water recharge rates.

Ground-water discharge-duration curves were developed from streamflow records at the six gaging stations for water years 1967-91 using the hydrograph-separation computer program HYSEP. Comparison of the stream and ground-water discharge at selected durations between the 50 and 99 percentiles showed that ground-water discharge was about 85.7 percent of stream discharge throughout the range of flow durations at the six gaging stations. Estimates of ground-water discharge per square mile for the 16 stations were obtained by multiplying the stream discharges per square mile by 85.7 percent. Estimates of ground-water discharge per square mile could be underestimated at stations where ground-water underflow occurs.

In 1991-92, the USGS drilled wells, conducted seismic-refraction surveys, and collected additional well and hydrologic data in order to evaluate lateral boundaries, depth, and hydrogeologic characteristics of surficial deposits in Buzzards Bay Basin. No data on surficial deposits were collected in the Mattapoisett River subbasin and Plymouth-Carver aquifer areas because detailed aquifer studies were done by the USGS in these two areas during the 1980’s. In river subbasins studied, data from well logs and seismic-refraction surveys indicated that lateral boundaries and saturated thicknesses of most stratified-drift deposits were consistent with those previously mapped in the 1970’s; however, minor changes in areal extent and (or) saturated thickness were indicated for several small areas in each of the studied river subbasins.

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APPENDIX A

Table A1. Discharge measurements made and measurements used in analyses at low-flow partial-record stations and discontinued streamflow-gaging stations in and near Buzzards Bay Basin, southeastern Massachusetts, water years 1965-93

[Locations of low-flow partial-record stations and discontinued streamflow-gaging stations are shown in figures 2 and 6 and are described in tables 2 and 3. lat, latitude; long, longitude. Discharge is in cubic feet per second. ft, foot; mi, mile; mi^2, square mile]

Date	Discharge	Date	Discharge	Date	Discharge	Date	Discharge
01105885. Red Brook tributary to Buttermilk Bay (Buzzards Bay). Lat 41°46′32″, long 70°37′51″, Plymouth County on right bank at downstream end of sedimentation basin on downstream side of State Highway 25, 1.3 mi upstream from mouth, 2.5 mi northeast of East Wareham, Massachusetts. Drainage area: 9.14 mi^2. Operated as a continuous-record gaging station 1981-86.							
01105890. Agawam River tributary to Wareham River. Lat 41°45′40″, long 70°40′40″, Plymouth County at culvert 800 ft below Mill Pond, at East Wareham, Massachusetts. Drainage area: 17.1 mi^2.							
9-24-69	32.8	7-27-70	28.8	10-15-70	31.2	7-21-86	33.5
10-17-69	35.0	9-16-70	34.6	8-18-71	24.4		
01105895. Weweantic River tributary to Buzzards Bay. Lat 41°46′12″, long 70°45′18″, Plymouth County at bridge on Fearing Hill Road, 0.25 mi southwest of South Wareham, Massachusetts. Drainage area: 56.1 mi^2. Operated as a continuous-record gaging station 1970-71.							
6-12-91	9.12	7-02-91	8.53				
01105905. Sippican River tributary to Weweantic River. Lat 41°44′03″, long 70°46′31″, Plymouth County at bridge on County Road, 2.5 mi north of Marion, Massachusetts. Drainage area: 28.1 mi^2.							
8-14-72	17.5	9-06-73	11.2	6-12-91	13.6	8-30-91	4.71
10-13-72	44.2	7-17-74	10.4	6-26-91	6.53	10-05-91	34.0
6-06-73	37.2	5-16-91	39.0	7-19-91	4.24	7-30-92	7.02
8-08-73	19.0	5-23-91	27.1	8-16-91	7.60	9-18-92	9.69
01105917. Mattapoisett River tributary to Buzzards Bay. Lat 41°39′45″, long 70°50′20″, Plymouth County 0.4 mi above bridge on U.S. Highway 6, 1.5 mi west of Mattapoisett, Massachusetts. Drainage area: 24.0 mi^2.							
9-08-65	0.21	3-22-82	53.0	5-17-91	22.9	8-16-91	2.08
8-14-72	6.92	5-18-82	17.0	6-21-91	7.88	8-30-91	1.14
6-06-73	30.3	7-14-82	8.30	6-26-91	3.78	10-05-91	19.6
9-05-73	9.21	8-30-82	9.20	7-11-91	1.48	7-30-92	1.94
8-19-74	.52	9-15-82	16.0	7-18-91	.90	9-17-92	11.9
01105926. Acushnet River tributary to Buzzards Bay. Lat 41°41′45″, long 70°54′52″, Plymouth County at bridge on Hamlin Road, 1.0 mi north of Acushnet, Massachusetts. Drainage area: 16.4 mi^2.							
8-23-72	6.58	7-17-74	4.23	6-26-91	2.10	10-05-91	11.6
10-12-72	25.5	8-19-74	.55	7-10-91	1.65	5-22-92	23.2
6-06-73	17.7	5-17-91	16.8	7-18-91	2.11	7-30-92	2.32
8-09-73	12.2	5-23-91	9.84	8-15-91	3.62	9-18-92	5.14
9-06-73	6.91	6-13-91	4.62	8-30-91	2.48		
01105928. Buttonwood Brook tributary to Buzzards Bay. Lat 41°36′15″, long 70°57′20″, Plymouth County at bridge on Russells Mills Road, 1.5 mi northwest of South Dartmouth, Massachusetts. Drainage area: 2.93 mi^2.							
8-23-72	0.30	9-06-73	0.51	5-21-92	1.29	8-26-92	2.14
6-06-73	.96	7-17-74	.45	6-17-92	.790	9-18-92	1.00
8-09-73	.69	8-19-74	.00	7-30-92	.226		
01105930. Paskamanset River tributary to Slocums River. Lat 41°40′43″, long 70°58′39″, Bristol County at bridge on Old Plainville Road, 4.0 mi northwest of New Bedford, Massachusetts. Drainage area: 8.12 mi^2.							
5-21-91	6.85	7-19-91	0.874	1-28-92	21.6	7-28-92	1.72
5-30-91	4.46	8-15-91	1.09	2-04-92	12.3	8-25-92	12.4
6-13-91	2.86	8-30-91	1.34	2-13-92	8.18	9-16-92	4.28
6-27-91	1.11	10-04-91	16.2	5-22-92	7.34	10-08-92	5.93
7-10-91	.74	1-21-92	9.92	6-18-92	6.01	10-08-92	5.98
011059302. Paskamanset River tributary to Slocums River. Lat 41°40′13″, long 70°58′21″, Bristol County 0.8 mi west of airport tower at intersection of airport boundary fence and New Bedford water main line, 1.4 mi northwest of New Bedford, Massachusetts. Drainage area: 8.45 mi^2.							
10-08-92	5.98	10-08-92	5.97				

Table A1. Discharge measurements made and measurements used in analyses at low-flow partial-record stations and discontinued streamflow-gaging stations in and near Buzzards Bay Basin, southeastern Massachusetts, water years 1965-93—*Continued*

011059315. Paskamanset River tributary to Slocums River. Lat 41°37′36″, long 70°59′12″, Bristol County near sewer pumping station at end of access road from Tucker Road at Friends Academy, 0.9 mi south of North Dartmouth, Massachusetts. Drainage area: 18.1 mi^2.

Date	Discharge	Date	Discharge	Date	Discharge	Date	Discharge
9-18-91	3.63	7-28-92	3.95	9-16-92	8.17		

011059318. Unnamed tributary to Paskamanset River. Lat 41°36′37″, long 70°00′11″, Bristol County at culvert on Chase Road 2.3 mi south of North Dartmouth, Massachusetts. Drainage area: 2.58 mi^2.

Date	Discharge	Date	Discharge	Date	Discharge	Date	Discharge
9-18-91	0.18	7-28-92	0.13	9-16-92	0.63		

01105932. Paskamanset River tributary to Slocums River. Lat 41°36′42″, long 70°59′39″, Bristol County 400 ft east of well A off access road from Chase Road, 100 ft below tributary inflow, 2.0 mi south of North Dartmouth, Massachusetts. Drainage area: 22.9 mi^2.

Date	Discharge	Date	Discharge	Date	Discharge	Date	Discharge
9-18-91	3.50	7-28-92	4.28	9-16-92	9.70		

011059326. Paskamanset River tributary to Slocums River. Lat 41°35′24″, long 70°59′50″, Bristol County 500 ft east of water filtration plant at well D off Chase Road, 3.4 mi west of South Dartmouth, Massachusetts. Drainage area: 25.8 mi^2.

Date	Discharge	Date	Discharge	Date	Discharge	Date	Discharge
9-18-91	3.32	7-28-92	4.68	9-16-92	9.98		

011059328. Unnamed tributary to Paskamanset River. Lat 41°35′17″, long 70°59′51″, Bristol County 800 ft south of water filtration plant on gravel road at well D off Chase Road, 3.4 mi west of South Dartmouth, Massachusetts. Drainage area: 0.25 mi^2.

Date	Discharge	Date	Discharge	Date	Discharge	Date	Discharge
9-16-92	0.05						

01105933. Paskamanset River tributary to Slocums River. Lat 41°35′07″, long 70°59′27″, Bristol County at bridge on Russells Mills Road, 3.0 mi west of South Dartmouth, Massachusetts. Drainage area: 26.2 mi^2.

Date	Discharge	Date	Discharge	Date	Discharge	Date	Discharge
8-23-72	4.00	5-22-91	16.3	8-30-91	4.06	5-22-92	15.2
10-12-72	32.5	5-30-91	10.1	9-18-91	3.76	6-18-92	11.2
6-06-73	21.3	6-14-91	5.45	10-04-91	39.7	7-28-92	4.31
8-09-73	7.81	6-28-91	2.28	1-22-92	20.6	8-25-92	30.4
9-06-73	6.76	7-10-91	1.55	1-29-92	64.6	9-16-92	10.0
7-17-74	7.93	7-19-91	1.09	2-04-92	28.3		
8-19-74	1.43	8-15-91	4.05	2-13-92	22.8		

01105935. Destruction Brook tributary to Slocums River. Lat 41°34′20″, long 71°00′47″, Bristol County at bridge on Slades Corner Road, 5.0 mi southwest of South Dartmouth, Massachusetts. Drainage area: 2.64 mi^2.

Date	Discharge	Date	Discharge	Date	Discharge	Date	Discharge
8-24-72	1.16	5-22-91	3.17	8-15-91	1.10	2-13-92	3.42
6-06-73	2.95	5-30-91	2.35	8-30-91	.88	5-22-92	2.38
8-09-73	.20	6-14-91	1.21	10-04-91	3.20	6-18-92	1.66
9-06-73	.89	6-27-91	.71	1-22-92	3.64	7-29-92	1.14
7-17-74	.94	7-10-91	.56	1-28-92	6.78	8-26-92	4.54
8-19-74	.30	7-19-91	.53	2-04-92	4.32	9-17-92	2.01

01105937. Shingle Island River tributary to East Branch Westport River. Lat 41°40′55″, long 71°01′05″, Bristol County at bridge on Old Fall River Road, 3.0 mi northwest of North Dartmouth, Massachusetts. Drainage area: 8.59 mi^2.

Date	Discharge	Date	Discharge	Date	Discharge	Date	Discharge
8-24-72	1.44	5-22-91	5.66	8-15-91	1.81	2-13-92	8.95
6-07-73	6.52	5-31-91	6.85	8-30-91	1.22	5-22-92	5.62
8-09-73	1.95	6-14-91	1.46	10-04-91	11.3	6-18-92	3.54
9-06-73	1.69	6-27-91	.49	1-21-92	9.48	7-29-92	1.18
7-18-74	2.13	7-11-91	.16	1-28-92	20.4	8-25-92	4.89
8-19-74	.04	7-18-91	.07	2-04-92	11.7	9-17-92	1.88

01105943. Shingle Island River tributary to East Branch Westport River. Lat 41°40′10″, long 71°01′32″, Bristol County at bridge on Hixville Road, 3.0 mi northwest of North Dartmouth, Massachusetts. Drainage area: 18.8 mi^2.

Date	Discharge	Date	Discharge	Date	Discharge	Date	Discharge
8-24-72	4.41	8-19-74	3.33	8-30-91	3.91	5-22-92	11.9
10-12-72	23.5	5-22-91	21.2	10-04-91	17.1	6-18-92	7.13
6-07-73	23.6	6-28-91	2.83	1-21-92	15.4	7-29-92	3.69
8-09-73	5.07	7-11-91	1.92	1-28-92	31.7	8-25-92	9.12
9-06-73	4.89	7-18-91	1.58	2-04-92	19.9	9-17-92	4.91
7-18-74	6.54	8-15-91	4.45	2-13-92	15.2		

Table A1. Discharge measurements made and measurements used in analyses at low-flow partial-record stations and discontinued streamflow-gaging stations in and near Buzzards Bay Basin, southeastern Massachusetts, water years 1965-93—*Continued*

Date	Discharge	Date	Discharge	Date	Discharge	Date	Discharge
01105945. East Branch Westport River tributary to Westport River. Lat 41°37′52″, long 71°03′15″, Bristol County at bridge on Forge Road, 0.8 mi north of Head of Westport, Massachusetts. Drainage area: 28.2 mi².							
7-19-91	2.07	6-18-92	10.8	8-26-92	16.5	9-18-92	8.82
5-21-92	21.9	7-29-92	6.32				
01105947. Bread and Cheese Brook tributary to East Branch Westport River. Lat 41°38′00″, long 71°03′46″, Bristol County at culvert on State Highway 177, 1.0 mi north of Head of Westport, Massachusetts. Drainage area: 8.70 mi².							
8-24-72	0.91	8-09-73	1.78	8-19-74	0.18	7-29-92	0.94
10-12-72	11.8	9-06-73	1.47	5-21-92	7.49	8-26-92	4.25
6-07-73	6.82	7-18-74	1.72	6-18-92	2.91	9-18-92	1.75
01105950. Kirby Brook tributary to East Branch Westport River. Lat 41°36′02″, long 71°04′25″, Bristol County at culvert on Drift Road, 1.5 mi south of Head of Westport, Massachusetts. Drainage area: 3.69 mi². Operated as a crest-stage gage partial record station 1964-1974.							
8-24-72	0.04	9-06-73	0.04	5-21-92	1.86	8-26-92	0.85
6-07-73	1.75	7-17-74	.05	6-17-92	.33	9-18-92	.37
8-09-73	.20	8-19-74	.00	7-30-92	.05		
01106000. Adamsville Brook tributary to West Branch Westport River. Lat 41°33′30″, long 71°07′47″, Newport County, on right bank 0.2 mi upstream from milldam at Adamsville, R.I., and 0.7 mi upstream from mouth. Drainage area: 7.91 mi². Operated as a continuous-record gaging station 1941-78, 1987.							
5-22-91	7.34	7-11-91	0.09	10-05-91	5.32	8-26-92	3.96
5-30-91	2.97	7-19-91	.12	5-21-92	5.58	9-18-92	1.93
6-14-91	1.59	8-15-91	2.88	6-17-92	2.35		
6-28-91	.28	8-30-91	1.30	7-29-92	.79		
01106005. Angeline Brook tributary to West Branch Westport River. Lat 41°33′05″, long 71°06′20″, Bristol County at culvert on Cornell Road, 2.5 mi northwest of Westport Head, Massachusetts. Drainage area: 3.22 mi².							
8-24-72	0.13	8-09-73	0.40	8-19-74	0.00	7-30-92	0.25
10-12-72	2.95	9-06-73	.19	5-21-92	1.91	8-26-92	1.32
6-07-73	2.18	7-17-74	.32	6-18-92	.56	9-18-92	.78

APPENDIX B

Table B1. Descriptions of locations for seismic-refraction survey lines conducted by the U.S. Geological Survey in Buzzards Bay Basin, southeastern Massachusetts

[Listed in order of increasing line number. Latitude and longitude are given in degrees, minutes, seconds. Original seismic-reflection data and detailed location maps in U.S. Geological Survey files]

Seismic-refraction line No.	Beginning		End		Starting location of line	Line direction
	Latitude ° ′ ″	Longitude ° ′ ″	Latitude ° ′ ″	Longitude ° ′ ″		
1	414635	704951	414641	704942	On Burgess Avenue (1,700 ft west of intersection with Walnut Plain Road), Rochester	SW to NE
2	414600	704917	414604	704915	On Walnut Plain Road (500 ft west of intersection with High Street), Rochester	SW to NE
3	414515	705040	414513	705034	On Mendall Road (400 ft southeast of intersection with Hartley and Neck Road), Rochester	NW to SE
4	414425	704939	414429	704938	On Mendall Road (2,050 south of intersection with Clapp Road), Rochester	S to N
5	414620	705524	414621	705516	On Dr. Braley Road (600 ft west of intersection with Rounsevell Road), Freetown	W to E
6	414148	705444	414144	705435	On Hamlin Street (500 ft east of Acushnet River), Acushnet	W to E
7	414046	705822	414104	705724	On New Plainville Road (400 ft east of intersection with Old Plainville Road), New Bedford	W to E
8	413627	710156	413628	710130	On dirt road (1,900 ft east of Fisher Road in Deerfield Swamp), Dartmouth	W to E
9	413520	710144	413520	710135	On Fisher Road (100 ft east of intersection with Gidley Town Road), Dartmouth	W to E
10	414058	710124	414051	710039	On Fall River Road (1,600 ft west of Shingle Island River), Dartmouth	W to E
11	41∞4039	710457	414038	710443	On Old Bedford Road (1,700 ft west of intersection with Highland Avenue), Westport	W to E
12	413909	710402	413910	710135	On Hemlock Street (400 ft east of intersection with High Street), Westport	W to E

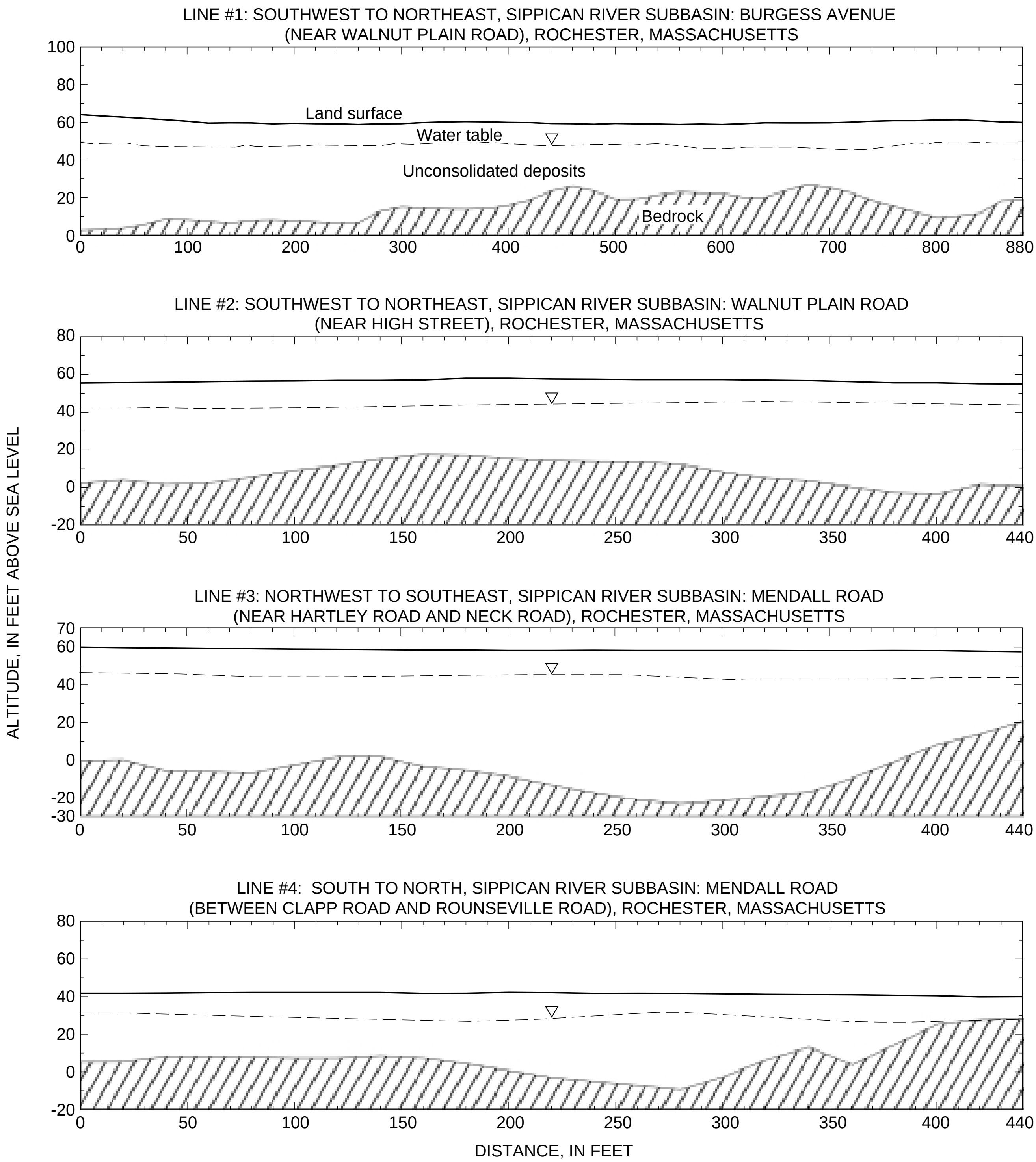

Figure B1. Geohydrologic sections based on seismic-refraction surveys in Buzzards Bay Basin, southeastern Massachusetts

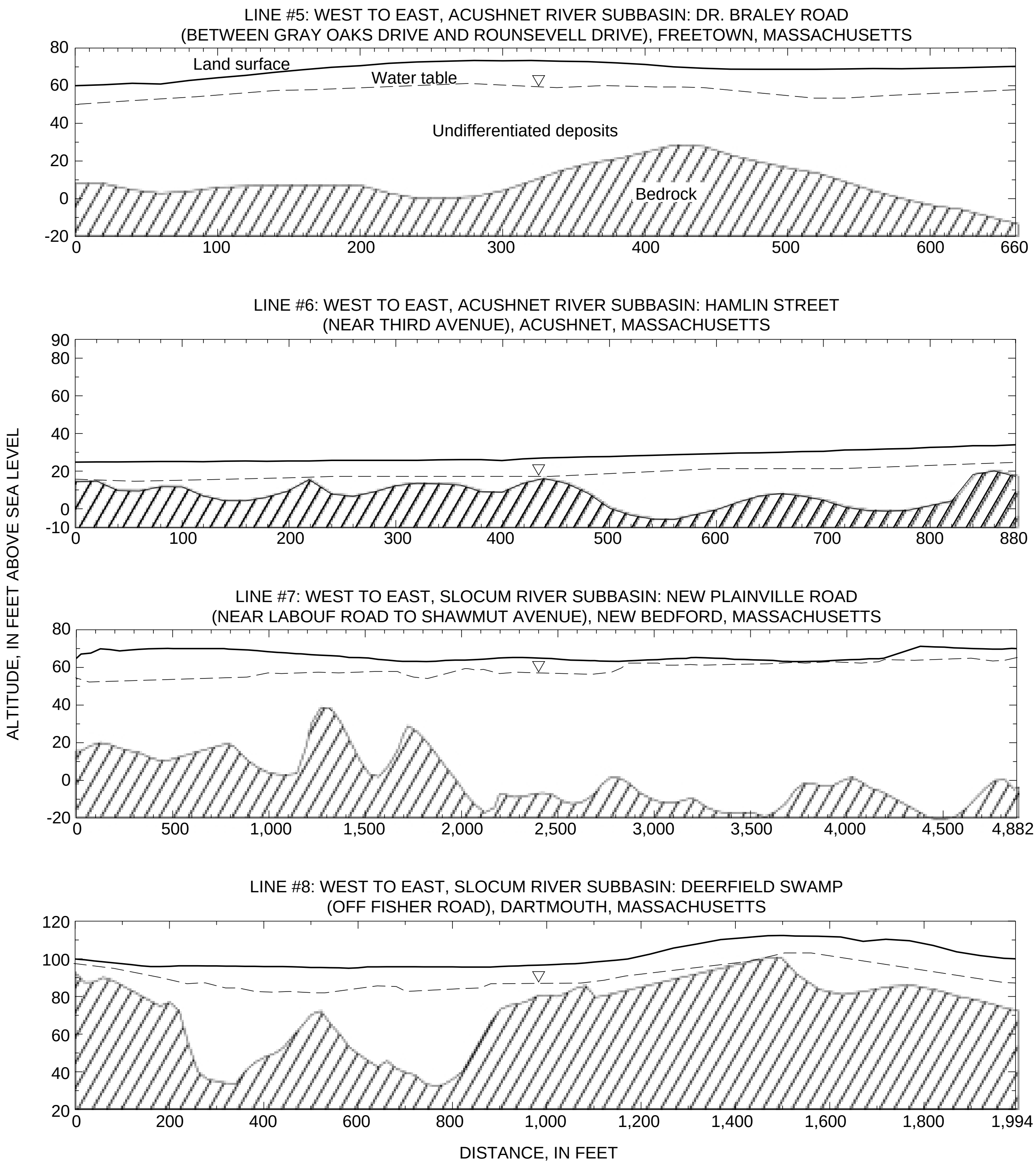

Figure B1.—*Continued*.

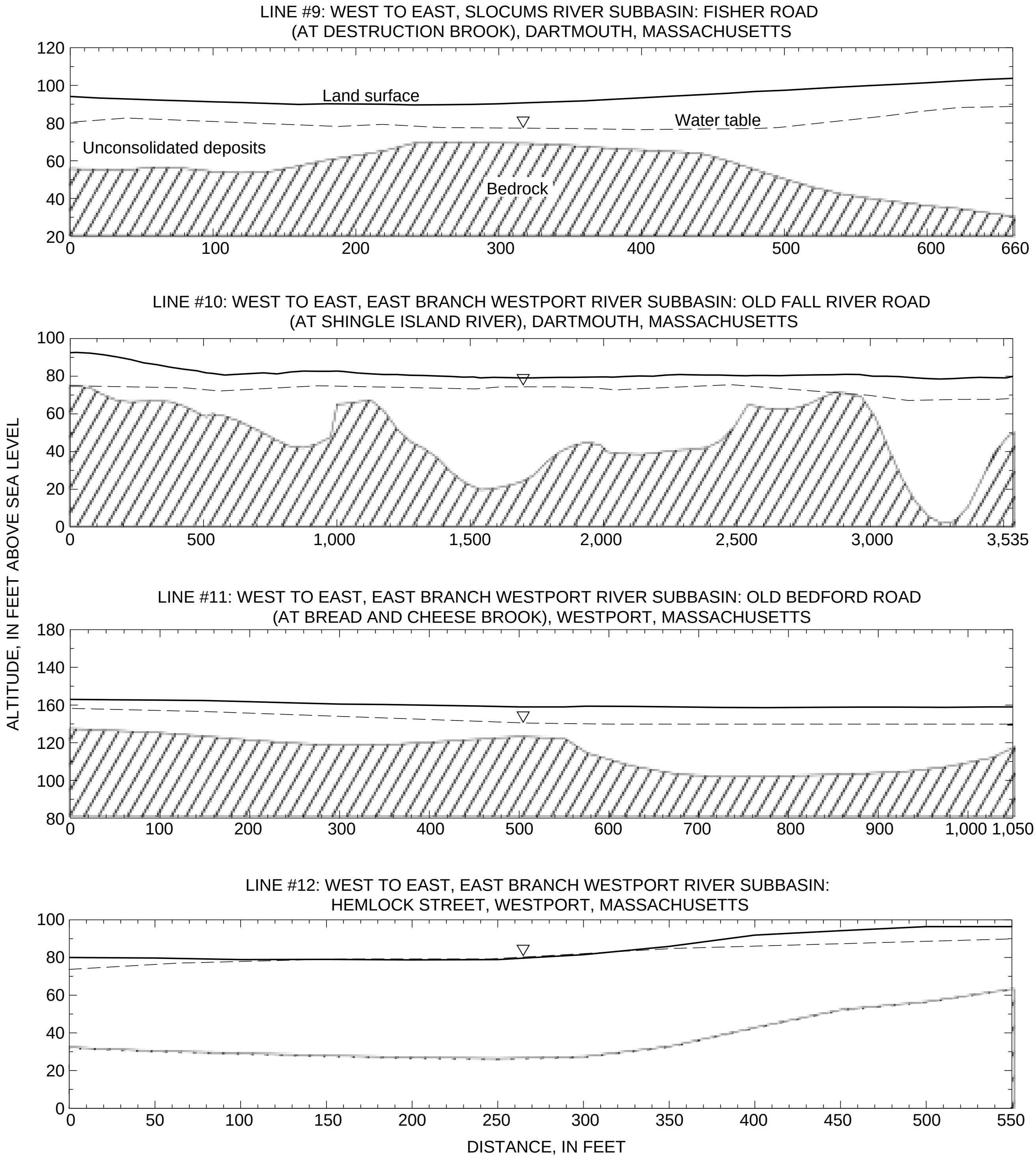

Figure B1.—*Continued*.

APPENDIX C

Table C1. Descriptions of locations and water levels in test wells drilled by the U.S. Geological Survey in Buzzards Bay Basin, southeastern Massachusetts, water year 1992

[**Well No.:** ADW is Acushnet, Mass.; DCW is Dartmouth, Mass.; F3W is Freetown, Mass.; MFW is Marion, Mass.; NGW is New Bedford, Mass.; RFW is Rochester, Mass. **Site identification No.:** Unique number for each site based on the latitude and longitude of the site. First six digits are latitude, next seven digits are longitude and the final two digits are a sequence number to uniquely identify each site. **Altitude of land surface:** Datum is sea level. Approximate altitudes interpolated from 7.5'minute topographic quadrangles are given in feet. **Water level:** in feet below land surface]

Date	Water level	Date	Water level	Date	Water level	Date	Water level
Well No.: ADW-84. Site identification No.: 414519070550301. Altitude: 48							
NOV 26, 1991	7.28	JAN 03, 1992	5.85	APR 16, 1992	7.03	JUN 30, 1992	7.78
DEC 19	6.23	22	5.74	MAY 13	7.32	AUG 26	7.73
23	5.96	FEB 13	5.81	JUN 08	7.37	SEP 22	7.96
Well No.: DCW-114. Site identification No.: 413910071020701. Altitude: 70							
DEC 19, 1991	2.00	JAN 03, 1992	2.25	MAY 13, 1992	2.34	AUG 25, 1992	2.51
23	2.13	FEB 13	2.53	JUN 08	1.91	SEP 22	3.33
30	2.00	APR 16	2.40	30	3.36		
Well No.: DCW-115. Site identification No.: 413421071004801. Altitude: 50							
NOV 27, 1991	0.99	JAN 22, 1992	2.44	MAY 22, 1992	2.63	JUL 29, 1992	3.34
DEC 19	1.60	FEB 04	2.40	JUN 08	1.37	AUG 25	1.63
23	1.95	13	2.81	18	2.73	SEP 17	2.61
30	2.23	APR 16	2.11	30	3.58	22	2.88
JAN 03, 1992	2.31	MAY 13	1.98				
Well No.: F3W-132. Site identification No.: 414336070593001. Altitude: 120							
NOV 26, 1991	4.92	JAN 03, 1992	5.48	APR 16, 1992	4.92	JUN 30, 1992	5.39
DEC 19	5.57	22	5.27	MAY 13	5.30	AUG 25	6.80
23	5.52	FEB 13	5.26	JUN 08	5.12	SEP 22	7.85
Well No.: MFW-37. Site identification No.: 414432070473501. Altitude: 22							
NOV 26, 1991	7.00	JAN 03, 1992	6.44	MAY 13, 1992	7.81	AUG 25, 1992	7.88
DEC 19	6.56	22	6.64	JUN 08	7.56	SEP 22	8.23
23	6.40	APR 16	7.58	30	8.30		
Well No.: NGW-66. Site identification No.: 414012070580201. Altitude: 57							
DEC 19, 1991	3.83	JAN 29, 1992	3.83	MAY 13, 1992	3.90	AUG 26, 1992	4.01
JAN 02, 1992	3.90	APR 16	3.90	JUN 30	4.66	SEP 22	4.50
08	3.81						
Well No.: NGW-67. Site identification No.: 414043070573801. Altitude: 72							
NOV 26, 1991	5.27	JAN 08, 1992	5.88	MAY 13, 1992	6.39	AUG 26, 1992	5.97
DEC 19	5.68	29	5.86	JUN 30	6.82	SEP 22	6.79
JAN 02, 1992	6.13	APR 16	6.23				
Well No.: RFW-338. Site identification No.: 414719070472301. Altitude: 50							
NOV 26, 1991	5.05	JAN 03, 1992	5.21	APR 16, 1992	5.54	JUN 30, 1992	5.99
DEC 19	6.00	22	5.17	MAY 13	5.52	AUG 25	6.07
23	5.61	FEB 13	5.35	JUN 08	5.52	SEP 22	6.76
Well No.: RFW-339. Site identification No.: 414731070472601. Altitude: 65							
NOV 26, 1991	2.99	JAN 22, 1992	3.20	MAY 13, 1992	3.58	AUG 25, 1992	3.29
DEC 23	3.14	FEB 13	3.59	JUN 08	3.31	SEP 22	3.11
JAN 03, 1992	3.12	APR 16	3.53	30	3.92		
Well No.: RFW-341. Site identification No.: 414638070494801. Altitude: 57							
NOV 26, 1991	4.19	JAN 03, 1992	5.13	APR 16, 1992	5.52	JUN 30, 1992	6.36
DEC 19	5.11	22	5.26	MAY 13	5.58	AUG 25	5.68
23	5.06	FEB 13	5.37	JUN 08	4.83	SEP 22	6.72

Table C2. Descriptions of lithology in test wells drilled by the U.S. Geological Survey in Buzzards Bay Basin, southeastern Massachusetts

[**Well No.**: ADW is Acushnet, Mass.; DCW is Dartmouth, Mass.; F3W is Freetown, Mass.; MFW is Marion, Mass.; NGW is New Bedford, Mass.; RFW is Rochester, Mass. **Lithologic logs:** depth in feet]

Lithologic logs		
Description of material	Depth	
	From	To
ADW-84		
Sand, medium to fine; trace gravel	0	12.5
Silt to very fine sand	12.5	21.5
Sand, fine; trace medium sand	21.5	28.5
Sand, very fine to fine; some silt; trace medium sand	28.5	51
Till	51	54
Refusal	54	
DCW-114		
Sand, medium	0	7
Boulder	7	12
Sand, fine; little gravel and coarse sand	12	21.5
Till	21.5	23
Refusal	23	
DCW-115		
Gravel, coarse; sand, coarse to very coarse	0	8.25
Refusal	8.25	
F3W-132		
Sand, very fine	0	8
Sand, fine to very fine; gravel, cobble	8	12
Sand, fine to very fine; gravel, granule to cobble	12	20
Sand, fine to very fine; trace gravel; trace silt	20	44
Refusal	44	
MFW-37		
Sand, fine to medium	0	9
Sand, very fine to fine; little silt	9	26.5
Sand, medium to fine; little gravel; little silt	26.5	38.5
Refusal	38.5	
NGW-66		
Fill	0	5
Sand, very fine to coarse; little gravel, granule to pebble; trace silt	5	30
Refusal	30	
NGW-67		
Sand, medium; some gravel	0	4.5
Sand, very fine; little silt	4.5	11.5
Sand, medium; little gravel	11.5	33.5
Sand, very fine; some silt	33.5	36.5
Silt	36.5	44.5
Sand, fine to medium; little gravel	44.5	46
Refusal	46	
RFW-338		
Sand, coarse; some gravel and medium sand	0	16
Sand, fine	16	18
Sand, very fine; little gravel; little silt	18	21
Sand, coarse	21	24
Sand, medium to very fine; little gravel	24	27.5
Till	27.5	28.5
Refusal	28.5	
RFW-339		
Fill	0	5
Sand, coarse; little gravel	5	8.5
Sand, medium; little gravel	8.5	24
Sand, very coarse; some gravel; some silt	24	25
Boulders, cobbles	25	26
Sand, very coarse; some gravel; some silt	26	29
Till	29	29.1
Refusal	29.1	
RFW-341		
Sand, medium to coarse; little gravel	0	14
Sand, very fine to medium; some gravel; some silt	14	21.5
Sand, medium; little gravel	21.5	24.5
Sand, very fine; some gravel; some silt	24.5	44
Refusal	44	