Cover: Photograph of the dam and fish ladder at the Hunt River near East Greenwich, Rhode Island.

Water Use and Availability in the West Narragansett Bay Area, Coastal Rhode Island, 1995–99

By Mark T. Nimiroski and Emily C. Wild

In cooperation with the Rhode Island Water Resources Board

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CONVERSION TABLE		
Multiply	**By**	**To obtain**
	Length	
foot (ft)	0.3048	meter (m)
inch (in.)	2.540	centimeter (cm)
inch (in.)	25.40	millimeter (mm)
inch (in.)	25,400	micrometer (µm)
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 mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic yard (yd^3)	0.7646	cubic meter (m^3)
gallon (gal)	3.785	liter (L)
gallon (gal)	0.1337	cubic feet (ft^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]
gallon per day per person (gal/d/person)	0.003785	cubic meter per day per person (m^3/d/person)
inch per day per acre (in/d/acre)	6.276	centimeter per day per hectare (cm/d/ha)
inch per year (in/yr)	2.540	centimeter per year (cm/yr)
million gallons per day (Mgal/d)	3,785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	1.547	cubic foot per second (ft^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]
million gallons per day per yard (Mgal/d/yd)	0.004139	million cubic meters per day per meter (Mm^3/d/m)
	Transmissivity	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

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 North American Vertical Datum of 1988 (NAVD 88).

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

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

Concentrations of sediment-quality constituents are given in percent (%), parts per million (ppm) and parts per billion (ppb).

Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft^3/d)/ft^2]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

ABBREVIATIONS and ACRONYMS

7Q10	7-day, 10-year flow
ABF	Aquatic Base Flow
CFR	Code of Federal Regulations
GIS	Geographic Information System
HAP	Hunt-Annaquatucket-Pettaquamscutt
HUC	Hydrologic Unit Code
IWR-MAIN	Institute of Water Resources, Municipal and Industrial Needs
MCD	Minor Civil Division
NCDC	National Climatic Data Center
NEWUDS	New England Water-Use Data System
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
PART	Computer program for base-flow calculation using streamflow partitioning
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 Encoding and Referencing System
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Administration
USGS	United States Geological Survey
UWRI	United Water of Rhode Island
WSO	Weather Station Observatory
WWTF	Wastewater-Treatment Facility

Water Use and Availability in the West Narragansett Bay Area, Coastal Rhode Island, 1995–99

By Mark T. Nimiroski and Emily C. Wild

Abstract

During the 1999 drought in Rhode Island, below-average precipitation caused a drop in ground-water levels and streamflow was below long-term averages. The low water levels prompted the U. S. Geological Survey and the Rhode Island Water Resources Board to conduct a series of cooperative water-use studies. The purpose of these studies is to collect and analyze water-use and water-availability data in each drainage area in the State of Rhode Island. The West Narragansett Bay study area, which covers 118 square miles in part or all of 14 towns in coastal Rhode Island, is one of nine areas investigated as part of this effort. The study area includes the western part of Narragansett Bay and Conanicut Island, which is the town of Jamestown. The area was divided into six subbasins for the assessment of water-use data. In the calculation of hydrologic budget and water availability, the Hunt, Annaquatucket, and Pettaquamscutt River Basins were combined into one subbasin because they are hydraulically connected.

Eleven major water suppliers served customers in the study area, and they supplied an average of 19.301 million gallons per day during 1995–99. The withdrawals from the only minor supplier, which was in the town of East Greenwich in the Hunt River Basin, averaged 0.002 million gallons per day. The remaining withdrawals were estimated as 1.186 million gallons per day from self-supplied domestic, commercial, industrial, and agricultural users. Return flows from self-disposed water (individual sewage-disposal systems) and permitted discharges accounted for 5.623 million gallons per day. Most publicly disposed water (13.711 million gallons per day) was collected by the Rhode Island Economic Development Corporation, and by the East Greenwich, Fields Point, Jamestown, Narragansett, and Scarborough wastewater-treatment facilities. This wastewater was disposed in Narragansett Bay outside of the study area.

The PART program, a computerized hydrograph-separation application, was used to determine water availability in the study area on the basis of low flows measured at a nearby index station, the Pawcatuck River at Wood River Junction, Rhode Island. Water availability was defined as the 75th, 50th, and 25th percentiles of the total base flow; the base flow minus the 7-day, 10-year flow; and the base flow minus the Aquatic Base Flow at the index station. The base-flow contributions per unit area of sand and gravel deposits and of till were computed for June, July, August, and September for the index station and multiplied by the areas of sand and gravel and till in the subbasins. The calculated base flows at the index station were lowest in August at the 75th, 50th, and 25th percentiles for total base flow and for two additional low-flow scenarios.

Because water withdrawals and use are greater during June, July, August, and September than at other times of the year, water availability was compared to water withdrawals in the subbasins for these summer months. Ratios were calculated by dividing the summer withdrawals by the water availability at the 75th, 50th, and 25th percentiles, and these percentiles of the base flow minus the two low flows for each subbasin. The closer this ratio is to one, the closer the withdrawals are to the estimated water available. These ratios allow comparisons of the use of water to the available water from one subbasin to another. The ratios were highest in July for the 50th percentile of the estimated gross yield minus the Aquatic Base Flow. The ratios ranged from 0.01 in the Providence and Seekonk subbasin to 0.38 in the Hunt-Annaquatucket-Pettaquamscutt subbasin for the 50th percentile of the gross yield minus the 7Q10 for August.

A long-term (1941–2000) water budget was calculated for the study area to assess the basin inflows and outflows. The water withdrawals and return flows used in the budget were from 1995 through 1999. Inflow was assumed to equal outflow. The total water budget was 146.29 million gallons per day for the combined Hunt-Annaquatucket-Pettaquamscutt subbasin, 48.71 million gallons per day for the Greenwich Bay subbasin, 238.98 million gallons per day for the Providence and Seekonk Rivers subbasin, and 21.32 million gallons per day for the Conanicut Island subbasin. The estimated inflows from precipitation, streamflow from upstream basins, and wastewater return flow for the entire study area were 59.3, 38.5, and 2.2 percent, respectively. The estimated outflows for the study area from evapotranspiration, streamflow, and water withdrawals were 24.9, 73.9, and 1.2 percent, respectively.

Introduction

A drought in Rhode Island during the summer of 1999 caused a large reduction in the availability of surface-water and ground-water supplies. The average precipitation at the Kingston, RI, climatological station for June was only 0.05 in., much lower than the long-term average precipitation of 3.94 in. for June (1971 through 2000). Because precipitation is a key component of surface-water runoff and ground-water infiltration, the rain deficit caused a period of little to no recharge; ground-water levels and streamflows dropped below the long-term averages throughout Rhode Island. The Hunt River near East Greenwich streamflow-gaging station had a monthly mean flow in August 1999 of 4.02 ft^3/s compared to the long-term August mean of 15.4 ft^3/s. The Woonasquatucket River was similarly affected, with the monthly mean flow in August 1999 at 11.7 ft^3/s compared to the long-term August mean monthly flow of 31.8 ft^3/s (fig. 1).

In response to this drought, the U.S. Geological Survey (USGS), in cooperation with the Rhode Island Water Resources Board (RIWRB), began a series of nine studies in different basins to collect and analyze water-use and water-availability data in each basin. The West Narragansett Bay study area covers 118 mi^2 in part or all of 14 towns in coastal Rhode Island. The study area includes the freshwater inputs to the western part of Narragansett Bay and Conanicut Island, which is the town of Jamestown.

The study area was divided into six subbasins. To assess the condition of the water supply in each subbasin, it was important to determine the current 5-year average water use and to assess the amount that could be withdrawn. Water-use data were collected from suppliers, and return-flow data were collected from permitted dischargers. In many cases, no metered data were available, or the metered data that were available were not apportioned by subbasin. In these cases estimates were calculated. Available water was estimated in each subbasin from streamflow data and areal extent of sand and gravel. Ratios of water use to availability were calculated for each subbasin.

Purpose and Scope

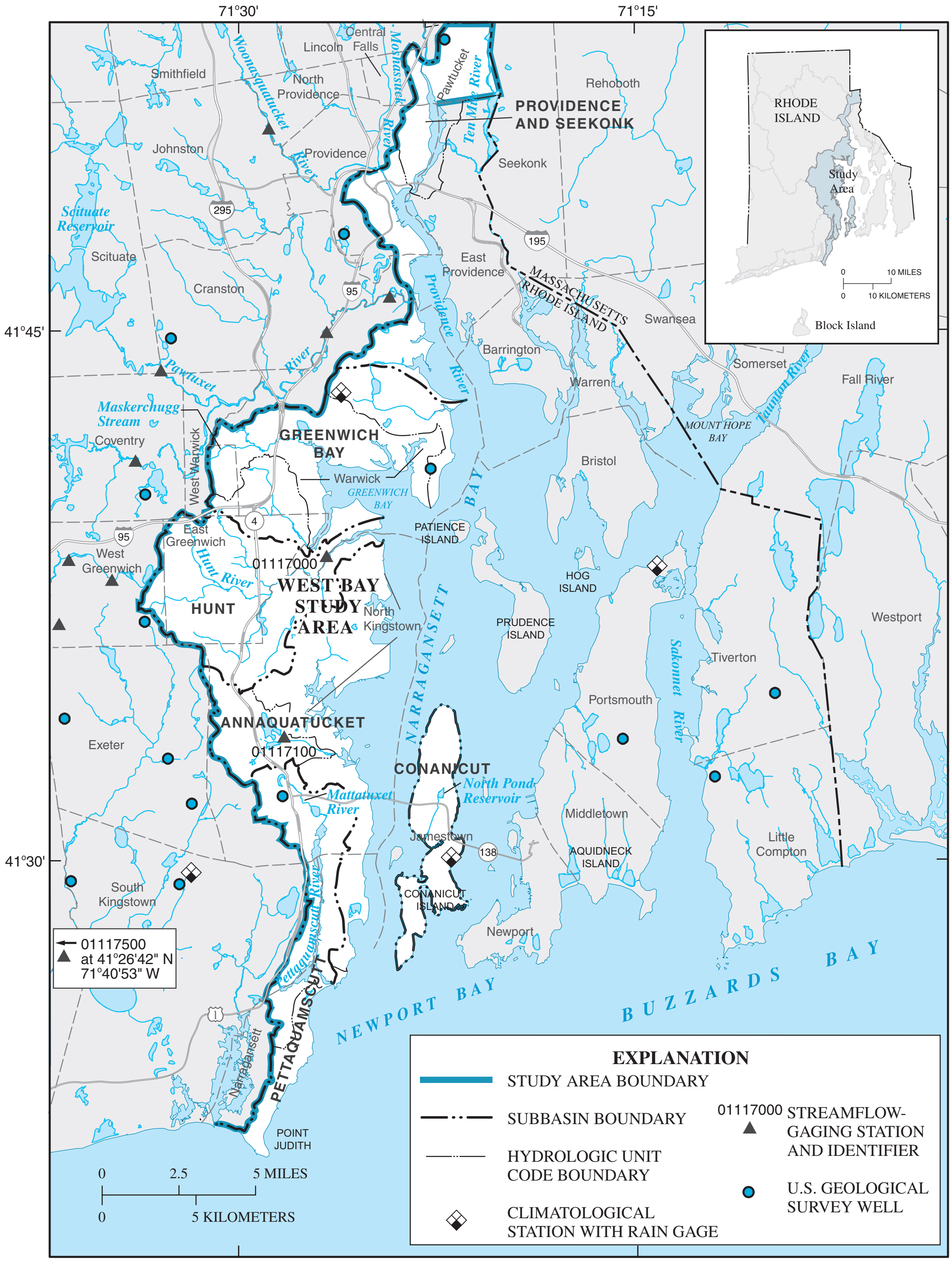
This report identifies the water-use components and assesses water use and availability during 1995–99 in the six subbasins of the West Narragansett Bay study area for periods of little to no recharge. Water-use data were collected by subbasin for municipal supply and disposal systems for calendar years 1995–99. If water-use data were not available for particular supply systems and categories, the data were estimated. The data were entered into the New England Water-Use Data System (NEWUDS) (Tessler, 2002). Water availability is also reported for the study area. The computer program PART (Rutledge, 1993) was used to calculate ground-water discharge, or base flow, during streamflow-recession periods on the basis of long-term data from the streamflow-gaging station at the Pawcatuck River at Wood River Junction. Base flows per unit area for sand and gravel and for till were calculated for the index station and applied to the areas of sand and gravel and till in the study-area subbasins. All calculated base flows are presented in the report. The report also describes the study-area water budget, which is based on the long-term period of record for streamflow and precipitation (1941–2000) and water-use components for the study period for all the subbasins.

Previous Investigations

The USGS has been collecting streamflow data at partial-record and continuous-record streamflow-gaging stations and has been monitoring ground-water levels for more than 60 years in the West Narragansett Bay study area. The data collected have been used in numerous hydrologic studies. Many studies have investigated the ground-water and surface-water resources and the water quality of the basins. The study area is within the Attleboro, Crompton, East Greenwich, East Providence, Narragansett Pier, Newport, Pawtucket, Providence, Prudence Island, Slocum, and Wickford USGS quadrangles. These quadrangles are published in the form of detailed thematic maps in reports describing the surficial geology (Chute, 1949; Schafer, 1961a, b; Smith, 1955, 1956) and bedrock geology (Moore, 1975; Nichols, 1956; Quinn and others, 1949; Quinn, 1952, 1959).

In addition, the USGS has published basin studies that provide information on hydrologic characteristics of the surficial deposits (till and stratified sand and gravel deposits), ground water, precipitation, streamflow, and water quality (Moore, 1975). A report by Ries (1990) provides techniques to estimate runoff from streams in Narragansett Bay. The most recent publication (Barlow and Dickerman, 2001) is a study of the Hunt-Annaquatucket-Pettaquamscutt (HAP) stream-aquifer system, and includes surface- and ground-water data and a numerical-simulation and optimization technique that was applied to the data to assist water suppliers in the study area.

Well records, lithologic logs, water-quality assessments, hydrologic characteristics of the surficial deposits (till and stratified sand and gravel deposits), and water-table information are provided in Allen (1953, 1956), Bierschenk (1959), Quinn and others (1948), and Roberts and Halberg (1945). Allen (1953) presents this information for Providence County, which includes part of the West Narragansett Bay study area. Lang (1961) presents information on ground-water-reservoir areas for the entire state, with the Providence-Warwick and Ten Mile areas covering some of the upper portions of the West Narragansett Bay study area, and the Hunt, Annaquatucket and Pettaquamscutt areas covering the ground-water reservoirs in the rest of the study area. Bedrock contours, water-table altitudes, well locations, and till and stratified sand and gravel deposits are described with respect to USGS quadrangle coverages in Allen and Gorman



Base map from U.S. Geological Survey, 1983, 1:24,000
Polyconic projection, 83 North American Datum

Figure 1. Locations of streamflow-gaging stations, USGS wells, and climatological stations in the West Narragansett Bay area, coastal Rhode Island.

(1959), Hahn (1959), Johnson and Marks (1959), Johnson (1962), and Schiner and Gonthier (1964). Lang and others (1960) describe lithologic logs and historical aquifer tests.

In addition to studies pertaining to surficial deposits in the basin and subbasins, information has been collected and compiled for water use in the study area and statewide water-use assessments (Craft and others, 1995; Horn, 2000; Horn and Craft, 1991; and Medalie, 1996). Information on major public-water suppliers has been collected through written and oral communication from them and the RIWRB. The suppliers also prepare water-supply management plans that are submitted to the RIWRB as a part of the state's Water Supply Systems Management Plan. Information on public disposal was collected (oral and written communication) from wastewater assessments that have been completed and submitted to the Rhode Island Department of Environmental Management (RIDEM) Office of Water Resources.

Description of the Study Area

The study area in central Rhode Island includes 118.1 mi^2, 25.6 of which are in the Annaquatucket subbasin, 20.6 in the Greenwich Bay subbasin, 24.5 in the Hunt subbasin, 12.8 in the Pettaquamscutt subbasin, 25.4 in the Providence and Seekonk subbasin, and 9.25 in the Conanicut Island subbasin (fig. 2). An additional area of 3.98 mi^2 contributes ground water to the study area from the Pawcatuck River Basin. Thirteen towns are partially within the study area, and Jamestown is the only town that is completely within the study area.

The Hunt, Annaquatucket, and Pettaquamscutt River Basins were considered separately for the water-use data collection, but in the calculation of hydrologic budget and water availability, the subbasins were combined into one subbasin (the HAP subbasin). Water-availability values are based on ground-water drainage areas, and the Hunt, Annaquatucket and Pettaquamscutt aquifers are hydraulically connected. It is difficult to track the flow of recharge as ground water from contributing areas into the subbasins, particularly as ground-water levels fluctuate during the year.

Population

In 1990 the study-area population was approximately 227,709 (U.S. Department of Commerce, 1990). The average population during 1995–1999 was 223,741, which is 23 percent of the total state population during the same period. The study area includes portions of the cities of Providence and Warwick, which had the highest populations of any cities in the state during the study period. Subbasin populations ranged from 5,032 in the Conanicut Island subbasin to 126,509 in the Providence and Seekonk subbasin during the study period (table 1).

Sand and Gravel Aquifers and Ground-Water Reservoirs

Sand and gravel aquifers in Rhode Island typically underlie stream valleys. The RIWRB has identified 21 sand and gravel aquifers in the state that have the potential to yield large quantities of water. These aquifers are defined as ground-water reservoirs by the RIWRB if they are underlain by sand and gravel, their transmissivities are equal to or greater than 4,000 ft^2/d, and their saturated thicknesses are equal to or greater than 40 ft (W.B. Allen, Rhode Island Water Resources Board, written commun., 1978). Parts or all of the Lower Blackstone-Moshassuck, Providence-Warwick, Ten Mile, Hunt, and HAP ground-water reservoirs are in the study area. The sand and gravel aquifers in this area are buried preglacial valleys. The extent of coverage of the sand and gravel deposits ranges considerably in the study area from 2 percent of the Conanicut Island subbasin to 78 percent of the Providence and Seekonk subbasin (table 2).

A mix of valley-fill stratified deposits and kame deposits surrounds many of the lakes in the downstream portion of the subbasins. The remaining area is covered by ground moraine, or till. The HAP aquifer's transmissivity ranges from zero at the boundary between the aquifer and the upland till and bedrock to a maximum reported value of 50,800 ft^2/d. Saturated thicknesses range from zero at the boundary between sand and gravel and till deposits to 120 ft in the area that parallels the Hunt River near Potowomut Pond (Barlow and Dickerman, 2001). In the Providence and Seekonk subbasin, the wells in unconsolidated deposits average 100 ft deep; the water table is 10 ft below land surface in the Providence area. The deposits are thinner upstream, the depth to bedrock is generally less than 50 ft, and the depth to the water table is generally 10-15 ft. The Providence-Warwick aquifer in the Greenwich Bay subbasin is an extension of a buried valley that cuts through the Providence area. This aquifer is composed of the thickest deposits in the subbasin, with an average thickness of 140 ft. It is more than 200 ft thick in the deepest part of the main valley where the depth to water is 10 ft (Allen, 1956). In the Conanicut Island subbasin, the areal extent of sand and gravel is limited and the till deposits are also generally thin, on average less than 20 ft. The majority of the wells on the island are finished in bedrock (table 2).

Barlow and Dickerman (2001) found that the ground-water boundary differs from the surface-water boundary in certain areas of the Hunt, Annaquatucket, and Pettaquamscutt subbasins. In these areas, the surface water drains to the Pawcatuck Basin, and the ground water drains to the HAP stream-aquifer system. In a concurrent study in the Usquepaug-Queen subbasin, it was estimated that

Base map from U.S. Geological Survey, 1983, 1:24,000
Polyconic projection, 83 North American Datum

Figure 2. Location of towns, counties, subbasins, hydrography, and sand and gravel deposits in the West Narragansett Bay area, coastal Rhode Island.

Table 1. Total town population by subbasins for 1990, estimated populations, and estimated populations on public and self-supply and on public and self-disposal of water in the West Narragansett Bay area, coastal Rhode Island, 1995–99.

[Total populations in Rhode Island 1990, from Rhode Island Geographic Information System (1991). Estimated 1995–99 population from the Rhode Island Economic Development Corporation (2000).]

City/Town (as in table 2)	Population		Estimated 1995–99 Population			
	1990	Estimated 1995–99	Supply		Disposal	
			Public	Self	Public	Self
Annaquatucket River Subbasin						
Exeter	13	14	0	14	0	14
Narragansett	2,178	2,293	2,184	110	970	1,324
North Kingstown	14,501	15,801	15,163	639	3,051	12,750
Warwick	10	10	10	0	0	10
Subbasin total	16,702	18,118	17,357	763	4,021	14,098
Greenwich Bay Subbasin						
East Greenwich	4,545	4,665	4,559	107	2,621	2,045
Warwick	35,178	34,594	34,438	156	9,046	25,548
West Warwick	7,096	7,037	6,894	143	6,493	543
Subbasin total	46,819	46,296	45,891	406	18,160	28,136
Hunt River Subbasin						
Coventry	69	72	71	1	12	61
East Greenwich	7,176	7,366	5,814	1,552	977	6,389
Exeter	13	14	0	14	0	14
North Kingstown	6,285	6,849	6,535	314	786	6,063
Warwick	1,371	1,348	1,316	32	90	1,258
West Greenwich	83	94	11	83	0	94
West Warwick	73	72	71	1	62	10
Subbasin total	15,070	15,815	13,818	1,997	1,927	13,889
Pettaquamscutt River Subbasin						
Narragansett	9,012	9,490	9,327	162	6,286	3,203
North Kingstown	1,624	1,770	1,459	311	126	1,643
South Kingstown	663	711	467	243	21	689
Subbasin total	11,299	11,971	11,253	716	6,433	5,535
Providence and Seekonk Rivers Subbasin						
Central Falls	906	855	855	0	842	12
Cranston	5,150	5,070	5,070	0	4,795	275
Pawtucket	45,069	42,293	42,262	32	41,029	1,265
Providence	50,168	47,286	47,227	59	46,111	1,175
Warwick	31,529	31,005	31,005	0	11,829	19,176
Subbasin total	132,822	126,509	126,419	91	104,606	21,903
Conanicut Island Subbasin						
Jamestown	4,997	5,032	2,420	2,612	2,126	2,906
Study area total	227,709	223,741	217,158	6,585	137,273	86,467

Table 2. Land-use and sand and gravel areas in the West Narragansett Bay area, coastal Rhode Island.

[Land-use areas were estimated by using the coverage from the Rhode Island Geographic Information System (1995a) and are in square miles (mi^2); <0.001, value not included in totals; --, not applicable]

City/Town	Basin land area	Area of sand and gravel	Agricultural	Commercial	Industrial
Annaquatucket River Subbasin					
Exeter	0.118	--	0.016	--	--
Narragansett	2.522	0.242	.082	0.080	--
North Kingstown	22.991	14.656	1.075	.487	1.352
Warwick	<.001	<.001	--	--	--
Subbasin total	25.631	14.898	1.173	0.567	1.352
Greenwich Bay Subbasin					
East Greenwich	2.185	0.773	0.126	0.189	0.011
Warwick	16.307	9.628	.466	.939	.466
West Warwick	2.072	.649	.025	.163	.173
Subbasin total	20.564	11.050	0.617	1.291	0.350
Hunt River Subbasin					
Coventry	0.044	0.044	--	--	--
East Greenwich	13.831	5.294	0.790	0.160	0.184
Exeter	.116	.054	.051	--	--
North Kingstown	7.786	6.292	.358	.148	.004
Warwick	1.474	1.445	.411	.030	--
West Greenwich	1.138	.011	.001	--	--
West Warwick	.076	.011	--	--	.047
Subbasin total	24.465	13.151	1.611	0.338	0.235
Pettaquamscutt River Subbasin					
Narragansett	4.036	0.540	0.146	0.044	0.031
North Kingstown	6.564	3.190	.481	.011	.008
South Kingstown	2.247	.479	.230	--	.014
Subbasin total	12.847	4.209	0.857	0.055	0.053
Providence and Seekonk Rivers Subbasin					
Central Falls	0.034	0.034	--	0.002	0.004
Cranston	.622	.622	--	.034	.004
Pawtucket	5.969	5.415	0.004	.511	.620
Providence	6.301	4.557	.003	.880	.466
Warwick	10.166	9.171	.309	.615	.098
Subbasin total	25.385	19.799	0.316	2.042	1.192
Conanicut Island Subbasin					
Jamestown	9.251	0.187	1.151	0.092	--

approximately 25 percent of the water within the subbasin drains to the Pawcatuck River Basin during the wet season (Zarriello and Bent, 2004). Because most of the water drains into the Hunt, Annaquatucket and Pettaquamscutt subbasins during the summer, this small area of the Usquepaug-Queen subbasin was included with the Hunt, Annaquatucket, and Pettaquamscutt subbasins in the calculation of summer water availability. Based on the surface-water drainage boundaries, approximately 37.4 percent of the study area is covered by stratified sand and gravel deposits. Based on the ground-water boundaries, however, approximately 37.8 percent of the study area is covered by stratified sand and gravel deposits. Because these studies have focused on inflow into the HAP stream-aquifer system as a whole and outflow from the Pawcatuck Basin, respectively, it is difficult to identify the subbasin into which the additional ground water is flowing. For this reason, the Hunt, Annaquatucket and Pettaquamscutt subbasins are treated as one system in this report (the HAP stream-aquifer system) for the discussions of hydrologic budget, availability, and ratios of use to availability, but as separate subbasins in the discussion of water use.

Climate

Long-term climatological records are available from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) for sites in Woonsocket, Kingston, and at T. F. Green Airport in Warwick, and are published in the series *Climatological Data New England* (NOAA, 2002). These monthly and annual summaries are the source for precipitation data used in this report (table 3). Rainfall records from the Woonsocket station have been collected from 1956 to the present (2005). Records from 1971 through 2000 for this station indicate that the average rainfall is 50.05 in/yr, with the highest monthly average in November (4.77 in.) and the lowest monthly average in June (3.65 in.). No temperature data were collected at this station. The station at Kingston has the longest precipitation record of all of the Rhode Island climatological stations (1889–2005). The yearly average precipitation at this station from 1971 through 2000 is 51.79 in., with the highest monthly average in September (4.16 in.) and the lowest monthly average in July (3.31 in.). The average annual temperature at this station is 49.94˚F for the 1971–2000 period. Records

Table 3. Summary of climatological data for the West Narragansett Bay area, coastal Rhode Island.

[Climatological data from monthly and annual summaries from the National Climate Data Center of the National Oceanic and Atmospheric Administration, 1971–2000 (2002). WSO, weather station observatory; ˚F, degrees Fahrenheit; in., inch]

Climatological station	Period of record used for study	Average temperature (°F)				
		June	July	August	September	Annual
Kingston, RI	1971–2000	65.6	71.1	69.9	62.7	49.9
	1995–99	66.5	71.9	70.3	63.7	50.9
T. F. Green Airport WSO, Warwick, RI	1971–2000	67.7	73.4	71.9	64.0	51.1
	1995–99	68.2	74.1	72.1	64.7	51.8

Climatological station	Period of record used for study	Average precipitation (in.)				
		June	July	August	September	Annual
Kingston, RI	1971–2000	3.94	3.31	4.40	4.16	51.79
	1995–99	4.11	2.73	4.36	4.47	53.11
T. F. Green Airport WSO, Warwick, RI	1971–2000	3.38	3.17	3.90	3.70	46.46
	1995–99	3.41	1.98	3.19	4.01	43.91
Woonsocket, RI[1]	1971–2000	3.65	3.67	4.28	4.09	50.05
	1995–99	3.51	3.93	3.13	4.29	51.58

[1]No temperature data are available for this station.

from the rainfall gage at T. F. Green Airport in Warwick have been collected from 1948 to the present (2005), and the 1971–2000 record indicates an average rainfall of 46.46 in/yr, with the highest monthly average in September (3.70 in.) and the lowest monthly average in July (3.17 in.). The average temperature at this station is 51.1°F (table 3). Rainfall records from the Kingston station were used for water-use estimates and budget calculations in this study because of the proximity of this station to the study area and the availability of NOAA data to the public. Although the climatological data from stations across the state are similar, differences in the data can be substantial, particularly if the periods of record are different.

Land Use

Land use was determined by using the Rhode Island Geographic Information Systems (RIGIS) land-use coverages and basin-boundary coverages. This information was used to aggregate commercial, industrial, and agricultural water-use estimates by the applicable towns and basins (tables 2 and 4). For water-supply districts, land-use area was used to aggregate the water-use categories by basin (table 5) if data were not available by category from the water supplier.

Land use within the Annaquatucket subbasin is predominately forested (26.8 percent), followed by residential (25.3 percent), wetlands (17 percent), transportation (7.5 percent), industrial (5.3 percent), agricultural (4.6 percent), and commercial (2.2 percent). Other land uses include 11.3 percent of the area in the subbasin.

Land use within the Greenwich Bay subbasin is predominately residential (47.3 percent), followed by forested (17.3 percent), wetlands (7.9 percent), commercial (6.3 percent), transportation (5.3 percent), agricultural (3.0 percent), and industrial (1.7 percent). Other land uses include 11.2 percent of the area in the subbasin.

Land use within the Hunt subbasin is predominately forested (37.9 percent), followed by residential (26.9 percent), wetlands (16.1 percent), agricultural (5.1 percent), transportation (2.7 percent), and industrial (2.3 percent). Other land uses include 9 percent of the area in the subbasin.

Land use within the Pettaquamscutt subbasin is predominately forested (38.8 percent), followed by residential (24.3 percent), wetlands (22.1 percent), agricultural (6.7 percent), and transportation (2.3 percent). Other land uses include 5.8 percent of the area in the subbasin.

Land use within the Providence and Seekonk subbasin is predominately residential (48.6 percent), followed by commercial (10.3 percent), industrial (6.9 percent), institutional (6.7 percent), salt/brackish water (6.3 percent), forested (4.5 percent), mixed urban (3.0 percent), wetlands (2.0 percent), transportation (1.6 percent), and water (1.5 percent). Other land uses include 8.6 percent of the area in the subbasin.

Land use within the Conanicut Island subbasin is predominately residential (34.8 percent), followed by forested (25.9 percent), wetlands (14 percent), agricultural (12.4 percent), and institutional (5.6 percent). Other land uses include 7.3 percent of the area in the subbasin.

These percentages reflect the more urban nature of the Providence and Seekonk and the Greenwich Bay subbasins compared to the other subbasins in the study area. These subbasins include large percentages of the areas of the cities of Providence and Warwick, 33 and 75 percent, respectively, which were the most populous cities in the State during the study period.

Surface Water

The data for surface water are disaggregated at the level of the 12-digit HUC, as defined by the Natural Resources Conservation Service (NRCS) (table 6). The Annaquatucket subbasin includes the western coastal portions of the Upper West Passage (010900040906) and part of the Lower West Passage (010900040908) basins. The Greenwich Bay (010900040903) subbasin is the same as its counterpart in the NRCS coverage, as are the Hunt (010900040904) and the Pettaquamscutt (010900050401) subbasins. The Providence and Seekonk Rivers subbasin includes the Providence and Seekonk Rivers (010900040901), the Pawtucket portions of the Ten Mile River Basin (010900040401), and the Upper Narragansett Bay subbasin (010900040902). The Conanicut Island subbasin includes the Jamestown portions of the Lower West Passage (010900040908) and Lower East Passage (010900040909).

The study area is characterized by several different hydrologic settings, including freshwater streams, tidally affected estuaries, and ground water discharging directly to the bay. The Hunt and Annaquatucket Rivers both flow directly into Narragansett Bay, and the Hunt subbasin is defined for this study as the area contributing water to Narragansett Bay from the mouth of the Hunt River. The Annaquatucket River originates at Secret Lake above Belleville Pond, which has an area of 159 acres and an average depth of 5 ft (Guthrie and Stolgitis, 1977). The Annaquatucket subbasin is defined for this study as the area contributing surface and ground water directly to Narragansett Bay from the Upper West Passage and Lower West Passage HUCs (table 6). The Pettaquamscutt River originates as the Mattatuxet River, and it flows through Silver Spring Lake, which has an area of 18 acres and an average depth of 5 ft (Guthrie and Stolgitis, 1977), and into Carp Pond. It becomes the Pettaquamscutt River where it flows into a tidally affected, brackish-water area. The Providence River part of the Providence and Seekonk Rivers subbasin begins at the confluence of two freshwater rivers that become tidally affected and brackish: the Woonasquatucket River, with a drainage area of 51.0 mi^2, and the Moshassuck River, with a drainage area of 23.8 mi^2. Inputs from these upstream basins are included in the hydrologic budget for the Providence and Seekonk subbasin. The Seekonk River is much more influenced by the saltwater of the bay than

Table 4. Land-use areas served by major public-water suppliers in the West Narragansett Bay area, coastal Rhode Island.

[Land-use areas were estimated by using the coverage from the Rhode Island Geographic Information System (1995a). mi², square mile; <0.001, value not included in totals; --, not applicable]

Major public supplier	Towns served	Total water-district area (mi²)	Area of water district in subbasin (mi²)	Agricultural (mi²)	Commercial (mi²)	Industrial (mi²)
		Annaquatucket River Subbasin				
Narragansett Water Department	Narragansett	6.943	0.868	0.042	0.051	--
North Kingstown Water Department	North Kingstown	28.974	17.505	.902	.487	0.113
RI Economic Development Corporation	North Kingstown	3.490	3.490	.004	--	1.240
United Water of Rhode Island	Narragansett	6.628	1.619	.039	.028	--
		Greenwich Bay Subbasin				
Kent County Water Authority	East Greenwich	9.587	2.815	0.125	0.189	0.011
	Warwick	10.490	9.277	.355	.673	.127
	West Warwick	7.968	2.072	.025	.163	.172
Warwick Water Authority	Warwick	24.549	7.029	.112	.266	.038
		Hunt River Subbasin				
Kent County Water Authority	Coventry	14.059	0.044	--	--	--
	East Greenwich	9.587	7.320	0.312	0.158	0.184
	Warwick	10.490	.060	--	.018	--
	West Warwick	7.968	.076	--	--	.047
North Kingstown Water Department	East Greenwich	.071	.071	--	--	--
	North Kingstown	28.974	6.182	.251	.233	.301
Warwick Water Authority	Warwick	24.549	1.310	.381	.010	--
		Pettaquamscutt River Subbasin				
Narragansett Water Department	Narragansett	6.943	2.910	0.040	0.070	0.026
North Kingstown Water Department	North Kingstown	28.974	3.088	.173	.004	.008
South Kingstown Water Department	South Kingstown	5.122	.426	.009	--	--
United Water of Rhode Island	Narragansett	6.628	2.605	.142	.020	.004
	South Kingstown	12.214	1.448	.176	--	.014
		Providence and Seekonk Rivers Subbasin				
East Providence Water District	Pawtucket	0.001	0.001	--	--	<0.001
Pawtucket Water Supply Board	Central Falls	1.289	.034	--	0.002	.004
	Pawtucket[1]	8.845	5.9681	0.004	.511	.620
	Providence	<.001	<.001	--	--	--
Providence Water Supply Board	Cranston	14.155	.616	--	.030	.004
	Providence	18.780	6.301	.003	.880	.466
Warwick Water Authority	Cranston	.010	.005	--	.004	--
	Warwick	24.549	10.223	.309	.614	.098
		Conanicut Island Subbasin				
Jamestown Water Division	Jamestown	4.415	4.415	0.579	0.087	--

[1]Pawtucket includes part of the Ten Mile River Basin in Rhode Island.

Table 5. Estimated water use by category, town, and subbasin in the West Narragansett Bay area, coastal Rhode Island, 1995–99.

[All towns are in Rhode Island unless otherwise noted. Mgal/d, million gallons per day; <0.001, value not included in totals; --, not applicable]

City/Town	Domestic supply (Mgal/d)		Commercial supply (Mgal/d)		Industrial supply (Mgal/d)		Agricultural supply (Mgal/d)		Total (Mgal/d)
	Public	Self	Public	Self	Public	Self	Public	Self	
Annaquatucket River Subbasin									
Exeter	--	0.001	--	--	--	--	<0.001	--	0.001
Narragansett	0.146	.008	0.015	--	--	--	.001	--	.170
North Kingstown	1.020	.046	.109	0.007	0.001	--	.012	0.193	1.388
Warwick	.001	--	--	--	--	--	--	--	.001
Subasin total	1.167	0.055	0.124	0.007	0.001	--	0.013	0.193	1.560
Greenwich Bay Subbasin									
East Greenwich	0.305	0.008	0.007	0.006	0.011	<0.001	<0.001	0.109	0.446
Warwick	2.307	.011	.533	--	.066	--	.003	.108	3.028
West Warwick	.462	.010	.031	--	.137	--	<.001	--	.640
Subasin total	3.074	0.029	0.571	0.006	0.214	<0.001	0.003	0.217	4.114
Hunt River Subbasin									
Coventry	0.005	<0.001	--	--	--	--	--	--	0.005
East Greenwich	.390	.110	0.006	0.005	0.182	<0.001	0.002	0.040	.735
Exeter	--	.001	--	--	--	--	<.001	.001	.002
North Kingstown	.438	.022	.061	.004	.052	--	.004	.036	.617
Warwick	.088	.002	.016	--	--	--	.003	<.001	.109
West Greenwich	.001	.006	--	--	--	--	<.001	<.001	.007
West Warwick	<.001	.005	--	--	.037	--	--	--	.042
Subasin total	0.922	0.146	0.083	0.009	0.271	<0.001	0.009	0.077	1.517
Pettaquamscutt River Subbasin									
Narragansett	0.625	0.012	0.008	--	0.100	--	0.002	0.078	0.825
North Kingstown	.098	.022	.002	<0.001	.232	--	.006	.002	.362
South Kingstown	.031	.017	--	--	.006	0.010	.001	.002	.067
Subasin total	0.754	0.051	0.010	<0.001	0.338	0.010	0.009	0.082	1.254
Providence and Seekonk Rivers Subbasin									
Central Falls	0.057	--	<0.001	--	0.014	--	--	--	0.071
Cranston	.340	--	.020	<0.001	.003	<0.001	--	--	.363
Pawtucket	2.832	0.002	.370	--	1.365	--	--	0.075	2.704
Providence	3.164	.004	2.422	--	.418	--	--	--	6.008
Warwick	2.078	--	.349	--	.039	--	0.001	<.001	2.467
Subasin total	7.016	0.006	2.987	<0.001	1.529	<0.001	0.001	0.075	11.613
Conanicut Island Subbasin									
Jamestown	0.162	0.185	0.014	0.001	0.026	--	0.003	0.038	0.429
Study area total	13.095	0.471	3.789	0.023	2.379	0.010	0.038	0.682	20.487

Table 6. Defined subbasins in the West Narragansett Bay study area in comparison to the 10-digit and 12-digit HUC areas in the National Hydrography Dataset, Rhode Island.

West Narragansett Bay study area in Rhode Island		National Hydrography Dataset for Narragansett Bay in Rhode Island						
		10-digit			12-digit			
Subbasin	Drainage area (mi^2)	Name	Number	Drainage area (mi^2)	Name	Number	Drainage area	Subbasin drainage area (mi^2)
Providence and Seekonk	25.385	Ten Mile River	0109000404	6.850	Ten Mile River[1]	010900040401	6.850[2]	3.176
Providence and Seekonk	25.385	Narragansett Bay	0109000409	196.743[3]	Seekonk and Providence Rivers	010900040901	24.403	13.050[4]
Providence and Seekonk	25.385				Upper Narragansett Bay[5]	010900040902	9.864	6.866
Greenwich Bay	20.564				Greenwich Bay	010900040903	21.173	20.564
Hunt River	24.465				Hunt River	010900040904	24.480	24.465
Annaquatucket	25.631				Upper West Passage[6]	010900040906	8.146	4.947
Annaquatucket[7]	25.631				Lower West Passage	010900040908	27.040	21.686
Conanicut Island[7]	9.251				Lower West Passage	010900040908	27.040	5.354
Conanicut Island[8]	9.251				Lower East Passage	010900040909	11.025	3.897
Pettaquamscutt	12.847	Southwest Coastal Waters	0109000504	27.459	Pettaquamscutt River	010900050401	16.882	12.939
Total West Narragansett Bay basin study area	118.143	Total NHD Narragansett Bay Basin		239.56	Total NHD Narragansett Bay Basin		149.863	

[1]Pawtucket portions of the Ten Mile are included in the Providence and Seekonk subbasin.

[2]Only the Rhode Island portions of the Ten Mile are in this total.

[3]Only the Rhode Island portions of the Narragansett Bay 10-digit HUC are in this total.

[4]Only Providence and Warwick portions of the Providence and Seekonk HUC (010900040901) are included in the Providence and Seekonk subbasin.

[5]Only areas of the Upper Narragansett Bay HUC (010900040902) in the western part of Narragansett Bay are included in the Providence and Seekonk subbasin. The rest of the area is in the East Bay study area.

[6]Only areas of the Upper West Passage HUC (010900040906) in the western part of Narragansett Bay are included in the Annaquatucket Subbasin. The rest of the HUC area is in the East Bay study area.

[7]The Lower West Passage HUC area is split between the Annaquatucket and Conanicut Island subbasins.

[8]Only the Jamestown portion of the Lower East Passage HUC area is included in this subbasin.

the freshwater of its tributaries. It receives contributions from the Blackstone River, with a drainage area of 475 mi^2, and the Ten Mile River, with a drainage area of 54 mi^2. The Blackstone River and Ten Mile River inflows are not included in the calculation of the hydrologic budget for the Providence and Seekonk subbasin because these tributaries flow into saltwater before they reach a confluence; the freshwater in these rivers could not be pumped out of the Seekonk River Basin. This subbasin includes ground water that discharges directly into the bay. The Greenwich Bay subbasin is defined as the entire area contributing surface water and ground water to Greenwich Bay, and the surface-water flow includes Maskerchugg Stream. The Conanicut Island subbasin includes the area of the entire island. The hydrography is detailed in fig. 2.

One active continuous-record streamflow-gaging station is in the study area, the Hunt River near East Greenwich (01117000) (fig. 1). This station has been continuously operated since 1941, and water-quality data has sporadically been collected. The drainage area upstream of the station is 22.9 mi^2, compared with 24.5 mi^2 at the mouth. Based on 59 years of data collected at this station (water years 1941–2000), the annual mean flow is 10.73 ft^3/s. One discontinued continuous-record streamflow-gaging station was also in the study area: the Annaquatucket River at Belleville (01117100), which was operated from 1961 to 1964 (Socolow and others, 2000). The drainage area upstream of this station is 6.4 mi^2, and the average discharge for the period of record was 18.2 ft^3/s. Additional partial-record measurements have been taken at 21 sites within the study area, primarily for the Hunt River study (Barlow and Dickerman, 2001).

Minor Civil Divisions

For the purposes of this study, the political subdivisions in the basin provide the basic unit by which data are collected and analyzed. The smallest level at which data are available is the minor civil division (MCD), a term that is used by the U.S. Census Bureau and generally indicates a town or city.

Polygons within the cities and towns were assigned population densities in the GIS coverages of U.S. Census Bureau TIGER data (Rhode Island Geographic Information System, 1991). The 1990 population coverages were merged with the USGS basin coverages to determine the population in the subbasins (table 1). In addition, the town land area within each subbasin was determined by overlaying town boundaries and basin-boundary coverages. The ratio of the 1990 populations to the study-period populations for towns within each subbasin represents the increase or decrease in the town's population (table 7). To estimate the study-period town populations on public and self-supply and public and self-disposal of wastewater, the population ratios described above were multiplied by the Census Bureau's 1990 populations on private wells and on public wastewater collection (table 1). (2000 census data, although available for this report, do not include data on public-water supply and disposal and self-supply and disposal of wastewater.) 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, 1996). For this report, public suppliers were categorized as major public suppliers if they have a system of distribution, and minor suppliers if they have closed systems serving only their own populations with no connections to other potable-water systems. Major public suppliers are listed in table 4 and the one minor supplier in table 8.

Subbasins

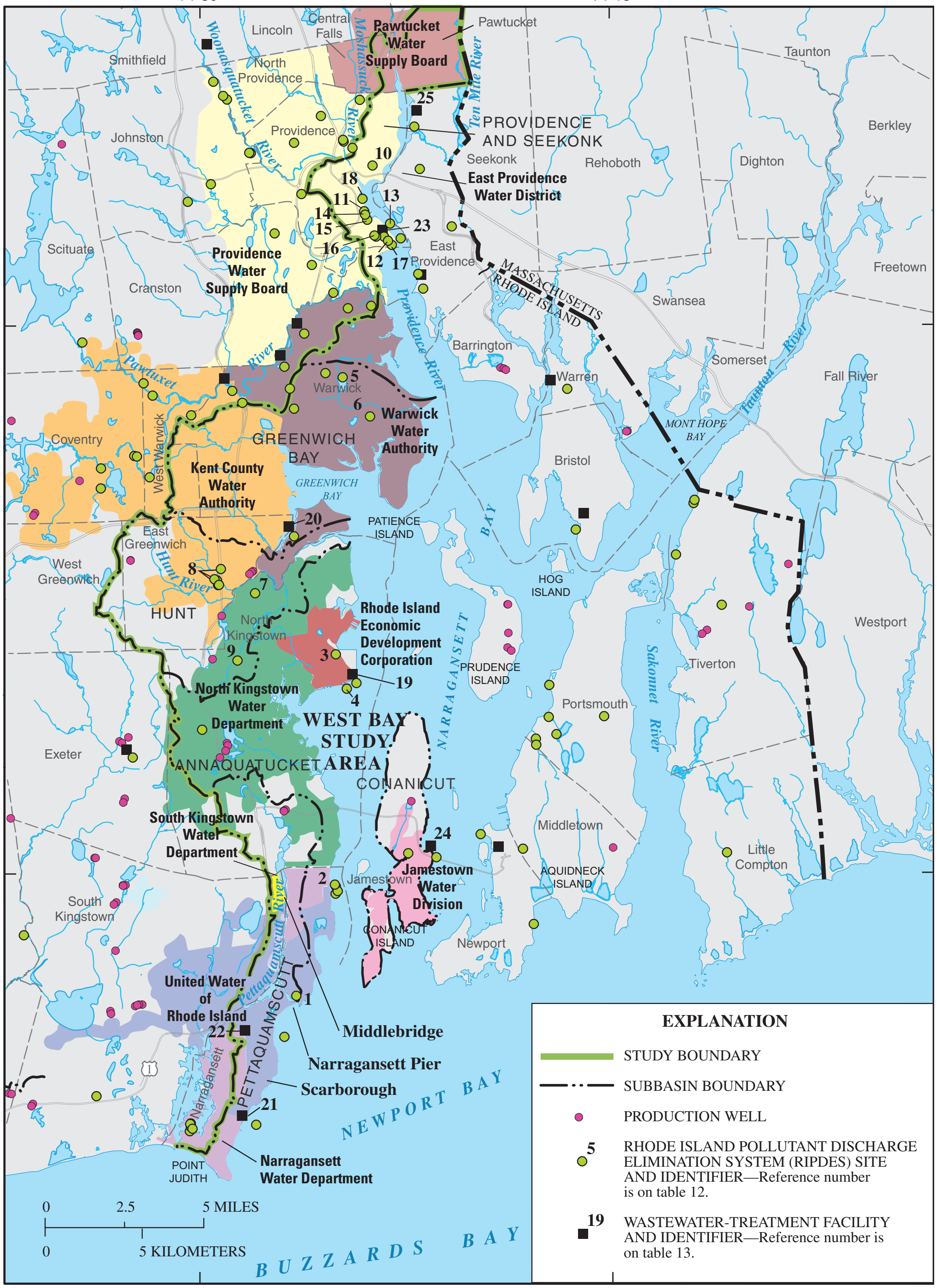
The six West Narragansett Bay subbasins are within Providence, Kent, Washington, and Newport Counties. Subbasins are shown on fig. 1. These subbasins were defined by merging Hydrologic Unit Code areas delineated by the NRCS to represent ground-water contributing areas to Narragansett Bay.

Annaquatucket River Subbasin

Four towns are partially within the Annaquatucket River subbasin: Exeter, Narragansett, North Kingstown, and Warwick. The town of Exeter covers 58.39 mi^2 and has a 5-year average population of 5,932 (table 7), of which 0.118 mi^2 (table 2) and 14 persons (table 1) are in the Annaquatucket subbasin. The town has no public-water supply. Outside of the study area, the Ladd School, a minor public-water supplier and wastewater-treatment facility, was in operation for 5 months (from January through May of 1995) during the study period. The facility is currently owned by the Rhode Island Economic Development Corporation (RIEDC) and is undeveloped (fig. 3).

The town of Narragansett covers 13.68 mi^2 and has a 5-year average population of 15,777 (table 7), of which 2.522 mi^2 (table 2) and 2,293 persons (table 1) are in the Annaquatucket subbasin. The Narragansett Water Department and United Water of Rhode Island (UWRI) (table 4, fig. 3) provide public-water supply to the town. The Narragansett Water Department supplies the town through wholesale and retail water purchases from UWRI, which withdraws its water from the Pawcatuck River Basin. Wastewater is collected and processed by the Narragansett Wastewater-Treatment Facility (WWTF) in the locality of Scarborough, and by the South Kingstown Regional WWTF (fig. 3).

The town of North Kingstown covers 43.42 mi^2 and has a 5-year average population of 25,906 (table 7), of which 22.991 mi^2 (table 2) and 15,801 persons (table 1) are in the Annaquatucket subbasin. The town is supplied by the North Kingstown Water Department (table 4, fig. 3). There is no public wastewater collection in North Kingstown. The RIEDC serves commercial and industrial customers from three wells, and also has a wastewater-treatment facility that



Base map from U.S. Geological Survey, 1983, 1:24,000
Polyconic projection, 83 North American Datum

Figure 3. Location of water-supply districts, RIPDES sites, and wastewater-treatment plants in the West Narragansett Bay area, coastal Rhode Island.

Table 7. Summary of total land area, land area in the study area, total 1990 populations, estimated 1995–99 populations, and land-use area by category in the West Narragansett Bay area, coastal Rhode Island.

[All towns are in Rhode Island. Total populations in Rhode Island 1990 from Rhode Island Geographic Information System (1991). Estimated 1995–99 population from the Rhode Island Economic Development Corporation (2000). Land-use areas in Rhode Island were estimated by using the coverage from the Rhode Island Geographic Information System (1995a). mi^2, square mile; --, not applicable]

City/Town	Total land area (mi^2)	Land area in the study area (mi^2)	Total populations		Estimated 1995–99 population in the study area	Total land-use area by category (mi^2)		
			1990	Estimated 1995–99		Commercial	Industrial	Agricultural
Central Falls	1.286	0.034	17,595	16,595	855	0.223	0.174	--
Coventry	62.45	.043	31,081	32,523	72	.627	.355	2.392
Cranston	28.90	.622	76,077	74,890	5,070	1.177	1.174	2.609
East Greenwich	16.25	16.015	11,807	12,120	12,031	.349	.195	.924
Exeter	58.39	.234	5,472	5,932	28	.140	.042	4.451
Jamestown	9.251	9.251	4,997	5,032	5,032	.092	--	1.151
Narragansett	13.68	6.558	14,983	15,777	11,783	.377	.032	.421
North Kingstown	43.42	37.381	23,774	25,906	24,420	.788	1.676	3.133
Pawtucket	8.846	8.282	72,828	68,343	42,293	.878	.964	.006
Providence	18.78	6.300	160,362	151,151	47,286	2.180	1.701	.008
South Kingstown	60.85	11.054	24,632	26,401	711	.490	.155	7.666
Warwick	35.02	27.843	85,457	84,038	66,957	2.598	1.138	1.217
West Greenwich	51.22	1.137	3,501	3,956	94	.227	.064	1.865
West Warwick	8.091	2.148	29,278	29,034	7,109	.557	.464	.108

Table 8. Minor suppliers by subbasin in the West Narragansett Bay area, coastal Rhode Island.

[Coefficient used for minor supplier population is 67 gal/d/person. BD, bedrock well; Mgal/d, million gallons per day]

Minor supplier	Town	Aquifer type	Estimated 1995–99	
			Population	Water withdrawals and use (Mgal/d)
Hunt River Subbasin				
Pheasant Ridge Homeowners Association	East Greenwich	BD	30	0.002
Study area total				0.002

serves the Quonset Point establishment, formerly a U.S. Navy Air Station, which the RIEDC currently (2004) owns and operates.

The city of Warwick covers 35.02 mi^2 and has a 5-year average population of 84,038 (table 7), of which less than 0.001 mi^2 (table 2) and fewer than 10 persons (table 1) are in the Annaquatucket subbasin. The city is publicly supplied by the Warwick Water Authority (table 4, fig. 3).

Greenwich Bay Subbasin

Three towns are partially within the Greenwich Bay subbasin: Warwick, West Warwick, and East Greenwich. The town of East Greenwich covers 16.25 mi^2 and has a 5-year average population of 12,120 (table 7), of which 2.185 mi^2 (table 2) and 4,665 persons (table 1) are in the Greenwich Bay subbasin. The town is publicly supplied by the Kent County Water Authority and the North Kingstown Water Department; however, only the Kent County Water Authority serves this subbasin (table 4, fig. 3). The East Greenwich WWTF (fig. 3) collects and processes wastewater for the community.

The city of Warwick covers 35.02 mi^2 and has a 5-year average population of 84,038 (table 7), of which 16.307 mi^2 (table 2) and 34,594 persons (table 1) are in the Greenwich Bay subbasin. The city is served by the Warwick Water Authority and the Kent County Water Authority (table 4, fig. 3). The Warwick WWTF and the West Warwick Regional WWTF collect and process wastewater for the city.

The town of West Warwick covers 8.091 mi^2 and has a 5-year average population of 29,034 (table 7), of which 2.072 mi^2 (table 2) and 7,037 persons (table 1) are in the Greenwich Bay subbasin. The town is publicly supplied by the Kent County Water Authority (table 4, fig. 3). The city's wastewater is collected and processed by the West Warwick Regional WWTF (fig. 3).

Hunt River Subbasin

Seven towns are partially within the Hunt River subbasin: Coventry, East Greenwich, Exeter, North Kingstown, Warwick, West Greenwich, and West Warwick. The town of Coventry covers 62.45 mi^2 and has a 5-year average population of 32,523 (table 7), of which 0.044 mi^2 (table 2) and 72 persons (table 1) are in the Hunt River subbasin. The town is publicly supplied by the Kent County Water Authority (table 4, fig. 3). The wastewater-collection area for the eastern section of Coventry is maintained by the West Warwick Regional WWTF.

The town of East Greenwich covers 16.25 mi^2 and has a 5-year average population of 12,120 (table 7), of which 13.831 mi^2 (table 2) and 7,366 persons (table 1) are in the Hunt River subbasin. The town is publicly supplied with water by the Kent County Water Authority and the North Kingstown Water Department (table 4, fig. 3). Wastewater is collected and processed by the East Greenwich WWTF. One minor water supplier serves a small population in the basin in this town (table 8).

The town of Exeter covers 58.39 mi^2 and has a 5-year average population of 5,932 (table 7), of which 0.116 mi^2 (table 2) and 14 persons (table 1) are in the Hunt River subbasin. The town has no publicly supplied drinking water.

The town of North Kingstown covers 43.42 mi^2 and has a 5-year average population of 25,906 (table 7), of which 7.786 mi^2 (table 2) and 6,849 persons (table 1) are in the Hunt River subbasin. The town is publicly supplied by the North Kingstown Water Department (table 4, fig. 3). There is no public wastewater collection in North Kingstown. The RIEDC serves commercial and industrial customers water from three wells and also has a wastewater-treatment facility that serves the Quonset Point establishment, formerly a U.S. Navy Air Station, which the RIEDC currently (2004) owns and operates.

The city of Warwick covers 35.02 mi^2 and has a 5-year average population of 84,038 (table 7), of which 1.474 mi^2 (table 2) and 1,348 persons (table 1) are in the Hunt River subbasin. The city is served by the Warwick Water Authority and the Kent County Water Authority (table 4, fig. 3). The Warwick WWTF and the West Warwick Regional WWTF collect and process wastewater for the city.

The town of West Greenwich covers 51.22 mi^2 and has a 5-year average population of 3,956 (table 7), of which 1.138 mi^2 (table 2) and 94 persons (table 1) are in the Hunt River subbasin. The town has no publicly supplied drinking water. A small area outside of the subbasin is served by the West Warwick Regional WWTF (fig. 3).

The town of West Warwick covers 8.091 mi^2 and has a 5-year average population of 29,034 (table 7), of which 0.076 mi^2 (table 2) and 72 persons (table 1) are in the Hunt River subbasin. The town is served by the Kent County Water Authority (table 4, fig. 3), and the town's wastewater is collected and processed by the West Warwick Regional WWTF (fig. 3).

Pettaquamscutt River Subbasin

Three towns are partially within the Pettaquamscutt River subbasin: Narragansett, North Kingstown, and South Kingstown. The town of Narragansett covers 13.68 mi^2 and has a 5-year average population of 15,777 (table 7), of which 4.036 mi^2 (table 2) and 9,490 persons (table 1) are in the Pettaquamscutt River subbasin. The Narragansett Water Department and the UWRI (table 4, fig. 3) provide public supply to the town. The Narragansett Water Department supplies the town through wholesale and retail water purchases from UWRI, which withdraws its water from the Pawcatuck River Basin. Wastewater is collected from the town by the Narragansett WWTF in the locality of Scarborough and southern part of Narragansett and by the South Kingstown Regional WWTF in the part of Narragansett north of Narragansett Pier.

The town of North Kingstown covers 43.42 mi^2 and has a 5-year average population of 25,906 (table 7), of which 6.564 mi^2 (table 2) and 1,770 persons (table 1) are in the Pettaquamscutt River subbasin. The North Kingstown Water Department (table 4, fig. 3) serves approximately 94 percent of the town. There is no public wastewater collection in North Kingstown. The RIEDC serves commercial and industrial customers with water from three wells and also has a wastewater-treatment facility that serves the Quonset Point establishment, formerly a U.S. Navy Air Station, which the RIEDC currently (2004) owns and operates.

The town of South Kingstown covers 60.85 mi^2 and has a 5-year average population of 26,401 (table 7), of which 2.247 mi^2 (table 2) and 711 persons (table 1) are in the Pettaquamscutt River subbasin. The town is publicly supplied by the South Kingstown Water Department (table 4, fig. 3), which purchases water from UWRI. The South Kingstown Regional WWTF serves the town.

Providence and Seekonk Rivers Subbasin

Five towns are partially within the Providence and Seekonk Rivers subbasin: Central Falls, Cranston, Pawtucket, Providence, and Warwick. The town of Central Falls covers 1.286 mi^2 and has a 5-year average population of 16,595 (table 7), of which 0.034 mi^2 (table 2) and 855 persons (table 1) are in the Providence and Seekonk Rivers subbasin. The town is publicly supplied by the Pawtucket Water Supply Board (table 4, fig. 3). Wastewater is collected by the Narragansett Bay Commission and is disposed outside of the basin at the Bucklin Point WWTF, which discharges to Narragansett Bay.

The town of Cranston covers 28.90 mi^2 and has a 5-year average population of 74,890 (table 7), of which 0.622 mi^2 (table 2) and 5,070 persons (table 1) are in the Providence and Seekonk Rivers subbasin. The town is publicly supplied by the Providence Water Supply Board (Providence Water) and the Warwick Water Authority (table 4, fig. 3). The U.S.

Filter Cranston Water Pollution Control Facility and the West Warwick WWTF collect and process wastewater for the areas served in Cranston.

The city of Pawtucket covers 8.846 mi^2 and has a 5-year average population of 68,343 (table 7), of which 5.969 mi^2 (table 2) and 42,293 persons (table 1) are in the Providence and Seekonk Rivers subbasin. A part of this area is in the Ten Mile River Basin, and is included in this subbasin. It will not be treated separately in this report. The city is publicly supplied by the Pawtucket Water Supply Board and the East Providence Water District (table 4, fig. 3). Wastewater is collected by the Narragansett Bay Commission, and is disposed outside of the basin at the Bucklin Point WWTF, which discharges to Narragansett Bay.

The city of Providence covers 18.78 mi^2 and has a 5-year average population of 151,151 (table 7), of which 6.301 mi^2 (table 2) and 47,286 persons (table 1) are in the Providence and Seekonk Rivers subbasin. Providence is the most populated part of the study area. Almost all of the city is publicly supplied by Providence Water; a small area of the city is supplied by the Pawtucket Water Supply Board, but this area is considered negligible for the purposes of this study. Wastewater is collected by the Narragansett Bay Commission and is disposed outside of the basin at the Fields Point WWTF (table 4, fig. 3).

The city of Warwick covers 35.02 mi^2 and has a 5-year average population of 84,038 (table 7), of which 10.166 mi^2 (table 2) and 31,005 persons (table 1) are in the Providence and Seekonk Rivers subbasin. The city is served by the Warwick Water Authority and the Kent County Water Authority (table 4, fig. 3). The Warwick WWTF and the West Warwick Regional WWTF collect and process wastewater for the city.

Conanicut Island Subbasin

In the Conanicut Island subbasin, there is only one town, Jamestown, and it covers the entire area of 9.251 mi^2 of the island; the entire area of the town is in the Conanicut Island subbasin. The town of Jamestown has a 5-year average population of 5,032 (table 7). The town is publicly supplied by the Jamestown Water Division, which operates a reservoir and a production well and also receives water from an interconnection with the North Kingstown Water Department (table 4, fig. 3). Wastewater is collected by the Jamestown WWTF and is discharged to Narragansett Bay.

Water Use

Water-use data in the West Narragansett Bay study area was organized by using NEWUDS (Tessler, 2002). This database was designed for the storage and retrieval of water-use data, including all of the categories of data collected for this study. NEWUDS is a useful tool because it also can organize the ancillary information that is important for understanding water-use data, such as whether the data are metered or estimated, or which subbasin the data are for, and it can track transactions between subbasins. Components of water-use data include water withdrawals, water use (public-supply systems and distributions, nonaccount use), consumptive water use, wastewater-system collections, and return flow. For the study period, data were categorized as either self- or public withdrawals. Conveyance losses are an example of nonaccount water use, and include leaks, system flushing, and firefighting uses within a system. Water-use categories in this report are domestic (indoor and outdoor household use), commercial (schools, hotels, restaurants, office buildings), industrial (manufacturing and processing), and agricultural (golf-course and crop irrigation, and livestock water). Public-supply water is withdrawn from both surface water and ground water, and self-supply water is withdrawn from ground water. Consumptive water use is the water removed from the system by humans, livestock, production, or evapotranspiration. Wastewater from local and regional public-wastewater systems is returned to surface-water bodies. Return flow to ground water or surface water includes site-specific discharges, permitted discharges, and aggregate discharges, all of which are self-disposed within the towns and subbasins. Water withdrawals, water use, consumptive water use, and returns were calculated for each subbasin by town for individual calendar years during the study period.

New England Water-Use Data System

Water-use data were entered into NEWUDS. The data consisted of site-specific and aggregate water withdrawals, uses, and discharges in the West Narragansett Bay study area. When available, monthly, quarterly, and yearly metered data were entered as received from suppliers and dischargers, and converted to million gallons per day for comparison of the data. Unmetered water withdrawals, uses, and discharges were estimated by category (domestic, industrial, commercial, and agricultural). The NEWUDS database was queried to obtain the average water use for the study period.

Public Water Supply and Interbasin Transfers

Public water suppliers are defined as those serving more than 25 people or having at least 15 service connections year round. These suppliers were categorized as major public suppliers that have a system of distribution (table 4) and minor suppliers with closed systems (table 8) that serve only their own populations. Eleven major public-water suppliers serve the West Narragansett Bay study area: the East Providence Water District, Jamestown Water Division, Kent County Water Authority, Narragansett Water Department, North Kingstown Water Department, Pawtucket Water Supply Board, Providence Water, RIEDC, South Kingstown Water Department, United Water of Rhode Island, and the Warwick

Water Authority. These major suppliers provide water for domestic, commercial, industrial, and agricultural uses. The difference between purchases and estimated distribution is the nonaccount water, unless the supplier provided distribution data by category and the purchases equal the total distribution. The systems for each major water supplier are diagrammed in figs. 4-13; the one minor water supplier is listed in table 8. Because limited data are available on water withdrawals by minor suppliers, the water use was estimated by multiplying 67 gal/d/person (the domestic water-use coefficient for public supply) by the population served (Korzendorfer and Horn, 1995).

The East Providence Water District received an average of 5.48 Mgal/d from Providence Water during the study period, and supplied customers in the city of East Providence. Customers in the East Providence part of the Providence and Seekonk subbasin are accounted for in the East Narragansett Bay study area.

The Jamestown Water Division withdrew an average of 0.213 Mgal/d from North Pond Reservoir from 1995 through 1998, and supplied customers in the town of Jamestown. The water department also has a well, from which they pumped an average of 0.014 Mgal/d from 1995 through 1998; however, this water is pumped into the North Pond Reservoir, so the total distribution in the system is based on withdrawals from the reservoir. The water district also imported 0.032 Mgal/d from the North Kingstown Water Department during the study period (fig. 4).

The Kent County Water Authority system includes the Mishnock wells 1, 2, and 3, the Spring Lake well, the East Greenwich well, and purchases from Providence Water and the Warwick Water Authority. The Mishnock and Spring Lake wells withdraw water from the Mishnock ground-water reservoir in the South Branch Pawtuxet subbasin. The Mishnock well 3 was not in operation during the study period.

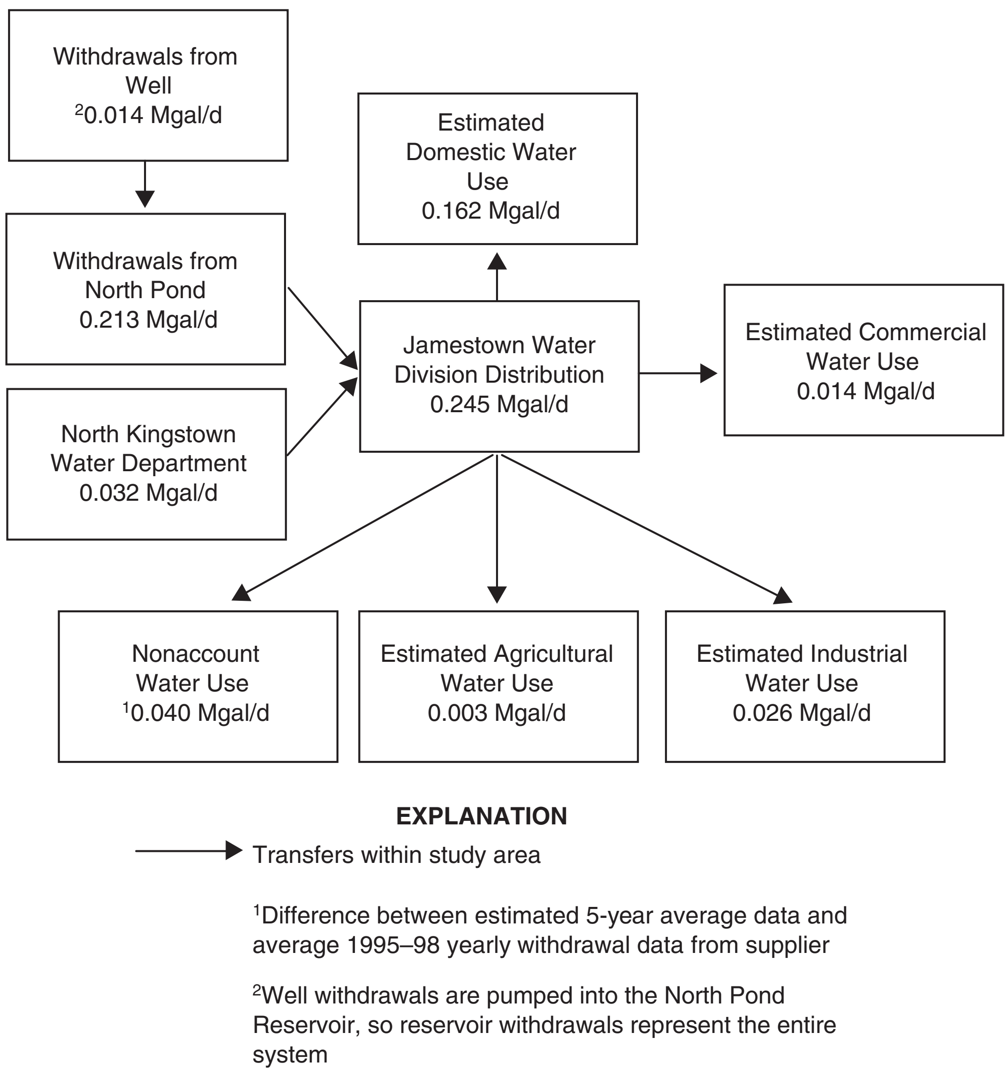


Figure 4. Jamestown Water Division withdrawals, distribution, and estimated use, West Narragansett Bay area, coastal Rhode Island.

This part of the supply system withdrew an average of 1.006 Mgal/d during the study period from the Mishnock aquifer. The East Greenwich well withdrew 0.586 Mgal/d from the Hunt-Annaquatucket-Pettaquamscutt aquifer. To supplement the system, the Kent County Water Authority purchased an average of 6.752 Mgal/d from Providence Water, as well as an average of 1.537 Mgal/d from the Warwick Water Authority during the study period. The Kent County Water Authority also sold an average of 0.221 Mgal/d to the Warwick Water Authority during the study period (fig. 5).

The Narragansett Water Department supplies the domestic, industrial, and commercial water users in the southern part of the town of Narragansett. The average purchase from United Water of Rhode Island and North Kingstown Water Department for the study period was 0.633 Mgal/d, which was imported from the Pawcatuck River Basin. From this water, an estimated 0.439 Mgal/d was used in the West Narragansett Bay study area and 0.194 Mgal/d was exported to the South Coastal study area (fig. 6).

The North Kingstown Water Department pumped an average of 2.785 Mgal/d from their nine wells during the study period and supplied water to the town of North Kingstown (fig. 7). Roughly 90 percent of the public supply in the town was provided by the North Kingstown Water Department; some of these customers were in the Pawcatuck River Basin. An estimated 0.090 Mgal/d was exported to the Pawcatuck River Basin. The North Kingstown Water Department also supplied 0.032 Mgal/d to the Jamestown Water Division from 1995 through 1998.

Providence Water, which serves 60 percent of the population of Rhode Island, is the largest public supplier in the state. Its source of water is the Scituate Reservoir in the Pawtuxet River Basin. Providence Water directly supplied an average of 39.2 Mgal/d to its retail customers during the study period. It supplied water to two major suppliers in the study area: the Kent County Water Authority and the Warwick Water Authority, who served their own retail customers. The total amount of water delivered to these suppliers averaged 16.36 Mgal/d for the period of study (fig. 8).

The Pawtucket Water Supply Board served its own retail customers directly, and supplied water through interconnections to five major suppliers who served their own retail customers. During the study period, it was estimated that 6.187 Mgal/d were directly supplied to customers in the West Narragansett Bay study area (fig. 9).

The RIEDC withdrew an average of 0.796 Mgal/d from three wells in the Annaquatucket subbasin from 1995 through 1998, and supplied customers in the town of North Kingstown (fig. 10). Roughly 10 percent of the public-supply area of the town of North Kingstown was supplied by RIEDC, but 74 percent of the industrial land-use area was within this district.

The South Kingstown Water Department supplied the domestic, industrial, and commercial water users along the coast in the southern part of the town with 0.389 Mgal/d from wells from 1995 through 1999. Wholesale purchases from United Water of Rhode Island of about 0.040 Mgal/d served the Middlebridge area in the Pettaquamscutt River subbasin (fig. 11).

The UWRI system includes the Tuckertown (four wells) and Howland (two wells) well fields in the Pawcatuck Basin; this supply system withdrew an average of 2.619 Mgal/d from the Mink aquifer during the study period. The retail distribution to customers in the study area was about 0.438 Mgal/d, and another 0.673 Mgal/d was a wholesale transfer to the Narragansett and South Kingstown Water Departments. About 1.508 Mgal/d of the UWRI water supply went to the South Coastal Drainage Basin or the Pawcatuck River Basin (fig. 12).

The Warwick Water Authority received 9.534 Mgal/d from Providence Water during the study period through two interconnections, at Natick Street and Pettaconsett Avenue, and supplied customers in the town of Warwick. In addition, the Warwick Water Authority purchased 0.221 Mgal/d from Kent County Water Authority through their interconnection on Potowomut Avenue. They supplied an average of 1.537 Mgal/d to the Kent County Water Authority through the interconnection on Bald Hill Road. An estimated 4.551 Mgal/d was supplied to customers in the study area, and the remaining 1.932 Mgal/d went to the Pawtuxet River Basin (fig. 13).

Domestic Water Use

Domestic water use is the water used by residential populations either from public supply or self-supply, which usually consists of an individual well (table 5). Because water suppliers provide information on populations served within towns rather than within subbasins, subbasin populations on public supply were estimated by merging the 1990 census blocks that have the domestic populations on individual wells with the basin coverages in GIS. The 1990 subbasin population that supplies its own water was subtracted from the total population for each subbasin. The ratio of the 1990 to 1995–99 populations in each subbasin was applied to obtain the subbasin population on public-supply and self-supply water for each town for the period of study (table 1). Because limited withdrawal data were available for the minor public supplier in the study area, the domestic water-use coefficient for public supply (67 gal/d/person) was applied to the population served by the minor supplier (Korzendorfer and Horn, 1995). Domestic consumptive water use (table 9) is assumed to be 15 percent of the estimated use (Solley and others, 1998).

Public-Supply Use

Public-supply domestic water use was calculated by multiplying the population by 67 gal/d/person (Korzendorfer and Horn, 1995) and ranged from no public supply in the Exeter portion of the Annaquatucket and Hunt subbasins to 3.164 Mgal/d in the Providence portion of the Providence and Seekonk subbasin (table 5).

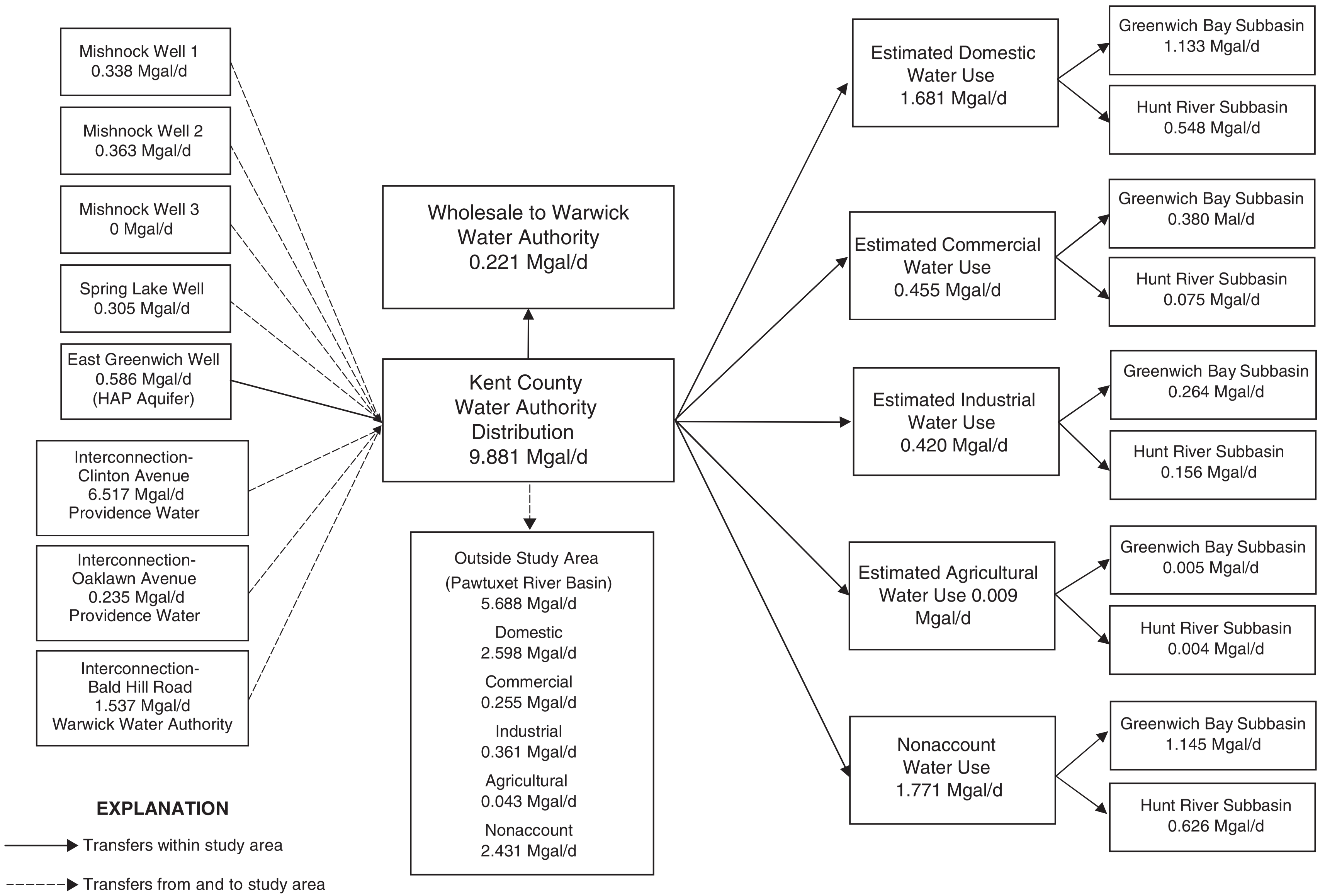


Figure 5. Kent County Water Authority withdrawals, distribution, and estimated use, West Narragansett Bay area, coastal Rhode Island. HAP, Hunt-Annaquatucket-Pettaquamscutt.

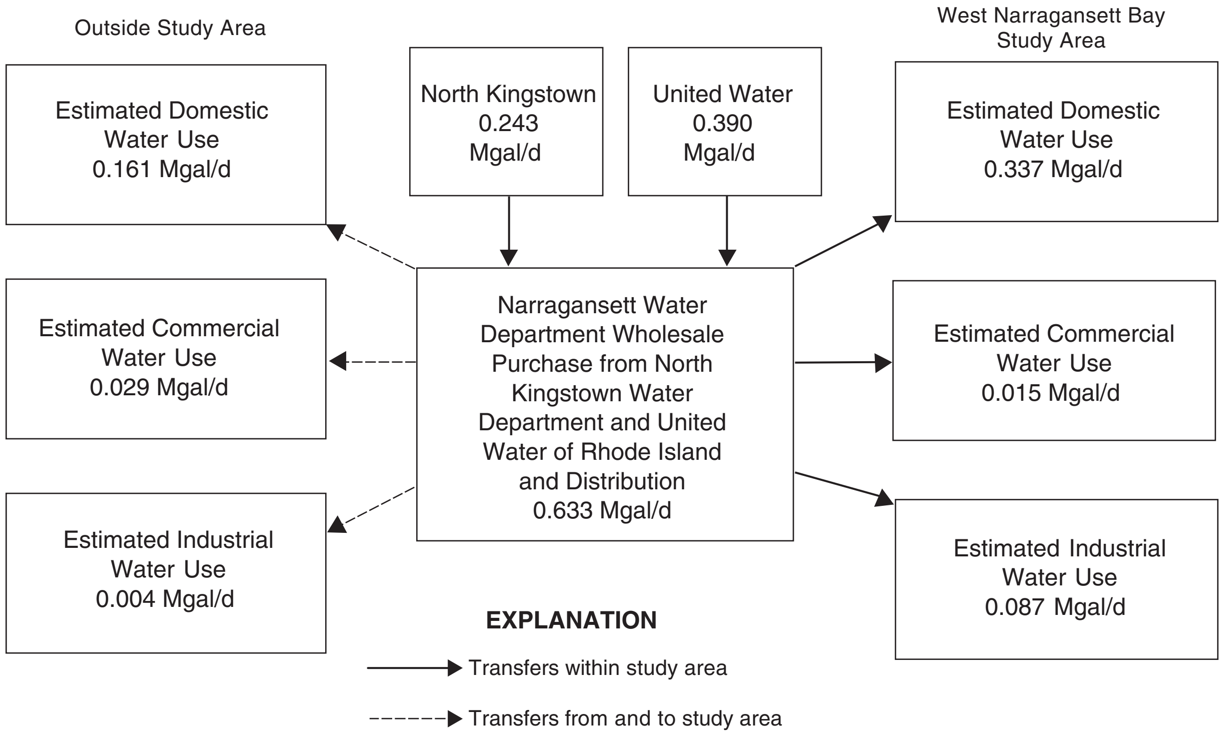


Figure 6. Narragansett Water Department distribution and estimated use, West Narragansett Bay area, coastal Rhode Island.

Self-Supply Use

Domestic self-supply withdrawals were estimated by multiplying the self-supply population by 71 gal/d/person (Korzendorfer and Horn, 1995). Estimated domestic withdrawals and use in the study area ranged from no self-supply in several towns in the Annaquatucket and the Providence and Seekonk subbasins to 0.185 Mgal/d in the town of Jamestown in the Conanicut Island subbasin (table 5).

Commercial and Industrial Water Use

Limited data are available on commercial and industrial water use from public supply and self-supply systems because withdrawals and use for these water-use categories are not regulated in Rhode Island. Commercial and industrial water-use estimates were derived from the total water use calculated for each town in the study area (table 10 in back of report) and divided into subbasins on the basis of the land-use type. Commercial and industrial consumptive water use (table 9) is assumed to be 10 percent of the estimated use (Solley and others, 1998).

Public-Supply Use

Information on commercial and industrial use of public-supply water included metered and unmetered data. If 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 volumes delivered to the commercial and industrial users together, and in other cases, no data for commercial and industrial users were available. The Standard Industrial Classification (SIC) codes classify government water use within the commercial water-use category; however, government water use was entered as a separate distribution into NEWUDS. Some water-supply-district service areas are in one or more subbasins, so public-supply commercial and industrial water uses were apportioned based on land-use area (table 7). Land-use coverages from RIGIS were merged with the water district, town, and subbasin coverages to obtain the commercial and industrial land-use areas within the supply districts for towns served in the study area (table 4).

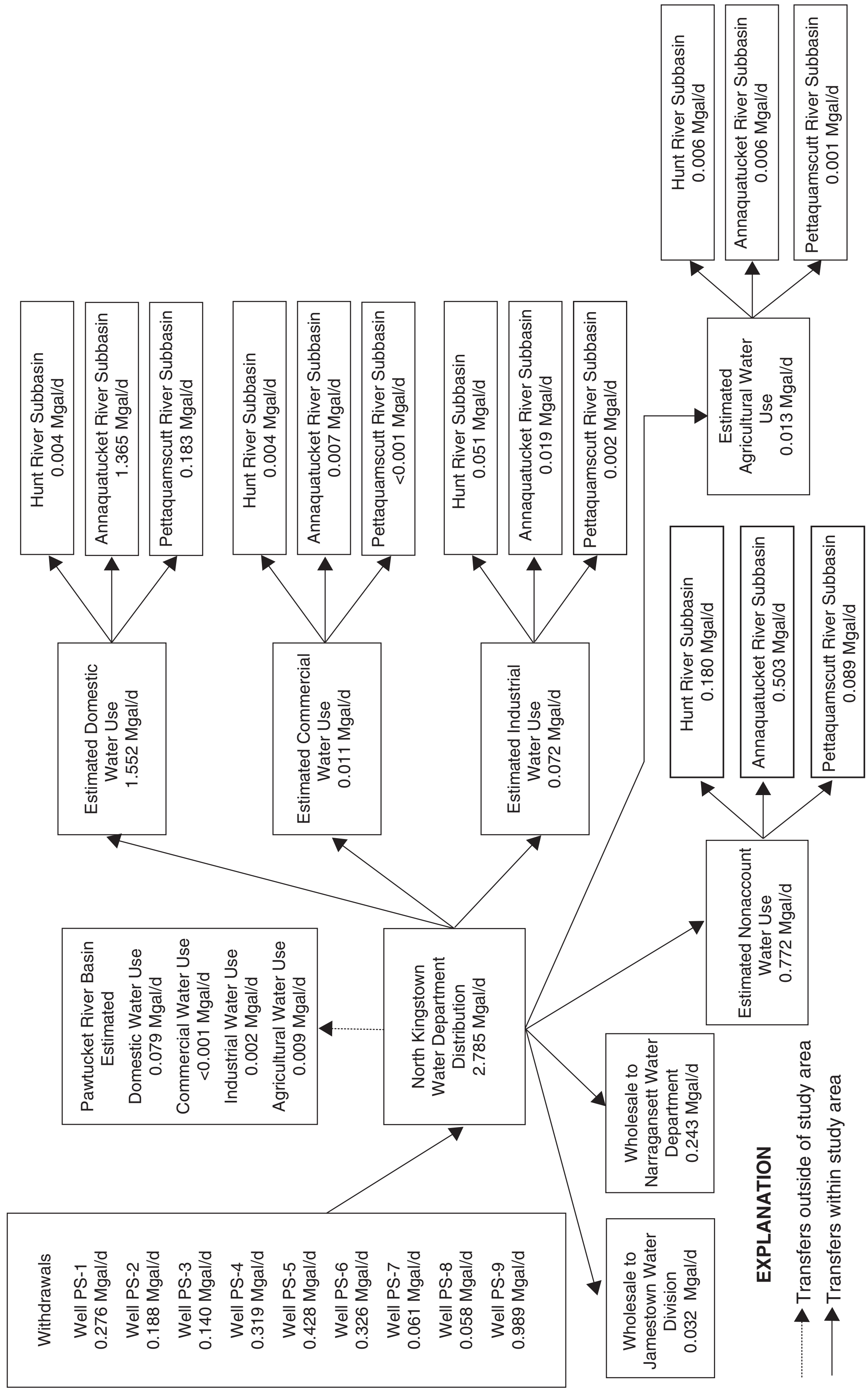


Figure 7. North Kingstown Water Department withdrawals, distribution, and estimated use, West Narragansett Bay area, coastal Rhode Island.

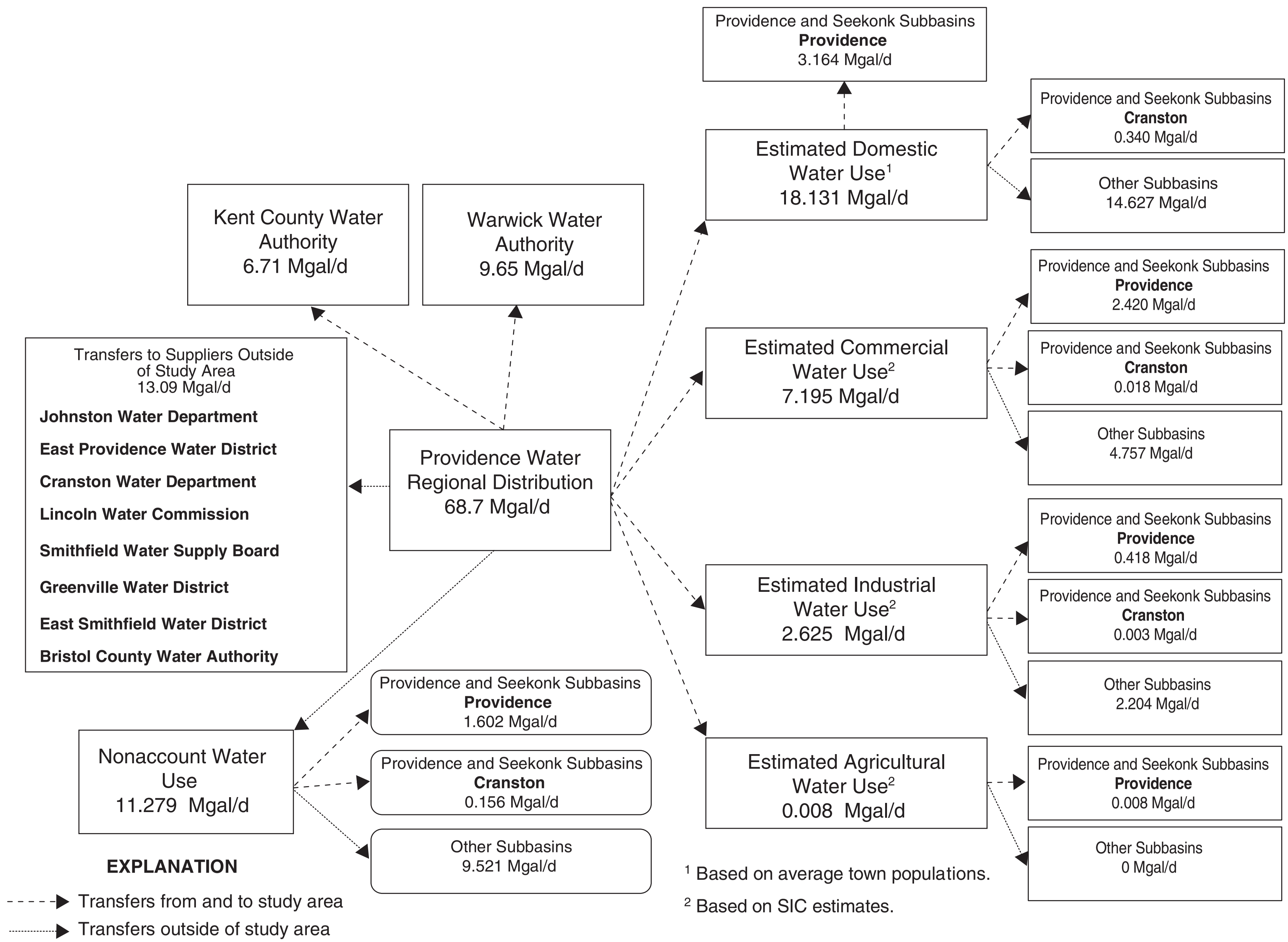


Figure 8. Providence Water Supply Board distribution and estimated use, West Narragansett Bay area, coastal Rhode Island.

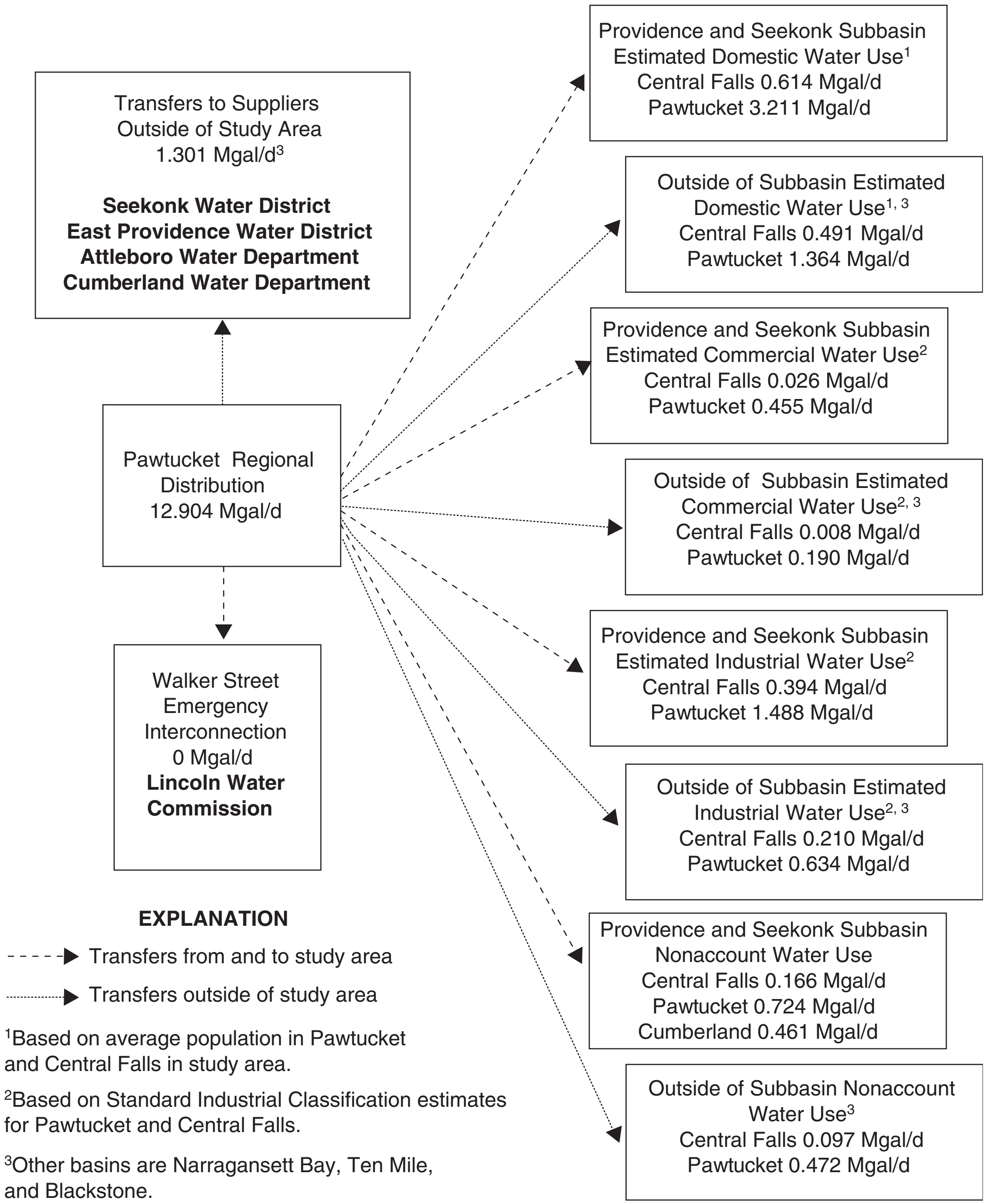


Figure 9. Pawtucket Water Supply Board distribution and estimated use, West Narragansett Bay area, coastal Rhode Island.

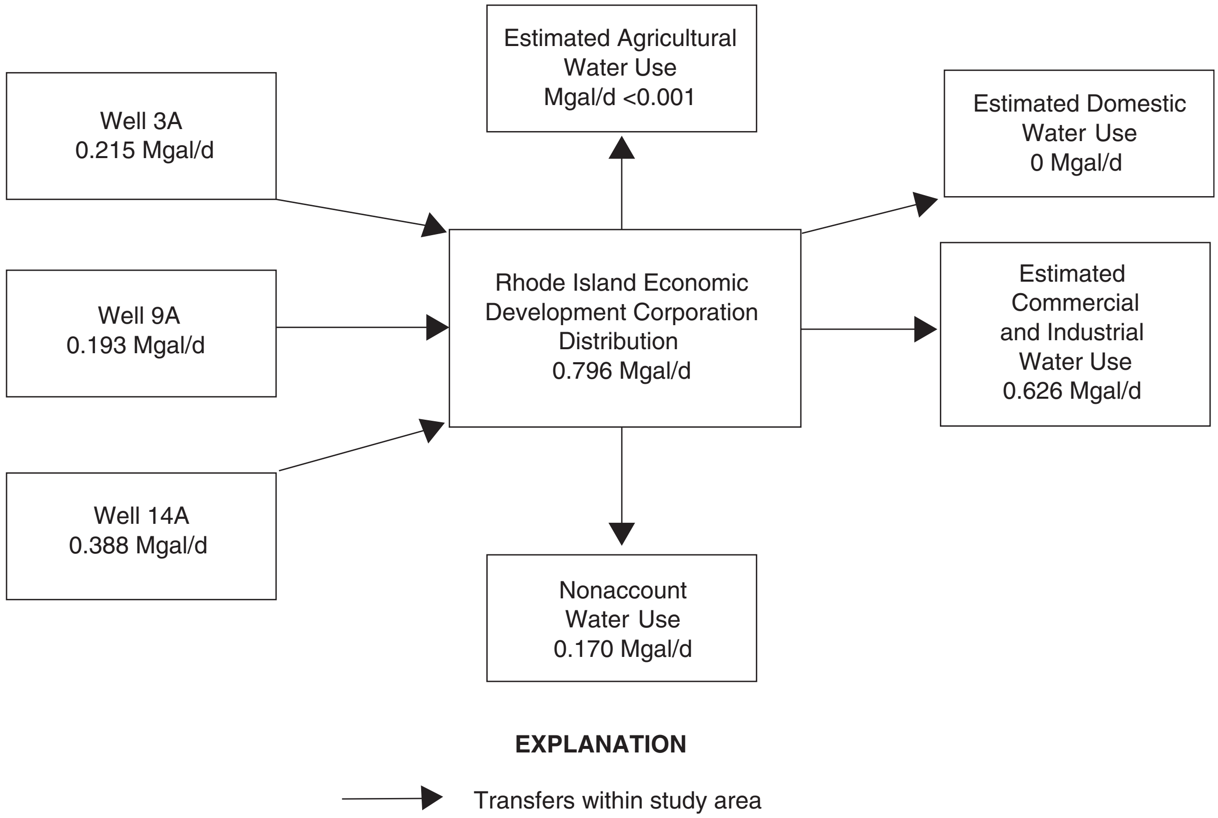


Figure 10. Rhode Island Economic Development Corporation withdrawals, distribution, and estimated use, West Narragansett Bay area, coastal Rhode Island.

Self-Supply Use

Commercial and industrial self-supply water use was calculated by multiplying the number of employees for the industrial and commercial sectors for each SIC code by a water-use coefficient (the number of gallons used on average by each employee) (table 10). The coefficients were obtained from the Institute of Water Resources, Municipal and Industrial Needs System (IWR-MAIN) as described in Horn (2000). The number of employees in each sector was obtained from the industrial and commercial directories, Export/Import Directory, High Tech Industries in Rhode Island, and Major Employers in Rhode Island, published by the RIEDC (1999, 2000a, 2000b). Self-supply commercial and industrial water use was estimated for each town by subtracting the estimated public-supply commercial and industrial use from the total aggregate. The results for commercial and industrial use are listed in table 5. The total values for each town were disaggregated by subbasin on the basis of the industrial and commercial land-use area for each town (table 2). Commercial use of self-supply water ranged from no self supply in several towns and basins to 0.007 Mgal/d in the North Kingstown portion of the Annaquatucket River subbasin. Most towns in most subbasins had no self-supply industrial water use. The South Kingstown portion of the Pettaquamscutt subbasin was the only area with substantial industrial self-supply (0.010 Mgal/d) (table 5).

Agricultural Water Use

Agricultural water use includes livestock use, crop irrigation, and golf-course irrigation. Crop and livestock use were estimated by multiplying acres irrigated and livestock counts by a coefficient for each acre and animal, respectively. Irrigated acreage and livestock counts were obtained from information provided by the U.S. Department of Agriculture (USDA), NRCS (formerly the Soil Conservation Service (SCS)), and the RIDEM Division of Agriculture. Golf-course irrigation was estimated from yardages from the Web sites World Golf.com (2002) and Golfcourse.com (2002). The value was estimated for each town and then disaggregated into the subbasins (table 5). Consumptive water use for agriculture was assumed to be 100 percent (table 9).

Livestock water use was estimated with a different coefficient for each type of livestock (Laura Medalie, U.S. Geological Survey, written commun., 1995). Because the data on livestock and irrigated acres data are reported in the 1997

Table 9. Estimated consumptive water use by town and subbasin in the West Narragansett Bay area, coastal Rhode Island, 1995–99.

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

City/Town	Domestic (Mgal/d)		Commercial (Mgal/d)		Industrial (Mgal/d)		Agricultural (Mgal/d)		Total (Mgal/d)
	Public	Self	Public	Self	Public	Self	Public	Self	
Annaquatucket River Subbasin									
Exeter	--	<0.001	--	--	--	--	<0.001	--	--
Narragansett	0.022	.001	0.002	--	--	--	.001	--	0.026
North Kingstown	.153	.007	.011	0.001	<0.001	--	.012	0.193	.377
Warwick	<.001	--	--	--	--	--	--	--	<.001
Subbasin total	0.175	0.008	0.013	0.001	<0.001	--	0.013	0.193	0.403
Greenwich Bay Subbasin									
East Greenwich	0.046	0.001	0.001	0.001	0.001	<0.001	<0.001	0.109	0.159
Warwick	.346	.002	.053	--	.007	--	.003	.108	.519
West Warwick	.069	.002	.003	--	.014	--	<.001	--	.088
Subbasin total	0.461	0.005	0.057	0.001	0.022	<0.001	0.003	0.217	0.766
Hunt River Subbasin									
Coventry	0.001	<0.001	--	--	--	--	--	--	0.001
East Greenwich	.058	.016	0.001	<0.001	0.018	<0.001	0.002	0.040	.135
Exeter	--	<.001	--	--	--	--	<.001	.001	.001
North Kingstown	.066	.003	.006	<.001	.005	--	.004	.036	.120
Warwick	.013	<.001	.002	--	--	--	.003	<.001	.018
West Greenwich	<.001	.001	--	--	--	--	<.001	<.001	.001
West Warwick	<.001	.001	--	--	.004	--	--	--	.005
Subbasin total	0.138	0.021	0.009	<0.001	0.027	<0.001	0.009	0.077	0.281
Pettaquamscutt River Subbasin									
Narragansett	0.094	0.002	0.001	--	0.010	--	0.002	0.078	0.187
North Kingstown	.015	.003	<.001	<0.001	.023	--	.006	.002	.049
South Kingstown	.005	.002	--	--	.001	0.001	.001	.002	.012
Subbasin total	0.114	0.007	0.001	<0.001	0.034	0.001	0.009	0.082	0.248
Providence and Seekonk Rivers Subbasin									
Central Falls	0.009	--	<0.001	--	0.001	--	--	--	0.010
Cranston	.051	--	.002	<0.001	<.001	<0.001	--	--	.053
Pawtucket	.425	<0.001	.037	--	.136	--	--	0.075	.673
Providence	.475	.001	.242	--	.042	--	--	--	.760
Warwick	.312	--	.035	--	.004	--	0.001	<.001	.352
Subbasin total	1.272	0.001	0.316	<0.001	0.183	<0.001	0.001	0.075	1.848
Conanicut Island Subbasin									
Jamestown	0.016	0.018	0.001	<0.001	0.003	--	0.003	0.038	0.079
Study area total	2.176	0.060	0.397	0.002	0.269	0.001	0.038	0.682	3.625

Table 10. Estimated water use for each 2-digit Standard Industrial Classification code by town in the West Narragansett Bay area, coastal Rhode Island, 1995–99.

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

Two-digit Standard Industrial Classification category and code	IWR-MAIN coefficient	Water use, in million gallons per day				
		Central Falls	Coventry	Cranston	East Greenwich	Exeter
Mining [14]	--	--	--	--	--	--
Construction [15-17]	35	--	--	0.009	--	--
Industrial [20-39]						
Food [20]	469	--	--	.162	0.003	--
Textile mills [22]	315	0.291	0.020	.008	--	--
Finished apparel [23]	13	--	--	--	--	--
Wood, lumber [24]	78	--	--	--	--	<0.001
Furniture [25]	30	--	--	--	--	--
Paper products [26]	863	.175	--	.237	--	--
Printing, publishing [27]	42	--	--	.0001	<.001	--
Chemical products [28]	289	.004	.102	.069	--	--
Petroleum refining [29]	1,045	--	--	--	--	--
Rubber [30]	119	--	--	.15	--	.024
Leather [31]	148	--	--	.007	--	--
Stone, clay, glass, and concrete [32]	202	.101	--	.141	--	--
Primary metals [33]	178	--	--	.012	.026	--
Fabricated metal [34]	95	.013	--	.066	.002	--
Machinery [35]	58	.01	.009	.029	.085	--
Electrical equipment [36]	71	--	<.001	.035	.072	--
Transportation equipment [37]	63	--	--	--	--	--
Instruments [38]	66	--	.001	.039	.003	--
Jewelry, precious metals [39]	36	.009	.008	.040	.003	--
Total industrial [20-39]	--	0.603	0.140	0.995	0.193	0.024
Commercial [40-97]						
Transportation, communication, utilities [40-49]	51	--	--	0.019	0.013	--
Wholesale trade [50-51]	58	--	--	.034	--	--
Retail trade [52-59]	58	--	0.034	.290	.006	--
Finance, insurance, real estate [60-67]	71	--	--	.008	--	--
Services [70-89]	106	0.034	--	.375	.004	0.017
Public administration [91-97]	71	--	--	--	--	--
Total commercial [40-97]	--	0.034	0.068	0.726	0.023	0.017

Table 10. Estimated water use for each 2-digit Standard Industrial Classification code by town in the West Narragansett Bay area, coastal Rhode Island, 1995–99.—Continued

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

Two-digit Standard Industrial Classification category and code	IWR-MAIN coefficient	Water use, in million gallons per day				
		Jamestown	Narragansett	North Kingstown	Pawtucket	Providence
Mining [14]	--	--	--	--	--	--
Construction [15-17]	35	--	--	--	0.005	0.072
Industrial [20-39]						
Food [20]	469	<0.001	0.103	0.011	.210	.176
Textile mills [22]	315	--	--	--	.580	.058
Finished apparel [23]	13	--	--	<.001	.0003	.001
Wood, lumber [24]	78	--	--	.003	--	--
Furniture [25]	30	--	--	.008	.022	.003
Paper products [26]	863	--	--	--	.526	.582
Printing, publishing [27]	42	--	--	--	.025	.069
Chemical products [28]	289	.026	--	.020	.019	.019
Petroleum refining [29]	1,045	--	--	--	--	--
Rubber [30]	119	--	--	.109	.158	.044
Leather [31]	148	--	--	--	--	.001
Stone, clay, glass, and concrete [32]	202	--	--	--	.003	
Primary metals [33]	178	--	--	--	.283	.055
Fabricated metal [34]	95	--	--	.014	.049	.125
Machinery [35]	58	--	<.001	.003	.015	.026
Electrical equipment [36]	71	--	--	.002	.026	.048
Transportation equipment [37]	63	--	--	.087	--	.026
Instruments [38]	66	--	--	.030	.098	.075
Jewelry, precious metals [39]	36	--	--	.001	.107	.215
Total industrial [20-39]	--	0.020	0.103	0.288	2.121	1.523
Commercial [40-97]						
Transportation, communication, utilities [40-49]	51	--	<0.001	0.001	0.016	0.435
Wholesale trade [50-51]	58	<0.001	--	.008	.003	.038
Retail trade [52-59]	58	--	.025	.038	.048	.122
Finance, insurance, real estate [60-67]	71	--	--	--	.048	.676
Services [70-89]	106	.015	.036	.119	.520	4.72
Public administration [91-97]	71	--	.011	.022	--	--
Total commercial [40-97]	--	0.015	0.072	0.188	0.635	5.991

Table 10. Estimated water use for each 2-digit Standard Industrial Classification code by town in the West Narragansett Bay area, coastal Rhode Island, 1995–99.—Continued

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

Two-digit Standard Industrial Classification category and code	IWR-MAIN coefficient	Water use, in million gallons per day			
		South Kingstown	Warwick	West Greenwich	West Warwick
Mining [14]	--	--	--	--	--
Construction [15-17]	35	--	0.022	--	--
Industrial [20-39]					
Food [20]	469	0.052	.009	--	--
Textile mills [22]	315	.008	.030	0.009	0.090
Finished apparel [23]	13	--	--	--	--
Wood, lumber [24]	78	--	--	--	--
Furniture [25]	30	--	.016	--	--
Paper products [26]	863	--	.022	--	--
Printing, publishing [27]	42	--	.007	--	--
Chemical products [28]	289	.003	.010	.068	.147
Petroleum refining [29]	1,045	--	--	--	--
Rubber [30]	119	--	.004	.003	.015
Leather [31]	148	--	--	--	--
Stone, clay, glass, and concrete [32]	202	--	--	--	.015
Primary metals [33]	178	--	.039	--	--
Fabricated metal [34]	95	--	.050	--	.060
Machinery [35]	58	--	.026	.058	.008
Electrical equipment [36]	71	.110	.146	--	.030
Transportation equipment [37]	63	.001	--	--	--
Instruments [38]	66	.007	.038	--	<.001
Jewelry, precious metals [39]	36	--	.054	--	.001
Total industrial [20-39]	--	0.181	0.473	0.138	0.504
Commercial [40-97]					
Transportation, communication, utilities [40-49]	51	--	0.075	0.001	0.020
Wholesale trade [50-51]	58	--	.008	--	.006
Retail trade [52-59]	58	0.014	.363	--	--
Finance, insurance, real estate [60-67]	71	--	.166	--	.066
Services [70-89]	106	.365	.860	--	.014
Public administration [91-97]	71	--	--	--	--
Total commercial [40-97]	--	0.379	1.472	0.001	0.106

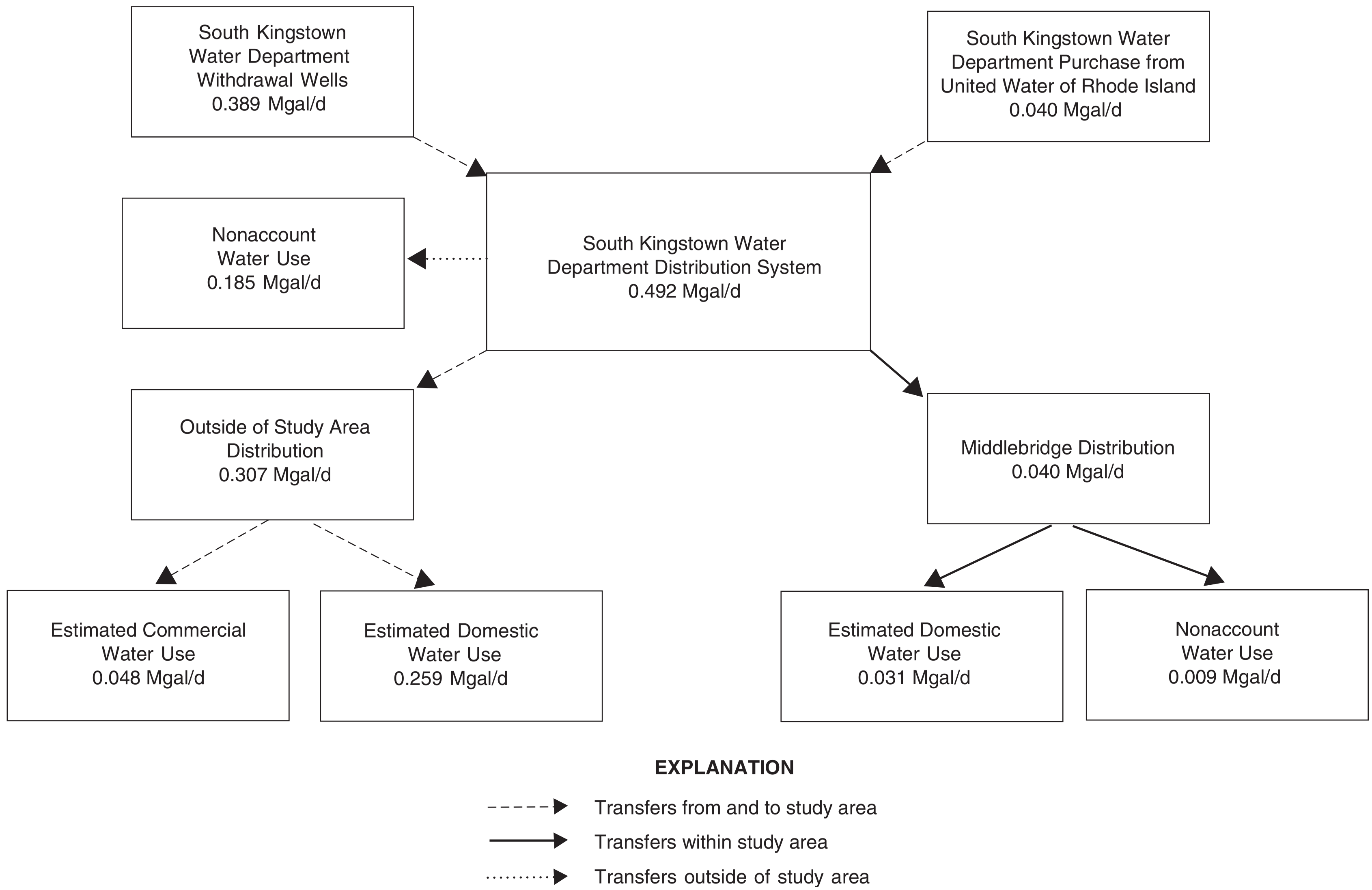


Figure 11. South Kingstown Water Department withdrawals, distribution, and estimated use, West Narragansett Bay area, coastal Rhode Island.

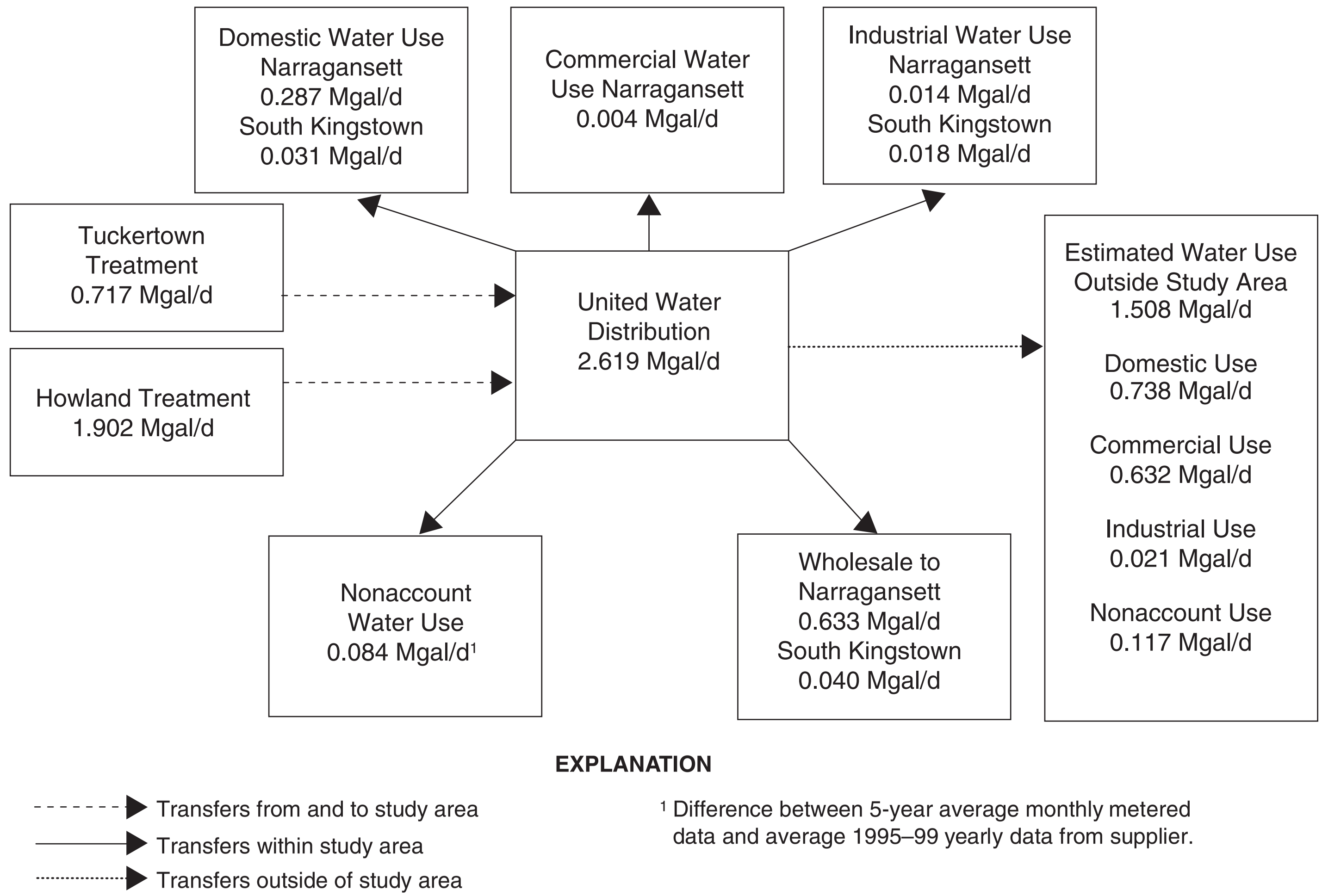


Figure 12. United Water of Rhode Island distribution and estimated use, West Narragansett Bay area, coastal Rhode Island.

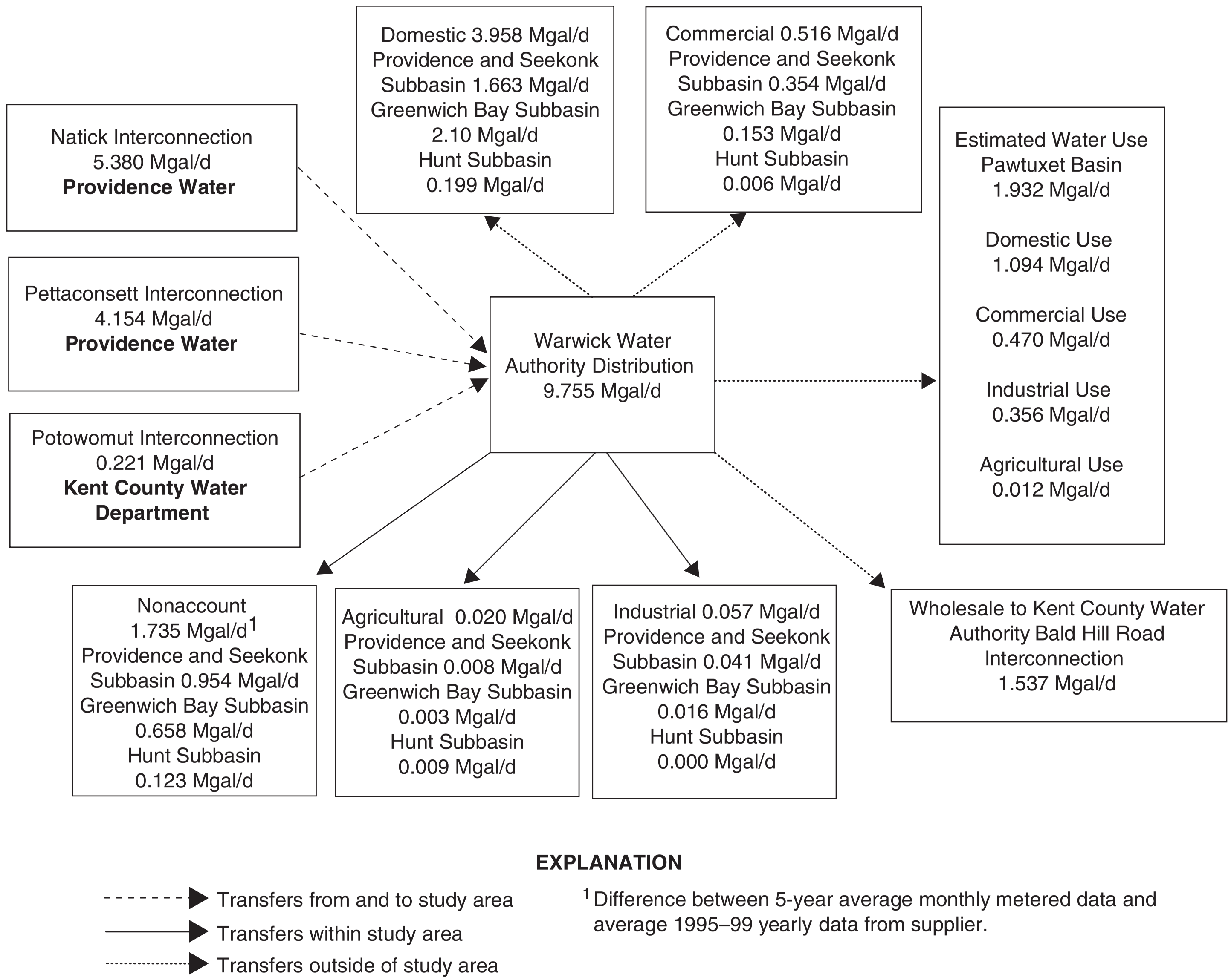


Figure 13. Warwick Water Authority distribution and estimated use, West Narragansett Bay area, coastal Rhode Island.

Census of Agriculture at the county level, the estimates were disaggregated on the basis of the percentage of agricultural land use by town and then subbasin. The livestock water-use estimate represents a year-round usage. Although about 60 percent of livestock water use is consumptive, and the other 40 percent is returned to the ground water (Horn and others, 1994), this distinction was negligible for the study area. Livestock water use accounted for 1.0 percent of the agricultural water use in the study area during the study period.

Crop irrigation was estimated with a coefficient of 1 in/week/acre (equivalent to 0.143 in/d/acre) of water to irrigate crop land (Laura Medalie, U.S. Geological Survey, written commun., 2000). The monthly deficit of water was determined by subtracting the average monthly rainfall from the 0.143 in/day/acre needed, and multiplying the water deficit by the number of the irrigated acres. The resulting value was disaggregated into the water use by subbasin on the basis of agricultural land-use area (table 2).

Golf-course irrigation was estimated with the coefficient of 0.0116 Mgal/d for each 1,000 yards (Laura Medalie, U.S. Geological Survey, written commun., 2000). This coefficient was comparable to the average withdrawal rate of 0.0117 Mgal/d for each 1,000 yards summarized in the 2000 water-use compilation for Massachusetts (Hutson and others, 2004). According to the USDA (1993), most irrigation occurs during June, July, and August; therefore, it was assumed that crop and golf-course irrigation water was used during these months.

It was assumed that golf courses were self-supplied in the study area, and the rest of the agricultural use was apportioned into self or public supply on the basis of the percentage of agricultural land use in the water districts in each town. Public-supply agricultural use ranged from no public supply in several towns to 0.012 Mgal/d in the North Kingstown portion of the Annaquatucket subbasin. Self-supply agricultural use ranged from no self-supply in several towns to 0.193 Mgal/d in the North Kingstown portion of the Annaquatucket subbasin (table 5). Self-supply accounted for 95 percent of the agricultural water use in the study area.

Return Flow and Interbasin Transfers

In Rhode Island, commercial and industrial dischargers are required to report to the RIDEM Office of Water Resources the rates of water returned to the environment through surface water and ground water. The return flow in the study area ranged from 0.176 Mgal/d in the Conanicut Island subbasin to 1.703 Mgal/d in the Greenwich Bay subbasin (table 11).

Site-Specific Return Flow

Small systems in Rhode Island that release water back into the environment are identified through the RIDEM Rhode Island Pollutant Discharge Elimination System (RIPDES), and some of these systems are required to report their discharge values. Return-flow data were collected from RIDEM for these small systems in the study area (table 12). These return flows are conveyed by discharge pipes that dispose water used during commercial and industrial processes (operations), but also include condensation from air-conditioning systems. The total of the average RIPDES return flows in the study area was 267.357 Mgal/d. Most of this return flow was cooling water from the Narragansett Electric power plant (266.687 Mgal/d), and was not included with the return flows in this study because it is not freshwater. The remaining 0.670 Mgal/d of return flow occurred in the Annaquatucket subbasin (0.189 Mgal/d), the Hunt subbasin, (0.182 Mgal/d), and the Providence and Seekonk subbasin (0.298 Mgal/d) (table 12).

Monthly data were collected for WWTFs in or serving the towns in the study area. The WWTFs include the RIEDC North Kingstown WWTF, the East Greenwich WWTF, the Scarborough WWTF, the Narragansett WWTF, the Fields Point Facility in Providence, and the Jamestown WWTF. The Bucklin Point Facility in East Providence serves population in the study area, but is not in the study area. The average discharge for the study period from these plants was 131.503 Mgal/d (table 13). The publicly disposed water in the study area is considered an out-of-basin transfer because the water is discharged to Narragansett Bay (table 11).

Aggregate Return Flow

Aggregate return flow was estimated for domestic, industrial, and commercial water use. Domestic populations with septic systems were assumed to return 85 percent of the water used to ground water, and to consume 15 percent (Solley and others, 1998). Populations on public disposal were used to determine the populations on self-disposal of water (table 1). To estimate the self-disposal domestic water use, the population (table 1) was multiplied by the self-supplied domestic water-use coefficient of 71 gal/d/person, converted to Mgal/d, and multiplied by 85 percent (table 11). For this study, it was estimated that 90 percent of industrial and commercial return flow is disposed to ground water and that 10 percent is consumed (Horn, 2000).

Interbasin Transfers

Wastewater collected from towns and treated at the RIEDC North Kingstown, East Greenwich, Scarborough, Narragansett, Bucklin Point, Fields Point, and Jamestown WWTFs was exported from the study area to Narragansett Bay. Estimated populations on public-disposal systems (table 1) and estimates of publicly disposed industrial and commercial water from water districts were used to determine the water exports. Exports were 10.983 Mgal/d (table 14).

Most of the public water supply, 22.319 Mgal/d, was imported to the basin. The result was a net gain of 11.336 Mgal/d (table 14). Within the balance of the water withdraw-

Table 11. Estimated domestic, commercial, industrial, and metered return flow in the West Narragansett Bay area, coastal Rhode Island, 1995–99.

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

City/Town	Estimated domestic return flow (Mgal/d)		Estimated commercial return flow (Mgal/d)		Estimated industrial return flow (Mgal/d)		Metered return flow		Total self-disposal and metered return flow (Mgal/d)
	Public	Self	Public	Self	Public	Self	RIPDES	Wastewater-treatment facilities	
Annaquatucket River Subbasin									
Exeter	--	0.001	--	--	--	--	--	--	0.001
Narragansett	0.055	.080	0.013	--	--	--	0.160	--	.240
North Kingstown	.174	.769	.098	0.006	0.001	--	.029	0.890	.804
Warwick	<.001	--	--	--	--	--	--	--	--
Subbasin total	0.229	0.850	0.111	0.006	0.001	--	0.189	0.890	1.045
Greenwich Bay Subbasin									
East Greenwich	0.149	0.123	0.006	0.005	0.010	<0.001	--	0.905	0.128
Warwick	.515	1.542	.480	--	.059	--	--	--	1.542
West Warwick	.370	.033	.028	--	.123	--	--	--	.033
Subbasin total	1.034	1.698	.514	0.005	0.192	<0.001	--	0.905	1.703
Hunt River Subbasin									
Coventry	0.001	0.004	--	--	--	--	--	--	0.004
East Greenwich	.056	.386	0.005	0.005	0.164	<0.001	0.132	--	.523
Exeter	--	.001	--	--	--	--	--	--	.001
North Kingstown	.045	.366	.055	.004	.047	--	.050	--	.420
Warwick	.005	.076	.014	--	--	--	--	--	.076
West Greenwich	--	.006	--	--	--	--	--	--	.006
West Warwick	<.001	.004	--	--	.033	--	--	--	.004
Subbasin total	0.107	0.843	0.074	0.009	0.244	<0.001	0.182	--	1.034
Pettaquamscutt River Subbasin									
Narragansett	0.358	0.193	0.007	--	0.090	--	--	3.304	0.193
North Kingstown	.007	.099	.002	<0.001	.209	--	--	--	.099
South Kingstown	.001	.042	--	--	.005	0.009	--	--	.051
Subbasin total	0.366	0.334	0.009	<0.001	0.214	0.009	--	3.304	0.343
Providence and Seekonk Rivers Subbasin									
Central Falls	0.048	0.001	<0.001	--	0.013	--	--	--	0.001
Cranston	.273	.017	.018	<0.001	.003	<0.001	--	--	.017
Pawtucket	2.337	.076	.333	--	1.229	--	--	--	.076
Providence	2.626	.071	2.180	--	.376	--	266.986	102.012	.071
Warwick	.674	1.157	.314	--	.035	--	<.001	--	1.157
Subbasin total	5.958	1.322	2.845	<.001	1.656	<.001	266.986	102.012	1.322
Conanicut Island Subbasin									
Jamestown	0.121	0.175	0.013	0.001	0.023	--	--	0.416	0.176
Study area total	7.815	5.222	3.566	0.021	2.330	0.009	267.357	107.527	5.623

Table 12. RIPDES sites by town and subbasin in the West Narragansett Bay area, coastal Rhode Island, 1995–99.

[**SIC**, Standard Industrial Classification; **Mgal/d**, million gallons per day; RI, Rhode Island; RIPDES, Rhode Island Point Discharge Elimination System; <0.001, value not included in totals; NA, data not available; --, not applicable]

Return flow site	Reference number	City/Town	Discharge permit number	Receiving water body	SIC code	Return flow 1995–99 (Mgal/d)
Annaquatucket River Subbasin						
Dunes Club	1	Narragansett	RI0020362	Narragansett Bay	7363	<0.001
U.S. Environmental Protection Agency	2	Narragansett	RI0000949	Narragansett Bay	9511	.160
RI Air National Guard	3	North Kingstown	RI0021555	Narragansett Bay	9711	.028
VG Seafarms	4	North Kingstown	RI0023256	Narragansett Bay	2092	.001
Subbasin total	--	--	--	--	--	0.189
Greenwich Bay Subbasin						
RI Airport Corporation	5	Warwick	RI0021598	Narragansett Bay	4881	NA
Sun Refining and Marketing	6	Warwick	RI0021831	Narragansett Bay	4924	<.001
Subbasin total	--	--	--	--	--	<0.001
Hunt River Subbasin						
Brown and Sharpe Manufacturing Company	7	North Kingstown	RI0000051	Hunt River	3823	0.048
Stanley Bostich	8	East Greenwich	RI022942	Hunt River	3546	.132
Toray Plastics	9	North Kingstown	RI0021644	Hunt River	3086	.002
Subbasin total	--	--	--	--	--	0.182
Pettaquamscutt River Subbasin						
No RIPDES sites	--	--	--	--	--	--
Providence and Seekonk Rivers Subbasin						
Brown University	10	Providence	RI0023159	Narragansett Bay	8221	<0.001
C.H. Sprague and Son	11	Providence	RI0001384	Narragansett Bay	3961	NA
Lehigh Portland Cement	12	Providence	RI0001643	Narragansett Bay	1771	<.001
Motiva Enterprises	13	Providence	RI0001481	Narragansett Bay	5171	.170
Northeast Petroleum	14	Providence	RI0021962	Narragansett Bay	4924	.074
Northland Environmental	15	Providence	RI0021172	Narragansett Bay	2869	.001
Providence Gas	16	Providence	RI0021024	Narragansett Bay	4924	.052
Providence Terminal Associates	17	Providence	RI0021857	Narragansett Bay	4924	.002
Subbasin subtotal	--	--	--	--	--	0.298
Narragansett Electric[1]	18	Providence	RI0000434	Narragansett Bay	4911	266.687
Subbasin total	--	--	--	--	--	266.986
Conanicut Island Subbasin						
No RIPDES sites	--	Jamestown	--	--	--	--
Study area total	--	--	--	--	--	267.357

[1]Narragansett Electric does not use freshwater, so this RIPDES does not affect the freshwater supply.

Table 13. Return flow from wastewater-treatment facilities within and outside of the West Narragansett Bay area, coastal Rhode Island, 1995–99.

[**Reference No.:** Shown on figure 3. **RIPDES:** Rhode Island Point Discharge Elimination System; Mgal/d, million gallons per day; <0.001, value not included in totals; --, not applicable]

Wastewater-treatment facility	Reference No.	RIPDES discharge-permit number	Receiving water body (subbasin)	Average discharge (Mgal/d)
Return flow to the West Narragansett Bay study area				
RIEDC North Kingstown Wastewater Treatment Facility	19	RI0100404	Narragansett Bay (Annaquatucket subbasin)	0.890
East Greenwich Wastewater Treatment Facility	20	RI010030	Greenwich Bay (Greenwich Bay subbasin)	.905
Scarborough Wastewater Treatment Facility	21	RI0100188	Narragansett Bay (Pettaquamscutt subbasin)	.665
South Kingstown Regional Wastewater Treatment Facility	22	RI0100374	Narragansett Bay (Pettaquamscutt subbasin)	2.639
Narragansett Bay Commission Fields Point Wastewater Treatment Facility	23	RI0100315	Narragansett Bay (Providence and Seekonk subbasin)	102.012
Jamestown Wastewater Treatment Facility	24	RI0001619	Narragansett Bay (Conanicut Island subbasin)	.476
Study area total	--	--	--	107.587
Return flow to facility outside the West Narragansett Bay study area				
Narragansett Bay Commission Bucklin Point Facility	25	RI0100072	Seekonk River	23.916
Total	--	--	--	23.916

Table 14. Summary of estimated water withdrawals, imports, exports, use, nonaccount water use, consumptive use, and return flow in the West Narragansett Bay area, coastal Rhode Island, 1995–99.

[**Nonaccount:** A loss of water through the system. **Consumptive use:** A basin export. **Net import and exports:** The algebraic sum of the potable water and wastewater imports and exports, not including nonaccount and consumptive water uses. **AG**, agricultural; **COM**, commercial; **DOM**, domestic; **IND**, industrial; Mgal/d, million gallons per day; <0.001, values not included in town and subbasin totals; +, potable water and wastewater imported to subbasin and basin; -, potable water and wastewater exported from subbasin and basin; --, water use not applicable]

Subbasin	Water withdrawals (Mgal/d)	Potable water imports (+) and exports (-) (Mgal/d)	Total water use, public and self (Mgal/d)		Consumptive use (Mgal/d)	Return flow (Mgal/d)		Wastewater imports (+) and exports (-) (Mgal/d)	Net imports (+) and exports (-) (Mgal/d)
	Public and self		Use (DOM, COM, IND, AG)	Non-account (public use)		Surface water	Ground water		
Annaquatucket	3.836	-1.603	1.560	0.673	0.403	--	1.045	+0.144	-1.459
Greenwich Bay	.252	+6.742	4.114	2.880	.766	--	1.703	-1.645	+5.097
Hunt	.820	+1.683	1.517	.986	.281	0.182	.852	-.202	+1.481
Pettaquamscutt	.143	+1.284	1.254	.182	.248	--	.343	-.663	+.621
Providence and Seekonk	.080	+14.181	11.613	2.648	1.848	--	1.322	-8.443	+5.738
Conanicut Island	.437	+.032	.429	.040	.079	--	.176	-.174	-.142
Study area total	5.568	+22.319	20.487	7.409	3.625	0.182	5.441	-10.983	+11.336

Table 15. U.S. Geological Survey streamflow-gaging stations and minimum streamflows pertinent to the West Narragansett Bay area, coastal Rhode Island.

[Station drainage areas are from Socolow and others (2000). Water years are from October to September and may differ from the period of record in the data report. **7Q10**, 7-day, 10-year flow. **ABF**, Aquatic base flow, the median of the monthly mean flows for August. USGS, U.S. Geological Survey; ft^3/s, cubic foot per second; Mgal/d, million gallons per day; mi^2, square mile]

USGS stream-gaging station number	Station name	Drainage area (mi^2)	Mean flow (Mgal/d) [water years]	Mean flow (ft^3/s)	Minimum flows			
					7Q10 (Mgal/d) [water years]	7Q10 (ft^3/s)	ABF (Mgal/d) [water years]	ABF (ft^3/s)
01117000	Hunt River at East Greenwich, RI	22.9	10.73 [1941–2002]	46.6	0.82 [1941–2002]	1.27	7.24 [1941–2002]	11.2
01117500	Pawcatuck River at Wood River Junction, RI	100.0	126 [1941–2002]	195	17.1 [1941–2002]	26.4	45.4 [1941–2002]	70.3

als, use, nonaccount use, consumptive use, and return flows, a percent error can be attributed to the addition of metered and estimated water-use components for each category. Public water-supply withdrawals are metered, for example, but the use by subbasin is estimated, and the return flow is both metered and estimated. Similarly, RIPDES data are metered but the withdrawal and use is estimated.

Water Availability

During periods of little or no precipitation, streamflow is primarily from ground-water discharge, known as base flow; direct runoff is assumed to be negligible. Water withdrawals are often 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 base-flow calculations are conservative, because actual streamflows generally are greater than base flow except during periods of no recharge from precipitation.

Because most of the study area is ungaged and records from the Hunt River station in the study area are affected by ground-water withdrawals, estimates of available water had to be based on streamflows measured at a streamflow-gaging station in a nearby basin. The 1941–2000 period of record was used to calculate availability for the study-area subbasins (table 15). First, an index station was chosen whose upstream areal percentages of sand and gravel and till are similar to those in the study area. Sand and gravel deposits cover 37.8 percent of the study area and 47 percent of the drainage area of the Pawcatuck River at Wood River Junction streamflow-gaging station (01117500). Sand and gravel deposits contributed 57 percent of the base flow at the index station, and till contributed 43 percent (Dickerman and Bell, 1993). This station was also used as the index station for the study of the Hunt-Annaquatucket-Pettaquamscutt stream-aquifer system, which is in the West Narragansett Bay study area (Barlow and Dickerman, 2001). Second, the base-flow components of the streamflow were calculated by using the computerized program PART (Rutledge, 1993, 1998). Flow-duration values for the 75th, 50th, and 25th percentiles of base flow and for these base flows minus the 7Q10 (7-day 10-year flow) and ABF (Aquatic Base Flow) were calculated. Third, these base flows were apportioned according to the areas of sand and gravel and of till upstream of the index station to give flows per unit area in Mgal/d/mi^2. Finally, the flows per unit area for each type of deposit in the drainage area of the index station were multiplied by the respective areas of each type of deposit in the study area subbasins. Estimates of available water in the study area, called the gross yields, were calculated as the sum of the available gross yields from the two types of deposits.

Ratios of water withdrawals to availability were calculated to determine how much of the available ground water is used during June, July, August, and September for the study area. The closer the ratio is to one, the closer the withdrawals are to the estimated water available. The ratios were calculated for the water availability at the 75th, 50th, and 25th percentiles of the estimated gross yield, the estimated gross yield minus the 7Q10 low flow, and the estimated gross yield minus the ABF for each of the subbasins. In the

Conanicut Island subbasin, the total water available includes the safe yield from a reservoir—the maximum yield that can be delivered even through a severe drought—as well as the estimated base flow. In the summer months except June, many calculated values for availability are lower than the values of ABF. This results in no available water, because ABF is subtracted from the gross yield in the calculation of water availability. For this reason, discussion is limited to ranges of available water from the gross yield and gross yield minus the 7Q10 low flows.

Summer Water Availability by Subbasin

Four major public suppliers withdrew water from the study area during the study period. Three of these suppliers are in the HAP subbasin, and the other is in the Conanicut Island subbasin. Because monthly withdrawal rates are available (table 16), it is possible to calculate the use during the summer months (June, July, August, and September) and compare it to the availability for the same period. Because no monthly data were available from self-supplied users or the minor public supplier, their average use for the study period was added to the major supplier values to get total subbasin use (table 16). Summer water withdrawals are divided by the availability to give the water-availability ratio. These ratios allow for comparison between subbasins within the study area, and between study areas in the state. An example in fig. 14. shows such a comparison for the ratio of the 50th percentile of the gross yield for August minus the 7Q10 low flow to the August use. The ratios range from 0.01 in the Providence and Seekonk subbasin to 0.38 in the HAP subbasin.

In the Greenwich Bay subbasin, the estimated water availability for the gross yield from the sand and gravel deposits at the 50th percentile ranged from 15.091 Mgal/d in June to 5.756 Mgal/d in September. Contributions from till deposits ranged from 4.706 Mgal/d in June to 1.795 Mgal/d in September (table 17). The total water availability in the subbasin at the 50th percentile ranged from 19.797 Mgal/d in June to 7.551 Mgal/d in September. The available water for the gross yield minus the 7Q10 low flow ranged from 16.059 Mgal/d in June to 4.457 Mgal/d in September (table 18). The average water withdrawal for the subbasin was 0.252 Mgal/d for the study period (table 16); there was no variation during the summer months because the withdrawal data were estimates of the self-supplied use. The ratios for the gross-yield scenario at the 50th percentile ranged from 0.013 in June to 0.033 in September, and from 0.016 in June to 0.046 in August and September for the gross yield minus the 7Q10 low flow (table 19).

Table 16. Average water withdrawals for June, July, August, and September in the subbasins of the West Narragansett Bay study area, coastal Rhode Island, 1995–99.

[Mgal/d, million gallons per day]

Subbasins	Average water withdrawals, 1995–99 (Mgal/d)			
	June	July	August	September
Greenwich Bay subbasin	0.252	0.252	0.252	0.252
Hunt–Annaquatucket–Pettaquamscutt Rivers subbasin[1]	6.289	7.568	6.669	5.255
Providence and Seekonk Rivers subbasin	.080	.080	.080	.080
Conanicut Island subbasin[2]	.461	.421	.373	.445
Study area total	7.082	8.321	7.374	6.032

[1]Rhode Island Economic Development Corporation data for the Hunt–Annaquatucket–Pettaquamscutt subbasin available only for 1995–98.

[2]Data for the Jamestown Water Division available only for 1995–98.

Because the Hunt, Annaquatucket, and Pettaquamscutt aquifers are hydrologically interconnected, the water availability is calculated by using the area of all three subbasins. In these subbasins, the estimated water availability for the sand and gravel deposits at the 50th percentile ranged from 46.895 Mgal/d in June to 17.887 Mgal/d in September for the gross yield. Contributions from till deposits ranged from 16.119 Mgal/d in June to 6.148 Mgal/d in September for the gross yield (table 17). The total water availability in the subbasins (gross yield) at the 50th percentile ranged from 63.014 Mgal/d in June to 24.035 Mgal/d in September, and for the gross yield minus the 7Q10 low flow, ranged from 51.115 in June to 12.137 Mgal/d in September (table 18). The average water withdrawal for the subbasins was 6.445 Mgal/d for the study period (table 16), and the withdrawals ranged from 5.333 Mgal/d in September to 7.568 Mgal/d in July. The ratios for the gross-yield scenario at the 50th percentile ranged from 0.100 in June to 0.227 in August, and from 0.123 in June to 0.432 in September for the gross yield minus the 7Q10 low flow (table 19).

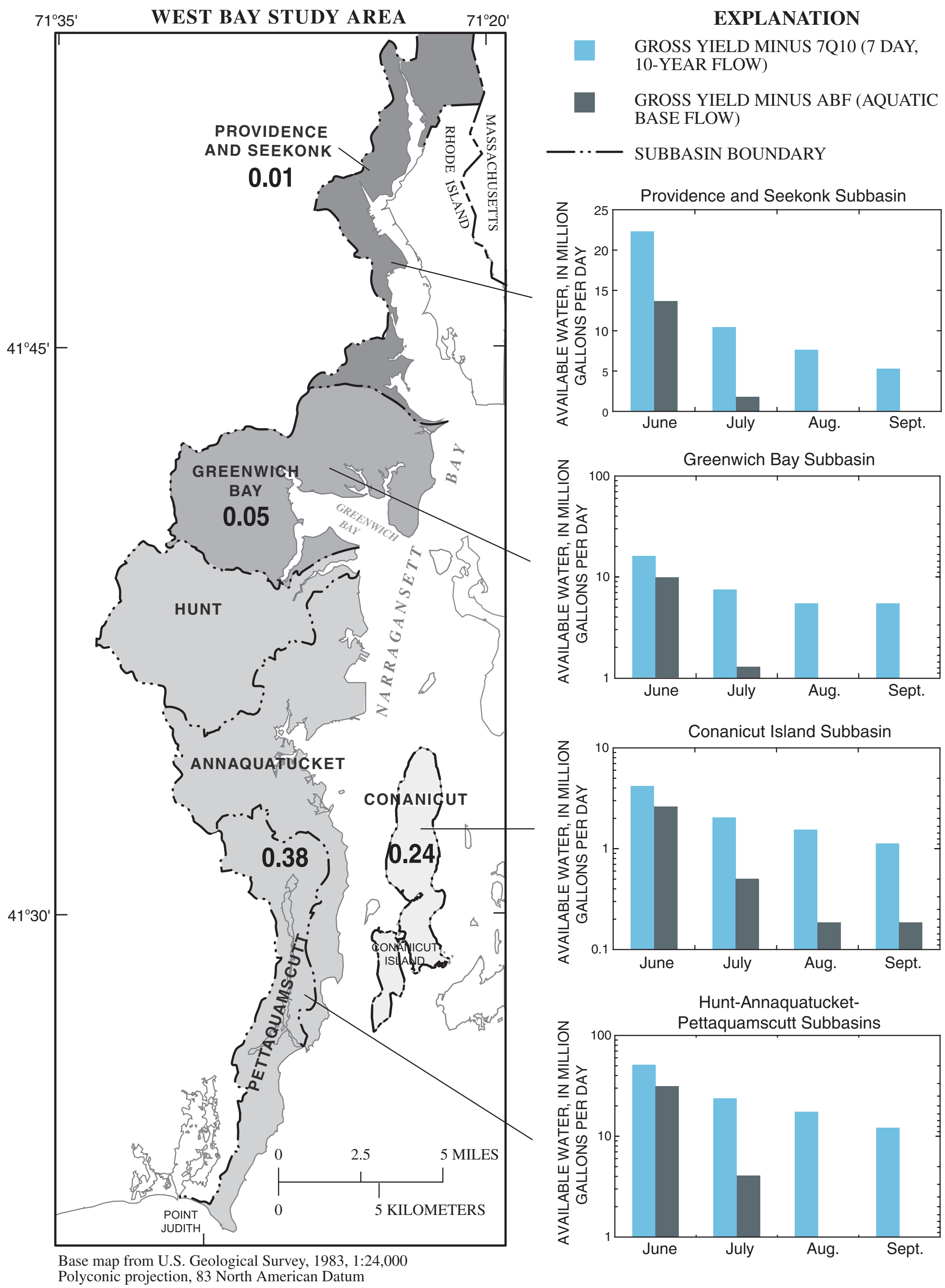


Figure 14. Ratio of withdrawals (1995-99) to estimated availability (1957–99) during August and graphs of availability for June, July, August, and September for the West Narragansett Bay area, coastal Rhode Island.

In the Providence and Seekonk subbasin, the estimated water availability for the sand and gravel deposits at the 50th percentile ranged from 25.227 Mgal/d in June to 9.622 Mgal/d in September for the gross yield. Contributions from the till deposits ranged from 9.448 Mgal/d in June to 3.604 Mgal/d in September for the gross yield (table 17). The total water availability in the subbasin at the 50th percentile ranged from 34.675 Mgal/d in June to 13.226 Mgal/d in September, and from 22.318 Mgal/d in June to 5.299 Mgal/d in September for the gross yield minus the 7Q10 low flow (table 18). The average water withdrawal for the subbasins was 0.080 Mgal/d for the study period (table 16); there was no variation during the summer months because the data were estimates of the self-supply use. The results for the ratios for the gross-yield scenario at the 50th percentile ranged from 0.002 in June to 0.006 in September, and from 0.004 in June to 0.015 in September for the gross yield minus the 7Q10 low flow (table 19).

The Conanicut Island subbasin is unique because the area of sand and gravel deposits is only 2 percent of the entire subbasin area. For this reason, most of the water is assumed to come from the till. There is also a fixed amount of surface water available from the North Pond Reservoir in addition to the available ground water. The safe yield for the drought of record for this reservoir is 0.185 Mgal/d, and this amount is added to the amount of available ground water to give the gross yield. The safe yield from the South Pond Reservoir is not included in the calculation because of water-quality issues (Pare Engineering Corporation, 2003). The estimated water availability in the subbasin from sand and gravel deposits at the 50th percentile ranged from 0.265 Mgal/d in June to 0.101 Mgal/d in September for the gross yield. Contributions from the till deposits ranged from 4.642 Mgal/d in June to 1.771 Mgal/d in September for the gross yield (table 17). The total water availability in the subbasin at the 50th percentile ranged from 5.092 Mgal/d in June to 2.057 Mgal/d in September, and under the 7Q10 criteria, ranged from 4.166 Mgal/d in June to 1.130 Mgal/d in September (table 18). The average water withdrawal for the subbasin was 0.425 Mgal/d for the study period (table 14), and these ranged from 0.461 Mgal/d in June to 0.373 Mgal/d in August. The ratios for the gross-yield scenario at the 50th percentile ranged from 0.090 in June to 0.216 in September, and from 0.111 in June to 0.393 in September for the gross yield minus the 7Q10 low flow (table 19).

Because the method for calculating water availability in this study uses ground-water discharge rates calculated from streamflow, this method is not ideal for calculating water availability on an island, where there is a lens of freshwater over seawater. In a study on the water use and availability for this island (Veeger and others, 2001), water availability was estimated to be 2.794 Mgal/d +- 0.698 Mgal/d. This value is based on a recharge rate of 4.91 to 8.11 in/yr from precipitation. This recharge rate was multiplied by the area of the island to give a volume per year. The volume of water per year was converted to million gallons per day. This method uses a recharge rate, in contrast to the methods in this study, which use ground-water discharge rates. The availability value calculated by Veeger is similar to values calculated for the island in this study. The average of the 25th percentile of the gross yield for the summer months is 2.464 Mgal/d. On the basis of these calculations, there will be at least this much available water in 75 percent of the years during the summer months, with no low flows (7Q10 or ABF) subtracted from the available water.

Water Budget

A long-term water budget (1941-2000) was calculated on the basis of the assumption that inflow equals outflow for the subbasins of the study area. This assumption implies that the change in storage from surface-water bodies and aquifers is negligible. Inflow to the basin includes precipitation, streamflow from upstream basins, ground-water inflow, and return flow (from septic systems, RIPDES, and WWTFs). Outflow from the basin includes evapotranspiration, streamflow out of the basin, water withdrawals (public supply and self-supply domestic, commercial, industrial, and agricultural), and ground-water underflow (table 20). Because the HAP aquifers are hydrologically interconnected, they were calculated as one unit for the water budget.

The average precipitation at Kingston, RI, was 48.02 in/yr for the period 1941–2000, which was chosen to match the record for the Hunt River near East Greenwich streamflow-gaging station. The average precipitation was converted to 2.286 Mgal/d/mi^2 for the area of the Hunt River station, and this value was multiplied by the area of the subbasins. The only subbasin that receives surface-water inflow from upstream basins is the Providence and Seekonk Rivers subbasin, which receives 175.132 Mgal/d from the Woonasquatucket and Moshassuck Rivers. Data on ground-water inflow were not available for this study. Return flow includes the average 1995–1999 disposal of water from septic systems, RIPDES, and WWTFs in the study area. Evapotranspiration was estimated as 0.958 Mgal/d/mi^2, which is the difference between precipitation and outflow at the mouth. Outflow was estimated as 1.327 Mgal/d/mi^2, which is the mean annual flow per square mile at the Hunt River near East Greenwich (01117000) station. The streamflow out of each subbasin (outflow) was estimated as the difference between the sum of the inflows and the sum of withdrawals and evapotranspiration. Finally, data on ground-water underflow out of the basin were not available for this study.

The budget of the HAP subbasin in this study is similar to a budget calculated previously by a ground-water model for in this area (Barlow and Dickerman, 2001). The two studies used different drainage areas, but comparable terms for stream outflow (SF_0). The SF_0 in the previous study is 49.7 Mgal/d for the study area of 39.6 mi^2, which gives an outflow of 1.25

Mgal/d/mi^2. The current study found an SF_0 of 81.068 Mgal/d for the total contributing area of 62.943 mi^2, for an outflow from the HAP subbasin of 1.288 Mgal/d/mi^2. This difference is minor, and can be partially explained by the different period of record used in the two studies (1941–96 for the Hunt study and 1941–2000 for the West Narragansett Bay study).

Summary and Conclusions

During the 1999 drought in Rhode Island, below-average precipitation caused a drop in ground-water levels and streamflow was below long-term averages. The low water levels prompted the U. S. Geological Survey, in cooperation with the Rhode Island Water Resources Board, to conduct a series of water-use studies to collect and analyze data on water use and availability in each of nine drainage areas in Rhode Island. This report describes water use and availability from 1995 through 1999 in the West Narragansett Bay study area, which covers 118 square miles in part or all of 14 towns in coastal Rhode Island. The study area includes the western part of Narragansett Bay and Conanicut Island, which is the town of Jamestown. The estimated population in the study area during the 1995–99 study period was 227,709, which was 23 percent of the total state population during the same period.

Subbasins in the study area were delineated by using the Natural Resources Conservation Service 12-digit Hydrologic Unit Code areas, with some of the subbasins composed of combined Hydrologic Unit Code areas. Land use and population were calculated by basin and by town to separate categories of water withdrawals, use, and disposal. Most of the public water supply, 19.912 Mgal/d, was imported from and disposed outside the study area. Withdrawals in the study area averaged 4.40 Mgal/d. Public-supply and self-supply domestic, commercial, and industrial withdrawals were mostly from ground water. Self-supply domestic, industrial, commercial, and agricultural withdrawals averaged 1.264 Mgal/d. Agricultural withdrawals for irrigation were assumed to be from both surface water and ground water, and were estimated by using techniques from previously published studies. The estimated water withdrawals from minor water suppliers were 0.002 Mgal/d. Total water use in the study area averaged 20 Mgal/d. The average return flow in the basin was 5.623 Mgal/d, which included effluent from permitted facilities and self-disposed water.

Streamflow data were analyzed to calculate the availability of water in the subbasins. The PART program, a computerized hydrograph-separation application, was applied to streamflow records from an index streamflow-gaging station to determine water availability based on the 75th, 50th, and 25th percentiles of the total base flow; the base flow minus the 7-day, 10-year (7Q10) low flow; and the base flow minus the Aquatic Base Flow (ABF). The index station selected for the study area was the Pawcatuck River at Wood River Junction (01117500).

Results from the PART program indicated that the base flows at the index station were lowest in September at the 75th and 25th percentiles and in August at the 50th percentile. The base-flow contribution from sand and gravel deposits at the index streamflow-gaging station was 71 percent of the total base flow, and the contribution from till deposits was 29 percent. The base-flow contributions per unit area of sand and gravel and of till in the drainage area for the index station were calculated for June, July, August, and September. These contributions were multiplied by the areas of sand and gravel and of till in the subbasins. Estimates included the gross yield at the 75th, 50th, and 25th percentiles, as well as these yields minus the 7Q10 and ABF low flows.

The 50th percentile for the September gross yield was the lowest value for all subbasins: 7.551 Mgal/d for the Greenwich Bay subbasin, 24.035 Mgal/d for the Hunt-Annaquatucket Pettaquamscutt (HAP) subbasin, 13.266 Mgal/d for the Providence and Seekonk subbasin, and 2.057 Mgal/d for the Conanicut Island subbasin. The gross yield at the 50th percentile minus the 7Q10 low flow was also lowest in September, with 4.457 Mgal/d for the Greenwich Bay subbasin, 12.137 Mgal/d for the HAP subbasin, 5.299 Mgal/d for the Providence and Seekonk subbasin, and 1.130 Mgal/d for the Conanicut Island subbasin.

Ratios of total withdrawals to total availability were calculated for June, July, August, and September for the subbasins. The closer the ratio is to one, the more closely the withdrawals equal the estimated water available. The ratios allow comparisons of water use to the available water from one subbasin to another. The ratios were calculated for the gross yield at the 75th, 50th, and 25th percentiles, and the total water available was defined as the sum of the contributions from till and sand and gravel deposits in the subbasins.

The withdrawals in July for the study period were higher than in the other summer months, but the ratios were closer to one in the study area in August for most of the flow durations. Availabilities were generally lowest in September, but there was no ratio to report in many cases because there was less water available than the 7Q10 and ABF low flows. The ratio for the gross yield at the 50th percentile for the study area was 0.129 in August and 0.230 for the gross yield minus the 7Q10 low flow. The ratios were highest for all of the selected scenarios and months for the Hunt-Annaquatucket-Pettaquamscutt subbasin. The ratios for this area in September were 0.219 for the gross yield at the 50th percentile, and 0.432 for the gross yield minus the 7Q10 low flow.

A long-term hydrologic budget was calculated for the study area to identify and assess the subbasin inflow and outflows. The water withdrawals and return flows used in the budget were from the period of study, 1995–99. It was assumed that the inflow of 455.3 Mgal/d equaled the outflow in the study area. The estimated inflows from precipitation, streamflow from upstream basins, and return flow were 59.3, 38.5 and 2.2 percent, respectively. The estimated outflows from evapotranspiration, streamflow, and water withdrawals were 24.9, 73.9, and 1.2 percent, respectively.

Table 17. Summary of water availability from sand and gravel deposits and from till for June, July, August, and September in the West Narragansett Bay area, coastal Rhode Island, 1995–99.

[**7Q10:** 7-day, 10-year low flow; **ABF:** Aquatic Base Flow; Mgal/d, Million gallons per day; Mgal/d/mi^2, million gallons per day per square mile; mi^2, square mile; --, no available water]

Subbasin	Estimated gross yield for June (Mgal/d)[1]			Estimated gross yield minus 7Q10 for June (Mgal/d)			Estimated gross yield minus ABF for June (Mgal/d)		
	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile
Estimated Yields from Sand and Gravel Deposits									
Greenwich Bay subbasin	19.275	15.091	12.019	16.426	12.241	9.170	11.687	7.504	4.432
Hunt–Annaquatucket–Pettaquamscutt stream-aquifer system[2]	59.898	46.895	37.350	51.044	38.040	28.495	36.319	23.317	13.773
Providence and Seekonk Rivers subbasin	32.222	25.227	20.092	27.459	20.464	15.329	19.538	12.543	7.409
Conanicut Island subbasin	.338	.265	.211	.281	.215	.161	.205	.132	.078
Total estimated yields from sand and gravel deposits	111.733	87.478	69.672	95.217	70.960	53.155	67.749	43.496	25.692
Estimated Yields from Till Deposits									
Greenwich Bay subbasin	6.011	4.706	3.748	5.123	3.818	2.860	3.645	2.340	1.382
Hunt–Annaquatucket–Pettaquamscutt stream-aquifer system[2]	20.588	16.119	12.838	17.545	13.075	9.794	12.484	8.015	4.734
Providence and Seekonk Rivers subbasin	12.068	9.448	7.525	2.488	1.854	1.389	1.770	1.136	.671
Conanicut Island subbasin	5.929	4.642	3.697	5.053	3.766	2.821	3.595	2.308	1.363
Total estimated yields from till deposits	44.596	34.915	28.078	30.209	22.513	16.864	21.494	13.799	8.150
Total estimated yields	156.329	122.393	97.480	125.426	93.473	70.019	89.233	57.295	33.842

Subbasin	Estimated gross yield for July (Mgal/d)[1]			Estimated gross yield minus 7Q10 for July (Mgal/d)			Estimated gross yield minus ABF for July (Mgal/d)		
	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile
Estimated Yields from Sand and Gravel Deposits									
Greenwich Bay subbasin	11.093	8.566	6.904	8.244	5.717	4.055	3.506	0.978	--
Hunt–Annaquatucket–Pettaquamscutt stream-aquifer system[2]	34.472	26.620	21.455	25.617	17.766	12.601	10.895	3.041	--
Providence and Seekonk Rivers subbasin	18.544	14.320	11.542	13.781	9.557	6.779	5.861	1.636	--
Conanicut Island subbasin	.195	.150	.121	.145	.100	.071	.061	.017	--
Total estimated yields from sand and gravel deposits	64.304	49.656	40.022	47.787	33.140	23.506	20.323	5.672	--
Estimated Yields from Till Deposits									
Greenwich Bay subbasin	3.460	2.672	2.153	2.571	1.783	1.265	1.093	0.305	--
Hunt–Annaquatucket–Pettaquamscutt stream-aquifer system[2]	11.849	9.150	7.375	8.805	6.106	4.331	3.745	1.045	--
Providence and Seekonk Rivers subbasin	6.945	5.363	4.323	1.248	.866	.614	.531	.148	--
Conanicut Island subbasin	3.412	2.635	2.124	2.536	1.759	1.247	1.079	.301	--
Total estimated yields from till deposits	25.666	19.800	15.975	15.160	10.514	7.457	6.448	1.799	--
Total estimated yields	89.970	69.476	55.997	62.947	43.654	30.963	26.771	7.471	--

[1]Estimated gross yields based on the Pawcatuck River at Wood River Junction, RI, station (Mgal/d/mi^2).

Table 17. Summary of water availability from sand and gravel deposits and from till for June, July, August, and September in the West Narragansett Bay area, coastal Rhode Island, 1995–99.—Continued

[**7Q10:** 7-day, 10-year low flow; **ABF:** Aquatic Base Flow; Mgal/d, Million gallons per day; Mgal/d/mi², million gallons per day per square mile; mi², square mile, --, no available water]

Subbasin	Estimated gross yield for August (Mgal/d)[1]			Estimated gross yield minus 7Q10 for August (Mgal/d)			Estimated gross yield minus ABF for August (Mgal/d)		
	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile
Estimated Yields from Sand and Gravel Deposits									
Greenwich Bay subbasin	10.227	7.021	5.055	7.378	4.172	2.206	2.640	--	--
Hunt–Annaquatucket–Pettaquamscutt stream-aquifer system[2]	31.782	21.817	15.710	22.928	12.963	6.855	8.204	--	--
Providence and Seekonk Rivers subbasin	17.097	11.737	8.451	12.334	6.973	3.688	4.414	--	--
Conanicut Island subbasin	.179	.123	.089	.129	.073	.039	.046	--	--
Total estimated yields from sand and gravel deposits	59.285	40.698	29.305	42.769	24.181	12.788	15.304	--	--
Estimated Yields from Till Deposits									
Greenwich Bay subbasin	3.190	2.190	1.577	2.301	1.301	0.688	0.823	--	--
Hunt–Annaquatucket–Pettaquamscutt stream-aquifer system[2]	10.924	7.499	5.400	7.881	4.456	2.356	2.820	--	--
Providence and Seekonk Rivers subbasin	6.403	4.396	3.165	1.117	.632	.334	.400	--	--
Conanicut Island subbasin	3.146	2.160	1.555	2.270	1.283	.679	.812	--	--
Total estimated yields from till deposits	23.663	16.245	11.697	13.569	7.672	4.057	4.855	--	--
Total estimated yields	82.948	56.943	41.002	56.338	31.853	16.845	20.159	--	--

Subbasin	Estimated gross yield for September (Mgal/d)[1]			Estimated gross yield minus 7Q10 for September (Mgal/d)			Estimated gross yield minus ABF for September (Mgal/d)		
	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile
Estimated Yields from Sand and Gravel Deposits									
Greenwich Bay subbasin	8.101	5.756	4.062	8.222	4.551	1.899	0.514	--	--
Hunt–Annaquatucket–Pettaquamscutt stream-aquifer system[2]	25.175	17.887	12.624	16.320	9.032	3.770	1.598	--	--
Providence and Seekonk Rivers subbasin	13.543	9.622	6.791	8.779	4.859	2.028	.860	--	--
Conanicut Island subbasin	.142	.101	.071	.092	.051	.021	.009	--	--
Total estimated yields from sand and gravel deposits	46.961	32.366	23.548	33.413	18.493	7.718	2.981	--	--
Estimated Yields from Till Deposits									
Greenwich Bay subbasin	2.526	1.795	1.267	1.638	0.906	0.378	0.160	--	--
Hunt–Annaquatucket–Pettaquamscutt stream-aquifer system[2]	8.653	6.148	4.339	5.610	3.105	1.296	.549	--	--
Providence and Seekonk Rivers subbasin	5.072	3.604	2.543	.795	.440	.184	.078	--	--
Conanicut Island subbasin	2.492	1.771	1.250	1.616	.894	.373	.158	--	--
Total estimated yields from till deposits	18.743	13.318	9.399	9.659	5.345	2.231	0.945	--	--
Total estimated yields	65.704	46.684	32.947	43.072	22.788	9.949	3.926	--	--

[1]Estimated gross yields based on the Pawcatuck River at Wood River Junction, RI, station (Mgal/d/mi²).

[2]The Hunt–Annaquatucket–Pettaquamscutt stream-aquifer system, as delineated in Barlow and Dickerman (2001), includes ground-water inputs from the Chipuxet (0.80 mi² of sand and gravel and 0.15 mi² of till) and Usquepaug–Queen (1.28 mi² of sand and gravel and 1.75 mi² of till) subbasins.

Table 18. Summary of total water availability for June, July, August, and September in the West Narragansett Bay area, coastal Rhode Island, 1995–99.

[**7Q10:** 7-day, 10-year low flow; **ABF:** Aquatic Base Flow, Mgal/d, Million gallons per day; mi^2, square mile, Mgal/d/mi^2, million gallons per day per square mile; --, no available water]

Subbasin	Estimated gross yield for June (Mgal/d)[1]			Estimated gross yield minus 7Q10 for June (Mgal/d)			Estimated gross yield minus ABF for June (Mgal/d)		
	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile
Greenwich Bay subbasin	25.286	19.797	15.767	21.549	16.059	12.030	15.332	9.844	5.814
Hunt–Annaquatucket–Pettaquamscutt stream-aquifer system[2]	80.486	63.014	50.188	68.589	51.115	38.289	48.803	31.332	18.507
Providence and Seekonk subbasin	44.290	34.675	27.617	29.947	22.318	16.718	21.308	13.679	8.080
Conanicut Island subbasin[3]	6.452	5.092	4.093	5.526	4.166	3.167	3.985	2.625	1.626
Total estimated yields	156.514	122.578	97.665	125.611	93.658	70.204	89.418	57.480	34.027
Subbasin	**Estimated gross yield for July (Mgal/d)[1]**			**Estimated gross yield minus 7Q10 for July (Mgal/d)**			**Estimated gross yield minus ABF for July (Mgal/d)**		
	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile
Greenwich Bay subbasin	14.553	11.238	9.057	10.815	7.500	5.320	4.599	1.283	--
Hunt–Annaquatucket–Pettaquamscutt stream-aquifer system[2]	46.321	35.770	28.830	34.422	23.872	16.932	14.640	4.086	--
Providence and Seekonk subbasin	25.489	19.683	15.865	15.029	10.423	7.393	6.392	1.784	--
Conanicut Island subbasin[3]	3.792	2.970	2.430	2.866	2.044	1.503	1.325	.503	0.185
Total estimated yields	90.155	69.661	30.162	63.132	43.839	31.148	26.956	7.656	0.185
Subbasin	**Estimated gross yield for August (Mgal/d)[1]**			**Estimated gross yield minus 7Q10 for August (Mgal/d)**			**Estimated gross yield minus ABF for August (Mgal/d)**		
	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile
Greenwich Bay subbasin	13.417	9.211	6.632	9.679	5.473	2.894	3.463	--	--
Hunt–Annaquatucket–Pettaquamscutt stream-aquifer system[2]	42.706	29.316	21.110	30.809	17.419	9.211	11.024	--	--
Providence and Seekonk subbasin	23.500	16.133	11.616	13.451	7.605	4.022	4.814	--	--
Conanicut Island subbasin[3]	3.150	2.468	1.829	2.584	1.541	.903	1.043	0.185	0.185
Total estimated yields	83.133	57.128	41.187	56.523	32.038	17.030	20.344	0.185	0.185
Subbasin	**Estimated gross yield for September (Mgal/d)[1]**			**Estimated gross yield minus 7Q10 for September (Mgal/d)**			**Estimated gross yield minus ABF for September (Mgal/d)**		
	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile
Greenwich Bay subbasin	10.627	7.551	5.329	9.860	4.457	2.277	0.674	--	--
Hunt–Annaquatucket–Pettaquamscutt stream-aquifer system[2]	33.828	24.035	16.963	21.930	12.137	5.066	2.147	--	--
Providence and Seekonk subbasin	18.615	13.226	9.334	9.574	5.299	2.212	.938	--	--
Conanicut Island subbasin[3]	2.819	2.057	1.506	1.893	1.130	.579	.352	0.185	0.185
Total estimated yields	65.889	46.869	33.132	43.257	22.973	10.134	4.111	0.185	0.185

[1]Based on the Pawcatuck River at Wood River Junction, RI, station (Mgal/d/mi^2).

[2]The Hunt–Annaquatucket–Pettaquamscutt stream-aquifer system, as delineated in Barlow and Dickerman (2001), includes ground-water inputs from the Chipuxet (0.80 mi^2 of sand and gravel and 0.15 mi^2 of till) and Usquepaug-Queen (1.28 mi^2 of sand and gravel and 1.75 mi^2 of till) subbasins.

[3]Conanicut Island subbasin includes the safe yield of 0.185 Mgal/d from the North Pond Reservoir.

Table 19. Summary of ratios of water withdrawals to availability for June, July, August, and September in the West Narragansett Bay area, coastal Rhode Island, 1995–99.

[**7Q10:** 7-day, 10-year low flow; **ABF:** Aquatic Base Flow, Mgal/d, Million gallons per day; Mgal/d/mi², million gallons per day per square mile; mi², square mile, --, no available water]

Subbasin	Water withdrawals to water available for June (Mgal/d)			Water withdrawals to water available for June minus 7Q10 (Mgal/d)			Water withdrawals to water available for June minus ABF (Mgal/d)		
	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile
Greenwich Bay subbasin[1]	0.010	0.013	0.016	0.012	0.016	0.021	0.016	0.026	0.043
Hunt–Annaquatucket–Pettaquamscutt stream-aquifer system[2]	.078	.100	.125	.091	.123	.164	.129	.201	.340
Providence and Seekonk subbasin[1]	.002	.002	.003	.003	.004	.005	.004	.006	.010
Conanicut Island subbasin[3]	.071	.090	.113	.083	.111	.146	.116	.176	.283
Total study area ratio	0.045	0.058	0.072	0.056	0.076	0.101	0.079	0.123	0.208

Subbasin	Water withdrawals to water available for July (Mgal/d)			Water withdrawals to water available for July minus 7Q10 (Mgal/d)			Water withdrawals to water available for July minus ABF (Mgal/d)		
	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile
Greenwich Bay subbasin[1]	0.017	0.022	0.028	0.023	0.034	0.047	0.055	0.020	--
Hunt–Annaquatucket–Pettaquamscutt stream-aquifer system[2]	.163	.212	.262	.219	.317	.447	.517	--	--
Providence and Seekonk subbasin[1]	.003	.004	.005	.005	.008	.011	.012	.045	--
Conanicut Island subbasin[3]	.111	.142	.173	.147	.206	.280	.318	.837	--
Total study area ratio	0.092	0.119	0.148	0.132	0.190	0.267	0.308	--	--

Subbasin	Water withdrawals to water available for August (Mgal/d)[1]			Water withdrawals to water available for August minus 7Q10 (Mgal/d)			Water withdrawals to water available for August minus ABF (Mgal/d)[3]		
	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile
Greenwich Bay subbasin[1]	0.018	0.027	0.038	0.026	0.046	0.087	0.073	--	--
Hunt–Annaquatucket–Pettaquamscutt stream-aquifer system[2]	.156	.227	.316	.216	.383	.724	.605	--	--
Providence and Seekonk subbasin[1]	.003	.005	.007	.006	.010	.019	.017	--	--
Conanicut Island subbasin[3]	.106	.151	.204	.144	.242	.413	.357	--	--
Total study area ratio	0.089	0.129	0.179	0.130	0.230	0.433	0.362	--	--

Subbasin	Water withdrawals to water available for September (Mgal/d)			Water withdrawals to water available for September minus 7Q10 (Mgal/d)			Water withdrawals to water available for September minus ABF (Mgal/d)[3]		
	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile
Greenwich Bay subbasin[1]	0.024	0.033	0.047	0.026	0.046	0.111	0.374	--	--
Hunt–Annaquatucket–Pettaquamscutt stream-aquifer system[2]	.155	.219	.310	.240	.432	--	--	--	--
Providence and Seekonk subbasin[1]	.004	.006	.008	.008	.015	.036	.085	--	--
Conanicut Island subbasin[3]	.158	.216	.295	.235	.393	.768	--	--	--
Total study area ratio	0.091	0.129	0.182	0.139	0.251	0.595	--	--	--

[1] Based on the Pawcatuck River at Wood River Junction, RI station (Mgal/d/mi²).

[2] The Hunt–Annaquatucket–Pettaquamscutt stream-aquifer system, as delineated in Barlow and Dickerman (2001), includes ground water inputs from the Chipuxet (0.80 mi² of sand and gravel and 0.15 mi² of till) and Usquepaug–Queen (1.28 mi² of sand and gravel and 1.75 mi² of till) subbasins.

[3] Conanicut Island subbasin includes the safe yield of 0.185 Mgal/d from the North Pond Reservoir.

Table 20. Average water budget by subbasin for the West Narragansett Bay area, coastal Rhode Island.

[**RIPDES:** Rhode Island Pollution Discharge Elimination System; **WWTF:** Wastewater Treatment Facility; Mgal/d, in/yr, inches per year; million gallons per day; mi², square mile; --, unknown]

Water-budget component	Greenwich Bay subbasin	Hunt–Annaqutucket–Pettaquamscutt subbasin	Providence and Seekonk subbasin	Conanicut Island subbasin	Study area total
Estimated inflow (Mgal/d)					
Precipitation (P_T)[1]	47.006	143.866	58.026	21.146	270.044
Streamflow from upstream subbasins (SF_I)	--	--	175.132	--	175.132
Ground-water inflow (GW_I)	--	--	--	--	--
Return flow ($WWRF_I$)[2]	1.703	2.422	5.823	.176	10.124
Total inflow	48.709	146.288	238.981	21.322	455.300
Estimated outflow (Mgal/d)					
Evapotranspiration (ET)[3]	19.716	60.343	24.338	8.870	113.267
Streamflow (SF_O)[4]	28.741	81.068	214.563	12.015	336.387
Water withdrawals (W)[5]	.252	4.877	.080	.437	5.646
Ground-water underflow (GW_U)	--	--	--	--	--
Total outflow	48.709	146.288	238.981	21.322	455.300
Streamflow (SF_O) per square mile (Mgal/d/mi²)	1.398	1.288	2.142	1.299	1.743
Total contributing area (mi²)	20.564	62.943	100.185	9.251	192.943

[1]Based on average precipitation (48.02 in/yr) at Kingston, RI, 1941–2000.

[2]Return flow based on the total return flow from septic, RIPDES, and WWTFs in the subbasins of the West Narragansett Bay area, 1995–99.

[3]Evapotranspiration based on the difference between the average precipitation at Kingston, RI, and average monthly flow per unit area (1.327 Mgal/d/mi²) at the Hunt River at East Greenwich stream-gaging station.

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

[5]Water-withdrawal types include domestic, commercial, industrial, and agricultural served by public and self-supply in the subbasins of the West Narragansett Bay area, 1995–99.

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Glossary

Glossary

7-day, 10-year 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) Median flow during the month of August determined by the U.S. Fish and Wildlife Service to be adequate to protect indigenous aquatic fauna throughout the year. It can be calculated as long as there is "USGS gaging data for at least 25 years of unregulated flow, and the drainage area at the streamflow-gaging station is at least 50 square miles" (U.S. Fish and Wildlife Service, 1981).

B

Base flow Streamflow from ground-water discharge.

C

Commercial water use Water used 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 of 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 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.

G

Gross yield The volumetric flow of water estimated to come from both sand and gravel and till deposits in an ungaged area without the subtraction of low flows based on aquatic-habitat requirements.

I

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

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

Interconnections Links between water-supply districts to convey water. These connections can be for wholesale distributions or used as water-supply backups.

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

M

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

Major user In Rhode Island, it is defined as a customer that uses more than 3 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 water suppliers Water withdrawn to supply a site-specific public population, for example, nursing homes, condominium complexes, and mobile home parks.

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 water used for fire fighting. It comprises authorized and unauthorized water uses.

O

Outfall Refers to 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 Wastewater collected from users or groups of users, conveyed to a wastewater-treatment plant, and then released as return flow into the hydrologic environment or sent back to users as reclaimed wastewater.

Public water system Water withdrawn by public and private water systems, and then delivered to users or groups of users. Public water systems provide water for a variety of uses, such as domestic, commercial, industrial, agricultural, and public water use.

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 Water return flow from public and private wastewater-collection systems.

Public-supplied water Water distributed to domestic, industrial, commercial, agricultural, or other customers by a public or private water-supply system.

R

Return flow Water that is returned to surface or ground water after use or wastewater treatment, and 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

Safe yield The amount of water that can be safely delivered from a surface-water reservoir even during a severe drought.

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-supplied water Water withdrawn from a ground- or surface-water source by a user and not obtained from a public or private 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 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, including 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 other 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 hydrologic system for use, including public water supply, industry, commercial, domestic, irrigation, livestock, and thermoelectric power-generation water uses.

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