Estimated Water Use and Availability in the East Narragansett Bay Study Area, Rhode Island, 1995–99

By Emily C. Wild

Prepared in cooperation with the Rhode Island Water Resources Board

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Conversion Factors, Datums, and Abbreviations

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
square foot (ft^2)	0.09290	square meter (m^2)
square inch (in^2)	6.452	square centimeter (cm^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
million gallons (Mgal)	3,785	cubic meter (m^3)
	Flow rate	
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meters per second (m^3/s)
million gallons per day per square mile [(Mgal/d)/mi^2]	1,461	cubic meter per day per square kilometer [(m^3/d)/km^2]
inch per hour (in/h)	0.0254	meter per hour (m/h)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

To convert water-use data to cubic feet per second, multiply million gallons per day by 1.5466.

ABBREVIATIONS and ACRONYMS

7Q10	7-day, 10-year low flow
ABF	Aquatic Base Flow
CFR	Code of Federal Regulations
CSO	Combined sewer overflow
FGDC	Federal Geographic Data Committee
HUC	hydrologic unit code
IWR-MAIN	Institute of Water Resources, Municipal and Industrial Needs System
MCD	minor civil division
NCDC	National Climatic Data Center
NEWUDS	New England Water-Use Data System
NRCS	Natural Resources Conservation Service
RIDEM	Rhode Island Department of Environmental Management
RIEDC	Rhode Island Economic Development Corporation
RIGIS	Rhode Island Geographic Information System
RIPDES	Rhode Island Pollutant Discharge Elimination System
RIWRB	Rhode Island Water Resources Board
SCS	Soil Conservation Service
SIC	Standard Industrial Classification
TIGER	Topologically Integrated Geographic Coding and Referencing
USDA	U. S. Department of Agriculture
USEPA	U. S. Environmental Protection Administration
USGS	U. S. Geological Survey
WBD	Watershed Boundary Dataset
WSO	weather-station observatory
WWTF	wastewater-treatment facility

Estimated Water Use and Availability in the East Narragansett Bay Study Area, Rhode Island, 1995–99

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Abstract

Water availability became a concern in Rhode Island during a drought in 1999, and further investigation was needed to assess the current demands on the hydrologic system from withdrawals during periods of little to no precipitation. The low ground-water levels and streamflows measured in Rhode Island prompted initiation of a series of studies on water use and availability in each major drainage area in Rhode Island for the period 1995–99. The investigation of the East Narragansett Bay area is the last of these studies. The East Narragansett Bay study area (130.9 square miles) includes small sections of the Ten Mile and Westport River Basins in Rhode Island. The area was divided into three regions (islands and contiguous land areas separated by the bay) within each of which the freshwater water use and availability were assessed.

During the study period from 1995 through 1999, three major public water suppliers in the study area withdrew 7.601 million gallons per day (Mgal/d) from ground-water and surface-water reservoirs. The estimated water withdrawals by minor public water suppliers during the study period were 0.063 Mgal/d. Total self-supply domestic, industrial, commercial, and agricultural withdrawals from the study area averaged 1.891 Mgal/d. Total water use in the study area averaged 16.48 Mgal/d, of which about 8.750 Mgal/d was imported from other basins. The average return flow to freshwater within the basin was 2.591 Mgal/d, which included effluent from permitted facilities and septic systems. The average return flow to saltwater (Narragansett Bay) outside of the basin was about 45.21 Mgal/d and included discharges by permitted facilities (wastewater-treatment plants and Rhode Island Pollutant Discharge Elimination Systems).

The PART program, a computerized hydrograph-separation application, was used for the data collected at two selected index stream-gaging stations in the East Narragansett Bay study area to determine water availability on the basis of the 75th, 50th, and 25th percentiles of the total base flow; the base flow for the 7-day, 10-year low-flow scenario; and the base flow for the Aquatic Base Flow scenario for both stations. Base flows in the study area were lowest in September for the 75th, 50th, and 25th percentiles. The safe yields determined for the surface-water reservoirs (14.10 Mgal/d) were added to the estimated available ground water (gross yield) in the Southeastern Narragansett and East Narragansett Islands regions to give the total available water.

The water availability in the study area at the 50th percentile ranged from 33.18 Mgal/d in September to 94.62 Mgal/d in June, water availability for the 7-day, 10-year low-flow scenario at the 50th percentile ranged from 21.87 Mgal/d in September to 83.03 Mgal/d in June, and water availability for the Aquatic Base Flow scenario at the 50th percentile ranged from 14.10 Mgal/d in August and September to 65.48 Mgal/d in June.

Because water withdrawals and use are greater during the summer than at other times of the year, water availability in June, July, August, and September was compared to water withdrawals in the three regions. For the study period, the withdrawals in July were higher than in the other summer months. For the 50th percentile, the ratios of water withdrawn to water available were close to one in August for the estimated basic and Aquatic Base Flow scenarios and in September for the estimated 7-day, 10-year low-flow scenario. For the 25th percentile, the ratios were close to one in August for the estimated basic and for the 7-day, 10-year low-flow scenario, and were close to one in July for the estimated Aquatic Base Flow scenario.

A long-term water budget was calculated for the East Narragansett Bay study area to identify and assess inflows and outflows by region. The water withdrawals and return flows used in the budget were from 1995 through 1999. Total inflow and outflow were calculated separately for each region. Inflow was assumed to equal outflow; the total water budget was 292.1 Mgal/d for the study area. Precipitation and return flow were 99 and less than 1 percent of the total estimated inflow to the study area, respectively. Evapotranspiration, streamflow, and water withdrawals were 47, 49, and 3 percent of the total outflow from the study area, respectively.

Introduction

Water availability became a concern to the State of Rhode Island during a drought in 1999, and an investigation was needed to assess water use and availability in the state, including the East Narragansett Bay area (fig. 1). The area, which consists of islands and parts of major areas separated by the bay, was divided into three regions within each of which freshwater water use and availability were assessed. The Northeastern Narragansett region consists of the towns Barrington, Bristol, East Providence, and Warren; the Southeastern Narragansett region consists of the towns Little Compton and Tiverton; and the East Narragansett Islands region consists of the towns Middletown, Newport, and Portsmouth. The entire area of each town is included in the study area.

During the summer of 1999, the average precipitation for the Kingston, Rhode Island, climatological station for June was only about 0.05 in., compared to the 30-year (1971–2000) long-term average precipitation of 3.936 in. for June. Because precipitation is a key component of surface-water runoff and ground-water infiltration (fig. 2), the rain deficiency caused a period of little to no recharge. As a result, ground-water levels and streamflows dropped below their long-term averages throughout Rhode Island.

To address water-use and availability concerns in Rhode Island, the U.S. Geological Survey (USGS), in cooperation with the Rhode Island Water Resources Board (RIWRB), began a series of nine water-use and availability investigations in different basins or areas for the calendar years 1995–1999. The RIWRB serves as a water-sourcing agency to ensure future water availability for residential growth and economic development for all Rhode Islanders (Rhode Island Water Resources Board, 2003). The purpose of the studies was to determine the relations between the components of the hydrologic cycle (fig. 2) and the water-use components (fig. 3) during periods of little to no recharge. The East Narragansett Bay area may present less concern than other areas to the State of Rhode Island in the assessment of water use and availability, however, because surface-water withdrawals and wholesale water purchases from outside the study area were the predominant water sources for public suppliers during the study period. The results of this study and additional studies of other basins in or adjacent to Rhode Island will be used to compare water demands to water availability for times of little to no recharge, particularly during June, July, August, and September.

Purpose and Scope

This report identifies the water-use components and assesses the water use and availability in the three coastal areas (regions) of the East Narragansett Bay study area for calendar years 1995–1999. To estimate water use, data on water withdrawals, use, and discharges were collected for the towns in the study area. These data were organized and retrieved by using the New England Water-Use Data System (NEWUDS). The methods used to estimate the ground-water availability for the three regions are described for streamflow-recession periods in the summer. The concept of safe yield, defined by the Rhode Island Water Resources Board (2008) as “a substantial withdrawal that can be continuously supplied from a surface-water-supply source without adverse effects throughout a critical dry period with a 1-percent chance of occurrence, or one [a dry period] that is equivalent to the drought of record, whichever is more severe.” Previously determined safe yields were used to determine the surface water available from reservoirs, and these values were added to the estimated ground water available to determine the total water available (or the total gross yield). Finally, the report presents a study-area water budget. It summarizes the components of the hydrologic cycle for the long-term period of record for the index stream-gaging station for each region and selected water-use components for the study period.

Previous Investigations

The USGS has been monitoring ground-water levels for about 15 years (as of 2007) in the East Narragansett Bay study area in Rhode Island. Historically, there was one continuous stream-gaging station in the study area at which discharge data were collected from 1940 through 1987. Few studies have described the ground-water and surface-water resources in the East Narragansett Bay area. The study area includes parts of the Bristol, East Providence, Fall River, Newport, Providence, Prudence Island, Sakonnet Point, and Tiverton USGS quadrangles. The USGS has published these quadrangles in detailed thematic maps that describe the bedrock geology (Lyons, 1977; Moore, 1975; Pollock, 1964; Quinn, 1959; Quinn and Springer, 1954) and surficial geology (Smith, 1955, 1956). Several previous ground-water investigations were completed by the USGS in cooperation with the RIWRB (Allen and Blackhall, 1950; Allen and Gorman, 1959; Bierschenk, 1954, 1959; and Schiner, 1964a, 1964b).

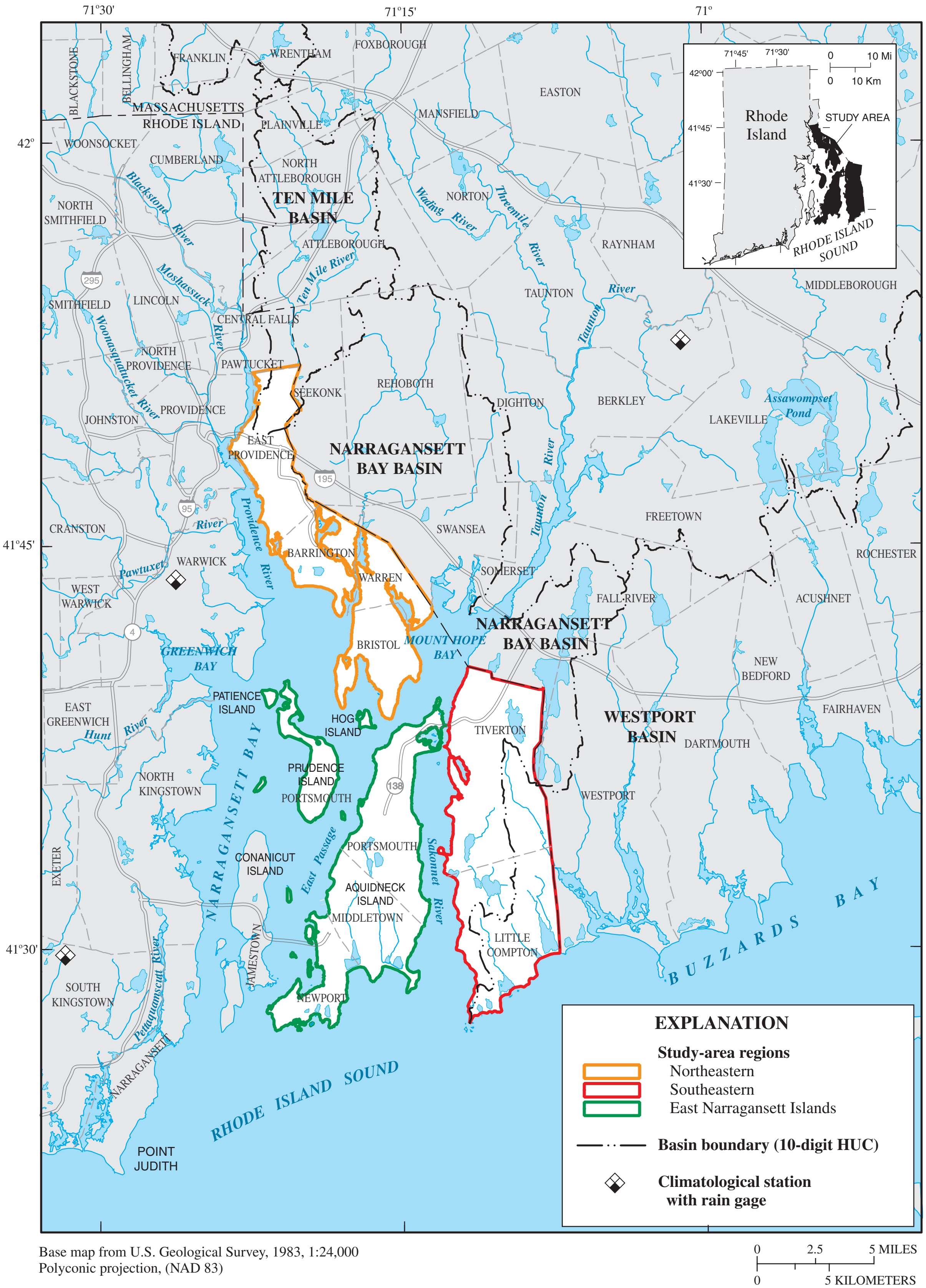


Figure 1. The East Narragansett Bay study area and regions, eastern Rhode Island, and the contiguous basins in Massachusetts.

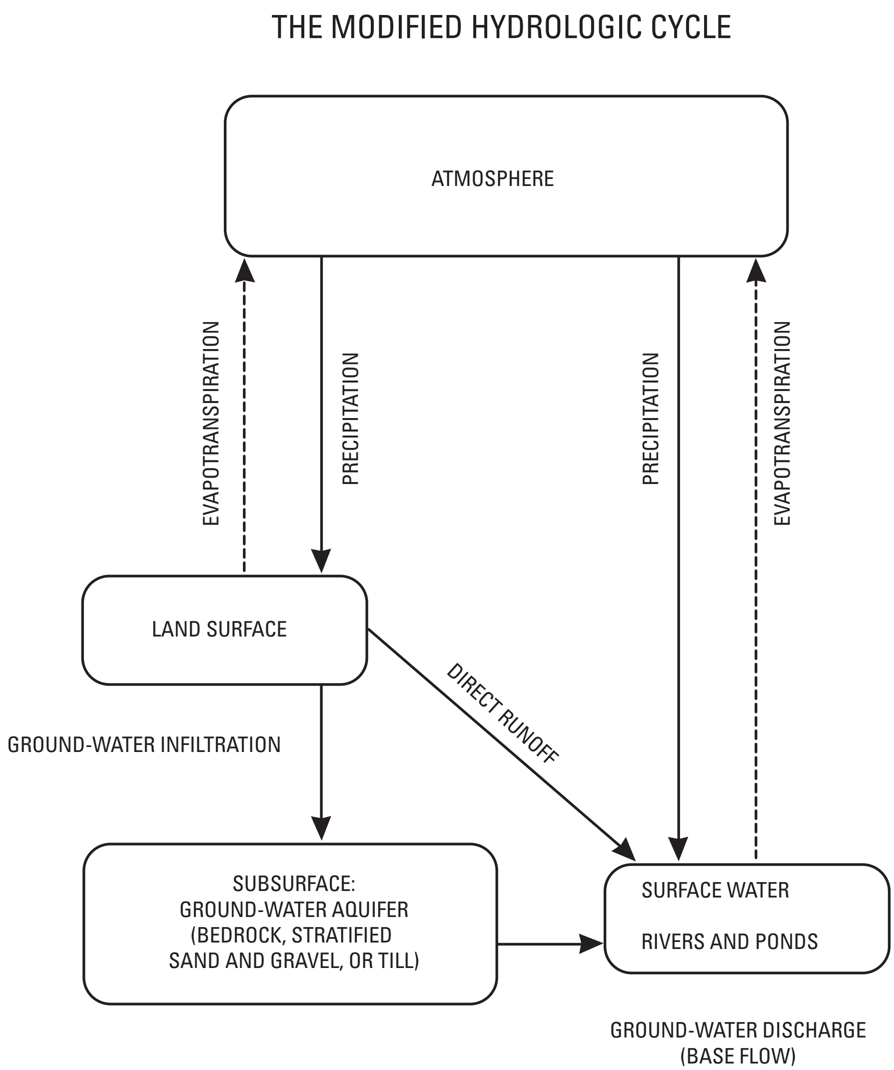


Figure 2. The modified hydrologic cycle.

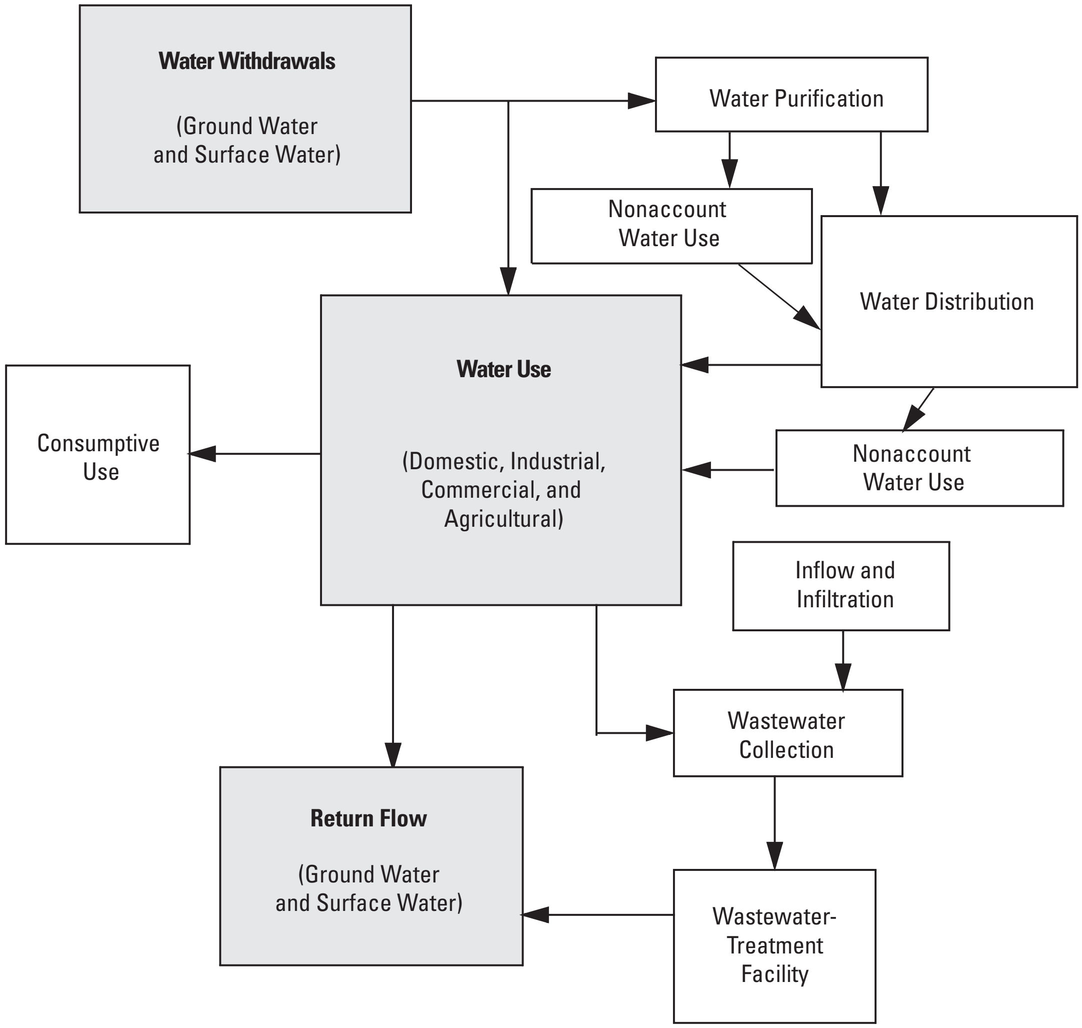


Figure 3. The components of water use.

In addition, information on water use has been collected and compiled in methodological and statewide studies (Craft and others, 1995; Horn, 2000; Horn and Craft, 1991; and Medalie, 1996). The public water suppliers are required to submit Water-Supply Management Plans to the RIWRB as a part of the state's Water Supply Systems Management Plan program. That information was used in this study and in recent publications on water use and availability (Barlow, 2003; Wild and Nimiroski, 2004, 2005; and Nimiroski and Wild, 2005).

The East Narragansett Bay Study Area

The East Narragansett Bay study area is in eastern Rhode Island (fig. 1). Land area in the study area totals about 130.9 mi^2, of which about 21.29 mi^2 is in the Westport River drainage area, and 3.668 mi^2 of which about is in the Ten Mile River drainage area. The study area includes nine Rhode Island towns. In 1990, the study-area population was about 179,800, and the estimated population during the study period was about 175,000 (table 1). Withdrawal data from public suppliers for Massachusetts municipalities for the years 1995 and 1998 were not available, and therefore water-use and availability assessments for Massachusetts were not included in the study.

Water use and availability were assessed separately for the three regions of the East Narragansett Bay (Northeastern Narragansett, Southeastern Narragansett, and Eastern Narragansett Islands) because the regions in the area of the investigation are separated along the bay and coast by saltwater (fig. 1). Prudence, Patience, and Hog Islands were included in the Eastern Narragansett Islands region. The bay and coastal drainage areas are unique because there is little relief and there are multiple areas of direct runoff to the bay and ocean. Because of these characteristics, there is limited surface-water data collection for these areas. The USGS, however, has been collecting ground-water levels from observation wells in Little Compton and Portsmouth since 1992. The water levels for the wells were analyzed only to illustrate the fluctuations of the water table during the droughts in 1999 and 2002 and were not part of this study.

Table 1. Total town populations by region for 1990, estimated populations for 1995–99, and estimated public- and self-supply and public- and self-disposal populations in the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

[Total 1990 populations in Rhode Island from Rhode Island Geographic Information System (1991). Estimated 1995–99 population from the Rhode Island Economic Development Corporation (2001).]

City/town	Population		Estimated 1995–99 population			
	1990	Estimated 1995–99	Supply		Disposal	
			Public	Self	Public	Self
Northeastern Narragansett region						
Barrington	15,847	15,728	14,909	819	15,619	109
Bristol	21,600	21,984	18,877	3,107	19,468	2,516
East Providence	50,375	48,173	48,053	120	46,844	1,329
Warren	11,384	11,369	9,845	1,524	10,028	1,341
Region total	**99,206**	**97,254**	**91,684**	**5,570**	**91,959**	**5,295**
Southeastern Narragansett region						
Little Compton	3,335	3,343	88	3,255	53	3,290
Tiverton	14,315	14,194	8,501	5,693	877	13,317
Region total	**17,650**	**17,537**	**8,589**	**8,948**	**930**	**16,607**
East Narragansett Islands region						
Middletown	17,751	18,970	15,837	3,133	16,543	2,427
Newport	28,343	24,536	24,528	8	24,073	463
Portsmouth	16,853	16,721	16,114	607	2,729	13,992
Region total	**62,947**	**60,227**	**56,479**	**3,748**	**43,345**	**16,882**
Study-area total	**179,803**	**175,018**	**156,752**	**18,266**	**136,234**	**38,784**

Climate

Precipitation and temperature data for the climatological station at Kingston, Rhode Island on the University of Rhode Island campus and the Providence Weather Station Observatory (WSO) climatological station for the airport in Warwick, Rhode Island were compiled by using the monthly and annual summaries published in the series “Climatological Data New England” from the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA). In addition, the precipitation data for the climatological station at Taunton, Massachusetts were included because of the proximity of the station to the study area (table 2).

Summary precipitation data are presented in order to establish the differences in precipitation along the state and coastal areas and the differences between the long-term precipitation and the precipitation during the study period (table 2). During the study period, the average monthly precipitation ranged from 2.728 in. (July) to 4.474 in. (September) for the summer months (June-September) at the Kingston climatological station. At the climatological station in Taunton, Massachusetts, the average monthly precipitation ranged from 2.808 in. (August) to 4.010 in. (September) for the summer. Precipitation and temperature data for the climatological stations are summarized in table 2.

Land Use

Land use was tabulated, by town, from the Rhode Island Geographic Information Systems (RIGIS) land-use coverages (table 3). For water-supply districts, the municipality land-use area was used to aggregate the water-use categories by town and defined regions in the study area (table 4). The total commercial, industrial, and agricultural land-use areas were 3.493 mi^2, 1.827 mi^2, and 8.517 mi^2, respectively, within the East Narragansett Bay study area (table 5). The commercial land-use area for the public-supply districts ranged from 0.083 mi^2 to 1.074 mi^2 for the Stone Bridge Fire District and East Providence Water Department service areas in the East Narragansett Bay study area, respectively. The industrial land-use area ranged from 0.049 mi^2 for the North Tiverton Fire District to 0.750 mi^2 for the East Providence Water Department service areas in the East Narragansett Bay study area, and there was no industrial land-use area within the Stone Bridge Fire District and Tiverton Water District. The agricultural land-use area ranged from 0.103 mi^2 for the Stone Bridge Fire District to 4.033 mi^2 for the Portsmouth Water and Fire District service areas in the East Narragansett Bay study area.

Table 2. Summary of climatological data pertinent to the East Narragansett Bay study area, eastern Rhode Island.

[Climatological data from monthly and annual summaries from the National Climate Data Center of the National Oceanic and Atmospheric Administration, 1971–2000. MA, Massachusetts; RI, Rhode Island; WSO, weather station observatory; °F, degrees Fahrenheit; in., inches]

Climatological station	Period of record [study period]	June	July	August	September	Annual
		Average temperature (°F)				
Kingston, RI	1971–2000	65.63	71.06	69.91	62.72	49.94
	[1995–99]	66.50	71.88	70.32	63.74	50.91
Providence Airport WSO, Warwick, RI	1971–2000	67.65	73.37	71.88	63.99	51.13
	[1995–99]	68.20	74.14	72.08	64.74	51.84
		Average total monthly precipitation (in.)				
Taunton, MA	1971–2000	3.414	3.960	3.967	4.033	48.44
	[1995–99]	3.806	3.312	2.808	4.010	48.84
Kingston, RI	1971–2000	3.936	3.308	4.400	4.163	51.79
	[1995–99]	4.106	2.728	4.356	4.474	53.11
Providence Airport WSO, Warwick, RI	1971–2000	3.382	3.169	3.904	3.704	46.46
	[1995–99]	3.414	1.978	3.190	4.014	43.91

Table 3. Town land area and land-use area by category in the regions of the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

[Land-use areas were estimated by using the coverage from the Rhode Island Geographic Information System, 1995a. mi^2, square miles]

City/town	Land area (mi^2)	Land-use area by category (mi^2)		
		Commercial	Industrial	Agricultural
Northeastern Narragansett region				
Barrington	8.519	0.178	0.019	0.491
Bristol	9.502	.272	.209	1.087
East Providence	13.70	1.075	.749	.186
Warren	6.120	.247	.147	1.320
Region total	**37.84**	**1.772**	**1.124**	**3.084**
Southeastern Narragansett region				
Little Compton	22.05	0.094	0.000	5.696
Tiverton	30.00	.486	.049	3.802
Region total	**52.05**	**0.580**	**0.049**	**9.498**
East Narragansett Islands region				
Middletown	12.50	0.695	0.276	3.496
Newport	7.445	.387	.115	.229
Portsmouth	21.10	.316	.318	4.643
Region total	**41.05**	**1.398**	**0.709**	**8.368**
Study-area total	**130.94**	**3.750**	**1.882**	**20.95**

Table 4. Land-use areas by category for towns and public water suppliers in the regions of the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

[Land-use areas for the water suppliers were estimated by using the coverages from the Rhode Island Geographic Information System (1995a,b). mi^2, square miles; --, not applicable]

City/town	Water suppliers	Total land area in water-supply district (mi^2)	Land-use area by category in the East Narragansett Bay study area (mi^2)		
			Commercial	Industrial	Agricultural
		Northeastern Narragansett region			
Barrington	Bristol County Water Authority[1]	8.455	0.179	0.019	0.480
Bristol	Bristol County Water Authority[1]	7.807	.272	.209	.701
East Providence	East Providence Water Department[1]	13.65	1.074	.750	.186
Warren	Bristol County Water Authority[1]	3.834	.240	.144	.467
		Southeastern Narragansett region			
Little Compton	--	--	--	--	--
Tiverton	North Tiverton Fire District[2]	2.685	0.191	0.049	0.114
	Stone Bridge Fire District[2]	2.553	.083	.000	.103
	Tiverton Fire District[2]	1.382	.101	.000	.171
	Tiverton total	**6.620**	**0.375**	**0.049**	**0.388**
		East Narragansett Islands region			
Middletown	Newport Water Works	7.916	0.678	0.276	1.682
	Portsmouth Water and Fire District	.302	.000	.000	.180
	Middletown total	**8.218**	**0.678**	**0.276**	**1.862**
Newport	Newport Water Works	6.846	.360	.115	.225
Portsmouth	Newport Water Works	1.437	.029	.019	.355
	Portsmouth Water and Fire District	13.39	.286	.246	3.853
	Portsmouth total	**14.83**	**0.315**	**0.265**	**4.208**
Study-area total		**70.26**	**3.493**	**1.827**	**8.517**

[1] Wholesale purchase from the Providence Water Supply Board.
[2] These districts are in Tiverton, Rhode Island.

Table 5. Land-use areas by category for the public water suppliers in the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

[Land-use areas for the water suppliers were estimated by using the coverages from the Rhode Island Geographic Information System (1995a,b). mi^2, square miles]

Water suppliers	Total land area in water-supply district (mi^2)	Land-use area by category in the East Narragansett Bay study area (mi^2)		
		Commercial	Industrial	Agricultural
Bristol County Water Authority[1]	20.10	0.691	0.372	1.648
East Providence Water Department[1]	13.65	1.074	.750	.186
North Tiverton Fire District[2]	2.685	.191	.049	.114
Stone Bridge Fire District[2]	2.553	.083	.000	.103
Tiverton Fire District[2]	1.382	.101	.000	.171
Newport Water Works	16.20	1.067	.410	2.262
Portsmouth Water and Fire District	13.69	.286	.246	4.033
Water-supplier totals	**70.26**	**3.493**	**1.827**	**8.517**

[1] Wholesale purchases from the Providence Water Supply Board.

[2] These districts are in Tiverton, Rhode Island.

Study-Area Regions and Minor Civil Divisions

The East Narragansett Bay study area differs from study areas based on river basins within the state because this study area incorporates the remaining individual land areas next to the bay and in more than one major drainage basin. The three regions (Northeastern Narragansett, Southeastern Narragansett, and East Narragansett Islands regions) are separated from each other by the saltwater body of Narragansett Bay and were individually assessed for freshwater use and availability for this study. In addition, the East Narragansett Islands region comprises several independent islands that were analyzed together for this region analysis.

The USGS boundaries for this study were based on the availability of freshwater, whereas the other boundaries defined by the Watershed Boundary Dataset (WBD) from the Natural Resources Conservation Service (NRCS) are presented for comparison for the state and local agencies that are analyzing several aspects of land-use area by watersheds (table 6, fig. 4). The differences exist because the NRCS defined the land-area boundaries for this study area on the basis of surface-water drainage to saltwater, but the purpose of this study was to evaluate freshwater. The WBD was developed by using the standards for delineation established by the Federal Geographic Data Committee (FGDC) in 2002. The study area is part of the Narragansett Bay USGS 8-digit Hydrologic Unit Code area (HUC) and the Cape Cod USGS 8-digit HUC area, as well as several 10-digit (5 subwatersheds) and 12-digit (13 subwatersheds) cataloging units defined by the NRCS basin coverage. A specific example of the WBD coverages and the study area definitions is evident for Aquidneck Island. Aquidneck Island (officially known as Rhode Island, according to the USGS maps), was divided into five 12-digit WBD cataloging units, the Upper East Passage (010900040907), the Lower East Passage (010900040909), the Coastal Aquidneck (010900040911), the Sakonnet River (010900040910) and the Mt. Hope Bay (010900040905) (fig. 4). Because of these differences, the study area was grouped differently by the three regions and apportioned by towns for the assessment (table 6).

The 1990 U.S. Census Bureau's Topologically Integrated Geographic Coding and Referencing (TIGER) data, entered into RIGIS, was used to estimate total populations of towns or cities (called minor civil divisions (MCDs) by the U.S. Census Bureau) by adding the census tracts by town. Total region populations were calculated by adding town populations by region. Total town-population data compiled by the Rhode Island Economic Development Corporation (RIEDC) (2001) for the study period (1995–99) were averaged to give the total average town population and added by region to give total average region population.

Public water suppliers are defined by the U.S. Environmental Protection Agency (USEPA) as suppliers serving more than 25 people or having 15 service connections year round (Code of Federal Regulations (CFR), title 40, part 141, section 2, 1996). To estimate the 1995–99 town populations on public water and self-supplies and public wastewater and self-disposal, population ratios were calculated on the basis of the data obtained by merging the 1990 populations on private wells and the 1990 populations on public wastewater collection that were available through RIGIS (1991) by overlaying town boundaries.

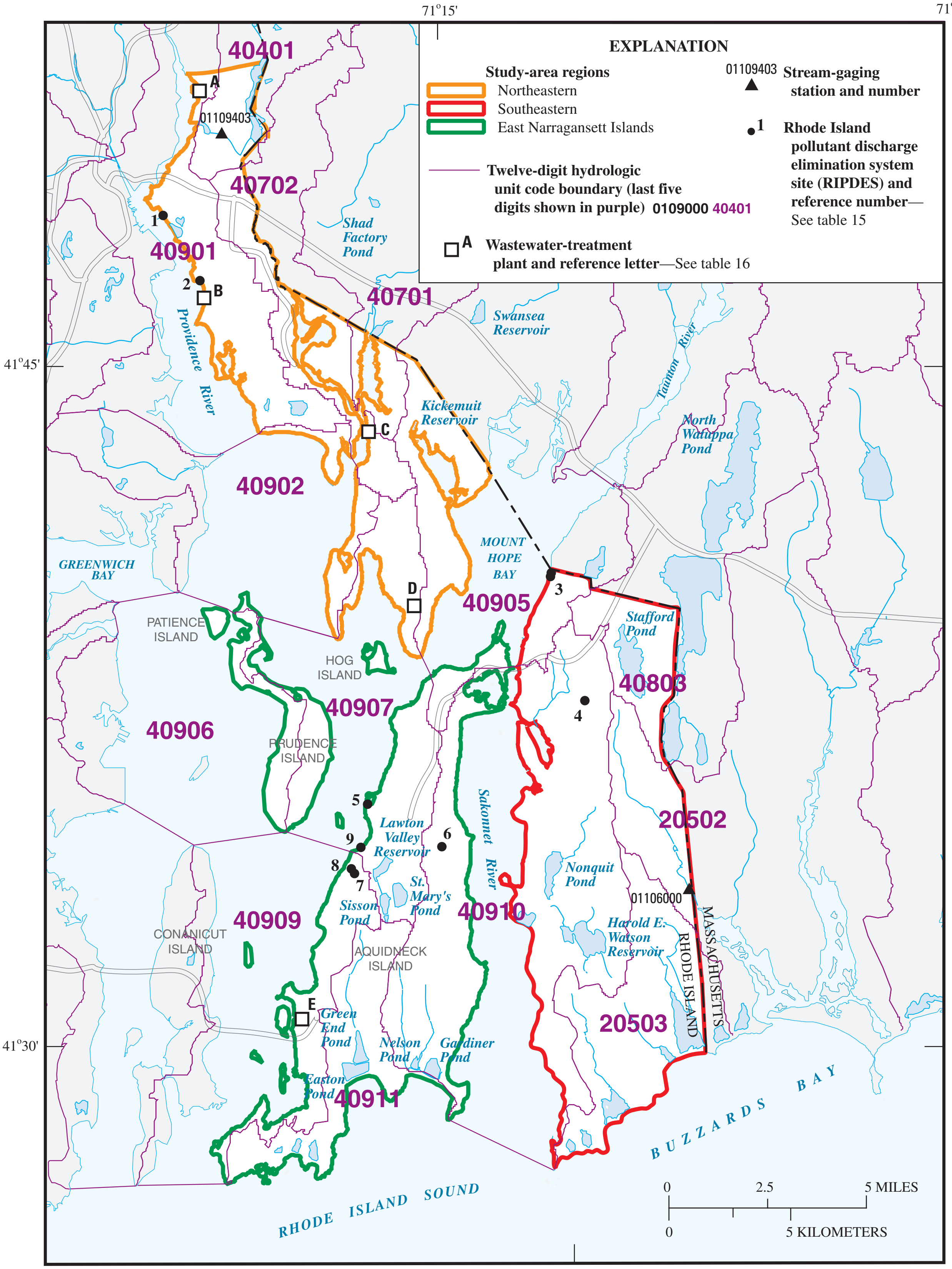
Table 6. Defined 10-digit and 12-digit cataloging units in the Watershed Boundary Dataset and in the East Narragansett Bay study area in Rhode Island.

[The total land area for the study area is 130.94 mi^2. Differences between the NRCS WBD and previous coverages are the results of delineating the islands and shorelines. HUC, hydrologic unit code; --, not applicable]

Watershed Boundary Dataset for Narragansett Bay in Rhode Island						12-digit cataloging units in the East Narragansett Bay study area	
10-digit cataloging units			12-digit cataloging units				
Name	Number	Drainage area (mi^2)	Name	Number	Drainage area (mi^2)	Name	Land within study area (mi^2)
Rhode Island Sound–Gooseberry Neck to Sakonnet Point[1]	0109000205	21.64	Westport River–Noquochoke Lake to mouth	010900020502	6.812	Westport River–Noquochoke Lake to mouth	6.812
			Rhode Island Sound–Richmond Pond to Sakonnet Point	010900020503	14.82	Rhode Island Sound–Richmond Pond to Sakonnet Point	14.82
Ten Mile River[2]	0109000404	6.850	Ten Mile River	010900040401	6.850	Ten Mile River	3.660
Palmer River[2]	0109000407	12.21	Palmer River	010900040701	2.196	Palmer River	2.196
			Barrington and Warren Rivers	010900040702	10.01	Barrington and Warren Rivers	10.01
Lower Taunton River[2]	0109000408	6.165	Quequechan River	010900040803	6.163	Quequechan River	6.163
Narragansett Bay[2]	0109000409	196.7	Seekonk and Providence Rivers	010900040901	24.40	Seekonk and Providence Rivers	11.10
			Upper Narragansett Bay	010900040902	9.864	Upper Narragansett Bay	2.767
			Greenwich Bay	010900040903	21.17	Greenwich Bay	--
			Hunt River	010900040904	24.48	Hunt River	--
			Mount Hope Bay	010900040905	10.71	Mount Hope Bay	5.851
			Upper West Passage	010900040906	8.146	Upper West Passage	--
			Upper East Passage	010900040907	14.58	Upper East Passage	11.53
			Lower West Passage	010900040908	27.04	Lower West Passage	--
			Lower East Passage	010900040909	11.02	Lower East Passage	6.222
			Sakonnet River	010900040910	35.81	Sakonnet River	35.81
			Coastal Aquidneck	010900040911	9.505	Coastal Aquidneck	9.505
Total for the Watershed Boundary Dataset 10-digit cataloging units		**243.6**	**Total for the Watershed Boundary Dataset 12-digit cataloging units**		**243.6**	**Study-area total**	**126.45**

[1]Cape Cod 8-digit HUC.

[2]Narragansett 8-digit HUC.



Base map from U.S. Geological Survey, 1983, 1:24,000
Polyconic projection, (NAD 83)

Figure 4. Surface-water reservoirs, stream-gaging stations, and wastewater-treatment plants associated with the East Narragansett Bay study area, eastern Rhode Island and southeastern Massachusetts, 1995–99.

The resultant ratios of the populations of the towns on private wells (self-supply) and wastewater collection (public disposal) to the total 1990 populations were applied to the total 1995–99 populations to determine the 1995–99 populations on self-supply and 1995–99 populations on public disposal (table 1). The 1995–99 populations on public supply and self-disposal were determined by subtracting the 1995–99 populations on self-supply and 1995–99 populations on public disposal, respectively, from the total 1995–99 population of the town (table 1). This calculation was based on the assumption that the ratios remained the same from 1990 to the period 1995–99. Public suppliers were categorized into major public water suppliers that have a system of distribution and minor public water suppliers that have closed systems. Minor public water suppliers withdraw and use the water on a common property that serves a specific residential population, for example, nursing homes, condominium associations, and mobile home parks.

Northeastern Narragansett Region

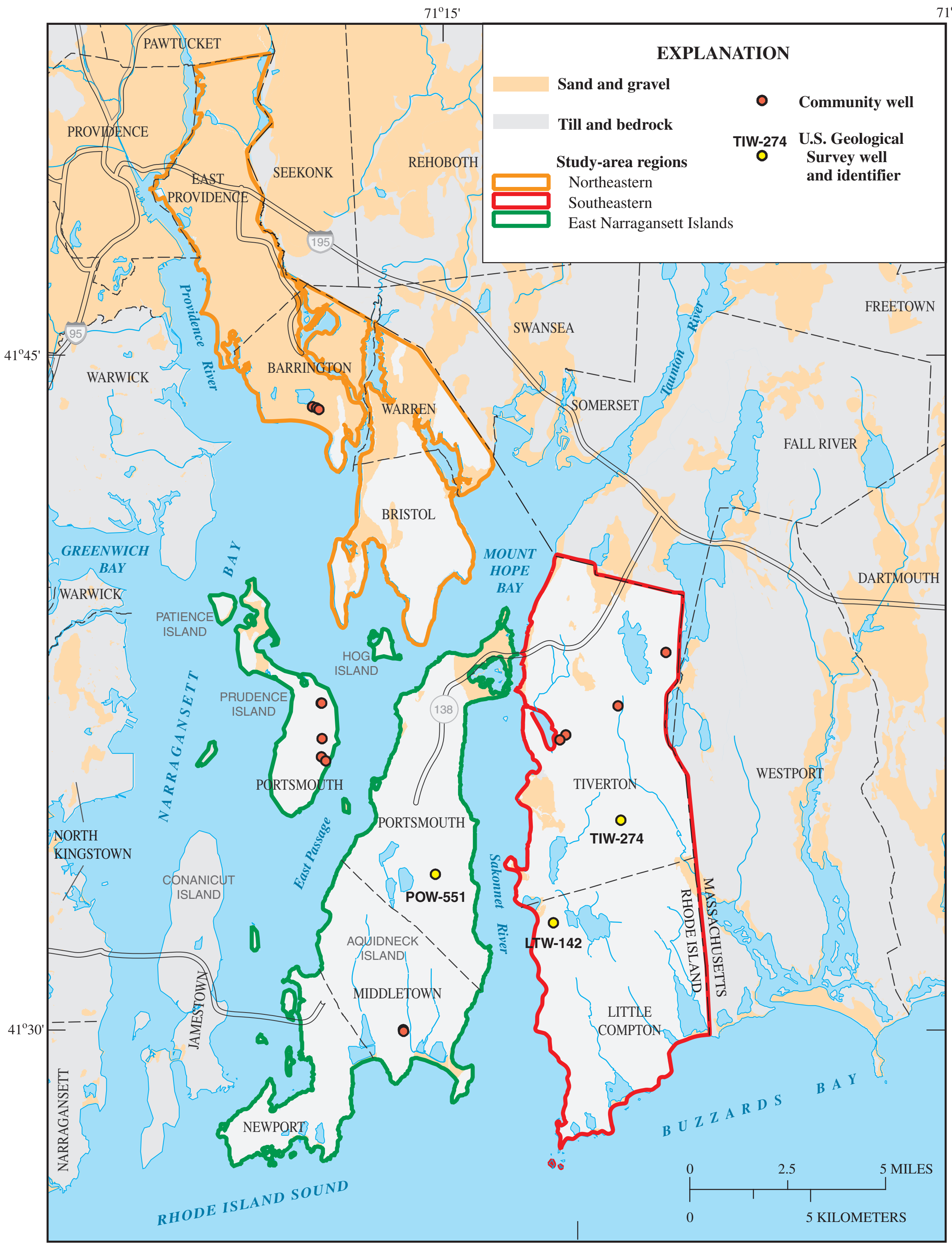
The Northeastern Narragansett region (37.84 mi^2) is in the northeastern section of the East Narragansett Bay in Rhode Island along the Massachusetts border. Towns in the region include Barrington, Bristol, East Providence, and Warren (fig. 1). Land areas and land-use areas by category are summarized in table 3. The border with Massachusetts is defined by the Ten Mile River and Runnins River in East Providence. The region has several saltwater streams and ponds that drain into the bay; these streams and ponds include the Hundred Acre Cove, Barrington River, Palmer River, Warren River, and Kickemuit River. The surficial deposits in the region are 63 percent sand and gravel (fig. 5).

The town of Barrington is on the northern part of the Narragansett Bay in eastern Rhode Island (fig. 1). The total land area is 8.519 mi^2 (table 3), of which about 6 percent is in the Palmer River 12-digit WBD cataloging unit, about 40 percent is in the Barrington and Warren Rivers 12-digit WBD cataloging unit, about 43 percent is in the Seekonk and Providence Rivers 12-digit WBD cataloging unit, and about 11 percent is in the Upper Narragansett Bay 12-digit WBD cataloging unit. The estimated total town population for the study period was 15,728 (table 1). Barrington is in the Bristol County Water Authority service area (table 4). The town is in the wastewater-collection area for the East Providence Wastewater-Treatment Facility that discharges to the bay.

The town of Bristol is on the northern part of the Narragansett Bay in eastern Rhode Island (fig. 1). The total land area is 9.502 mi^2 (table 3), of which 9 percent is in the Barrington and Warren Rivers 12-digit WBD cataloging unit, 57 percent is in the Upper Narragansett Bay and Upper East Passage 12-digit WBD cataloging units, and 34 percent is in the Mount Hope Bay 12-digit WBD cataloging unit. The estimated total town population for the study period was 21,984 (table 1). Bristol is in the Bristol County Water Authority service area (table 4). The town has a wastewater-collection facility that discharges to the bay, the Bristol Wastewater-Treatment Facility.

The City of East Providence is on the northern part of the Narragansett Bay in eastern Rhode Island (fig. 1). The total land area is 13.70 mi^2 (table 3), of which about 7 percent is in the Ten Mile River 12-digit WBD cataloging unit, about 53 percent is in the Seekonk and Providence Rivers 12-digit WBD cataloging unit, and about 20 percent is in the Barrington and Warren Rivers 12-digit WBD cataloging unit. The estimated town population for the study period was 48,173 (table 1). The East Providence Water Department supplies water to the residents of the town. Wastewater is collected in the town by the East Providence Wastewater-Treatment Facility and the Narragansett Bay Commission's facility at Bucklin Point in East Providence.

The town of Warren is on the northern part of the Narragansett Bay in eastern Rhode Island (fig. 1). The total land area is 6.120 mi^2 (table 3), of which about 27 percent is in the Palmer River 12-digit WBD cataloging unit, about 13 percent is in the Barrington and Warren Rivers 12-digit WBD cataloging unit, and about 60 percent is in the Mount Hope Bay 12-digit WBD cataloging unit. The estimated total town population for the study period was 11,369 (table 1). Wastewater is collected in the town by the Warren Wastewater-Treatment Facility.



Base map from U.S. Geological Survey, 1983, 1:24,000
Polyconic projection, (NAD 83)

Figure 5. Surficial geology and selected withdrawal wells for the regions in the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

Southeastern Narragansett Region

The Southeastern Narragansett region (52.05 mi^2) is in the southeastern section of the East Narragansett Bay in Rhode Island. The towns in the region include Little Compton and Tiverton (fig. 1). Land areas and land-use areas by category are summarized in tables 3 and 4. There are several small brooks that drain into the Atlantic Ocean from Little Compton—Adamsville Brook, Cold Brook, Sisson Brook, Dundery Brook, as well as some unnamed brooks. In Tiverton, there are a few small brooks that drain into what is referred to as the Sakonnet River, which is the area in Narragansett Bay between Aquidneck Island and the towns of Little Compton and Tiverton. About 8 percent of the region is thin (less than 40 ft thick) stratified sand and gravel deposits (fig. 5). There is one discontinued stream-gaging stations in the region (fig. 4), Adamsville Brook at Adamsville, Rhode Island (station 01106000), where the USGS collected surface-water data from 1940 through 1987.

The town of Little Compton is on the southern part of the southeastern Narragansett Bay (fig. 1). The total land area is 22.05 mi^2 (table 3), of which about 3 percent is in the Westport River-Noquochoke Lake to mouth 12-digit WBD cataloging unit, about 64 percent is in the Rhode Island Sound-Richmond Pond to Sakonnet Point 12-digit WBD cataloging unit, and about 33 percent is in the Sakonnet River 12-digit WBD cataloging unit. The estimated total town population for the study period was 3,343 (table 1). There are no major water suppliers in the town, and no wastewater-treatment facilities.

The town of Tiverton is on the northern part of the southeastern Narragansett Bay in Rhode Island (fig. 1). The total land area is 30.00 mi^2 (table 3), of which about 20 percent is in the Westport River-Noquochoke Lake to mouth 12-digit WBD cataloging unit, about 2 percent is in the Rhode Island Sound-Richmond Pond to Sakonnet Point 12-digit WBD cataloging unit, about 20 percent is in the Quequechan River 12-digit WBD cataloging unit, about 7 percent is in the Mount Hope Bay 12-digit WBD cataloging unit, and about 51 percent is in the Sakonnet River 12-digit WBD cataloging unit. The estimated town population for the study period was 14,194 (table 1). There are three major public water suppliers in Tiverton: the North Tiverton Fire District, the Stone Bridge Fire District, and the Tiverton Fire District. Three minor public water suppliers serve small populations in the town.

East Narragansett Islands Region

The East Narragansett Islands region (41.05 mi^2) is in the center of Narragansett Bay in Rhode Island. The towns in the region include Middletown, Newport, and Portsmouth (fig. 1). Land areas and land-use areas by category are summarized in tables 3 and 4. The region area has minimal sand and gravel deposits that compose about 5 percent of the total glacial deposits (fig. 5). Because the glacial deposits on the islands are thin and the area is flat, small brooks drain into the East Passage that runs between Aquidneck and Prudence and Conanicut Islands and into the Sakonnet River along the east side of Aquidneck Island.

The city of Newport is on the southern part of Aquidneck Island in the eastern part of Narragansett Bay in Rhode Island (fig. 1). The city includes Goat Island, Rose Island, and Coasters Harbor Island, which are in the center of Narragansett Bay in Rhode Island. Forty-seven percent of the city's land area is in the Lower East Passage 12-digit WBD cataloging unit, and 53 percent is in the Coastal Aquidneck 12-digit WBD cataloging unit. The total land area is 7.445 mi^2 (table 3). The estimated total population for the study period was 24,536 (table 1). The Newport Water Works supplies the city's public water, and the Newport Wastewater-Treatment Facility serves the city for the collection of wastewater. The service area includes one retail customer, the U.S. Navy, which is on Coasters Harbor Island in the East Passage.

Portsmouth occupies the northern part of Aquidneck Island, and the town includes Patience Island, Prudence Island, Hope Island, and Hog Island, which are in the center of Narragansett Bay in Rhode Island (fig. 1). The total land area is 21.10 mi^2 (table 3), of which 6 percent is in the Mount Hope Bay12-digit HUC, 60 percent is in the Upper West Passage, Upper East Passage, and Lower East Passage 12-digit WBD cataloging units, 33 percent is in the Sakonnet River 12-digit WBD cataloging unit, and 1 percent is in the Coastal Aquidneck 12-digit WBD cataloging unit. The estimated town population for the study period was 16,721 (table 1). The area of Portsmouth on Aquidneck Island is served by the Portsmouth Water and Fire District and the Newport Water Works's public water-supply systems (table 4). The only other area with a service area and resource for public supply is on Prudence Island, where the Prudence Island Utility, a minor public water supplier, serves residents and commercial customers for this part of Portsmouth.

Middletown is between Newport and Portsmouth on Aquidneck Island. The total land area is 12.50 mi^2 (table 3), of which 18 percent is in the Lower East Passage 12-digit WBD cataloging unit, 43 percent is in the Sakonnet 12-digit WBD cataloging unit, and 39 percent is in the Coastal Aquidneck 12-digit WBD cataloging unit. The estimated population for the study period was 18,970 (table 1). Middletown is served by the Portsmouth Water and Fire District and the Newport Water Works' public water-supply systems (table 4), and the Newport Wastewater-Treatment Facility serves the town for the collection of wastewater. One minor public water supplier serves a small population.

Water Use

The data for the water-use components for the East Narragansett Bay study area were organized by using NEWUDS. Components of water use include water withdrawals, public-supply systems and distributions, nonaccount use, water use by category, consumptive water use, wastewater-system collections, and return flow (fig. 3). For the study period, data were categorized as either public-supply withdrawals from ground-water and surface-water systems or self-supply withdrawals from the ground-water system (fig. 6). Conveyance losses are an example of nonaccount water use (which is unmetered) in public-supply systems, and include leaks, system flushing, and fire-hydrant use within the systems. The nonaccount water use for a public-supply system is the total distribution minus the public-supply distributions for the water-use categories in the system. Water-use categories used in this report are domestic, commercial, industrial, and agricultural for public-supply and self-supply users (fig. 7). Consumptive water use refers to water removed from the environment through uses by humans, livestock, production, or evapotranspiration. Wastewater from local and regional public-wastewater systems is returned to a surface-water body. Return flow to ground water or surface water includes site-specific permitted discharges and aggregate discharges from septic systems, which were assessed by town and region for the study area (fig. 8). Water withdrawals, water use, consumptive use, and return flow were calculated for each region by town for the calendar years during the study period. Analyses of the data indicated that more than 50 percent of the total water use was from surface-water withdrawals (16 percent) and wholesale water purchases (38 percent) from outside the basin; these were the predominant water sources for public suppliers in the study area during the study period from 1995 through 1999.

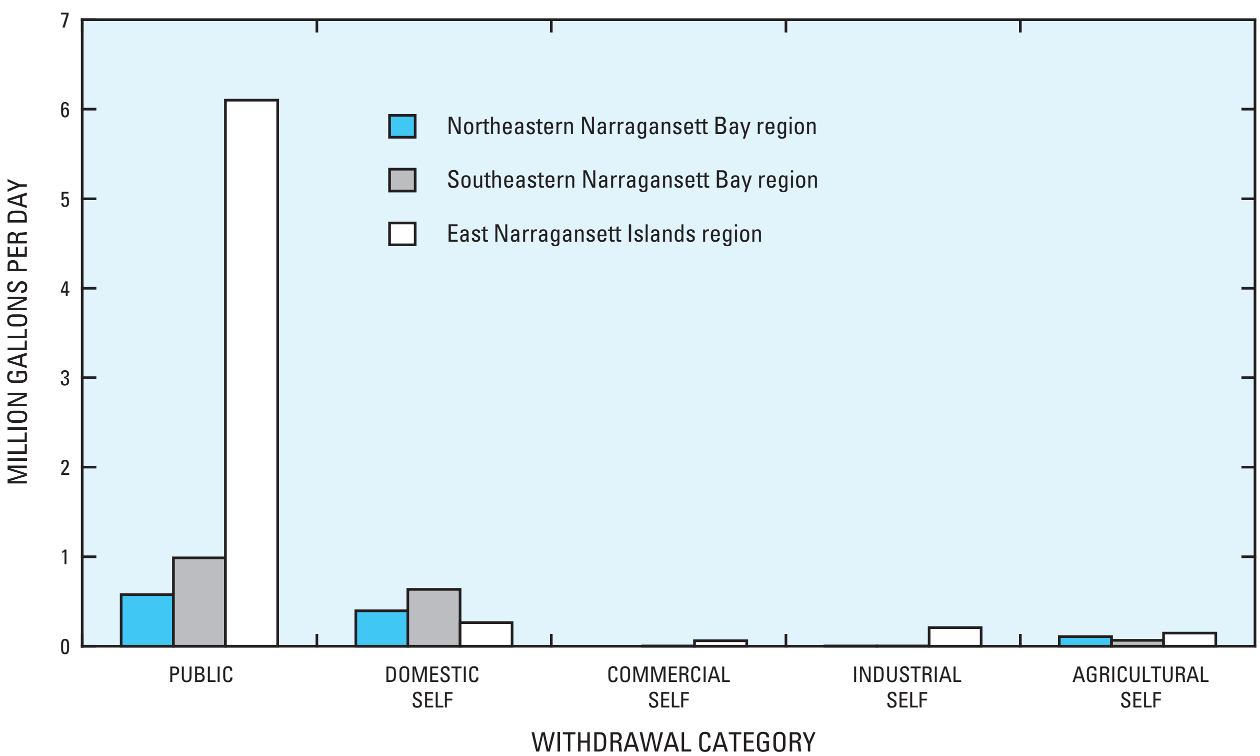


Figure 6. Public-supply withdrawals, and self-supply domestic, commercial, industrial, and agricultural withdrawals for the regions in the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

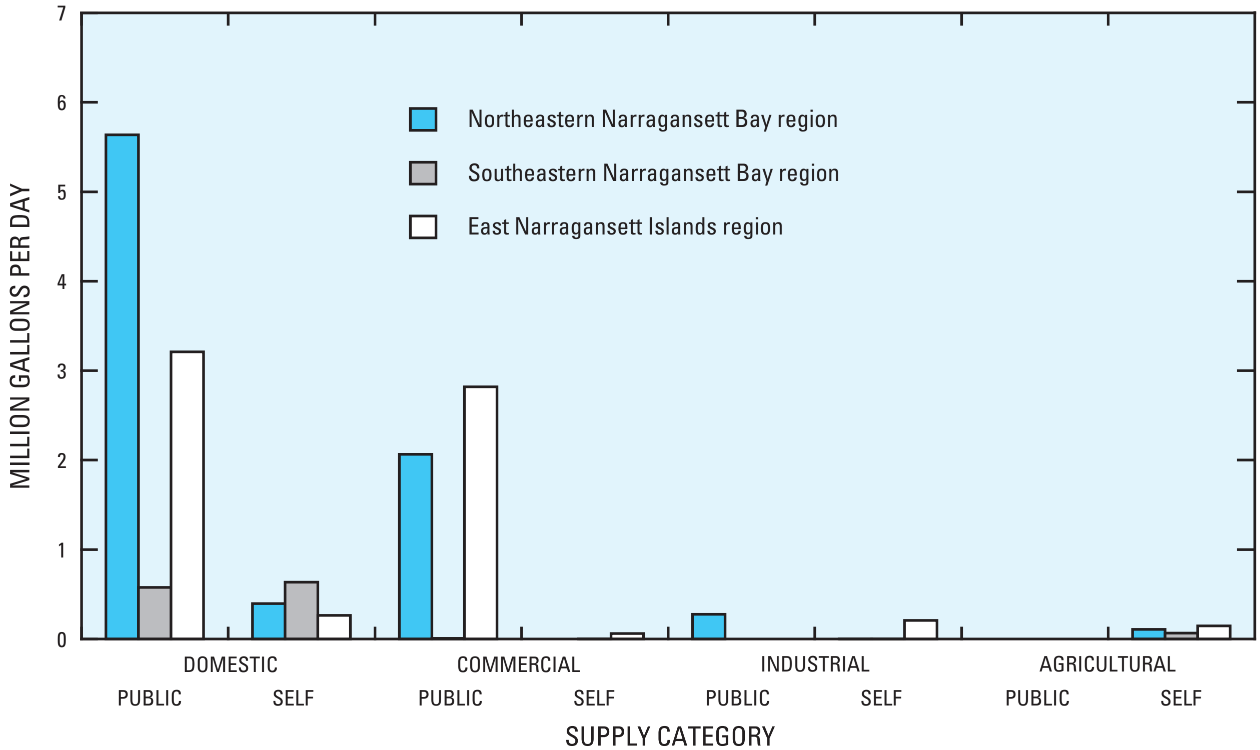


Figure 7. Public-supply and self-supply domestic, commercial, industrial, and agricultural water use for the regions in the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

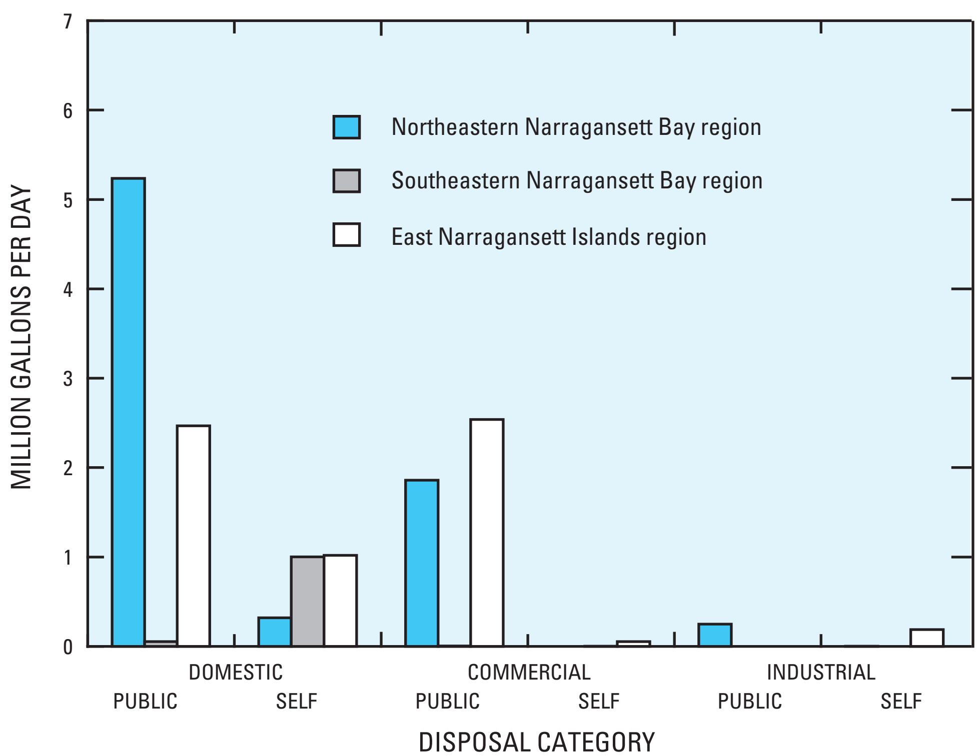


Figure 8. Wastewater-treatment facilities, Rhode Island Pollutant Discharge Elimination System, and self-disposed domestic, commercial, and industrial water return flow for the regions in the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

New England Water-Use Data System

The NEWUDS database was used as a tool to track the water withdrawn and used in the East Narragansett Bay study area. The database was queried to obtain the average water use for the study period, and the results of the analyses are in the tables and figures of this report. The data entered into the NEWUDS database consist of site-specific and aggregate water withdrawals, uses, and discharges. When available, monthly, quarterly, and (or) yearly metered (or reported) data were entered into the database, and were converted to common units (Mgal/d) for comparison. Unmetered water withdrawals, uses, and discharges were estimated, by category, by means of previously published methods (Wild and Nimiroski, 2004). Documentation describing database development and how to use the database are presented in the reports by Tessler (2002) and Horn (2003), respectively.

Public Water Supply and Potable-Water Interbasin Transfers

Public water suppliers were categorized as two types: major public suppliers that have a system of distribution (fig. 9) and minor suppliers that have closed systems. Three major public water suppliers withdraw water from the study area: Bristol County Water Authority, Stone Bridge Fire District, and the Newport Water Works (table 7). Seven major public water suppliers, however, serve the study area: Bristol County Water Authority, East Providence Water Department, North Tiverton Fire District, Stone Bridge Fire District, Tiverton Fire District, Newport Water Works, and the Portsmouth Water and Fire District, which supply the domestic, commercial, industrial, and agricultural sectors (table 8). Five minor public water suppliers serve small public populations, such as nursing homes, condominium associations, and mobile home parks (table 9). The total withdrawals from public water supplies by town and region are summarized in table 10.

For the purpose of this study, potable interbasin transfer is water that is conveyed from public water suppliers across hydrologic divides or boundaries separating defined study areas. The water is an import, or a gain to the basin or region, if the water is withdrawn in another basin or region and used within the study area. The water is an export, or a loss to the basin or region if the water is withdrawn within the study area, but used in another basin or defined study area.

The Bristol County Water Authority supplies the domestic, industrial, commercial, and agricultural water users in the towns of Barrington, Bristol, and Warren. The water-supply system for this study includes well withdrawals, wholesale purchases from the East Providence Water Department, the Providence Water Supply Board, and reservoir withdrawals imported to Rhode Island from Massachusetts (table 8). The average withdrawals for the study period were 0.576 Mgal/d from the Nayatt well field in Barrington; however, withdrawals from this well field have ceased since the study period. Wholesale water totals of 0.280 Mgal/d and 0.311 Mgal/d were purchased from the East Providence Water Department and the Providence Water Supply Board, respectively (table 8); however, currently (2004), the only purchases were from the Providence Water Supply Board. A total of 2.618 Mgal/d of surface water was imported from the Massachusetts reservoirs; however, currently (2004), the Bristol County Water Authority does not import water from the Warren Reservoir in Swansea, Massachusetts. The Bristol County Water Authority made 53 percent of the total withdrawals in the region and 6 percent of the total withdrawals in the East Narragansett Bay study area. The water withdrawals, purchases, and estimated distributions are summarized in figure 10.

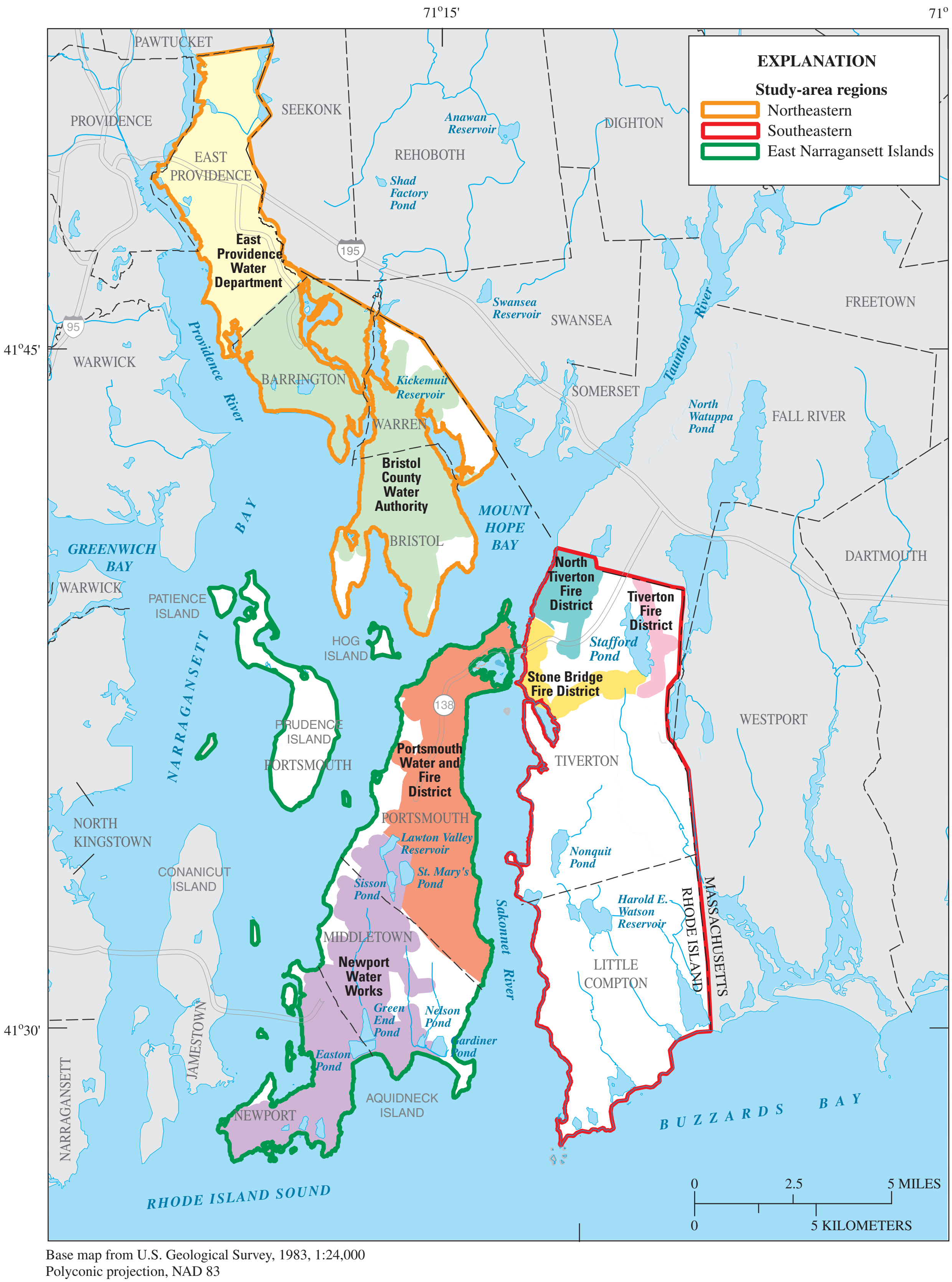


Figure 9. Rhode Island water-supply districts in the East Narragansett Bay study area, 1995–99.

Table 7. Public-supply withdrawals in the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

[All towns/cities assumed to be in Rhode Island unless otherwise noted. Mgal, million gallons; Mgal/d, million gallons per day; --, not applicable or data not available].

Source	City/town	Reservoir characteristics				Water withdrawals 1995-99 (Mgal/d)
		Safe yield (Mgal/d)	Drainage area (mi^2)	Surface area (mi^2)	Storage capacity (Mgal)	
Bristol County Water Authority						
Nayatt well field	Barrington	--	--	--	--	0.576
Stone Bridge Fire District						
Stafford Pond[1]	Tiverton	1.90	2.10	0.761	16,000	0.976
Newport Water Works						
Watson Reservoir[2]	Little Compton (small part in Tiverton)	--	3.7	0.131	1,600	--
Nonquit Pond[3]	Tiverton	--	6.0	.278	562	--
St. Mary's Pond[4]	Portsmouth	--	.80	.181	245	--
Lawton Valley Reservoir[5]	Portsmouth	--	1.1	.131	328	--
Sisson Pond[6]	Portsmouth	--	.4	.141	122	--
North and South Easton Ponds[7]	Middletown-Newport line	--	3.75	.402	645	--
Nelson and Gardiner Ponds[8]	Middletown	--	2.88	.205	377	--
Intake from North and South Easton Ponds[1]	Newport	--	--	--	--	1.949
Lawton Valley Reservoir intake[5]	Portsmouth	--	--	--	--	4.100
Total for Newport Water Works		**12.2**	**18.63**	**1.924**	**3,879**	**6.049**
Study-area total		**14.10**	**20.73**	**2.685**	**19,879**	**7.601**

[1] Stafford Pond safe yield is determined by the City of Fall River's Watuppa Water Supply Board in Massachusetts.

[2] Watson Reservoir is used for storage only, and the usable storage is 1,300 Mgal.

[3] Nonquit Pond usable storage is 400 Mgal.

[4] St. Mary's Pond usable storage is 240 Mgal.

[5] Lawton Valley Reservoir usable storage is 315 Mgal.

[6] Sisson Pond usable storage is 111 Mgal.

[7] North and South Easton Ponds usable storage is 527 Mgal.

[8] Nelson and Gardiner Ponds usable storage is 353 Mgal.

Table 8. Public water-supply imports and wholesale purchases to the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

[All towns/cities assumed to be in Rhode Island unless otherwise noted. Mgal/d, million gallons per day; --, not applicable or data not available]

Water supplier	Wholesale water supplier	City/town	Description and location of withdrawal source	Imports and(or) wholesale purchases 1995-99 (Mgal/d)
Bristol County Water Authority[1]	--	Warren	Warren Reservoir, Swansea, Massachusetts	2.618
	Providence Water Supply Board	Scituate	Regional distribution from the Scituate Reservoir	.311
	East Providence Water Department	--	Purchase from Providence Water Supply Board	.280
East Providence Water Department	Providence Water Supply Board	--	Purchase from Providence Water Supply Board	5.484
North Tiverton Fire District	Fall River Water Department	Fall River, Massachusetts	North Watuppa and Copicut Reservoirs	.200
	Stone Bridge Fire District	Tiverton	Stafford Pond	.134
Portsmouth Water and Fire District	Newport Water Works	Portsmouth	Lawton Valley Reservoir	.584
	Stone Bridge Fire District	Tiverton	Stafford Pond	.437
Tiverton Fire District[2]	Stone Bridge Fire District	Tiverton	Stafford Pond	.035

[1] Bristol County Water Authority currently (2004) does not use the reservoir for supply. Water is purchased wholesale from the Providence Water Supply Board.

[2] The North Tiverton Fire District currently (2004) operates the Tiverton system.

Table 9. Minor public suppliers by region in the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

[Coefficient used for minor-supplier population is 67 gal/d/person. All wells are completed in bedrock. Gal/d/person, gallons per day per person; Mgal/d, million gallons per day, --, not applicable]

Minor supplier	Town	Estimated 1995-99	
		Population	Water withdrawals and use (Mgal/d)
Northeastern Narragansett region			
--	--	--	--
Southeastern Narragansett region			
Four Seasons Mobile Home Park	Tiverton	41	0.003
Heritage Park	Tiverton	75	.005
Lawrence Sunset Cove Association	Tiverton	39	.003
Total		**155**	**0.011**
East Narragansett Islands region			
Meadowlark Mobile Home Park	Middletown	175	0.012
Prudence Island Utility Corporation	Portsmouth (Prudence Island)	600	.040
Total		**775**	**0.052**
Study-area total		**930**	**0.063**

Table 10. Ground-water and surface-water withdrawals by town and region in the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

[Public-supply domestic, commercial, and industrial water withdrawals are from ground water (wells). Irrigation-water withdrawals (in the agricultural category) are assumed to be 81 percent from surface water (ponds and rivers) and 13 percent from ground water (wells). Livestock water withdrawals are assumed to be 9 percent from surface water and 82 percent from ground water. The remaining 6 percent for irrigation and 9 percent for livestock are estimated to be from public supply (Soil Conservation Service, 1993). All values are in Mgal/d, million gallons per day; --, not applicable; <0.001, value not included in totals.]

City/Town	Public-supply withdrawals	Self-supply withdrawals				Total
		Domestic	Commercial	Industrial	Agricultural	
Northeastern Narragansett region						
Barrington	0.576	0.058	--	--	0.022	0.656
Bristol	--	.221	--	--	.015	.236
East Providence	--	.008	--	--	.062	.070
Warren	--	.108	0.001	0.002	.009	.120
Region total	**0.576**	**0.395**	**0.001**	**0.002**	**0.108**	**1.082**
Southeastern Narragansett region						
Little Compton	--	0.231	<0.001	0.003	0.046	0.277
Tiverton	0.987	.404	.002	--	.019	1.412
Region total	**0.987**	**0.635**	**0.002**	**0.003**	**0.065**	**1.692**
East Narragansett Islands region						
Middletown	0.012	0.222	0.013	0.031	0.036	0.314
Newport	1.949	<.001	.047	.023	.021	2.040
Portsmouth	4.140	.043	<.001	.154	.090	4.427
Region total	**6.101**	**0.265**	**0.060**	**0.208**	**0.147**	**6.781**
Study-area total	**7.664**	**1.295**	**0.063**	**0.213**	**0.320**	**9.555**

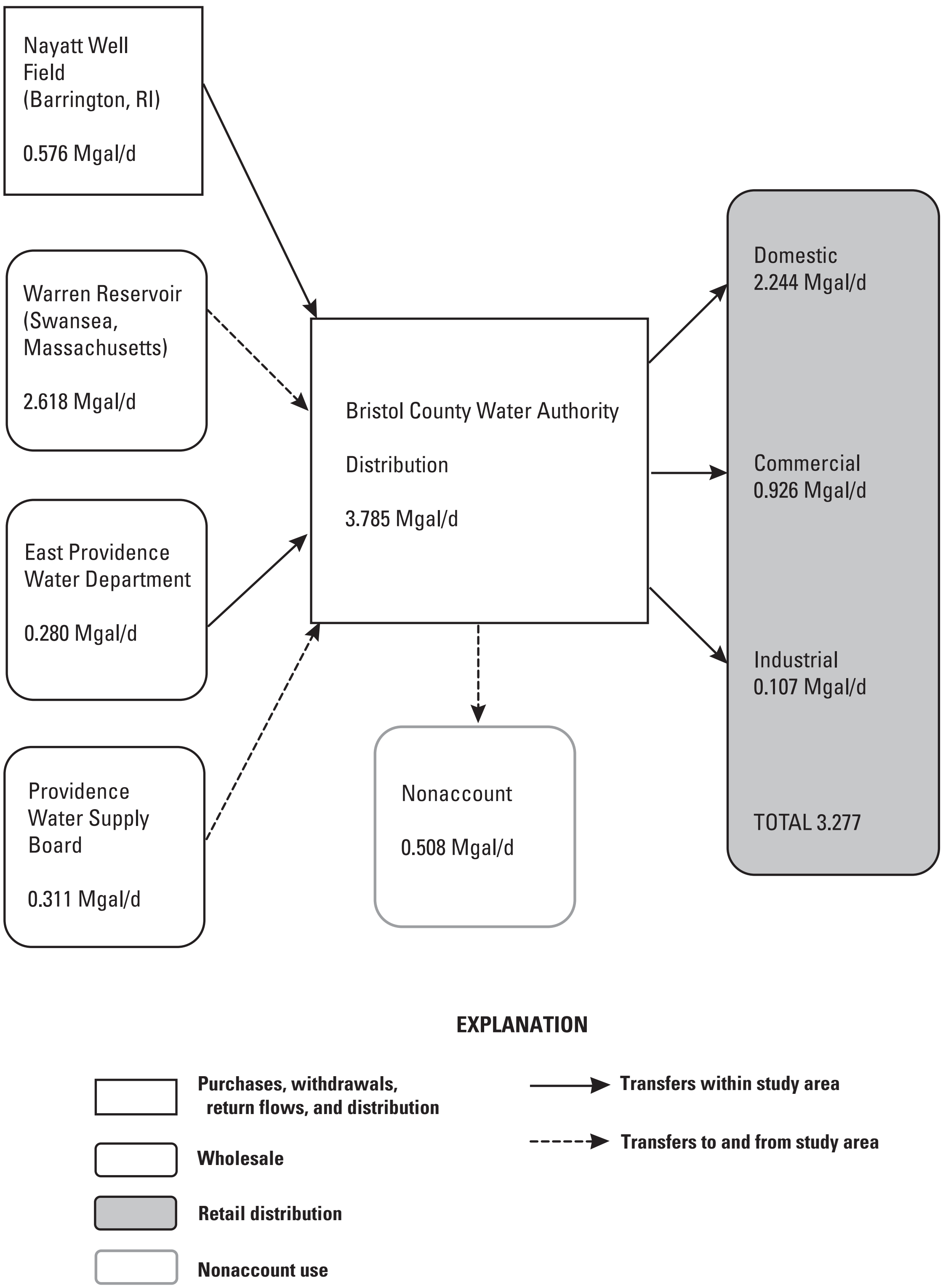


Figure 10. Bristol County Water Authority withdrawals, imports, treatment, distributions, and estimated water uses in the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

The East Providence Water Department system only purchases water (they do not withdraw water) from the Providence Water Supply Board's Scituate Reservoir in the Pawtuxet River Basin. The East Providence supply system purchased an average of 5.484 Mgal/d during the study period (table 8). As previously discussed, the East Providence Water Department sold water to the Bristol County Water Authority during the study period. The purchases, wholesales, and estimated distributions for the East Providence Water Department system are summarized in figure 11.

The North Tiverton Fire District purchased about 0.200 Mgal/d of water from the Fall River Water Department (Watuppa Water Board) as an import to the state and study area; and the district purchased about 0.134 Mgal/d of water from the Stone Bridge Fire District in Tiverton, Rhode Island (table 8). During the study period, the Tiverton Fire District served a small area in the study area and purchased about 0.035 Mgal/d from the Stone Bridge Fire District. Currently, however, the Tiverton Fire District's is operated by the North Tiverton Fire District (table 8). The North Tiverton Fire District's wholesale purchases and estimated distributions are summarized in figure 12.

The Stone Bridge Fire District withdrew an average of 0.976 Mgal/d during the study period from Stafford Pond in Tiverton (table 7). As previously discussed, the Stone Bridge Fire District sells water wholesale to the North Tiverton Fire District and the Tiverton Fire District. In addition, the Stone Bridge Fire District sells water to the Portsmouth Water and Fire District on Aquidneck Island. The Stone Bridge Fire District withdrew 58 percent of its total withdrawals in the Southeastern Narragansett region and 10 percent in the study area. The surface-water withdrawals and distributions are summarized in figure 13.

The largest major water supplier in the East Narragansett Bay study area is the Newport Water Works in the East Narragansett Islands region. This supplier withdrew an average of 6.049 Mgal/d during the study period from a series of nine surface-water reservoirs (table 7). About 0.584 Mgal/d was sold wholesale to the Portsmouth Water and Fire District (table 8). The Newport Water Works withdrew 89 percent of its total withdrawals in the East Narragansett Islands region and 63 percent of the total withdrawals in the East Narragansett Bay study area. The water withdrawals, distributions, and use are summarized in figure 14 for the Newport Water Works.

Five minor public water suppliers serve the East Narragansett Bay study area (table 9). Limited data are available on these water withdrawals; therefore, water use was estimated by applying the water-use coefficient for public water supply (67 gal/d/person in Rhode Island) determined by Korzendorfer and Horn (1995) to the estimated population on public water. The total of the estimated water withdrawn in the study area by minor suppliers was 0.063 Mgal/d. Estimated water withdrawals for the regions were 0.011 Mgal/d in the Southeastern Narragansett region and 0.052 Mgal/d in the East Narragansett Islands region; no minor public water suppliers were in the Northeastern Narragansett region. Estimated water withdrawals for the individual minor suppliers ranged from 0.003 Mgal/d to 0.040 Mgal/d.

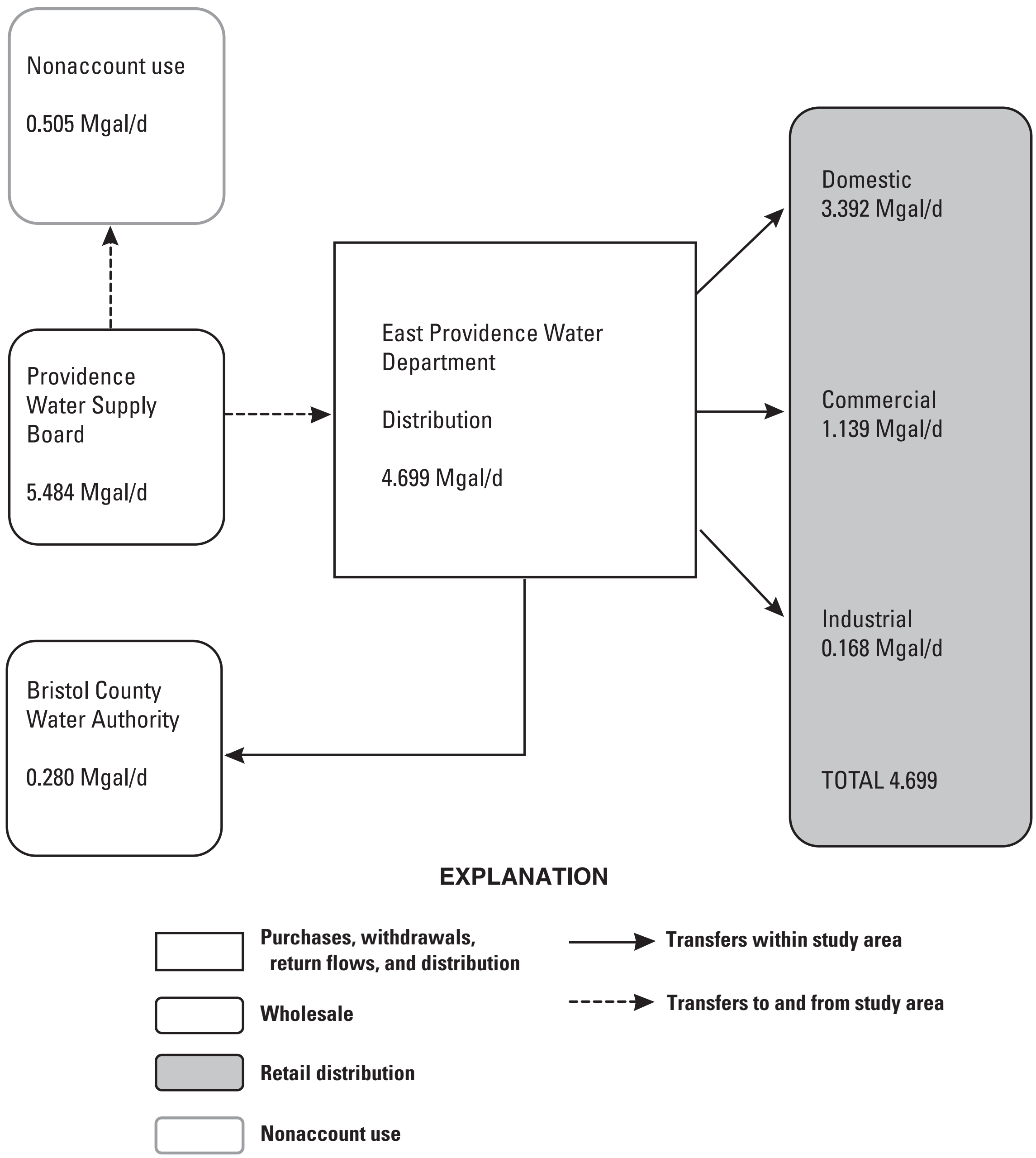


Figure 11. East Providence Water District imports, wholesale purchases, distributions, and estimated water uses in the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

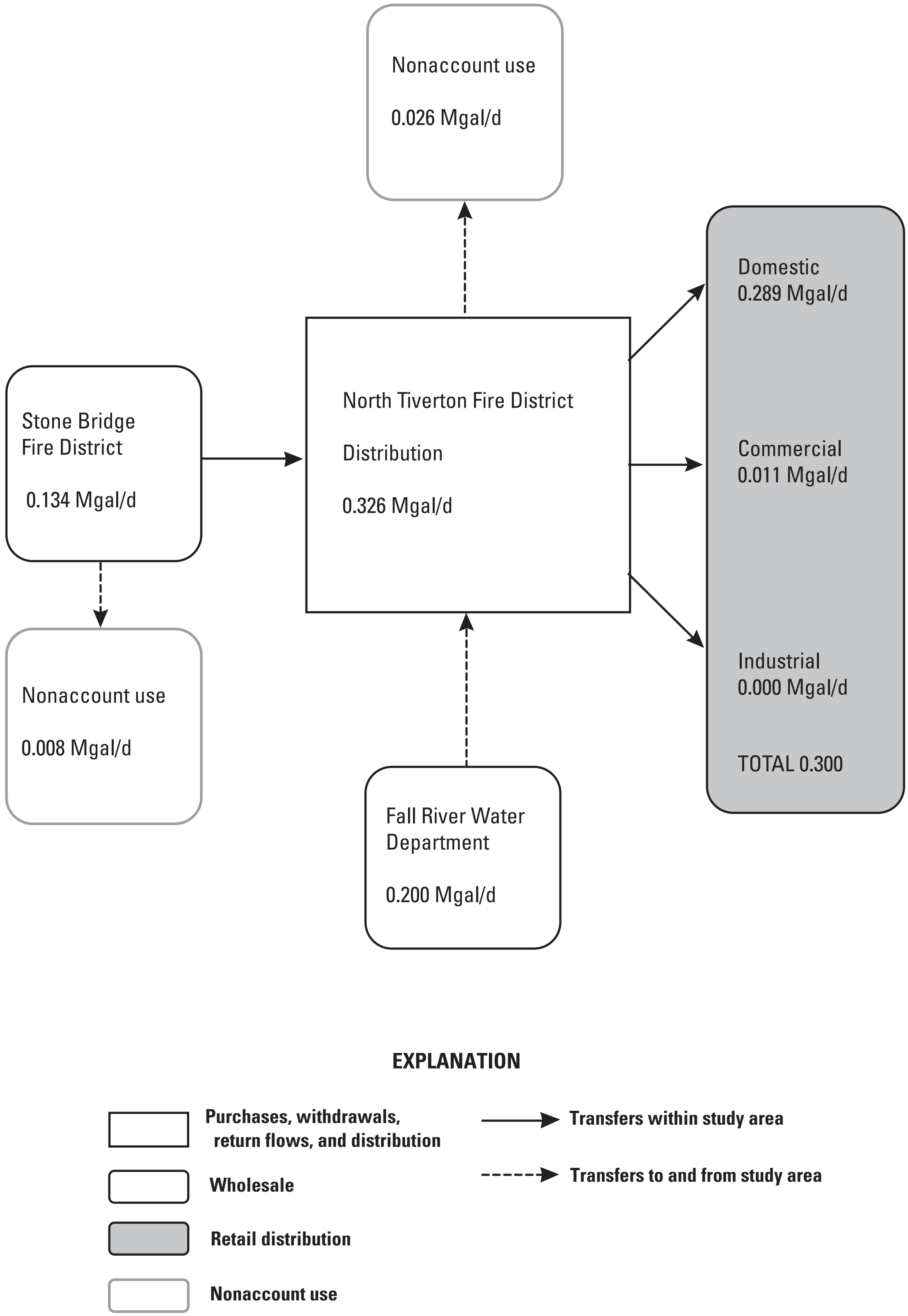


Figure 12. North Tiverton Fire District imports, wholesale purchases, distributions, and estimated water uses in the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

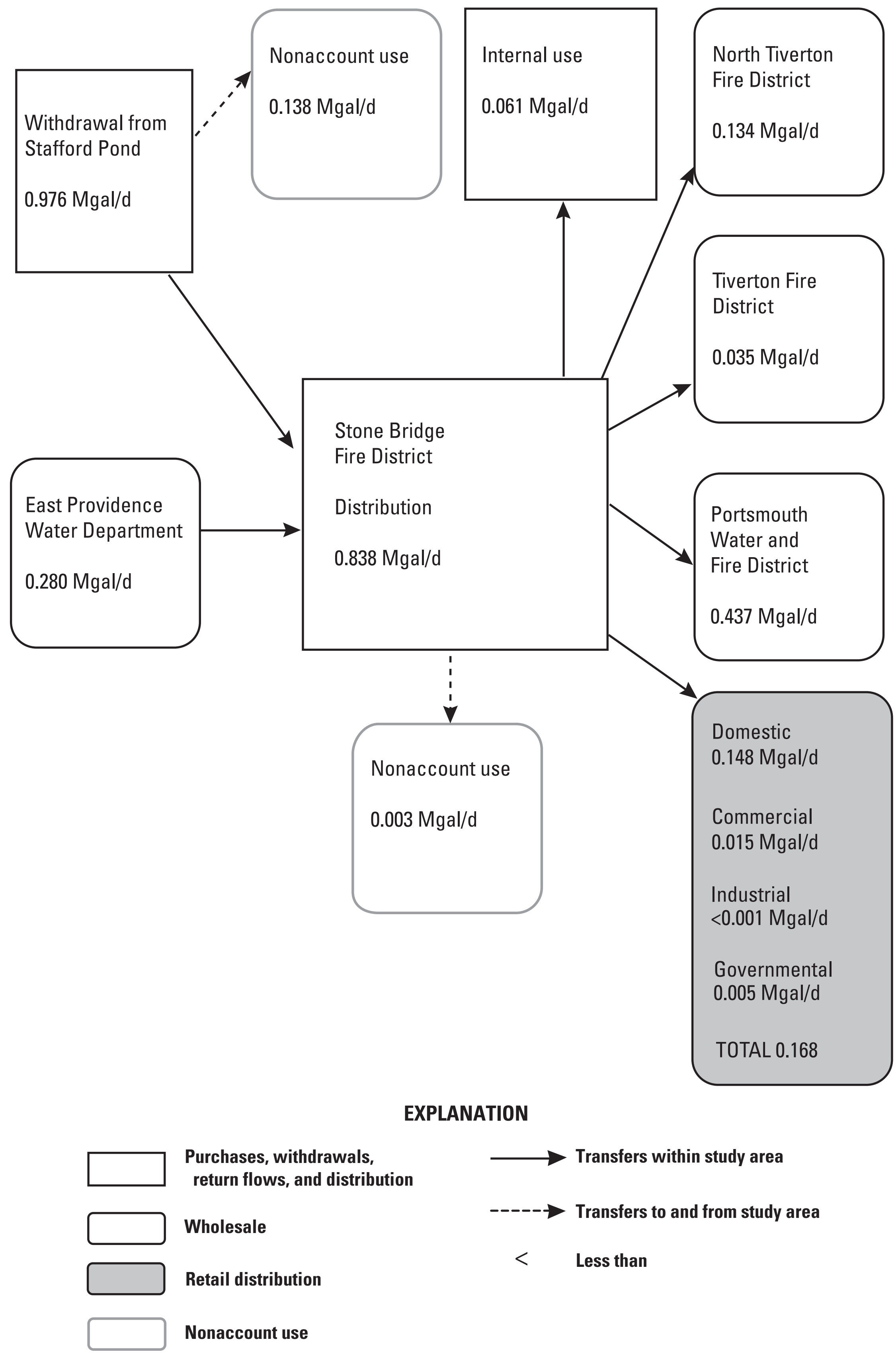


Figure 13. Stone Bridge Fire District withdrawals, distributions, and estimated water uses in the East Narragansett Bay study area, 1995–99.

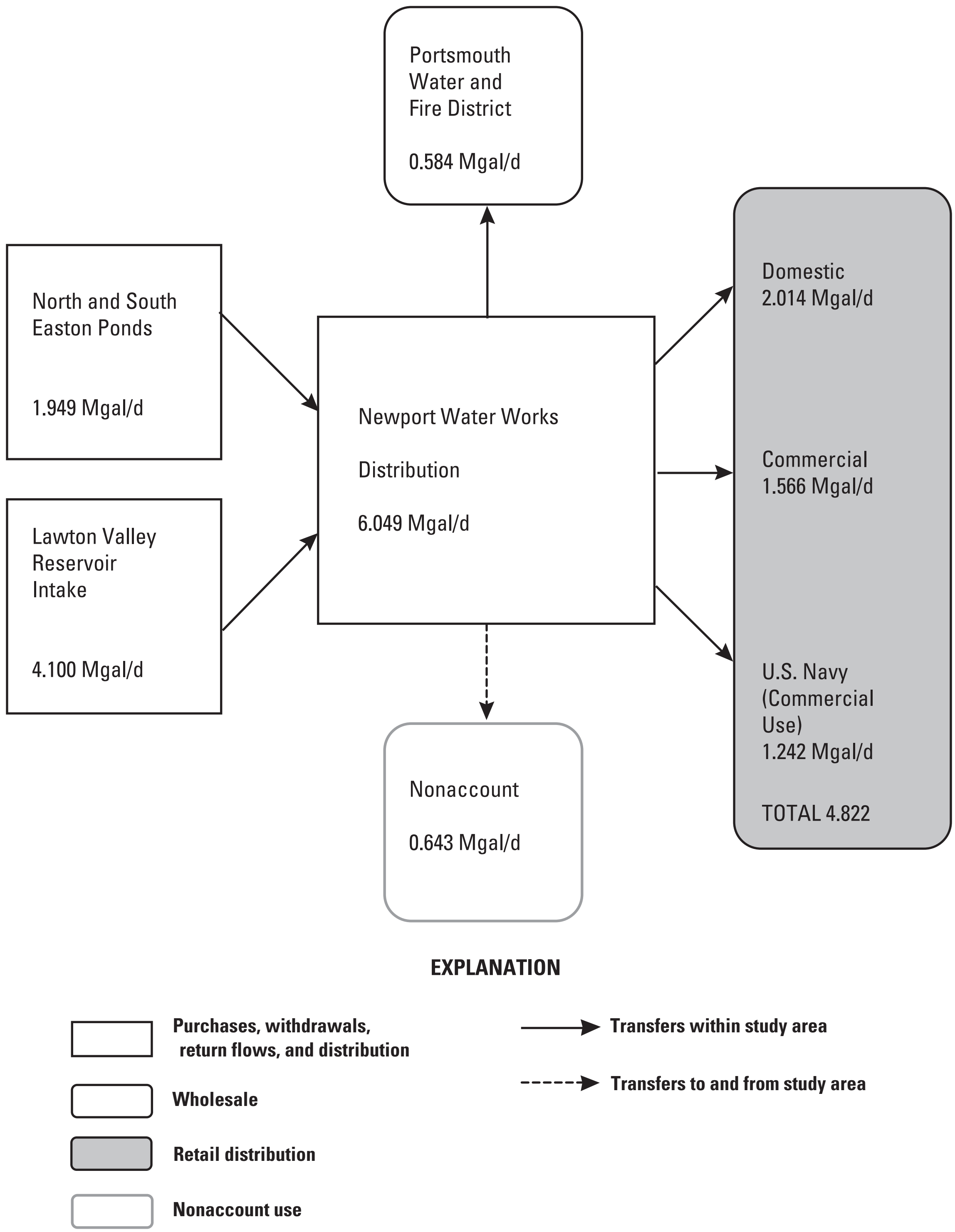


Figure 14. Newport Water Works withdrawals, distributions, and estimated water uses in the East Narragansett Bay study area and basin exports, 1995–99.

Domestic Water Use

Domestic water use is the amount of water used by residential populations served either by public supplies or by private wells. To calculate the water use for this category, population estimates in Rhode Island were multiplied by the water-use coefficients 71 gal/d/person for self-supply domestic water use and 67 gal/d/person for public-supply domestic water use; these coefficients were based on the 1990 National water-use compilation (Korzendorfer and Horn, 1995).

Public-Supply Use

Region populations on public supply were estimated by merging the 1990 census-block coverages, which include information about the domestic populations on private wells, with the town coverages obtained from RIGIS. The ratios of 1990 self- and public-supply populations to the total 1990 populations were multiplied by the average population in the study area for 1995–99 to give the self- and public-supply population for 1995–99 (table1). When domestic water-use data (listed as residential in the Water-Supply Management Plans) were available, the domestic data were used instead of a calculation based on ratios. Because limited withdrawal data are available for the five minor public water suppliers in the study area, the water-use coefficient for domestic public water supply was applied to populations served by each minor supplier.

Public-supply domestic water use was 5.636 Mgal/d in the Northeastern Narragansett region; 0.576 Mgal/d in the Southeastern Narragansett region; and 3.211 Mgal/d in the East Narragansett Islands region for this water-use category. The estimated domestic use of public-supply water by town and region is listed in table 11 and illustrated in figure 7.

Self-Supply Use

The average population from 1995 through 1999 that withdrew self-supply water for each region was estimated from the 1990 population and from the ratio of growth for 1995 through 1999 within each region (table 1). Domestic water withdrawals and uses in the regions were 0.395 Mgal/d in the Northeastern Narragansett region, 0.635 Mgal/d in the Southeastern Narragansett region, and 0.265 Mgal/d in the East Narragansett Islands region for this water-use category (figs. 6 and 7, tables 10 and 11).

Commercial and Industrial Water Use

Limited data are available on commercial and industrial water use from public- and self-supply systems because withdrawals and use for these water-use categories (figs. 6 and 7) are not regulated in Rhode Island unless the withdrawal point is adjacent to a wetland (Rhode Island Department of Environmental Management, 2001). Commercial and industrial water-use estimates, therefore, were derived from the total calculated water use and apportioned for each town by the land-use type and water-supply district. Commercial and industrial consumptive water use (table 12) is assumed to be 10 percent of the total water use (Solley and others, 1998).

Public-Supply Use

Information on the delivery of water to commercial and industrial users of public-supply water included metered (or reported) and unmetered water-use data. When the data were available, the public suppliers provided the delivery volume and the number of service connections for commercial and industrial water users. In some cases, the suppliers reported the commercial and industrial uses together, and in other cases the information was not available. Government water use is accounted for within the commercial water-use category according to the Standard Industrial Classification (SIC) codes. For this study, government water use was entered as a separate distribution into NEWUDS if the supplier collected the data to this level of detail. Because some water-supply districts serve one or more towns and regions, the public commercial and industrial water uses were apportioned by percentages of the land-use areas (table 4). Land-use coverages from RIGIS were merged with the water-supply and town coverages to obtain the percentage of commercial and industrial land use within the supply districts for towns served in the East Narragansett Bay study area. Commercial use of public-supply water was 2.065 Mgal/d in the Northeastern Narragansett region; 0.007 Mgal/d in the Southeastern Narragansett region; and 2.820 Mgal/d in the East Narragansett Islands region. Industrial use of public-supply water was 0.275 Mgal/d in the Northeastern Narragansett region; 0.001 Mgal/d in the Southeastern Narragansett region. This water-use category was not applicable in the East Narragansett Islands region during the period of study.

Table 11. Estimated water use by town and region in the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

[Mgal/d, million gallons per day; --, not applicable; <0.001, value not included in totals]

City/Town	Domestic supply (Mgal/d)		Commercial supply (Mgal/d)		Industrial supply (Mgal/d)		Agricultural supply (Mgal/d)		Total water use (Mgal/d)
	Public	Self	Public	Self	Public	Self	Public	Self	
Northeastern Narragansett region									
Barrington	1.035	0.058	0.240	--	0.006	--	--	0.022	1.361
Bristol	.856	.221	.365	--	.060	--	--	.015	1.517
East Providence	3.392	.008	1.139	--	.168	--	--	.062	4.769
Warren	.353	.108	.321	0.001	.041	0.002	--	.009	.835
Region total	**5.636**	**0.395**	**2.065**	**0.001**	**0.275**	**0.002**	**--**	**0.108**	**8.482**
Southeastern Narragansett region									
Little Compton	0.006	0.231	--	<0.001	--	0.003	--	0.046	0.286
Tiverton	.570	.404	0.007	.002	0.001	--	--	.019	1.003
Region total	**0.576**	**0.635**	**0.007**	**0.002**	**0.001**	**0.003**	**--**	**0.065**	**1.289**
East Narragansett Islands region									
Middletown	1.061	0.222	0.994	0.013	--	0.031	--	0.036	2.357
Newport	1.070	<.001	1.770	.047	--	.023	--	.021	2.931
Portsmouth	1.080	.043	.056	<.001	--	.154	--	.090	1.423
Region total	**3.211**	**0.265**	**2.820**	**0.060**	**--**	**0.208**	**--**	**0.147**	**6.711**
Study-area total	**9.423**	**1.295**	**4.892**	**0.063**	**0.276**	**0.213**	**--**	**0.320**	**16.48**

Table 12. Consumptive water use by town and region in the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

[All values are in Mgal/d, million gallons per day. --, not applicable; <0.001, value not included in totals]

City/town	Domestic		Commercial		Industrial		Agricultural		Total consumptive water use
	Public	Self	Public	Self	Public	Self	Public	Self	
Northeastern Narragansett region									
Barrington	0.155	0.009	0.002	--	0.001	--	--	0.022	0.189
Bristol	.128	.033	.036	--	.006	--	--	.015	.218
East Providence	.509	.001	.114	--	.017	--	--	.062	.703
Warren	.053	.016	.032	<0.001	.004	<0.001	--	.009	.114
Region total	**0.845**	**0.059**	**0.184**	**<0.001**	**0.028**	**<0.001**	**--**	**0.108**	**1.224**
Southeastern Narragansett region									
Little Compton	0.001	0.035	--	--	--	<0.001	--	0.046	0.082
Tiverton	.086	.061	0.001	<0.001	<0.001	--	--	.019	.167
Region total	**0.087**	**0.096**	**0.001**	**<0.001**	**<0.001**	**<0.001**	**--**	**0.065**	**0.249**
East Narragansett Islands region									
Middletown	0.159	0.033	0.099	0.001	--	0.003	--	0.036	0.331
Newport	.161	<.001	.177	.005	--	.002	--	.021	.366
Portsmouth	.162	.006	.006	--	--	.015	--	.090	.279
Region total	**0.482**	**0.039**	**0.282**	**0.006**	**--**	**0.020**	**--**	**0.147**	**0.976**
Study-area total	**1.414**	**0.194**	**0.467**	**0.006**	**0.028**	**0.020**	**--**	**0.320**	**2.449**

Self-Supply Use

Self-supply commercial and industrial water-use estimates were calculated from the employee counts published in the RIEDC's "Export/Import Directory" (2000a), "High Tech Industries in Rhode Island" (1999), and "Major Employers in Rhode Island" (2000b). The number of employees in the industrial and commercial sectors for each Standard Industrial Classification (SIC) code were multiplied by the U.S. Army Corp of Engineers' Institute for Water Resources Municipal and Industrial Needs (IWR-MAIN) water-use coefficient (in gal/d/person) for each town (table 13) as described in Horn (2000). The estimated use by commercial and industrial facilities on public water were subtracted from the total aggregate use to obtain the estimated total self-supply use for these categories. The results for commercial and industrial withdrawals and use are listed in tables 10 and 11. Commercial use of self-supply water was 0.001 Mgal/d in the Northeastern Narragansett region; 0.002 Mgal/d in the Southeastern Narragansett region; and 0.060 Mgal/d in the East Narragansett Islands region (figs. 6 and 7). Industrial use of self-supply water in the East Narragansett Bay study area was 0.002 Mgal/d in the Northeastern Narragansett region; 0.003 Mgal/d in the Southeastern Narragansett region; and 0.208 Mgal/d in the East Narragansett Islands region. Commercial and industrial water use by region and town are listed in table 11.

Agricultural Water Use

The estimated agricultural water use (livestock, crop irrigation, and golf-course irrigation) for each town was obtained from information provided by the U.S. Department of Agriculture (USDA) NRCS, formerly the Soil Conservation Service (SCS). Nine percent of withdrawals and use for livestock were assumed to be from surface water (streams and ponds) and 82 percent from ground water (wells); these livestock water-use rates were previously estimated in a study completed by the SCS (1993). Likewise, eighty-one percent of withdrawals and use for irrigation (golf courses and crops) were assumed to be from surface water and 13 percent from ground water (Soil Conservation Service, 1993). The remaining 9 percent of livestock use and 6 percent of irrigation use were assumed to be from public-supply distributions.

The water-use coefficients for each type of livestock (Laura Medalie, U.S. Geological Survey, written commun., 1995) were multiplied by the number of livestock of each type. Because the livestock and crop-irrigation data are reported in the 1997 Census of Agriculture for the county level (U.S. Department of Agriculture, 1997a, b), the estimates were disaggregated on the basis of the number of farms in the town and the percentage of agricultural land use by town. The livestock water-use estimates represent a year-round usage. Although it is estimated that 60 percent of livestock water use is consumptive and 40 percent is returned to ground water (Horn and others, 1994), this distinction was negligible for each town in the East Narragansett Bay study area. Thus, agricultural water was assumed to be 100 percent consumed (table 12) (Horn and others, 1994). Livestock water use is minimal in the study area, and accounted for about 6 percent of the agricultural water withdrawals during the summer and less than one percent of the annual agricultural water withdrawals during the study period.

The amount of water needed to irrigate crops was estimated for each town in the study area. Irrigated-cropland acreage needed to be estimated for each town because it is not reported at the town level; irrigated-cropland acreage was estimated by multiplying agricultural land-use area (in acres) by the ratio of cropland area to agricultural land area for the county in which each town is located. The amount of water needed to irrigate crops in each town was assumed to be about 1 in/week/acre (or 0.143 in/day/acre) minus the average monthly rainfall for the study area.

Similarly, the amount of water needed to irrigate golf courses was estimated for each town in the study area. This was done by compiling a list of golf courses for each town and obtaining the total yardages of each golf course from the Web sites WorldGolf.com (2002) and GolfCourse.com (2002). In turn, the amount of water used to irrigate each golf course was estimated by applying a previously published water-use coefficient of 0.0116 Mgal/d per 1,000 golf-course yards (Laura Medalie, U.S. Geological Survey, written commun., 2000); this coefficient was developed by using reported golf-course water-use data. The amount of water needed to irrigate golf courses for each town was determined by adding together the amounts of water used to irrigate all of the golf courses in each town. A similar water-use coefficient has been used by others (Wild and Nimiroski, 2004). Most notably, irrigation was done during June, July, and August; therefore, it was assumed that crop- and golf-course irrigation was done during these months (Soil Conservation Service, 1993).

Total agricultural water use was determined for each town and region by adding together the amounts of water used for livestock, crops, and golf courses. The total amount of water used for this purpose was calculated to be about 0.108 Mgal/d in the Northeastern Narragansett region; 0.065 Mgal/d in the Southeastern Narragansett region; and 0.147 Mgal/d in the East Narragansett Islands region (figs. 6 and 7, tables 10 and 11).

Table 13. Estimated water use per 2-digit Standard Industrial Classification code by town in the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

[SIC, Standard Industrial Classification; IWR-MAIN, Institute for Water Resources Municipal and Industrial Needs. IWR-MAIN coefficient is in gallons per day per person. gal, gallons; Mgal/d, Million gallons per day; --, not applicable; <0.001, value not used in totals]

2-digit SIC category and code	IWR-MAIN coefficient	Estimated water use in city/town (Mgal/d)								
		Barrington	Bristol	East Providence	Little Compton	Middletown	Newport	Portsmouth	Tiverton	Warren
Industrial [20-39]										
Food [20]	469	--	0.033	0.050	0.003	--	0.009	--	--	0.040
Textile Mills [22]	315	--	.047	.002	--	0.008	--	0.003	--	--
Finished apparel [23]	13	--	<.001	<.001	--	--	<.001	--	--	.001
Wood, lumber [24]	78	--	--	--	--	--	--	--	--	--
Furniture [25]	30	--	--	.009	--	--	--	--	--	--
Paper Products [26]	863	--	.021	.259	--	--	--	--	--	.008
Printing, Publishing [27]	42	--	<.001	.010	--	.002	--	--	--	--
Chemical Products [28]	289	--	--	.153	--	--	--	--	--	--
Petroleum Refining [29]	1045	--	--	--	--	--	--	--	--	--
Rubber [30]	119	--	.034	.041	--	.001	--	--	--	.012
Leather [31]	148	--	--	--	--	--	.001	--	--	--
Stone, clay, glass, and concrete [32]	202	--	--	--	--	--	.004	--	--	--
Primary metals [33]	178	--	.001	.006	--	--	--	--	--	--
Fabricated metal [34]	95	--	.004	.012	--	--	--	.009	--	--
Machinery [35]	58	--	.010	.008	--	.001	--	.001	--	.006
Electrical equipment [36]	71	--	<.001	.013	--	.003	--	.010	<0.001	--
Transportation equipment [37]	63	--	.018	.035	--	.005	.007	.028	--	.019
Instruments [38]	66	<0.001	<.001	.020	--	.010	.002	.099	--	--
Jewelry, precious metals [39]	36	--	<.001	.063	--	<.001	--	.004	<.001	.012
Total Industrial [20-39]		**<0.001**	**0.168**	**0.681**	**0.003**	**0.030**	**0.023**	**0.154**	**<0.001**	**0.098**
Commercial [40-97]										
Transportation, communication, utilities [40-49]	51	0.001	--	--	--	<0.001	0.006	--	--	0.007
Wholesale trade [50-51]	58	<.001	--	0.001	--	--	.002	--	--	--
Retail trade [52-59]	58	.009	0.013	.025	--	.077	.059	--	0.003	.006
Finance, insurance, real estate [60-67]	71	--	--	--	--	.027	.026	--	--	--
Services [70-89]	106	.002	.107	.035	<0.001	.414	.368	0.056	.006	.012
Public administration [91-97]	71	--	--	.011	--	--	.218	--	--	--
Total Commercial [40-97]		**0.012**	**0.120**	**0.072**	**<0.001**	**0.518**	**0.679**	**0.056**	**0.009**	**0.025**

Return Flow and Wastewater Interbasin Transfers

In Rhode Island, commercial and industrial dischargers are required to report to the Rhode Island Department of Environmental Management (RIDEM) Office of Water Resources the rates of water returned to the environment. These dischargers, referred to as Rhode Island Pollutant Discharge Elimination Systems (RIPDES), return wastewater to surface water (usually to rivers) or, in some cases, to the ground-water system. In addition, local and regional facilities that treat wastewater are required to report wastewater discharges into rivers in Rhode Island. When reported data from dischargers were not available, the return flow was estimated. Data were estimated for domestic, commercial, and industrial users on septic systems which were assumed to return water to the ground. The total surface-water return flow in the East Narragansett Bay study area was 0.003 Mgal/d, and the total estimated ground-water return flow was 2.587 Mgal/d (table 14). Wastewater interbasin transfers are wastewater conveyed across hydrologic divides and boundaries between defined study areas. The wastewater is an import, or a gain to an area if it is collected from another area. Wastewater is an export, or a loss to an area, if the wastewater in that area is collected, processed, and returned to the environment outside of that area.

Site-Specific Return Flow

In Rhode Island, commercial and industrial discharges that release water to the environment are identified as site-specific RIPDES sites, and some are required to report their discharges to the RIDEM. Return-flow data were collected from the RIDEM for these small discharges in the East Narragansett Bay study area (table 15). Discharge pipes dispose of water used during industrial and commercial processes. The water includes condensation from air-conditioning systems; thus, in systems that include air conditioning, it is possible for return flow to exceed intake. The total of the RIPDES discharges in the East Narragansett Bay study area to the rivers was 0.003 Mgal/d from one site in Tiverton in the Southeastern Narragansett region (table 15). Several other RIPDES sites in towns in the study area discharged about 1.544 Mgal/d to the bay (table 15).

Table 14. Estimated public- and self-disposed domestic, commercial, and industrial, and total self-disposed wastewater by region in the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

[Public disposal, wastewater collection to treatment plant; self-disposal, inflow to ground; RIPDES, Rhode Island Pollution Discharge Elimination System. Mgal/d, million gallons per day; --, not applicable; <0.001, value not included in totals]

City/Town	Estimated domestic disposal (Mgal/d)		Estimated commercial disposal (Mgal/d)		Estimated industrial disposal (Mgal/d)		Total self-disposal to study area (Mgal/d)
	Public	Self	Public	Self	Public	Self	
Northeastern Narragansett Region							
Barrington	0.890	0.007	0.216	--	0.005	--	0.007
Bristol	1.109	.152	.329	--	.054	--	.152
East Providence	2.668	.080	1.025	--	.151	--	.080
Warren	.571	.081	.289	.001	.037	.002	.084
Region total	**5.237**	**.320**	**1.859**	**.001**	**.248**	**.002**	**.323**
Southeastern Narragansett Region							
Little Compton	.003	.199	--	<.001	--	--	.199
Tiverton	.050	.804	.006	.002	.001	--	.809
Region total	**.053**	**1.002**	**.006**	**.002**	**.001**		**1.008**
East Narragansett Islands Region							
Middletown	.942	.146	.895	.012	--	.028	.186
Newport	1.371	.028	1.593	.042	--	.021	.091
Portsmouth	.155	.844	.050	<.001	--	.139	.983
Region total	**2.468**	**1.019**	**2.538**	**.054**	**--**	**.187**	**1.260**
Study-area total	**7.759**	**2.341**	**4.403**	**0.057**	**0.249**	**0.189**	**2.591**

Table 15. Return flows by region for the Rhode Island Pollutant Discharge Elimination System sites in the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

[Reference no. identifies the site on figure 4. The return flow to the study area is assumed to discharge to freshwater, whereas the discharge to Narragansett Bay is to saltwater and exported out of the study area. Mgal/d, Million gallons per day; --, not applicable]

Return-flow site	Reference no.	City/town (Locality)	Discharge-permit number	Receiving-water body	Return flow to Narragansett Bay
		Northeastern Narragansett Region			
Chevron Terminal	1	East Providence	RI0001325	Providence River	0.259
Mobil Pipe Line Co.	2	East Providence (Riverside)	RI0001333	Providence River	1.136
Region total					**1.395**
		Southeastern Narragansett Region			
Inland Fuel Terminals, Inc.	3	Tiverton	RI0000442	Mount Hope Bay	0.024
Tiverton High School	4	Tiverton	RI0100200	Sin and Flesh Brook	--[1]
Region total					**0.027**
		East Narragansett Islands Region			
Defense Fuel Depot – U.S. Naval Station	5	Newport	RI0020150	Narragansett Bay	0.122
International Manufacturing Services	6	Portsmouth	RI0021334	Sakonnet River	.001
Mother of Hope Novitiate (Freedom Bay Development)	7	Portsmouth	RI0020346	Narragansett Bay	.001
Portsmouth Middle School	8	Portsmouth	RI0100242	Narragansett Bay	<.001
Raytheon Corporation	9	Portsmouth	RI0000281	Weaver Cove	.001
Region total					**0.125**
Study area total					**1.544**

[1] One RIPDES site in Tiverton discharged 0.003 Mgal/d to a river in the study area.

Return Flow from Wastewater-Treatment Facilities

Monthly data were collected for public-disposal wastewater-treatment facilities (WWTFS) in or serving the towns in the East Narragansett Bay study area (table 16). The WWTFS serving populations in and outside of the East Narragansett Bay study area include the Bristol Wastewater-Treatment Facility, the East Providence Wastewater-Treatment Facility, Narragansett Bay Commission's facility at Bucklin Point (in East Providence), the Newport Wastewater-Treatment Facility, and the Warren Wastewater-Treatment Facility. All of the wastewater-treatment facilities were in the study area, and discharged the wastewater outside of the basin into Narragansett Bay. For Bristol, wastewater was collected in the study area and processed at the Bristol Wastewater-Treatment Facility. About 3.153 Mgal/d of wastewater, however, was discharged from the study area to Narragansett Bay during the study period. For Barrington and parts of East Providence, wastewater collection was in the study area and processed at the East Providence Wastewater-Treatment Facility. About 6.640 Mgal/d of wastewater, however, was discharged from the study area to Narragansett Bay from 1995 through 1999. The Narragansett Bay Commission's facility at Bucklin Point (in East Providence) is in the study area and received wastewater from East Providence in the study area as well as from communities outside of the study area. The Bucklin Point facility discharged about 23.92 Mgal/d of wastewater from the study area to Narragansett Bay during the study period. The Newport and Warren Wastewater-Treatment Facilities are in the study area, collected wastewater in the study area, and discharged about 8.126 and 1.826 Mgal/d, respectively, from the study area to Narragansett Bay from 1995 through 1999.

Table 16. Return flows to Narragansett Bay from wastewater-treatment facilities that are in the study area and serve towns in and outside of the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

[Reference letter identifies the site on figure 4. Mgal/d, million gallons per day]

Wastewater-treatment facility	Reference letter	Discharge-permit number	Cities/towns served in study area	Cities/towns served outside of the study area	Average discharge rate 1995–99 (Mgal/d)
Narragansett Bay Commission - Bucklin Point Wastewater-Treatment Facility[1]	A	RI0100315	East Providence	Central Falls, Cumberland, Lincoln, Pawtucket, Smithfield	23.92
East Providence Wastewater-Treatment Facility[2]	B	RI0100048	East Providence, Barrington	--	6.640
Warren Wastewater-Treatment Facility[3]	C	RI0100056	Warren	--	1.826
Bristol Wastewater-Treatment Facility	D	RI0100005	Bristol	--	3.153
Newport Wastewater-Treatment Facility[4]	E	RI0100293	Middletown, Newport, U.S. Naval Station	--	8.126

[1] Return flow to Providence River.

[2] Return flow to Seekonk River.

[3] Return flow to Warren River.

[4] Return flow to Newport Harbor.

Septic-System Return Flow

Return flow from septic systems was estimated for domestic, industrial, and commercial water use. Populations on public wastewater collection were used to determine the populations on septic systems (self-disposed water; table 1). An estimated 85 percent of the water used by domestic populations on septic systems was returned to ground water, and therefore 15 percent of the water used was consumed (Solley and others, 1998). To calculate the amount of domestic self-disposed water, the population was multiplied by the water-use coefficient for self-supply water use (71 gal/d/person), converted to Mgal/d, and multiplied by 0.85. The results for domestic self-disposed water are summarized by town and region in table 14 and illustrated by region in figure 8. An estimated 90 percent of industrial and commercial return flow is disposed to ground water, and the remaining 10 percent is consumptive water use (Horn, 2000). A summary of the consumptive water use for domestic, commercial, industrial, and agricultural water users by region is in table 12, and a summary of the return flow is in table 14.

Interbasin Transfers of Wastewater

Wastewater collected by the Narragansett Bay Commission’s facility at Bucklin Point from East Providence (1.685 Mgal/d) and wastewater from outside the Northeast Narragansett region (22.235 Mgal/d) is discharged directly to the bay. Some East Providence wastewater (5.529 Mgal/d) is collected by the East Providence WWTF, which also collects wastewater from the town of Barrington (1.11 Mgal/d) and discharges all of the water directly to the bay. Two other minor WWTFs (Warren and Bristol) in the region collect wastewater from the towns of Warren (1.826 Mgal/d) and Bristol (3.153 Mgal/d). This wastewater is discharged directly into the bay. Finally, a total of 8.126 Mgal/d of wastewater—collected from municipalities on Aquidneck Island in the East Narragansett Islands region—is also discharged directly to the bay. A total of about 43.66 Mgal/d of wastewater is disposed into the bay, of which 13.30 Mgal/d is collected from the Northeastern Narragansett region; the Southeastern Narragansett region does not collect or discharge wastewater.

Water-Use Summary

Within the computed balance of the water withdrawals, use by category, nonaccount water, consumptive, and return flows, there is a percentage error that is attributed to the summation of metered (or reported) and estimated water-use components for each category. Public water-supply withdrawals were metered (or reported), for example, and water use by region was estimated, and the return flow was metered (or reported) and estimated. Similarly, RIPDES data were metered (or reported) and the withdrawal and uses were estimated.

The water withdrawals in the East Narragansett Bay study area were 9.555 Mgal/d. A net amount of 8.750 Mgal/d of potable water was imported from other study areas:

- 8.413 Mgal/d was imported to the Northeastern Narragansett region;
- 0.236 Mgal/d of water withdrawn from the Southeastern Narragansett region was exported, and 0.337 Mgal/d of water was purchased by water suppliers in the Southeastern Narragansett region from suppliers outside the region (not including nonaccount water); and
- 0.573 Mgal/d was imported to the East Narragansett Islands region from the Southeastern Narragansett region.

The estimated total consumptive water use was 2.449 Mgal/d in the East Narragansett Bay study area and is considered a loss. The results are summarized in table 17.

The wastewater imports to and exports from the East Narragansett Bay study area were calculated from the total categorical water use (domestic, commercial, industrial, and agricultural) minus the consumptive use and minus the total return flow. The result is the wastewater imported to (+) or exported from (-) the study area. For the East Narragansett Bay study area, the total wastewater returned to Narragansett Bay (not including water from combined sewer overflow; CSO) was 11.439 Mgal/d; this total represents all public-disposal wastewater in the study area. As much as 42 percent of wastewater discharged from Bucklin Point may be composed of CSO. For the entire study area, the total of the imports and exports was a net loss of 2.692 Mgal/d. The totals for the regions were a net gain of 1.478 Mgal/d for the Northeastern Narragansett region; a net loss of 0.268 Mgal/d for the Southeastern Narragansett region; and a net loss of 3.902 Mgal/d for the East Narragansett Islands region. The results are summarized in table 17.

Table 17. Summary of estimated water withdrawals, imports, exports, use, nonaccount water use, consumptive use, and return flow in the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

[Nonaccount water is a loss of water through the system. Consumptive use is an export. Net import and exports are the sum of the potable water and wastewater imports and exports and do not include nonaccount and consumptive water uses. All values are in Mgal/d, million gallons per day; <0.001, values not included in town and study-area totals; DOM, domestic; COM, commercial; IND, industrial; AG, agricultural; +, potable distribution and wastewater collection imported to the study area; -, potable distribution and wastewater collection exported from the study area; --, not applicable]

Region	Total water withdrawals, public and self	Potable water imports (+) and exports (-)	Total water use, public and self		Consumptive use	Return flow		Wastewater imports (+) and exports (-)	Net imports (+) and exports (-)
			Use (DOM, COM, IND, AG)	Nonaccount (public use)		Surface water	Ground water		
Northeastern Narragansett Region	1.082	+8.413	8.482	1.013	1.224	--	0.323	-6.935	+1.478
Southeastern Narragansett Region	1.692	-.236	1.289	.167	.249	0.003	1.005	-.032	-.268
East Narragansett Islands Region	6.781	+.573	6.711	.643	.976	--	1.260	-4.475	-3.902
Study-area total	**9.555**	**+8.750**	**16.482**	**1.823**	**2.449**	**0.003**	**2.588**	**-11.442**	**-2.692**

Water Availability

During periods of little or no precipitation, streamflow is sustained primarily by inflow from surface-water storage (lakes and reservoirs) and from ground-water discharge; direct runoff is assumed to be negligible. Water withdrawals are commonly higher during the summer, and precipitation and ground-water discharge may be lower in the summer than the annual average. Therefore, it was important to estimate the amount of available water and to compare it to the withdrawals in the study area. Water-availability estimates that are made from stream base-flow calculations are conservative because actual streamflows generally are greater than base flow except during periods of no recharge from precipitation.

Summer Ground-Water Availability at Selected Index Stations

During times of little or no recharge in the form of precipitation, flows in the surface- and ground-water system originate from storage predominantly in the stratified sand and gravel deposits; water flows through the till deposits as well, but at a slower rate. The ground water discharging to streams during times of little or no recharge from precipitation is referred to as base flow. Ground-water availability during times of little or no precipitation can be estimated on the basis of streamflow data collected for selected index stream-gaging stations and the computer program PART. Index stations were chosen whose upstream areal percentages of sand and gravel deposits and till deposits are similar to those in the study area. For the East Narragansett Bay study area, two stream-gaging stations were selected for this analysis—the Adamsville Brook at Adamsville (station 01106000) and the Pawcatuck River at Wood River Junction (station 01117500). The data for Ten Mile River at Pawtucket Avenue at East Providence (station 01109403) were analyzed and are presented for comparison to the data for the Pawcatuck station; however, the data for the Ten Mile station were not used in this assessment of ground-water availability because of the regulation (multiple waste-water discharges and diversions from reservoirs) upstream of the station. These regulations alter flow during periods of little or no recharge (Rutledge, 1993, 1998). Drainage areas, mean flow, minimum flow statistics, and other data are presented for all three stations in table 18.

The PART program, a hydrograph-separation application (Rutledge, 1993, 1998), was applied to the data collected for the two selected index stations to determine the 75th, 50th, and 25th percentiles of the total base flow (the basic scenario), the 75th, 50th, and 25th percentiles of the base flow minus the 7-day, 10-year low-flow (the 7Q10 scenario), and the 75th, 50th, and 25th percentiles of the base flow minus the Aquatic Base Flow (the ABF scenario) for the summer months (table 19). (See Glossary at the back of the report for definitions of terms.) For each scenario, flows were apportioned according to the contributions of base flow from stratified sand and gravel and from till deposits upstream of the two index stations. The drainage areas of the index stations were multiplied by the areal percentages of the sand and gravel and till (surficial) deposits to obtain the areas of the surficial deposits upstream of the stations. Values of base-flow contributions from the two types of surficial deposits for the Pawcatuck index station were based on previous work by the U.S. Geological Survey (Dickerman and others, 1997). The areas of sand and gravel deposits and till deposits for each index station were divided into the estimated base flow from each type of deposit. The resulting values are base flows per unit area in million gallons per day per square mile (Mgal/d/mi^2) for the two types of deposits upstream of each index station. Finally, these base flows per unit area for each type of deposit, each index station, and each scenario were multiplied by the area of the same type of deposit in the region(s) assigned to that index station to give the gross yield, gross yield for 7Q10, and gross yield for ABF scenarios; the base flow calculated for the three regions is referred to as the gross yield. In regions with surface-water reservoirs, the gross yields were added to any previously published safe yields from reservoirs to give the total amount of water available in each region. It is important to note that because data from the Ten Mile station yielded higher per-square-mile base-flow values than data from the Pawcatuck station for both types of deposits, the values for the Ten Mile station were assumed to be affected by regulation upstream of the station and thus were not used.

Table 18. U.S. Geological Survey stream-gaging stations and minimum streamflows used in the analysis of water availability in the East Narragansett Bay study area, eastern Rhode Island.

[Water years are from October to September and may differ from the period of record in the data report. 7Q10, 7-day, 10-year low flow; ABF, Aquatic base flow, based on the median of the monthly means; Mgal/d, million gallons per day; USGS, U.S. Geological Survey; --, data from this station were not applied to any region.]

USGS stream-gaging-station number	Station name	Region to which flow data were applied	Drainage area (mi²)	Percent-age of sand and gravel	Mean flow (Mgal/d) [calendar years]	Minimum flows (Mgal/d)	
						7Q10 [water years]	ABF [calendar years]
01106000	Adamsville Brook at Adamsville, RI	Southeastern Narragansett and East Narragansett Islands	8.01	0.7	9.229 [1941–1977]	0.349 [1941–1978]	0.779 [1941–1978]
01109403	Ten Mile River at Pawtucket Avenue at East Providence, RI[1]	--	53.1	58	66.13 [1987–2002]	8.305 [1987–2002]	25.73 [1987–2002]
01117500	Pawcatuck River at Wood River Junction, RI	Northeastern Narragansett	100	47	126.7 [1941–2000]	17.07 [1942–2002]	45.45 [1941–2000]

[1]Because regulation and diversions upstream of the station affected estimated base flows, the data for this station were not used for estimating water availability during the summer months.

Table 19. Summer water availability from base flows for the selected index stream-gaging stations used in the water-availability analysis for the East Narragansett Bay study area, Rhode Island

[All values are in Mgal/d, million gallons per day; 75, 50, and 25 are percentiles. 7Q10, 7-day, 10-year low flow; ABF, Aquatic base flow, based on the median of the August monthly means; --, values less than zero and not used]

Month	Estimated base flow (Mgal/d)			Estimated base flow minus 7Q10 (Mgal/d)			Estimated base flow minus ABF (Mgal/d)		
	75	50	25	75	50	25	75	50	25
Adamsville River at Adamsville, RI stream-gaging station[1]									
June	4.921	3.528	2.414	4.572	3.179	2.065	4.142	2.749	1.635
July	1.797	.899	.450	1.448	.549	.100	1.018	.119	--
August	1.662	.584	.180	1.313	.235	--	.883	--	--
September	1.346	.325	.093	.997	--	--	.567	--	--
Ten Mile River at Pawtucket Ave., East Providence, RI stream-gaging station[2]									
June	80.93	53.24	44.31	72.63	44.93	36.01	55.20	27.50	18.58
July	48.24	31.57	23.53	39.94	23.26	15.22	22.51	5.833	--
August	26.80	19.66	14.15	18.50	11.35	11.39	1.068	--	--
September	26.77	19.69	14.92	18.47	11.39	6.619	1.038	--	--
Pawcatuck River at Wood River Junction, RI stream-gaging station[3]									
June	115.5	90.40	72.00	98.40	73.33	54.93	70.02	44.95	26.55
July	66.45	51.32	41.36	49.39	34.25	24.29	21.00	5.862	--
August	61.27	42.06	30.29	44.20	24.99	13.22	15.82	--	--
September	48.53	34.48	24.34	31.46	17.41	7.268	3.081	--	--

[1] Base-flow estimates for the station are from the years 1941 through 1977. The drainage area upstream of the station is 8.01 mi². Because the areal percentage of sand and gravel is only 0.7 percent, 100 percent of the base flow was assumed to be from till.

[2] Base-flow estimates for the station are from the years 1987 through 2002. The drainage area upstream of the station is 53.1 mi², of which 58 percent is sand and gravel. The contribution to base flow from sand and gravel is about 70 percent.

[3] Base-flow estimates for the station are from the years 1941 through 2000. The data have been previously published in Wild and Nimiroski (2004). The drainage area upstream of the station is 100 mi², of which 47 percent is sand and gravel. The contribution to base flow from sand and gravel is about 71 percent.

The Pawcatuck River at Wood River Junction streamgaging station was used as the index station for the Northeastern Narragansett region. For this station, it was estimated that about 71 percent of the base flow was from sand and gravel deposits and 29 percent was from till deposits (Dickerman and others, 1997). The Adamsville Brook stream-gaging station was used as the index station for the Southeastern and East Narragansett Islands regions. Because the percentage of sand and gravel deposits upstream of the Adamsville streamgaging station was less than 1 percent, all of the base flow was considered to be from till deposits. In addition to determining the water availability from ground water, previously published safe-yield values determined for surface-water reservoirs were added to the ground water available in the regions where there are withdrawals from surface-water reservoirs.

To illustrate long-term water-table fluctuations, figures 15-17 present water levels monitored at three USGS till wells in Rhode Island within the study area: Little Compton (LTW-142), Portsmouth (POW-551), and Tiverton (TIW-274). The wells are completed in different areas and show different water-table fluctuations for each well. In turn, these fluctuations demonstrate how ground-water availability can vary month to month, year to year, and decade to decade. For more information, current and historical data available from surfacewater and ground-water stations in Rhode Island can be accessed online from the National Water Information System database (http://waterdata.usgs.gov/ri/nwis/nwis).

Summer Water Availability in the Regions

The water-availability estimates for all the tested scenarios for the study area and regions are presented in table 20. The gross yield at the 50th percentile for the basic scenario ranged from 19.08 Mgal/d in September to 80.52 Mgal/d in June. The gross yield for the 50th percentile for the 7Q10 scenario ranged from 7.769 Mgal/d in September to 68.93 Mgal/d in June. The safe yields from the surfacewater reservoirs provided in an additional 14.10 Mgal/d, and this amount was added to the three gross yields for June, July, August, and September to give the total available water. The total available water for the basic scenario at the 50th percentile ranged from 33.18 Mgal/d in September to 94.62 Mgal/d in June. The total available water for the 7Q10

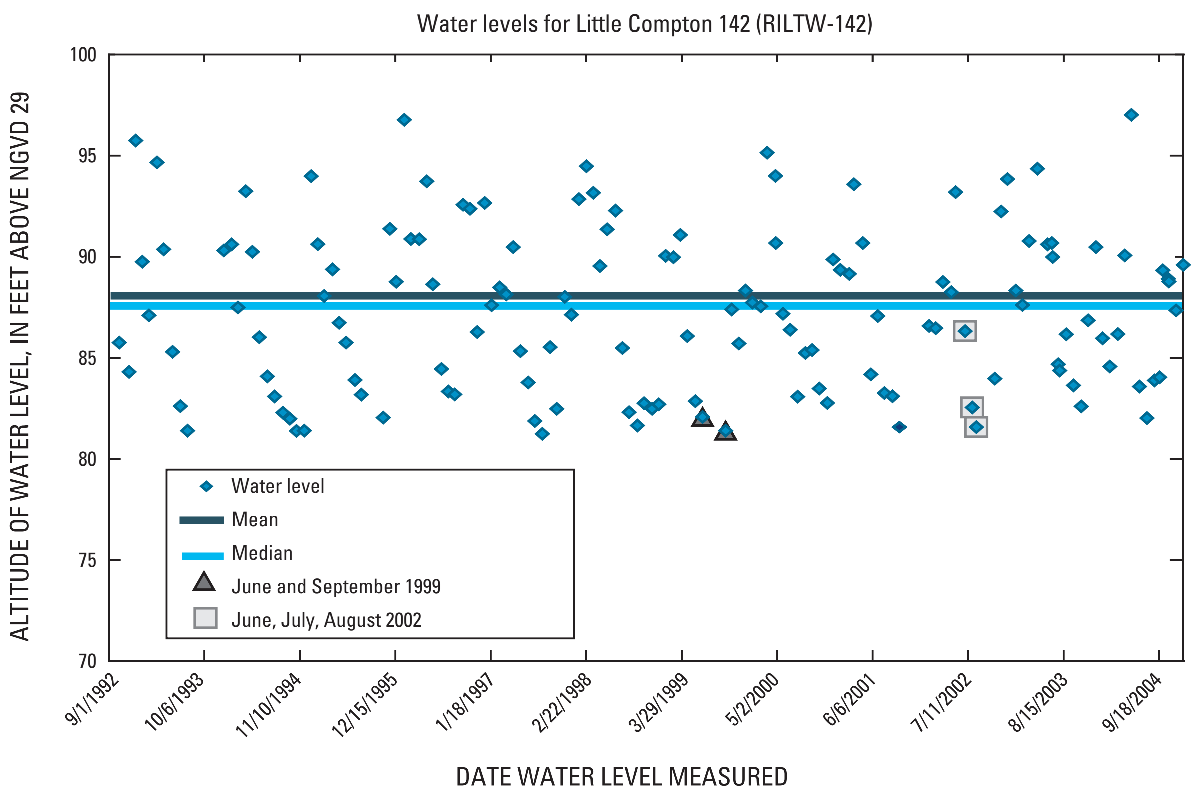


Figure 15. Water-level altitudes for Little Compton well 142, 1992–2004. Altitudes as a group are accurate within 10 ft.

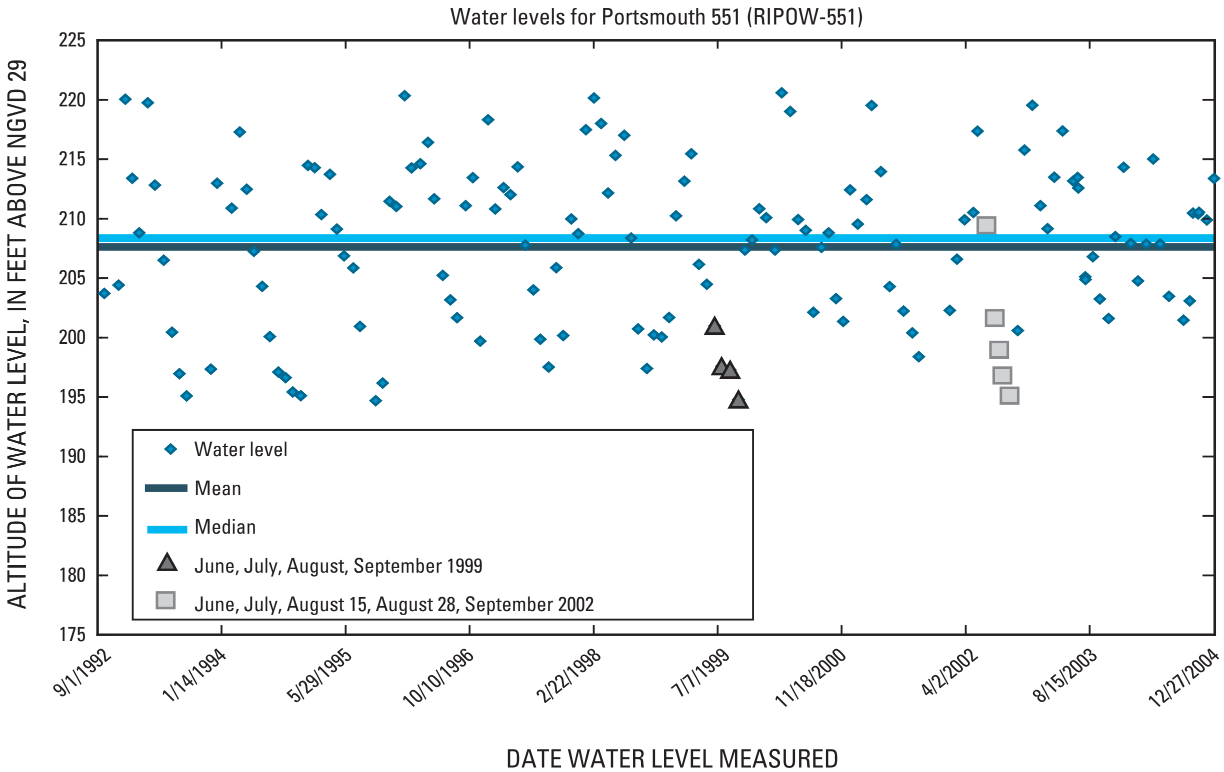


Figure 16. Water-level altitudes for Portsmouth well 551, 1992–2004. Altitudes of the group are accurate within 1 ft.

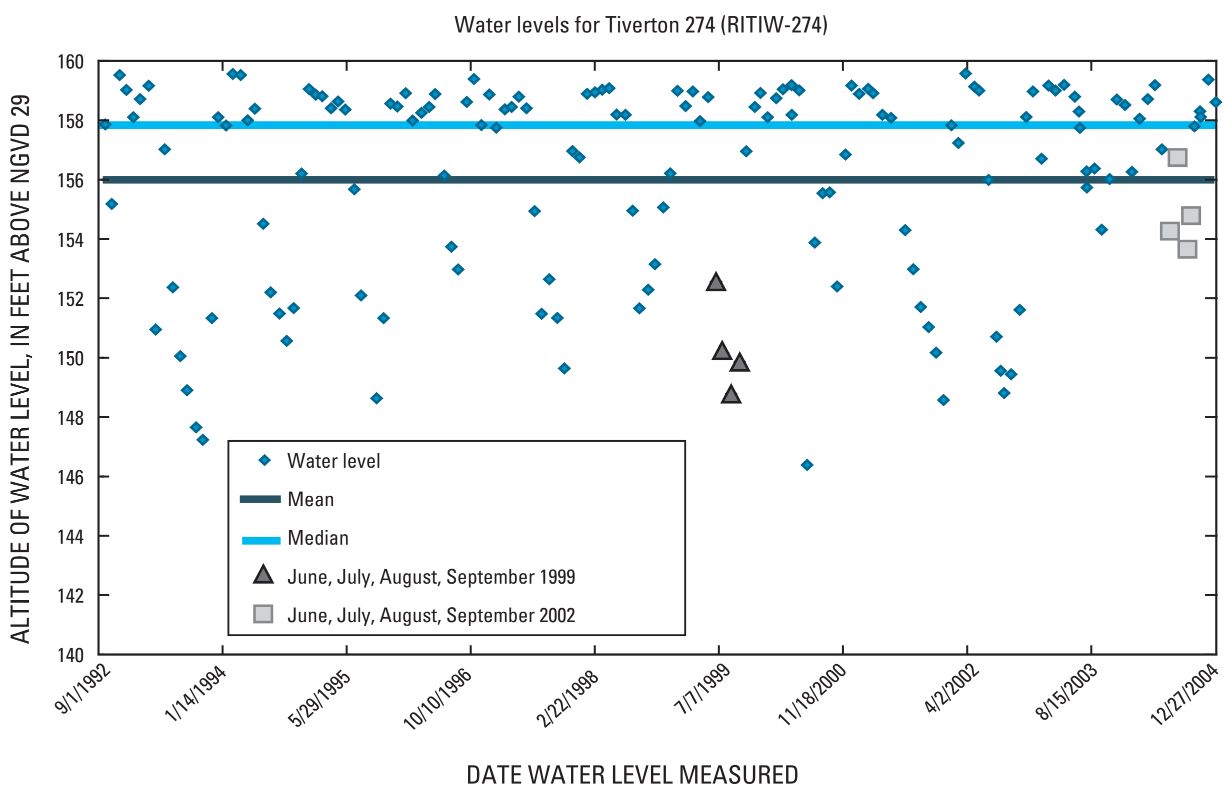


Figure 17. Water-level altitudes for Tiverton well 274, 1992–1994. Altitudes of the group are accurate within 5 ft.

Table 20. Estimated gross yield, gross yield for the 7-day, 10-year low flow, and gross yield for the Aquatic Base Flow and available water from ground water and surface-water reservoirs in June, July, August, and September in the East Narragansett Bay study area, Rhode Island.

[To calculate the total amount of water available for each scenario and region, add gross yield and safe yield. All values in Mgal/d, million gallons per day; 75, 50, and 25 are percentiles. 7Q10, 7-day, 10-year low flow; ABF, Aquatic Base Flow; --, values at station less than zero and not used]

Region	Safe yield	Basic scenario			7Q10 scenario			ABF scenario		
		75	50	25	75	50	25	75	50	25
		Estimated gross yield and available water for June								
Northeastern Narragansett[1]	--	51.52	40.33	32.12	43.90	32.72	24.51	31.24	20.06	11.85
Southeastern Narragansett[2]	[3]1.90	32.46	23.28	15.92	30.17	20.97	13.62	27.32	18.14	10.79
East Narragansett Islands [2]	[4]12.20	23.58	16.91	11.57	21.91	15.24	9.898	19.85	13.18	7.837
Total	14.10	107.6	80.52	59.61	95.98	68.93	48.03	78.41	51.38	30.48
Total available water		**121.70**	**94.62**	**73.71**	**110.10**	**83.03**	**62.13**	**92.51**	**65.48**	**44.58**
		Estimated gross yield and available water for July								
Northeastern Narragansett[1]	--	29.65	22.90	18.45	22.03	15.28	10.84	9.371	2.615	--
Southeastern Narragansett[2]	1.90	11.86	5.930	2.965	9.554	3.622	.660	6.717	0.785	--
East Narragansett Islands [3]	12.20	8.612	4.308	2.154	6.940	2.631	0.479	4.879	0.570	--
Total	14.10	50.12	33.14	23.57	38.52	21.53	11.98	20.97	3.970	--
Total available water		**64.22**	**47.24**	**37.67**	**52.62**	**35.63**	**26.08**	**35.07**	**18.07**	**14.10**
		Estimated gross yield and available water for August								
Northeastern Narragansett[1]	--	27.34	18.76	13.51	19.72	11.15	5.896	7.057	--	--
Southeastern Narragansett[2]	1.90	10.97	3.852	1.186	8.663	1.551	--	5.826	--	--
East Narragansett Islands [3]	12.20	7.968	2.798	0.862	6.293	1.126	--	4.232	--	--
Total	14.10	46.28	25.41	15.56	34.68	13.83	5.896	14.11	--	--
Total available water		**60.38**	**39.51**	**29.66**	**48.78**	**27.93**	**20.00**	**31.21**	**14.10**	**14.10**
		Estimated gross yield and available water for September								
Northeastern Narragansett[1]	--	21.65	15.38	10.86	14.04	7.769	3.242	1.375	--	--
Southeastern Narragansett[2]	1.90	8.882	2.146	0.614	6.578	--	--	3.741	--	--
East Narragansett Islands [3]	12.20	6.452	1.559	0.446	4.779	--	--	2.718	--	--
Total	14.10	36.98	19.08	11.92	25.40	7.769	3.242	7.834	--	--
Total available water		**51.08**	**33.18**	**26.02**	**39.50**	**21.87**	**17.34**	**21.93**	**14.10**	**14.10**

[1] Estimated gross yields based on base flow from the Pawcatuck River at Wood River Junction stream-gaging station, from 1941 through 2000.

[2] Estimated gross yields based on base flow from the Adamsville River stream-gaging station from 1941 through 1980.

[3] Safe yield from the Stone Bridge Fire District.

[4] Safe yield from the Newport Water Works.

scenario at the 50th percentile ranged from 21.87 Mgal/d in September to 83.03 Mgal/d in June (table 20). The most water was withdrawn in July and the least in September in the study area (table 21).

To compare the water withdrawals (table 21) to the total water available (table 20), the ratios of these two quantities were computed for the three scenarios for June, July, August, and September for the regions and the entire study area (table 22). The closer the ratio of the water withdrawn to the estimated water available is to one, the closer the withdrawals are to the estimated water available, and the net water available is less. The ratios for the basic scenario at the 50th percentile were highest in August (0.122) and for the 7Q10 scenario at the 50th percentile in September (0.179). The range of the ratios among the regions is shown for July, August, and September in figure 18. The ratios for June were omitted because they were uniformly low, indicating that the amount of available water exceeded the amount withdrawn. The cumulative withdrawals from upstream regions have not been accounted for in the water-availability ratios for the downstream regions.

Water Budget

Generally, the calculation of a water budget includes consideration of all parts of the hydrologic cycle (precipitation, evapotranspiration, ground water, and streamflow) and the water-use components (withdrawal, return flow, interbasin transfer, consumptive use, non-account water, and categorical water use). To determine the effects that humans have on each region, water budgets were calculated by region without considering the amount of water imported or exported to and from the region. The water-budget components are summarized in table 23.

Precipitation at Kingston, Rhode Island was estimated for the period of record for the index stations (table 23). An average precipitation of 50.88 in/yr (2.423 Mgal/d/mi^2) for the period of record 1987–2001 for the Ten Mile River index station was used for the Northeastern Narragansett region; for the Southeastern and East Narragansett Islands regions, an average precipitation of 45.81 in/yr (2.179 Mgal/d/mi^2) for the period of record 1941–1977 for the Adamsville station was used.

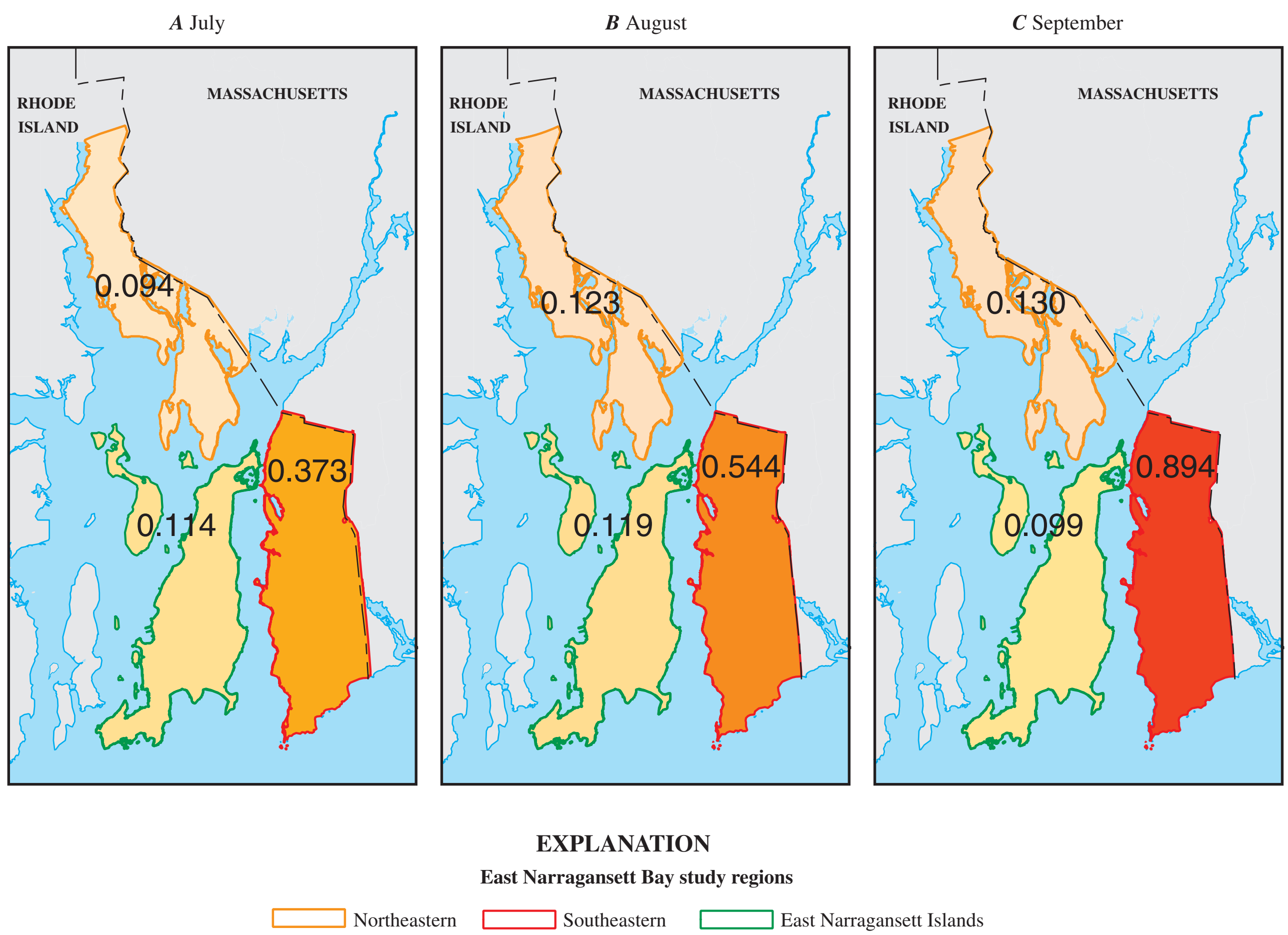


Figure 18. Withdrawal-to-water-availability ratios for (*A*) July, (*B*) August, and (*C*) September for the regions in the East Narragansett Bay study area at the 50th percentile for the 7-day, 10-year low-flow scenario.

Table 21. Average public- and self-supply withdrawals in June, July, August, and September in the regions of the East Narragansett Bay study area, eastern Rhode Island, 1995–99.

[All values are in Mgal/d, million gallons per day]

Regions	Average water withdrawals 1995–99 (Mgal/d)							
	June		July		August		September	
	Public	Self	Public	Self	Public	Self	Public	Self
Northeastern Narragansett	0.612	0.856	0.636	0.796	0.578	0.791	0.608	0.402
Southeastern Narragansett	1.159	.847	1.186	.875	1.132	.746	1.033	.665
East Narragansett Islands	.512	1.074	.590	1.098	.602	.987	.657	.555
Study-area total	**2.283**	**2.777**	**2.412**	**2.769**	**2.312**	**2.524**	**2.298**	**1.622**

Table 22. Estimated withdrawal-to-availability ratios for June, July, August, and September in the East Narragansett Bay study area, eastern Rhode Island.

[Results were obtained by dividing the total water withdrawals for each month in table 21 by the total available water in table 20. 75, 50, and 25 are percentiles. 7Q10, 7-day, 10-year low flow; ABF, Aquatic Base Flow; --, values at station less than zero and not used]

Region	Basic scenario			7Q10 scenario			ABF scenario		
	75	50	25	75	50	25	75	50	25
					June				
Northeastern region[1]	0.028	0.036	0.046	0.033	0.045	0.060	0.047	0.073	0.124
Southeastern region[2]	.057	.080	.113	.063	.088	.129	.069	.100	.158
East Narragansett Islands region[2]	.044	.054	.067	.046	.058	.072	.049	.062	.079
Study-area total	**0.042**	**0.053**	**0.069**	**0.046**	**0.061**	**0.081**	**0.055**	**0.077**	**0.114**
					July				
Northeastern region[1]	0.048	0.063	0.078	0.065	0.094	0.132	0.153	0.548	--
Southeastern region[2]	.150	.263	.424	.180	.373	.805	.239	.768	1.085
East Narragansett Islands region[2]	.081	.102	.118	.088	.114	.133	.099	.132	.138
Study-area total	**0.081**	**0.110**	**0.138**	**0.098**	**0.145**	**0.199**	**0.148**	**0.287**	**0.367**
					August				
Northeastern region[1]	0.050	0.073	0.101	0.069	0.123	0.232	0.194	--	--
Southeastern region[2]	.146	.326	.609	.178	.544	.988	.243	.988	.988
East Narragansett Islands region[2]	.079	.106	.122	.086	.119	.130	.097	.130	.130
Study-area total	**0.080**	**0.122**	**0.163**	**0.099**	**0.173**	**0.242**	**0.155**	**0.343**	**0.343**
					September				
Northeastern region[1]	0.047	0.066	0.093	0.072	0.130	0.312	0.735	--	--
Southeastern region[2]	.158	.420	.675	.200	.894	.894	.301	.894	.894
East Narragansett Islands region[2]	.065	.088	.096	.071	.099	.099	.081	.099	.099
Study-area total	**0.077**	**0.118**	**0.151**	**0.099**	**0.179**	**0.226**	**0.179**	**0.278**	**0.278**

[1]Available water based on base flow from the Pawcatuck River at Wood River Junction stream-gaging station for the period 1941 through 2000.

[2]Available water based on the sum of the base flow from the Adamsville River at Adamsville stream-gaging station for the period 1941 through 1980 and the safe yield from the surface-water reservoirs.

Table 23. Average long-term water budget by region for the East Narragansett Bay study area, eastern Rhode Island.

[All values in Mgal/d, million gallons per day; RIPDES, Rhode Island Pollution Discharge Elimination System; Mgal/d/mi^2, million gallons per day per square mile; mi^2, square miles; in/yr, inches per year]

Water-budget component	Rate of flow			
	Northeastern Narragansett region	Southeastern Narragansett region	East Narragansett Islands region	East Narragansett Bay study-area total
Estimated inflow				
Precipitation	[1]91.69	[2]113.4	[2]84.45	289.5
Return flow[3]	.323	1.008	1.260	2.591
Total inflow	**92.01**	**114.4**	**85.71**	**292.1**
Estimated outflow				
Evapotranspiration[4]	[5]43.48	[6]53.04	[6]41.83	138.4
Outflow[7]	47.45	59.67	37.10	144.1
Water withdrawals[8]	1.082	1.692	6.781	9.555
Total outflow	**92.01**	**114.4**	**85.71**	**292.1**
Streamflow per square mile	1.254	1.146	.904	1.101
Total drainage area at outlet[9]	37.84	52.05	41.05	130.9

[1] Based on average precipitation per unit area (50.88 in/yr, equivalent to 2.423 Mgal/d/mi^2) at Kingston, RI, for the period 1987–2001 (data from the National Oceanic and Atmospheric Administration, 2002a).

[2] Based on average precipitation per unit area (45.81 in/yr, equivalent to 2.179 Mgal/d/mi^2) at Kingston, RI, for the period 1941–1977 (data from the National Oceanic and Atmospheric Administration, 2002a).

[3] Based on the total return flow from septic, RIPDES, and wastewater-treatment facilities in the East Narragansett Bay study area, 1995–99.

[4] Evapotranspiration based on the difference between the average precipitation and average monthly flow at the index stream-gaging station assigned to the region.

[5] Based on the difference between the average annual precipitation per unit area (2.423 Mgal/d/mi^2; data from the National Oceanic and Atmospheric Administration, 2002a) and average annual flow per unit area (1.274 Mgal/d/mi^2) at the stream-gaging station Ten Mile River at Pawtucket Ave. at East Providence for the period 1987–2001.

[6] Based on the difference between the average annual precipitation per unit area (2.179 Mgal/d/mi^2; data from the National Oceanic and Atmospheric Administration, 2002a) and average annual flow per unit area (1.160 Mgal/d/mi^2) at the stream-gaging station Adamsville Brook at Adamsville for the period 1941–1977.

[7] Based on the sum of the inflows minus the sum of the withdrawals minus evapotranspiration.

[8] Water-withdrawal types include domestic, commercial, industrial, and agricultural from public and self-supply.

[9] Based on the sum of the regional drainage area and drainage areas upstream of the region.

Return flow includes the average rate of disposal from septic systems and RIPDES sites from 1995 through 1999. Evapotranspiration was estimated as the difference between the precipitation per unit area and the mean annual flow per unit area at each of the index stations. The outflow from each region was estimated as the sum of the inflows minus the withdrawals minus evapotranspiration.

The total water budget for the Northeastern Narragansett region was 92.01 Mgal/d. The estimated inflows from precipitation and return flow were 99 and less than 1 percent of the total water budget, and the estimated evapotranspiration, outflow, and water withdrawals were 47, 52, and 1 percent, respectively. The total water budget for the Southeastern Narragansett region was 114.4 Mgal/d. The estimated inflows from precipitation and return flow were 99 and less than 1 percent of the total water budget, and the estimated evapotranspiration, outflow, and water withdrawals were 46, 52, and 1 percent, respectively. The total water budget for the East Islands region was 85.71 Mgal/d. The estimated inflows from precipitation and return flow were 99 and 1 percent of the total water budget, and the estimated outflows from evapotranspiration, streamflow, and water withdrawals were 49, 43, and 8 percent, respectively. Ground-water underflow was considered to be negligible in all regions.

Summary

During a drought in 1999, ground-water levels and streamflows dropped below long-term averages throughout Rhode Island. Consequently, the State of Rhode Island became concerned about water availability, and an investigation was needed to assess water use and availability throughout the State. The U.S. Geological Survey (USGS), in cooperation with the Rhode Island Water Resources Board (RIWRB), completed a series of nine water use and availability investigations to describe the relations between the water-use and hydrologic-cycle components for surface and ground water during periods of little or no recharge. The investigation for the East Narragansett Bay study area (130.9 mi^2) in eastern Rhode Island is described here.

Water use and availability in the three regions of the East Narragansett Bay study area were estimated for periods of little or no recharge during the period 1995–99. Water-use data were collected by public-supply and wastewater-collection systems in the study area. Self-supply and other unavailable data were estimated by using previously published methods and additional methods developed in this study. Water availability for the three regions was calculated by a method of determining ground-water discharge during streamflow-recession periods in the summer (June–September). A basin water budget was also calculated to summarize the components of the hydrologic cycle on the basis of the long-term period of record and selected water-use components for the study period.

The three major water suppliers in the study area withdrew an average of 7.601 Mgal/d from ground water and surface water during the study period. The estimated water withdrawals from minor suppliers during the study period were 0.063 Mgal/d. Public- and self-supply domestic, commercial, industrial, and agricultural withdrawals in the study area were from ground water and surface water. Self-supply domestic, industrial, commercial, and agricultural withdrawals from the study area totaled 1.891 Mgal/d. Water use in the study area averaged 16.48 Mgal/d for 1995–99. The average return flow in the study area was 2.591 Mgal/d, which included effluent from one permitted facility and self-disposed wastewater from septic systems.

Ground-water availability was estimated from output from a computer-based hydrograph-separation application. Data were collected at selected index stream-gaging stations for the 75th, 50th, and 25th percentiles of the total base flow, the base flow minus the 7-day, 10-year low-flow (7Q10), and the base flow minus the Aquatic Base Flow (ABF). The index stations used were the Adamsville Brook at Adamsville (01106000) and the Pawcatuck River at Wood River Junction station (01117500). Data from the Adamsville station were used to compute water availability in the Southeastern Narragansett and East Islands regions. Data from the Pawcatuck station were used to compute water availability in the Northeastern Narragansett region.

Because water withdrawals and use are greater during the summer than other times in the year, water availability at the 75th, 50th, and 25th percentiles for June, July, August, and September was assessed and compared to the water withdrawals in the study area and regions. The average water withdrawals for the East Narragansett Bay study area ranged from 3.920 Mgal/d in September to 5.181 Mgal/d in July for the study period. The total water available from ground water and surface water ranged from 51.08 Mgal/d in September to 121.7 Mgal/d in June for the 75th percentile; from 33.18 Mgal/d in September to 94.62 Mgal/d in June for the 50th percentile; and from 26.02 Mgal/d in September to 73.71 Mgal/d in June for the 25th percentile. The water availability from ground water in the study area for the 50th percentile for the basic scenario ranged from 19.08 Mgal/d in September to 80.52 Mgal/d in June, and for the 7Q10 scenario ranged from 7.769 Mgal/d in September to 68.93 Mgal/d in June. The total safe yield for the surface-water reservoirs in the study area was 14.1 Mgal/d.

The ratios of water withdrawn to water available were calculated for June, July, August, and September as an indicator of net water availability within the three individual regions and in the study area as a whole. The closer the withdrawals are to the estimated water available, the closer the ratio is to one. The ratios were calculated for three flow scenarios for the 75th, 50th, and 25th percentiles for each region. Withdrawals were higher in July than in the other summer months.

A long-term water budget was calculated for the East Narragansett Bay study area to identify and assess the study area and region inflow and outflows. The water withdrawals and return flows used in the budget were from the period of study (1995–99). For the water budget, it was assumed that inflow equals outflow. The total water budget for the study area was 292.1 Mgal/d. The estimated inflows from precipitation and return flow were 99 and less than 1 percent of the budget, respectively. The estimated outflows from evapotranspiration, streamflow, and water withdrawals were 47, 49, and 3 percent of the budget, respectively.

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Glossary

7-day, 10-year low flow (7Q10): The discharge at the 10-year recurrence interval taken from a frequency curve of annual values of the lowest mean discharge for 7 consecutive days (the 7-day low flow).

A

Aquatic Base Flow (ABF): As established by the U.S. Fish and Wildlife Service, median flow during the month of August considered adequate to protect indigenous aquatic fauna throughout the year. It can be calculated as long as there are USGS stream-gaging data for at least 25 years of unregulated flow, and the drainage area at the stream-gaging station is at least 50 square miles (U.S. Fish and Wildlife, 1981).

B

Base flow: Streamflow from ground-water discharge.

C

Commercial water use: Water use for transportation; wholesale trade; retail trade; finance, insurance, and real estate; services; and public administration (the two-digit Standard Industrial Classification codes are in the range 40-97). The water can be from public or self-supply.

Consumptive use: Water that is removed from the environment through evaporation, transpiration, production, or consumed by humans or livestock.

Conveyance: Movement of water from one point to another, for example, water withdrawals, water distributions, and wastewater collection.

D

Distribution: The conveyance of water from a point of withdrawal or purification system to a user or other water customer.

Domestic water use: Water use for household purposes, such as drinking, food preparation, bathing, washing, clothes and dishes, flushing toilets, and watering lawns and gardens. Households include single and multifamily dwellings. Also called residential water use. The water may be obtained from a public water supply or may be self-supplied.

I

Industrial water use: Water use for food, tobacco, textile mill products, apparel, lumber and wood; furniture; paper; printing; chemicals; petroleum; rubber; leather; stone, clay, glass, and concrete; primary metal; fabricated metal; machinery; electrical equipment; transportation equipment; instruments; and jewelry, precious metals; for which the two-digit Standard Industrial Classification code range is 20-39. The water may be obtained from a public water supply or may be self-supplied.

Interbasin transfer: Conveyance of water across a drainage or river-basin divide.

Interconnection: Link between public-supply districts to convey water. These connections can be for wholesale distributions or water-supply backups.

Irrigation water use: The application of water to lands to assist in the growth of crops or pasture, including plants in greenhouses. Irrigation water use may also include application of water to maintain vegetative growth on recreational lands such as parks and golf courses and to provide frost and freeze protection of crops.

M

Major water supplier: A public or private water supplier that withdraws and distributes water to customers or other suppliers for use.

Major user: In Rhode Island, a customer that uses more than three million gallons of water per year.

Minor Civil Division (MCD): A term used by the U.S. Census Bureau, generally equivalent to a city or town.

Minor public water supplier: A site-specific organization or population—for example, a nursing home, condominium complex, or mobile-home park—that withdraws its own water.

N

Nonaccount water use: The difference between the metered (or reported) supply and the metered (or reported) use for a specific period of time, which includes periods during which water was used for fire fighting. It comprises authorized and unauthorized water uses.

O

Outfall: The outlet or structure through which effluent is finally discharged into the environment.

P

Per capita water use: The average volume of water used per person during a standard time period, generally per day.

PART: A computer program developed by A.T. Rutledge (1993 and 1998) to determine the mean rate of ground-water discharge.

Public wastewater system: A system that collects wastewater from users or groups of users, conveys the water to a wastewater-treatment plant, and then releases the water as return flow or sends the water back to users as reclaimed wastewater.

Public water use: Water supplied from a public water system and used for fire fighting, street washing, and municipal parks and swimming pools.

Public-disposed water: Wastewater return flow from public and private wastewater-collection systems.

Public-supply water: Water distributed to domestic, industrial, commercial, agricultural or other customers by a publicly or privately owned water-supply system.

R

Return flow: Water that is returned to surface or ground water after use or wastewater treatment, and thus becomes available for reuse. Return flow can go directly to surface water, directly to ground water through an injection well or infiltration bed, or indirectly to ground water through a septic system.

S

Self-disposed water: Water returned to the ground (septic systems) by a user or group of users that are not on a wastewater-collection system.

Self-supply water: Water withdrawn from a ground- or surface-water source by a user and not obtained from a publicly or privately owned water-supply system.

Standard Industrial Classification (SIC) code: Four-digit codes established by the U.S. Office of Management and Budget and used in the classification of establishments by type of activity in which they are engaged. The IWR-MAIN coefficients for industrial and commercial water use are based on the first two digits.

Surface-water return flow: Effluent that flows from a discharge pipe to a river or lake.

W

Wastewater: Water that carries wastes from domestic, industrial, and commercial consumers; a mixture of water and dissolved or suspended solids.

Wastewater treatment: The processing of wastewater for the removal or reduction of contained solids or other undesirable constituents.

Wastewater-treatment return flow: Water returned to the hydrologic system by wastewater-treatment facilities. Also referred to as effluent water.

Water purification: The processes that withdrawn water may undergo prior to use. Includes chlorination, fluoridation, and filtration.

Water supply: All of the processes that are involved in obtaining water for the user before use. Includes withdrawal, water treatment, and distribution.

Water use: (1) In a restrictive sense, the term refers to water that is actually used for a specific purpose, such as for domestic use, irrigation, or industrial processing. (2) More broadly, water use pertains to human interaction with and impact on the hydrologic cycle, and includes elements such as water withdrawal, distribution, consumptive use, wastewater collection, and return flow.

Withdrawal: The removal of surface water or ground water from the natural hydrologic system for uses such as public water supply, industry, commerce, domestic use, irrigation, livestock, and thermoelectric power generation.