Water Use and Availability in the Woonasquatucket and Moshassuck River Basins, North-Central Rhode Island

by Mark T. Nimiroski and Emily C. Wild

In cooperation with the
Rhode Island Water Resources Board

Scientific Investigations Report 2005-5031

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
Gale A. Norton, Secretary

U.S. Geological Survey
Charles G. Groat, Director

U.S. Geological Survey, Reston, Virginia: 2005

For sale by U.S. Geological Survey, Information Services
Box 25286, Denver Federal Center
Denver, CO 80225

For more information about the USGS and its products:
Telephone: 1-888-ASK-USGS
World Wide Web: http://www.usgs.gov/

Suggested citation:
Nimiroski, M.T., and Wild, E.C., 2005, Water use and availability in the Woonasquatucket and Moshassuck River Basins, north-central Rhode Island: U.S. Geological Survey Scientific Investigations Report 2005-5031, 44 p.

Contents

Figures

Tables

CONVERSION FACTORS, VERTICAL DATUM, ABBREVIATIONS AND ACRONYMS

Multiply	By	To obtain
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
cubic foot per second (ft^3/s)	0.0283	cubic meter per second (m^3/s)
cubic foot per second per square mile ($ft^3/s/mi^2$)	0.0109	cubic meter per second per square kilometer ($m^3/s/km^2$)
foot (ft)	0.3048	meter (m)
foot squared (ft^2)	0.3048	meter squared (m^2)
gallons per day per person (gal/d/person)	0.003785	cubic meter per day per person (m^3/wk/person)
inch (in)	2.54	centimeter (cm)
inches per week per acre (in/wk/acre)	6.274	centimeters per week per hectare (cm/d/ha)
inches per year (in/yr)	2.54	centimeter per year (cm/yr)
mile (mi)	1.609	kilometer (km)
million gallons per day (Mgal/d)	3,785	cubic meters per day (m^3/d)
million gallons per day (Mgal/d)	1.5466	cubic feet per second (ft^3/s)
million gallons per day per yard (Mgal/d/yd)	.00414	million cubic meters per day per meter ($Mm^3/d/m$)
million gallons per day per square mile (Mgal/d/mi^2)	1,462.1	cubic meter per day per square kilometer ($m^3/d/km^2$)
square mile (mi^2)	12.590	square kilometer (km^2)

Temperature is given in degrees Fahrenheit (°F), which can be converted to degrees Celsius (°C) by the following equation:

°C=(°F-32)/1.8

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

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

7Q10	7-day, 10-year flow
ABF	Aquatic Base Flow
GIS	Geographic Information System
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 baseflow calculation using streamflow partitioning
RIDEM	Rhode Island Department of Environmental Management
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	U.S. Environmental Protection Administration
USGS	U.S. Geological Survey
WSO	Weather Station Observatory
WWTF	Wastewater-Treatment Facility

Water Use and Availability in the Woonasquatucket and Moshassuck River Basins, North-Central Rhode Island

by Mark T. Nimiroski and Emily C. Wild

Abstract

The Woonasquatucket River Basin includes 51.0 square miles, and the Moshassuck River Basin includes 23.8 square miles in north-central Rhode Island. The study area comprises these two basins. The two basins border each other with the Moshassuck River Basin to the northeast of the Woonasquatucket River Basin. Seven towns are in the Woonasquatucket River Basin, and six towns are in the Moshassuck River Basin. To determine the water use and availability in the study area, water supply and discharge data were collected for these river basins for the 1995–99 period, and compared to estimated long-term water available.

The study area is unique in the State of Rhode Island, because no withdrawals from major public suppliers were made during the study period. Withdrawals were, therefore, limited to self-supplied domestic use, two minor suppliers, and one self-supplied industrial user. Because no metered data were available, the summer water withdrawals were assumed to be the same as the estimates for the rest of the year. Seven major water suppliers distribute an average of 17.564 million gallons per day for use in the study area from sources outside of the study area. The withdrawals from minor water suppliers were 0.017 million gallons per day in the study area, all in the town of Smithfield in the Woonasquatucket River Basin. The remaining withdrawals in the study area were estimated to be 0.731 million gallons per day by self-supplied domestic, commercial, industrial, and agricultural users.

Return flows in the study area included self-disposed water and disposal from permitted dischargers, including the Smithfield Sewage Treatment Plant. Return flows accounted for 4.116 million gallons per day in the study area. Most public-disposed water (15.195 million gallons per day) is collected by the Narragansett Bay Commission and is disposed outside of the basin in Narragansett Bay.

The PART program, a computerized hydrograph-separation application, was used at one index stream-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 flow criteria, and the base flow minus the Aquatic Base Flow criteria. The index station selected was the Branch River at Forestdale, which is close to the study area and has a similar percentage of sand and gravel area.

Water availability was estimated on the basis of base-flow contributions from sand and gravel deposits and till deposits at the index station. Flows were computed for June, July, August, and September 1957–2000, and a percentage of the total flow was determined to come from either sand and gravel deposits, or till, by using a regression equation. The base-flow contributions were converted to a flow per unit area at the station for the till and for the sand and gravel deposits and then applied to the deposits in the study area basins. These values were used to estimate the gross yield of base flow, as well as to subtract the two low flows (7-day, 10-year flow, and Aquatic Base Flow criteria). The results from the Branch River stream-gaging station were lowest in August at the 75th, 50th, and 25th percentile for total flow with either flow criteria subtracted. The estimated August gross yield at the 50th percentile from the Woonasquatucket River Basin was 12.94 million gallons per day, and 5.91 million gallons per day from the Moshassuck River Basin.

A ratio was calculated that is equal to total withdrawals divided by water availability. Water-availability flow scenarios at the 75th, 50th, and 25th percentiles for the basins, which are based on total water available from base-flow contributions from till and sand and gravel deposits in the basins, were assessed. The ratios were the highest in July for the 50th percentile estimated gross yield minus Aquatic Base Flow (ABF) flow criteria, where withdrawals are close to the available water. Ratios are not presented if the available water is less than the flow criteria. The ratio of withdrawals to the July gross yield at the 50th percentile minus Aquatic Base Flow was 0.796 for the Woonasquatucket and 0.275 for the Moshassuck River Basin.

A long-term hydrologic budget was calculated for the period of 1956–2000 for the Woonasquatucket River Basin and the period of 1964–2000 for the Moshassuck River Basin. The water withdrawals and return flows used in the budget were from 1995 through 1999. For the hydrologic budget, inflow was assumed to equal outflow and was about 120 million gallons per day in the Woonasquatucket River Basin and 56 million gallons per day in the Moshassuck River Basin. The estimated inflows from precipitation and water return flow were 97.3 and 2.7 percent, respectively, in the Woonasquatucket River Basin, and 98.3 and 1.7 percent, respectively, in the Moshassuck River Basin. The estimated outflows from evapotranspiration, streamflow, and water withdrawals were 43.4, 56.1, and 0.5 percent, respectively, in the Woonasquatucket River Basin, and 49.8, 50, and 0.2 percent, respectively, in the Moshassuck River Basin.

Introduction

The Woonasquatucket and Moshassuck River Basins are entirely in Providence County, which has 60 percent of the total population of the State of Rhode Island. During the 1999 drought, lower than average precipitation caused a drop in ground-water levels and streamflow below long-term averages, prompting the Rhode Island Water Resources Board (RIWRB), in cooperation with the U.S. Geological Survey (USGS), to conduct a series of water-use studies. The purpose of these studies is to collect and analyze water-use and availability data in each drainage area in the State of Rhode Island. The Woonasquatucket and Moshassuck study area is currently (2000) supplied primarily from water imported to the basin from the Pawtuxet River Basin; the development of alternative sources within the basin would help to reduce reliance on these outside sources. The Woonasquatucket and Moshassuck Rivers are included at the level of the 12-digit Hydrologic Unit Code (HUC), so the basins are not further subdivided.

Providence County had the highest population in the State: 621,602 persons, almost 60 percent of the total State population of 1,048,319, based on data from the U.S. Census Bureau (2000). The county also has the second largest percent increase (4.3 percent) in population growth of the five counties in the State during the 1990–2000 period. For years, water needs for the metropolitan Providence area were adequately met by the Providence Water Supply Board (Providence Water) reservoir in Scituate, RI (fig. 1). Interest in developing additional public-water supplies in the metropolitan area was limited until recent droughts, security threats, and increased demands suggested the need for supplementary and backup supplies.

Average precipitation at the Woonsocket, Rhode Island climatological station for June 1999 was approximately 0.50 in., compared to the 30-yr long-term (1971–2000) average precipitation for June of 3.65 in. Because precipitation is a key component of ground-water recharge, the rain deficiency resulted in a period of little to no recharge, and caused ground-water levels and streamflows to drop below the long-term averages throughout Rhode Island. The record for the Moshassuck River streamflow-gaging station (01114000) indicated a monthly mean discharge in July 1999 of 8.07 ft^3/s, compared to the long-term (1963–99) July mean of 18.9 ft^3/s. The record for the Woonasquatucket River streamflow-gaging station (01114500) indicated flows below long-term average, with the monthly mean for July of 11.7 ft^3/s compared to the long-term (1941–99) July monthly mean flow of 31.8 ft^3/s.

Purpose and Scope

This report assesses water use for the 1995–99 period, and long-term availability during periods of little to no recharge to the ground-water system in the Woonasquatucket and Moshassuck River Basins. To estimate water use, data were collected by basin for each town and system (supply and disposal) in the study area. Water withdrawals, users, and discharger information were organized and retrieved by using the New England Water-Use Data System (NEWUDS) for the study period, calendar years 1995–99. Water-availability results for the study area were calculated by using a computerized method (PART) for determining ground-water discharge during streamflow-recession periods during the summer. A basin water budget is presented, to summarize the components of the hydrologic cycle on the basis of the long-term period of record, 1956–2000 for the Woonasquatucket River Basin and 1964–2000 for the Moshassuck River Basin, and selected water-use components for the study period. The period of record used in this study is shorter for the Woonasquatucket River Basin than the full period of record for the streamflow-gaging station (1941–2000) because there was greater regulation on the Woonasquatucket River prior to 1956 than there is presently (Socolow and others, 2000).

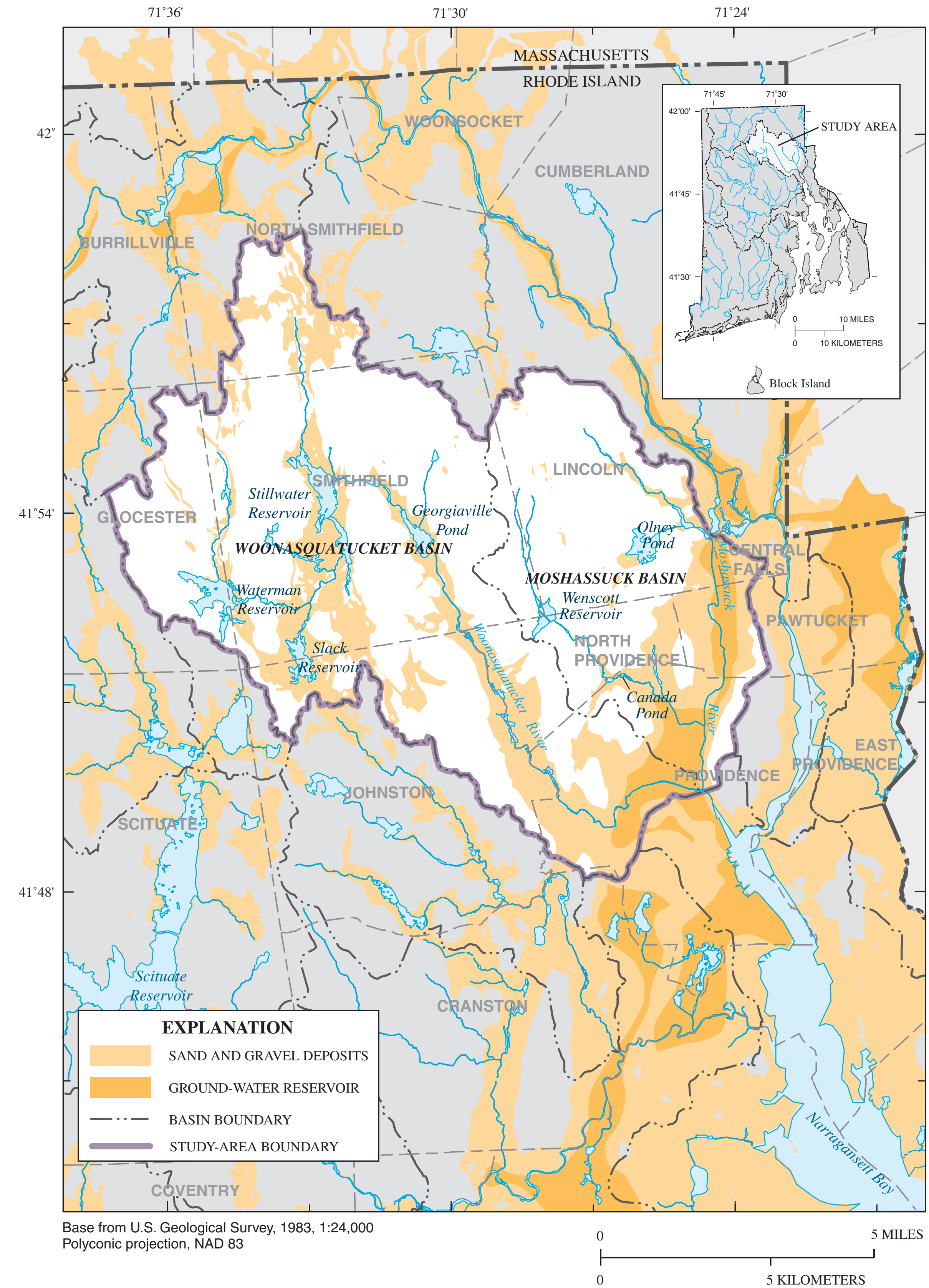


Figure 1. Location of towns, counties, basin boundaries, hydrography, and sand and gravel areas in the Woonasquatucket and Moshassuck River Basins, north-central Rhode Island.

Previous Investigations

The USGS has been collecting streamflow data from partial and continuous stream-gaging stations and has been monitoring ground-water levels for more than 60 years in the Woonasquatucket and Moshassuck River Basins. The data collected have been used for numerous hydrologic studies in the study area, including investigations of the ground-water and surface-water resources, as well as the water quality of the basins. The study area is within the Georgiaville, North Scituate, Pawtucket, and Providence USGS quadrangles. The USGS has published these quadrangles in detailed thematic maps describing the surficial and bedrock geology (Chute, 1949; Quinn, and others, 1949; Quinn, 1951, 1959; Richmond, 1952, 1953; Robinson, 1961; Smith, 1956). 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, streamflows, and water quality in various USGS Open-File Reports (OFR), Water-Resources Investigations Reports (WRIR), and Water-Supply Papers (WSP) and Rhode Island Department of Environmental Management Recharge Area Reports (RAR). RAR-1 (Trench and Morrissey, 1985), and WRIR 4-74 (Johnston and Dickerman, 1974) cover the Blackstone River Basin, but they also include a portion of the Moshassuck River Basin, equivalent to the Moshassuck River Basin minus the West River subbasin. WSP-1499A (Halberg and others, 1961) quantifies water resources of the Providence area. This area includes portions of the Woonasquatucket and Moshassuck River Basins, as well as some portions of the Pawtuxet River Basin, which is another study area, and the Providence River subbasin, which is part of the West Bay study area. WRIR 89-4164 (Ries, 1990) calculates the runoff to Narragansett Bay including the Moshassuck and Woonasquatucket River Basins. The most recent publication, OFR 00-276 (Church and others, 2000), discusses a contaminated reach of the Woonasquatucket River where diffusion samplers were deployed to determine the extent and distribution of volatile organic compounds (VOCs) at the Centerdale Manor Superfund site.

Previous investigations have been completed in cooperation with the RIWRB and have been published in various USGS Geological Bulletins (GB) and Hydrologic Bulletins (HB) and RIWRB Ground-Water Maps (GWM). The Geologic Bulletins provide well records, lithologic logs, water-quality assessments, hydrologic characteristics of the surficial deposits (till and stratified sand and gravel deposits), and water-table information.The information is typically delineated by USGS quadrangle (Bierschenk, 1959; Quinn and others, 1948; Richmond and Allen, 1951). GB-6 (Kinnison, 1953) is an exception; this report presents ground-water information for all of Rhode Island, with a section on Providence County, including the Woonasquatucket and Moshassuck River Basins. GB-11 (Lang, 1961) discusses ground-water reservoir areas for the entire State. The upper Woonasquatucket River Basin is one area discussed, and the Providence–Warwick area includes some of the lower Woonasquatucket River Basin and the Pawtuxet River Basin. The Moshassuck River Basin is part of the Blackstone ground-water area. Ground-Water Maps provide bedrock contours, water-table altitudes, well locations, and till and stratified sand and gravel deposits. Ground-water information is provided in this format for the North Scituate quadrangle in GWM-12 (Pollock, 1960). Hydrologic Bulletins describe lithologic logs and historical aquifer tests. HB-7 (Johnston, and Dickerman, 1974) covers the Blackstone River Basin, but also includes a portion of the Moshassuck River Basin.

In addition to studies pertaining to surficial deposits, information has been collected and compiled about water use in the study area and statewide (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 communications from the RIWRB and from the suppliers themselves. The suppliers also prepare and submit water-supply management plans for their water supply systems to the RIWRB, which incorporates the individual plans into the State's Water Supply Systems Management Plan. Information about public disposal was collected (oral and written communications) 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 north-central Rhode Island includes 74.8 mi^2, of which 51 are in the Woonasquatucket River Basin and 23.8 are in the Moshassuck River Basin. Ten towns are partially within the study area, and the entire study area is within Providence County. The water-use data are primarily collected at the town level, and then are disaggregated at the level of the 12-digit HUC, as defined by the Natural Resources Conservation Service (NRCS). The two basins are not further subdivided into subbasins for the purposes of this study because they match the 12-digit HUC. The surface-water drainage area is considered to be the same as the ground-water drainage area in these basins because few data are available on the ground-water system in the study area.

Population

In 1990 the study-area population was approximately 189,675. The 5-year average population from 1995 through 1999 was about 182,046 persons. During the 1995–99 study period, the population was roughly equally split between the two basins. 98,552 persons (54 percent) resided in the Woonasquatucket River Basin, and 83,494 persons (46 percent) in the Moshassuck River Basin. Seven cities and towns are partially within the Woonasquatucket River Basin and six in the Moshassuck River Basin. Of the cities and towns in the study area, Providence has the highest population, with a total of 151,151 during the study period. Of these, 79,907 live within the study area. City and town populations by basin for various years are shown in table 1.

Sand and Gravel Aquifers and Ground-Water Reservoirs

Sand and gravel aquifers in Rhode Island are typically located in stream valleys. The RIWRB has identified 21 sand and gravel reservoirs with the potential to yield large amounts of water (W.B. Allen, Rhode Island Water Resources Board, written commun., 1978). The Lower Blackstone-Moshassuck and the Providence-Warwick Ground-Water Reservoirs are both partially in the study area. The sand and gravel deposits cover about 30 percent of the area of the basins, with a mix of valley-fill stratified deposits and kame deposits around many of the lakes in the downstream portion of the basins. The remaining 70 percent is covered by ground moraine, or till. The sand and gravel aquifers in this area are buried preglacial valleys, and in some places, including the Pawtucket portion of the Moshassuck River Basin, the unconsolidated deposits that constitute the aquifer are thick compared to other areas of the State. The deepest USGS well in the study area, Pawtucket 79, penetrates 280 ft of unconslodated deposits over bedrock (Bierschenck, 1959). In general, the wells in unconsolidated deposits are 100 ft deep or less. The water table in the Providence area is approximately 10 ft below land surface. The deposits generally become thinner upstream, commonly less than 50 ft to bedrock, and 10–15 ft to the water table.

Climate

No local climatological data are collected in the Woonasquatucket or Moshassuck River Basins. Long-term records are available for sites in Woonsocket and Kingston, RI, and for T. F. Green State Airport in Warwick, RI, among other sites with data collection by the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) and published in the series Climatological Data New England. These monthly and annual summaries are the source for precipitation data used in this report (table 2). Rainfall records from the Woonsocket station have been collected from 1956 through present (2004). The 1971–2000 period of record indicates that the average rainfall

Table 1. Total city or town populations by basin for 1990, estimated 1995–99 populations, and estimated populations on public supply, self supply, public disposal, and self disposal in the Woonasquatucket and Moshassuck River Basins, north-central 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 (2001)]

City/Town	Population		Estimated 1995–99 Population			
	1990	Estimated 1995–99	Supply		Disposal	
			Public	Self	Public	Self
Woonasquatucket Basin						
Cranston	1,053	1,037	1,037	0	1,037	0
Glocester	1,732	1,742	63	1,679	61	1,681
Johnston	12,528	12,447	11,105	1,342	9,457	2,990
North Providence	15,315	14,896	14,888	8	14,694	202
North Smithfield	840	797	20	777	20	777
Providence	53,116	50,065	49,993	72	49,547	518
Smithfield	17,807	17,568	14,313	3,255	12,149	5,419
Basin total	102,391	98,552	91,419	7,133	86,965	11,587
Moshassuck Basin						
Central Falls	7,849	7,403	7,329	74	7,297	106
Lincoln	8,461	8,746	7,620	1,126	4,980	3,766
North Providence	16,871	16,409	16,392	17	16,074	335
Pawtucket	21,720	20,382	20,366	16	20,190	192
Providence	31,661	29,842	29,810	32	29,631	211
Smithfield	722	712	575	137	324	388
Basin total	87,284	83,494	82,092	1,402	78,496	4,998
Study Area Total						
Study area total	189,675	182,046	173,511	8,536	165,461	16,585

Table 2. Summary of climatological data pertinent to the Woonasquatucket and Moshassuck River Basins, north-central Rhode Island.

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

Climatological station	Period of record	June	July	August	September	Annual
		Average Temperature (°F)				
Kingston, RI	1971–2000	65.63	71.06	69.91	62.72	49.94
	1995–99	66.50	71.88	70.32	63.74	50.91
T.F. Green Airport WSO,	1971–2000	67.65	73.37	71.88	63.99	51.13
Warwick, RI	1995–99	68.20	74.14	72.08	64.74	51.84
		Average Precipitation (in.)				
Kingston, RI	1971–2000	3.936	3.308	4.400	4.163	51.79
	1995–99	4.106	2.728	4.356	4.474	53.11
T.F. Green Airport WSO,	1971–2000	3.382	3.169	3.904	3.704	46.46
Warwick, RI	1995–99	3.414	1.978	3.190	4.014	43.91
Woonsocket, RI[1]	1971–2000	3.653	3.666	4.279	4.093	50.05
	1995–99	3.506	3.932	3.126	4.290	51.58

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

is 50.05 in/yr, with the highest monthly average in November (4.769 in.) and the lowest monthly average in June (3.653 in.). No temperature data are collected at this station.

Rainfall records from the Woonsocket station were used for water-use estimates and budget calculations because of the proximity of the station to the study area and the availability of NOAA data to the public. The Kingston station has the longest precipitation record of the Rhode Island climatic stations (1889–present). The yearly average precipitation from 1971 through 2000 is 51.79 in., with the highest monthly average in September (4.163 in.) and the lowest monthly average in July (3.308 in.). During the same period, the average annual temperature at this station is 49.94°F.

Records from the rainfall gage at the Providence Weather Station Observatory (WSO) climatological station in Warwick, Rhode Island, have been collected from 1948 to present. The 1971–2000 record indicate an average rainfall of 46.46 in/yr with the highest monthly average in September (3.704 in.) and the lowest monthly average occurring in July (3.169 in.). The average temperature at this station is 51.13°F.

Land Use

Land use was calculated by using the Rhode Island Geographic Information Systems (RIGIS) land-use coverages and basin-boundary coverages. Land-use area was used to aggregate commercial, industrial, and agricultural water-use estimates into the applicable cities and towns and basins (table 3). For water-supply districs land-use area was used to aggregate the water-use categories by basin (tables 4 and 5).

Land within the Woonasquatucket River Basin is predominately forested (36.2 percent), followed by residential (28.2 percent), wetlands (10.8 percent), commercial (5.23 percent), agricultural (4.94 percent), transportation (3.88 percent), water (3.77 percent) and industrial (2.01 percent). Other land-use categories compose 4.97 percent of the area in the basin. Land within the Moshassuck River Basin is predominately residential (37.2 percent), followed by forest (24.1 percent), commercial (8.14 percent), wetlands (7.57 percent), industrial (4.90 percent), transportation (4.25 percent), agricultural (3.27 percent) and water (2.45 percent). Other land-use categories compose 8.12 percent of the area in the basin. These percentages reflect the less urban nature of the Woonasquatucket River Basin compared to the Moshassuck River Basin. The Woonasquatucket River Basin covers more land area within the city of Providence than does the Moshassuck River Basin, (5.6 and 4.0 mi^2, respectively); the Woonasquatucket River Basin includes substantial area in more rural communities in the central and western parts of the State, such as Glocester and North Smithfield, (6.1 and 4.4 mi^2, respectively) (table 3).

Table 3. Land areas and land-use areas in the Woonasquatucket and Moshassuck River Basins, north-central Rhode Island.

[Land-use areas were estimated by using the coverage from the Rhode Island Geographic Information System, 1995a. mi², square mile; --, not applicable]

City/Town	Land area	Agricultural	Commercial	Industrial
Land Area in Woonasquatucket River Basin (mi²)				
Cranston	0.1	--	0.001	0.010
Glocester	6.1	0.539	.057	.018
Johnston	8.0	.266	.237	.127
North Providence	2.5	--	.199	.055
North Smithfield	4.4	.327	.022	.011
Providence	5.6	.005	.488	.515
Smithfield	24.3	1.367	.658	.281
Total	51.0	2.504	1.662	1.017
Land Area in Moshassuck River Basin (mi²)				
Central Falls	0.5	--	0.050	0.060
Lincoln	12.0	0.653	.072	.408
North Providence	3.3	.034	.307	.053
Pawtucket	2.3	.002	.263	.288
Providence	4.0	--	.533	.325
Smithfield	1.7	.084	.038	.025
Total	23.8	0.773	1.263	1.159

Surface Water

A continuous-record streamflow-gaging station is located in each basin, the Woonasquatucket River at Centerdale (01114500) and the Moshassuck River at Providence (01114000) (fig. 2). The Woonasquatucket station has been continuously operated since 1941, with occasional water-quality data collected at the station. The drainage area upstream of the station is 38.3 mi², compared with 51 mi² at the mouth. Based on 59 years of data collected at this station (water years 1941 through 2000), the annual mean flow is 73.7 ft³/s. Some regulation on the Woonasquatucket River comes from the Smithfield Wastewater Treatment Facility (WWTF) and reservoirs upstream, particularly Waterman Reservoir. Because regulation on this stream was greater prior to 1956, the shorter period of record (1956 through 2000) was used in calculating the hydrologic budget. The Moshassuck streamflow-gaging station has been continuously operated since 1963, with occasional water-quality data collected at the station. The drainage area upstream of the station is 23.1 mi², compared with 23.8 mi² at the mouth. Based on 37 years of data collected at this station (water years 1963 through 2000), the annual mean flow is 40.6 ft³/s. The Moshassuck River is occasionally regulated at low flows. Measurements have been taken at four partial-record sites within the study area. Partial record stations have a staff gage with no continuous-monitoring equipment. There are two such stations within each basin: The Woonasquatucket River at Esmond (01114450) and the Stillwater River at Pleasant View Road (01114400) are both in the Woonasquatucket River Basin; and the West River at Providence (01113994) and the Moshassuck River near Saylesville (01113950) are both in the Moshassuck River Basin (fig. 2).

The Woonasquatucket River begins in North Smithfield downstream of Primrose Pond. It is joined at the Stillwater Reservoir by Latham Brook, Slack Reservoir, and Waterman Reservoir (by way of the Stillwater River), Sprague Upper and Lower Reservoirs (by way of the Stillwater River), and Hawkins Pond (by way of Reaper Brook). The Woonasquatucket River is also joined by Georgiaville Pond and Hawkins and Assapumpset Brooks. Georgiaville Pond has a surface area of 92 acres with an average depth of 13 ft and a maximum depth of 25 ft. Slack Reservoir has a surface area of 137 acres and an average depth of 8.5 ft, with a maximum depth of 15 ft. Upper Sprague Reservoir (fig. 1) has a surface area of 23 acres, an average depth of 10 ft, and a maximum depth of 18 ft (Guthrie and Stolgitis, 1977).

The Moshassuck River begins in Lincoln, is joined by the drainage from Olney Pond (by way of Threadmill Brook) and by Wenscott Reservoir (by way of the West River). The West River passes through one more named pond, Canada Pond, before it reaches the Moshassuck River (fig. 1). Olney Pond has a surface area of 120 acres, and an average depth of 8 ft. Its maximum depth is 15 ft. Wenscott Reservoir (fig. 1) has a surface area of 78 acres with an average depth of 7 ft, and a maximum depth of 11 ft. Canada Pond has a surface area of 23 acres, an average depth of 8 ft, and a maximum depth of 12 ft (Guthrie and Stolgitis, 1977). There is no published information for other surface water bodies in the study area.

The Woonasquatucket and Moshassuck Rivers meet in the city of Providence to form the Providence River, a tidally affected brackish stream. Below this portion of the basins is the upper part of Narragansett Bay. Much of the ground water in the Providence River subbasin discharges directly to Narragansett Bay.

Table 4. Land areas and land use by major public supplier in the Woonasquatucket and Moshassuck River Basins, north-central 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	Cities/Towns served	Total area within water district (mi²)	Woonasquatucket River Basin			
			Basin water district (mi²)	Agricultural (mi²)	Commercial (mi²)	Industrial (mi²)
East Smithfield Water District	Johnston	0.062	0.062	--	0.003	0.006
	North Providence	.508	.508	--	.001	.020
	Smithfield	2.685	2.685	0.028	.072	.068
Greenville Water District	Glocester	.119	.072	.050	.029	--
	Scituate	.020	--	.042	--	--
	Smithfield	6.37	6.34	.312	--	.093
Johnston Water District	Johnston	8.253	.031	--	--	--
Providence Water Supply Board	Cranston	14.155	.102	--	.001	.010
	Johnston	6.119	3.166	.071	.197	.119
	North Providence	5.286	2.017	--	.198	.035
	Providence	18.780	5.577	.005	.488	.515
Smithfield Water Supply Board	Lincoln	.005	--	--	--	--
	North Smithfield	.074	.011	--	--	--
	Smithfield	7.294	6.152	.390	.155	.076

Major public supplier	Cities/Towns served	Water district (mi²)	Moshassuck River Basin			
			Basin water district (mi²)	Agricultural (mi²)	Commercial (mi²)	Industrial (mi²)
Lincoln Water Commission	Lincoln	18.965	11.959	0.653	0.072	0.408
	Smithfield	.064	.064	.021	--	--
Providence Water Supply Board	Cranston	14.155	--	--	--	--
	Johnston	6.119	--	--	--	--
	North Providence	5.286	3.269	.034	.306	.053
	Providence	18.780	3.950	--	.533	.325
Pawtucket Water Supply Board	Central Falls	1.289	.474	--	.050	.060
	Pawtucket	8.845	2.312	.002	.263	.288
	Providence	<.001	--	--	--	--
Smithfield Water Supply Board	Lincoln	.005	--	--	--	--
	North Smithfield	0.074	--	--	--	--
	Smithfield	7.294	.484	.013	.029	.025

Table 5. Summary of total land area, land area in the study area, total 1990 populations, estimated 1995–99 populations, and land-use area by category for cities and towns partially or entirely in the Woonasquatucket and Moshassuck River Basins, north-central Rhode Island.

[All cities and 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 (2001). Land-use areas 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	1.3	0.5	17,595	16,595	7,403	0.223	0.174	---
Cranston	28.9	.1	76,077	74,890	1,037	1.177	1.174	2.609
Glocester	56.8	6.1	9,227	9,280	1,742	.279	.055	3.039
Johnston	24.3	8.0	26,606	26,433	12,447	.779	.398	1.412
Lincoln	19.0	12.0	18,086	18,696	8,746	.293	.612	.843
North Providence	5.8	5.8	32,186	31,305	31,305	.506	.108	.034
North Smithfield	24.8	4.4	10,498	9,966	797	.338	.248	1.289
Pawtucket	8.8	2.3	72,828	68,343	20,382	.878	.964	.006
Providence	18.8	9.6	160,362	151,151	79,907	2.180	1.701	.008
Smithfield	27.6	26	19,163	18,906	18,280	.699	.388	1.459

Minor Civil Division

For the purposes of this study, the political subdivisions in the basin provide the basic unit by which data were collected and analyzed. The smallest level at which data are available is the minor civil division (MCD). MCD is a term used by the U.S. Census Bureau, and is generally equivalent to a town or city. In the Woonasquatucket River Basin, there are seven cities and towns that are partially within the basin: Smithfield, Johnston, Glocester, Providence, North Smithfield, North Providence, and Cranston. In the Moshassuck River Basin, there are six cities and towns that are partially within the basin: Lincoln, Providence, North Providence, Pawtucket, Smithfield, and Central Falls. None of the cities and towns are entirely within one basin.

Polygons within the cities and towns were assigned population densities in geographic information system (GIS) coverages by using Census Bureau 1990 topologically integrated geographic encoding and referencing system (TIGER) data. These 1990 population coverages were merged with the USGS basin coverages to determine the populations in the Moshassuck and Woonasquatucket River Basins (table 1). Also, the town land area within each basin was determined by overlaying town-boundary and basin-boundary coverages. The ratio of the 1990 populations to the study period (1995–99) populations for towns by basin represents the percent change in the town's population. To estimate the study-period town populations on public and self water supply and on public and self wastewater disposal, the same percent change in population described above was multiplied by the 1990 population with private wells and the 1990 population with public-wastewater collection that was available from the Census Bureau. The results of these calculations are presented in table 6. The 2000 Census data, although available for this report, does not include data on public- and self-water supply and disposal. Public-water suppliers are defined by the U.S. Environmental Protection Agency (USEPA) as suppliers serving more than 25 people or having 15 service connections year-round [Code of Federal Regulations (CFR), title 40, part 141, section 2, 1996]. For this study, public suppliers were categorized as major public suppliers if they have a system of distribution, and minor suppliers were defined as those with closed systems serving only their own populations. Major public suppliers are listed in table 4 and minor public suppliers are listed in table 7.

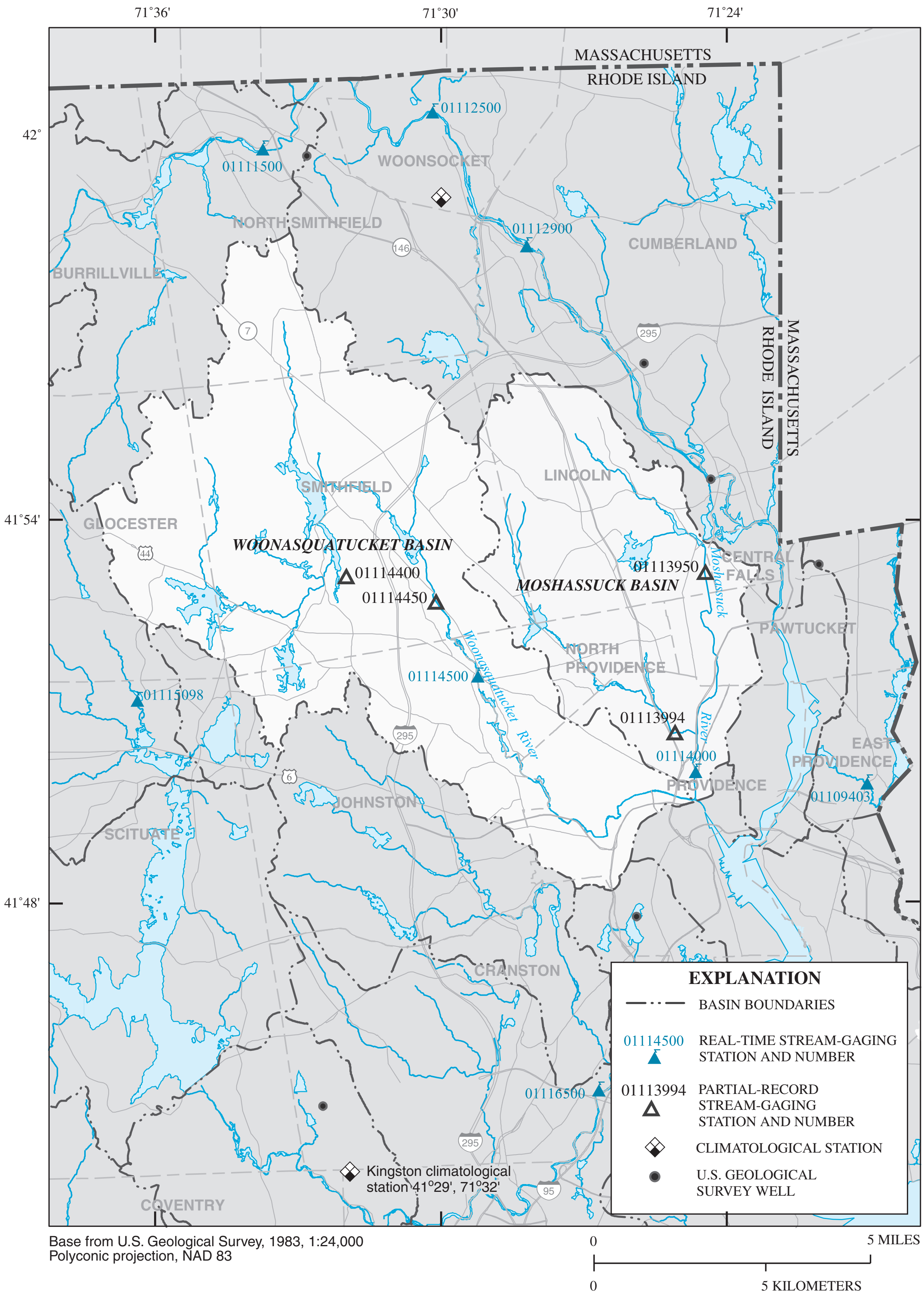


Figure 2. Location of streamflow-gaging stations, wells, and climatological stations in the Woonasquatucket and Moshassuck River Basins, north-central Rhode Island.

Table 6. Estimated water use by city or town and basin in the Woonasquatucket and Moshassuck River Basins, north-central Rhode Island, 1995–99.

[All cities and towns are in Rhode Island. Mgal/d, million gallons per day; --, 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	
Woonasquatucket Basin									
Cranston	0.069	--	0.001	--	0.009	--	--	--	0.079
Glocester	.004	0.119	--	--	--	--	0.001	0.027	.151
Johnston	.744	.095	.088	0.018	.060	0.004	.001	.001	1.011
North Providence	.997	.001	.098	--	.020	--	--	--	1.116
North Smithfield	.001	.055	--	.005	--	.004	--	.002	.067
Providence	3.350	.005	1.342	--	.461	--	.022	--	5.180
Smithfield	.959	.231	.214	.019	.097	.018	.004	.003	1.545
Basin total	6.124	0.506	1.743	0.042	0.647	0.026	0.028	0.033	9.149
Moshassuck Basin									
Central Falls	0.491	0.005	0.224	--	0.174	--	--	--	0.894
Lincoln	.511	.080	.086	--	.243	--	0.019	--	.939
North Providence	1.098	.001	.152	--	.020	--	.007	--	1.278
Pawtucket	1.365	.001	.190	--	.634	--	--	--	2.190
Providence	1.997	.002	1.462	--	.291	--	--	--	3.752
Smithfield	.038	.010	.010	0.003	.010	--	--	--	.071
Basin total	5.500	0.099	2.124	0.003	1.372	--	0.026	--	9.124
Study area total									
Study area total	11.624	0.605	3.867	0.045	2.019	0.026	0.054	0.033	18.273

Table 7. Minor suppliers by basin in the Woonasquatucket and Moshassuck River Basins, north-central Rhode Island.

[Both minor public suppliers are in the Woonasquatucket River Basin. There are none in the Moshassuck River Basin. Coefficient used for minor supplier population is 67. BD, bedrock well; gal/d/person, gallons per day per person; Mgal/d, million gallons per day]

Minor public supplier	Town	Aquifer type of well(s)	Estimated 1995–99	
			Population	Water withdrawals and use (Mgal/d)
Hebert Nursing Home	Smithfield	BD	143	0.010
Waterman Heights Nursing Home	Smithfield	BD	105	.007
Study area total				0.017

Woonasquatucket River Basin

The town of Cranston is in central Rhode Island, and covers 28.9 mi^2 (table 5).The estimated population for the study period is 74,890 (table 5) of which 0.1 mi^2 (table 2) and 1,037 persons (table 1) are in the Woonasquatucket River Basin. The town is publicly supplied by the Providence Water Supply Board (Providence Water).

The town of Glocester is in northwestern Rhode Island, and covers 56.8 mi^2 (table 5). The estimated 5-year-average population is 9,280 (table 5), of which 6.1 mi^2 (table 2) and 1,742 persons (table 1) are in the Woonasquatucket River Basin. Glocester has no major public-water suppliers, but the Greenville Water District does supply a small area in the town.

The town of Johnston is in central Rhode Island, and covers 24.3 mi^2 (table 5). The estimated population for the study period is 26,433 (table 5), of which 8.0 mi^2 (table 2) and 12,447 persons (table 1) are in the Woonasquatucket River Basin. The town was publicly supplied by the Johnston Water District for a portion of the study period, but those customers are now served as retail customers of Providence Water. Small areas of the town within the basin are served by the East Smithfield Water District.

The city of North Providence is in central Rhode Island, and covers 5.8 mi^2 (table 5). The estimated population for the study period is 31,305 (table 5), of which 2.5 mi^2 (table 2) and 14,896 persons (table 1) are in the Woonasquatucket River Basin. The town is publicly supplied by Providence Water. Small areas of the town within the basin are supplied by the East Smithfield Water District. Wastewater is collected by the Narragansett Bay Commission and is disposed outside of the basin at the Fields Point Wastewater Treatment Facility that discharges to Narragansett Bay.

The town of North Smithfield is in central Rhode Island, and covers 24.8 mi^2 (table 5). The estimated population for the study period is 9,966 (table 5) of which 4.4 mi^2 (table 2) and 797 persons (table 1) are in the Woonasquatucket River Basin. The town is publicly supplied by the North Smithfield Water District and the Woonsocket Water Division, but the publicly supplied areas are in the Blackstone River Basin. Small areas within the Woonasquatucket River Basin are supplied by the Smithfield Water Supply Board.

The city of Providence is in central Rhode Island, and covers 18.8 mi^2 (table 5). The estimated population for the study period is 151,151 (table 5), of which 5.6 mi^2 (table 2) and 50,065 persons (table 1) are in the Woonasquatucket River Basin. This area is the most populated portion of the basin. The city is publicly supplied by Providence Water. A small portion of the city (less than 0.001 mi^2) is supplied by the Pawtucket Water Supply Board, but this area is outside the basin, and 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 Wastewater Treatment Facility, which discharges to Narragansett Bay.

The town of Smithfield is in central Rhode Island, and covers 27.6 mi^2 (table 5). The estimated population for the study period is 18,906 (table 5), of which 24.3 mi^2 (table 2) and 17,568 persons (table 1) are in the Woonasquatucket River Basin. The town is served by three major suppliers, the East Smithfield Water District, the Greenville Water District, and the Smithfield Water Supply Board. All of these suppliers buy their water wholesale from Providence Water. The source of this water is the Scituate Reservoir, which is located outside the basin in the Pawtuxet River Basin (fig. 1). Wastewater is collected by the Smithfield Sewer Authority and is disposed of into the Woonasquatucket River at the Smithfield Wastewater Treatment Facility. Smithfield has two minor suppliers (table 7) that serve a total population of 248. These are the only minor suppliers in the study area.

Moshassuck River Basin

The city of Central Falls is in central Rhode Island, and covers 1.3 mi^2 (table 5). The estimated population for the study period is 16,595 (table 5), of which 0.5 mi^2 (table 2) and 7,403 persons (table 1) are in the Moshassuck River Basin. The city is publicly supplied by the Pawtucket Water Supply Board. The source of the water is in the Blackstone River Basin. Wastewater is collected by the Narragansett Bay Commission and is disposed outside of the basin at the Bucklin Point Wastewater Treatment Facility that discharges to Narragansett Bay.

The town of Lincoln is in central Rhode Island, and covers 19.0 mi^2 (table 5). The estimated population for the study period is 18,696 (table 5), of which 12.0 mi^2 (table 2) and 8,746 persons (table 1) are in the Moshassuck River Basin. The town is served by the Lincoln Water Commission; and although the Commission does have its own water-supply sources, these sources are located outside of the Moshassuck River Basin in the Blackstone River Basin. Lincoln buys its water from Providence Water. The source of this water is the Scituate Reservoir that is located outside the basin in the Pawtuxet River Basin. Wastewater is collected by the Narragansett Bay Commission and is disposed outside of the basin at the Bucklin Point Wastewater Treatment Facility, which discharges to Narragansett Bay.

The city of North Providence is in central Rhode Island and covers 5.8 mi^2 (table 5). The estimated population for the study period is 31,305 (table 5), of which 3.3 mi^2 (table 2) and

16,409 persons (table 1) are in the Moshassuck River Basin. The town is publicly supplied by Providence Water, whose source of water is the Scituate Reservoir that is located outside of the basin in the Pawtuxet River Basin. Wastewater is collected by the Narragansett Bay Commission and is disposed outside of the basin at the Fields Point Wastewater Treatment Facility, which discharges to Narragansett Bay.

The city of Pawtucket is in central Rhode Island and covers 8.8 mi^2 (table 5). The estimated population for the study period is 68,343 (table 5), of which 2.3 mi^2 (table 2) and 20,382 persons (table 1) are in the Moshassuck River Basin. The city is publicly supplied by the Pawtucket Water Supply Board, with water imported to the basin from the Blackstone River Basin. Wastewater is collected by the Narragansett Bay Commission and is disposed outside of the basin at the Bucklin Point Wastewater Treatment Facility, which discharges to Narragansett Bay.

The city of Providence is in central Rhode Island, and covers 18.8 mi^2 (table 5). The estimated population for the study period is 151,151 (table 5), of which 4.0 mi^2 (table 2) and 29,842 persons (table 1) are in the Moshassuck River Basin. The city is publicly supplied by Providence Water. The source of this water is the Scituate Reservoir, which is located outside the basin in the Pawtuxet River Basin. A small portion of the city (less than 0.001 mi^2) is supplied by the Pawtucket Water Supply Board, but the area is outside the basin and 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 Wastewater Treatment Facility, which discharges to Narragansett Bay.

The town of Smithfield is in central Rhode Island and covers 27.6 mi^2 (table 5). The estimated population for the study period is 18,906 (table 5), of which 1.7 mi^2 (table 2) and 712 persons (table 1) are in the Moshassuck River Basin. The town is served by three major suppliers: the East Smithfield Water District, the Greenville Water District, and the Smithfield Water District. All of these suppliers buy their water wholesale from Providence Water. The source of this water is the Scituate Reservoir, which is located outside the basin in the Pawtuxet River Basin. In addition, a small portion of the town within the basin is supplied by the Lincoln Water Commission.Wastewater is collected by the Smithfield Sewer Authority and is disposed of into the Woonasquatucket River at the Smithfield WWTF. Two minor suppliers serve a total population of 248 in Smithfield (table 7). These are the only minor suppliers in the study area.

Water Use

Components of water use include water withdrawals, public-supply systems and distributions, non-account use, consumptive water use, wastewater-system collections, and return flow. Data were categorized as either self-supply or public-supply withdrawals from surface water or ground water. Conveyance losses (which are unmetered) include leaks, system flushing, and fire fighting, and are examples of non-account water use in public-supply systems. The non-account water use for a system is the total distribution by the supplier minus the sum of the public-supply distributions for the water-use categories in the system. Water-use categories in this report are domestic, commercial, industrial, and agricultural for public-supply and self-supply users. Public-supply water is from a combination of surface-water and ground-water sources. Self-supply domestic, industrial, and commercial withdrawals are from ground-water sources. Consumptive water use is the water removed from the system through uses by humans, livestock, industrial and commercial production, or by 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, which are the estimated self-disposed discharges within each town and basin. Water withdrawals, water use, consumptive use, and returns were calculated for each basin by town for the calendar years during the study period.

New England Water-Use Data System

Water-use data were entered into the New England Water-Use Data System, a relational database referred to as NEWUDS. The data consist of site-specific and aggregate water withdrawals, uses, and discharges in the Woonasquatucket and Moshassuck River Basins. When available, monthly, quarterly, and yearly metered data were entered as received, and converted to common units (Mgal/d) for data comparison. Unmetered water withdrawals, uses, and discharges were estimated by category (domestic, industrial, commercial, and agricultural). The database was queried to obtain the average water use for the study period. For quality-assurance purposes, NEWUDS allows the data compiler to indicate the original data source, rate units, and method of rate determined (such as meter type) within the database. Documentation describing the database development and how to use the database have been summarized in the reports by Tessler (2002) and Horn (2003), respectively.

Public-Water Supply and Interbasin Transfers

Public-water suppliers are defined as suppliers serving more than 25 people or having 15 service connections year-round. These suppliers were categorized into major public suppliers that have distribution systems (table 4), and minor suppliers that have closed systems serving only their own populations (table 7). Seven major public-water suppliers serve the Woonasquatucket and Moshassuck River Basins: Providence Water Supply Board, Smithfield Water District, East Smithfield Water District, Greenville Water District, Johnston Water District, Pawtucket Water Supply Board, and Lincoln Water Commission (fig. 3). These major suppliers distribute water to domestic, commercial, industrial, and agricultural users. While a small part of the Johnston Water District (0.031 mi^2) is located in the Woonasquatucket River Basin, none of the commercial, industrial, or agricultural land use area served by the district is in the study area. This district lies primarily in the Pawtuxet River Basin. The systems for each major water supplier are summarized in figures 4–9. The two minor water suppliers are nursing homes (table 7).

Providence Water is the largest public supplier in the State, serving 60 percent of the population. Their source of water is the Scituate Reservoir. The generalized distribution system is shown in figure 4. Providence Water serves the population in two ways. First, it serves retail customers, including domestic users, who used an average of 18.131 Mgal/d during the study period, commercial users who averaged 7.196 Mgal/d, industrial users who averaged 2.625 Mgal/d, and agricultural users, who averaged 0.008 Mgal/d. A total of 11.279 Mgal/d was non-account water in their distribution system during the study period. Total retail customer supply averaged 39.2 Mgal/d during the study period. Second, Providence Water serves 10 major suppliers who, in turn, sell water to their own retail customers. The suppliers in this category within the study area are discussed in detail below, and the total amount of water delivered to these suppliers averaged 4.588 Mgal/d for the study period. Of this total, 0.759 Mgal/d was delivered to East Smithfield Water Department (fig. 5), 0.850 Mgal/d to Greenville Water District (fig. 6), 0.780 Mgal/d to Smithfield Water District (fig. 7), and 2.199 Mgal/d to the Lincoln Water Commission (fig. 8).

The Smithfield Water District received 0.780 Mgal/d from Providence Water during the study period and supplied customers in the town of Smithfield. Smithfield Water District also supplied 0.049 Mgal/d to the East Smithfield Water District and had an additional emergency interconnection with East Smithfield that was not used during the study period (fig. 7).

The East Smithfield Water District received 0.759 Mgal/d directly from Providence Water through two of their four interconnections, one with 0.592 Mgal/d and the other with 0.167 Mgal/d during the study period. The district received an additional 0.049 Mgal/d from the Smithfield Water District. An additional emergency interconnection with Smithfield was not used. The East Smithfield Water District supplied customers in the town of Smithfield (fig. 5).

The Greenville Water District is in Smithfield, and received 0.850 Mgal/d from Providence Water during the study period. The district supplied customers in the town of Smithfield (fig. 6). This supplier has no water supply of its own or any interconnections with suppliers other than Providence Water.

The Pawtucket Water Supply Board is similar to Providence Water. It serves retail customers directly, and supplies water through interconnections to four major suppliers outside of the study area who, in turn, have their own retail customers. Total distributions in the Pawtucket system during the study period were 12.296 Mgal/d. The major suppliers are detailed in figure 9. The Pawtucket Water Supply Board also transferred 1.301 Mgal/d to suppliers outside of the Moshassuck River Basin. During the study period, an estimated 2.897 Mgal/d were directly supplied to customers in the study area. Domestic users in Central Falls accounted for 0.491 Mgal/d, and 1.364 Mgal/d for Pawtucket. Commercial users in Central Falls accounted for 0.008 Mgal/d and 0.190 Mgal/d for Pawtucket. Industrial users in Central Falls accounted for 0.210 Mgal/d, and 0.634 Mgal/d for Pawtucket. The remaining 6.178 Mgal/d were supplied directly to customers who are outside of the study area (fig. 9).

The Lincoln Water Commission received an average of 2.199 Mgal/d from Providence Water during the study period and 0.041 Mgal/d from the Woonsocket Water Department (fig. 8). In addition, the commission withdrew 0.075 Mgal/d from its own sources. The Lincoln wells are outside of the study area in the Blackstone River Basin and were used only sporadically during the study period because of contamination problems.

Limited data are available for water withdrawals by the two minor water suppliers in the Woonasquatucket River Basin: Hebert Nursing Home and Waterman Heights Nursing Home (table 7). Water use was estimated by applying the water-use coefficient for public-water supply (67 gal/d/person) determined by Korzendorfer and Horn (1995).

Figure 3. Location of water-supply districts, Rhode Island Pollutant Discharge Elimination System sites, and wastewater-treatment plants in the Woonasquatucket and Moshassuck River Basins, north-central Rhode Island.

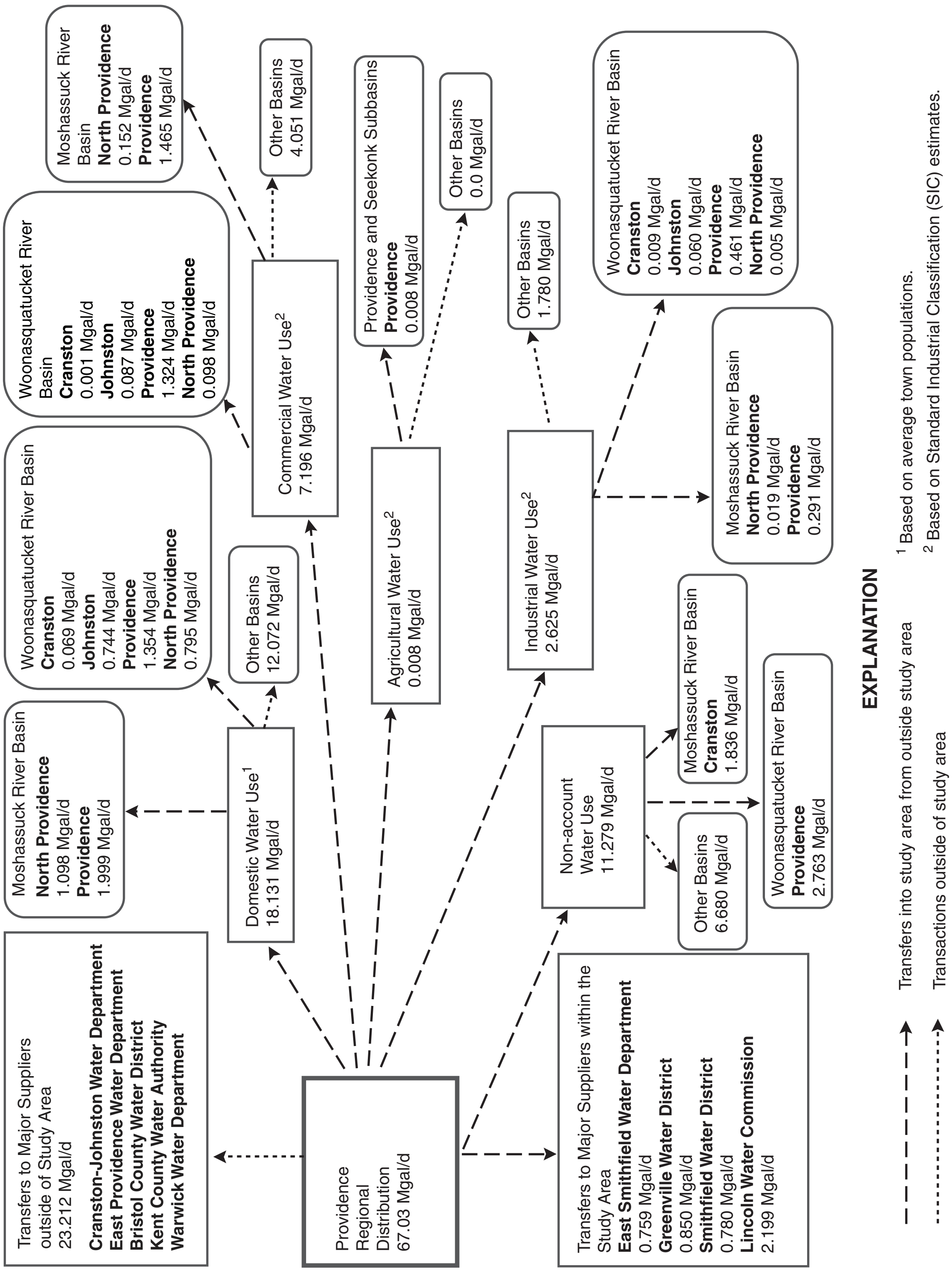


Figure 4. Providence Water Supply Board system, north-central Rhode Island (Mgal/d, million gallons per day).

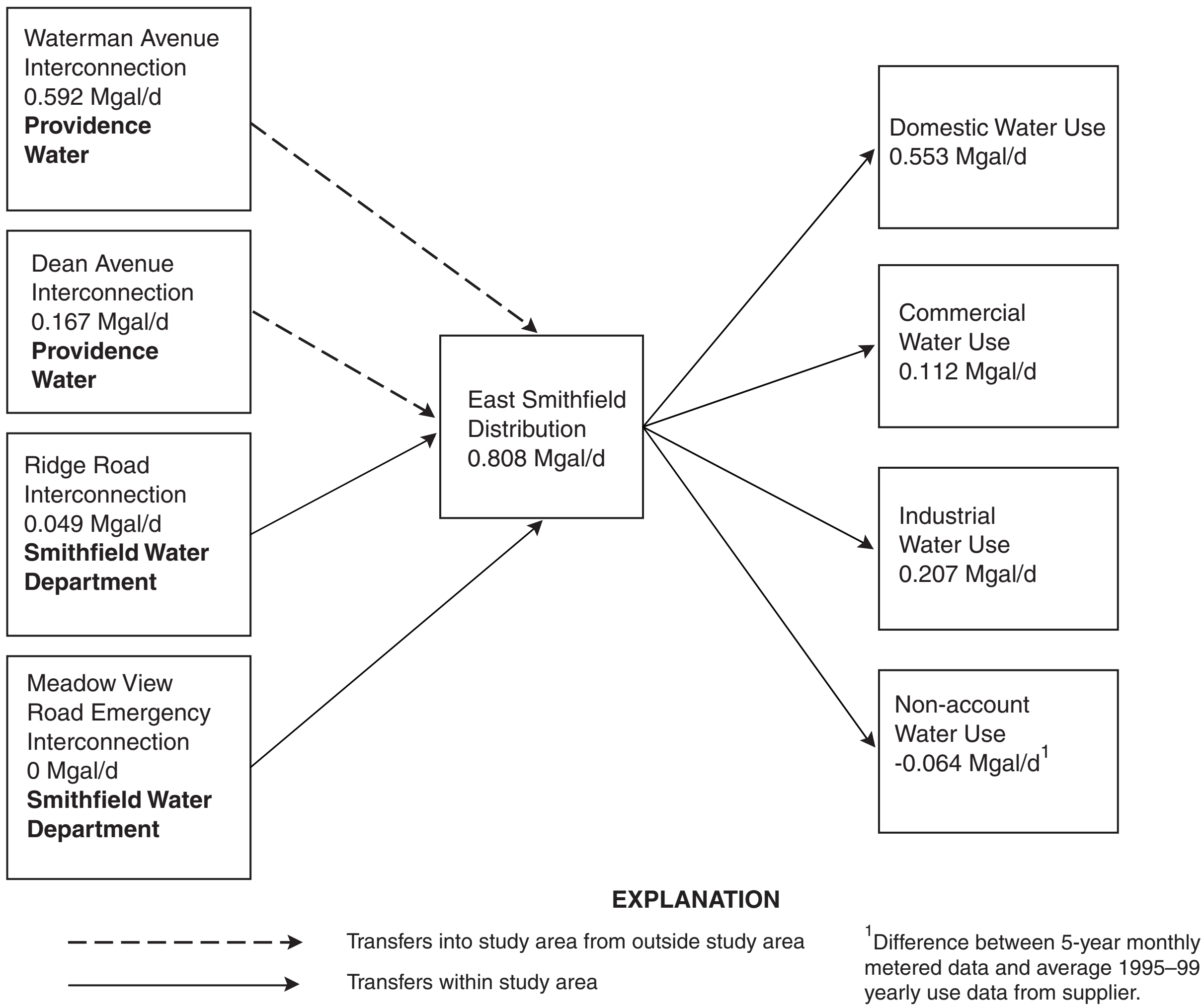


Figure 5. East Smithfield Water District system, north-central Rhode Island (Mgal/d, million gallons per day).

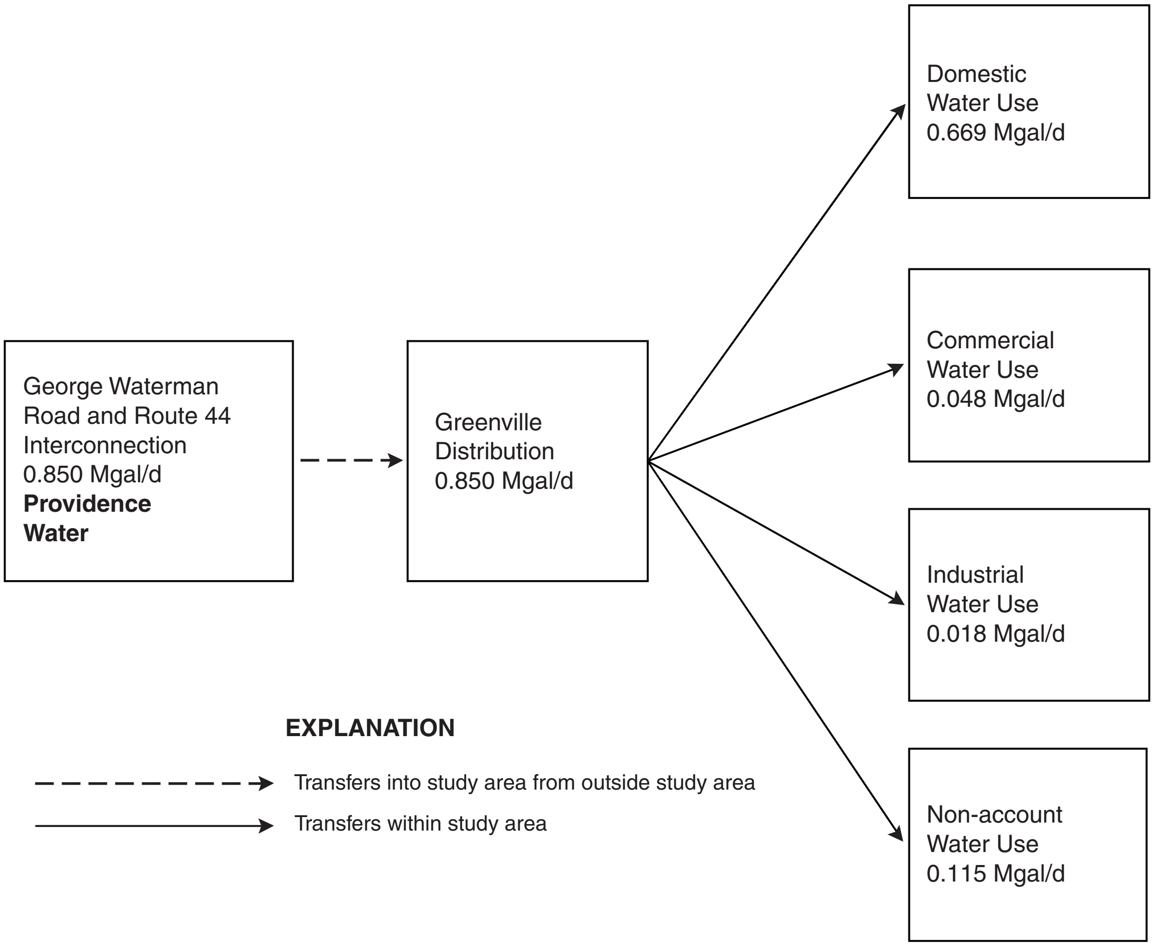
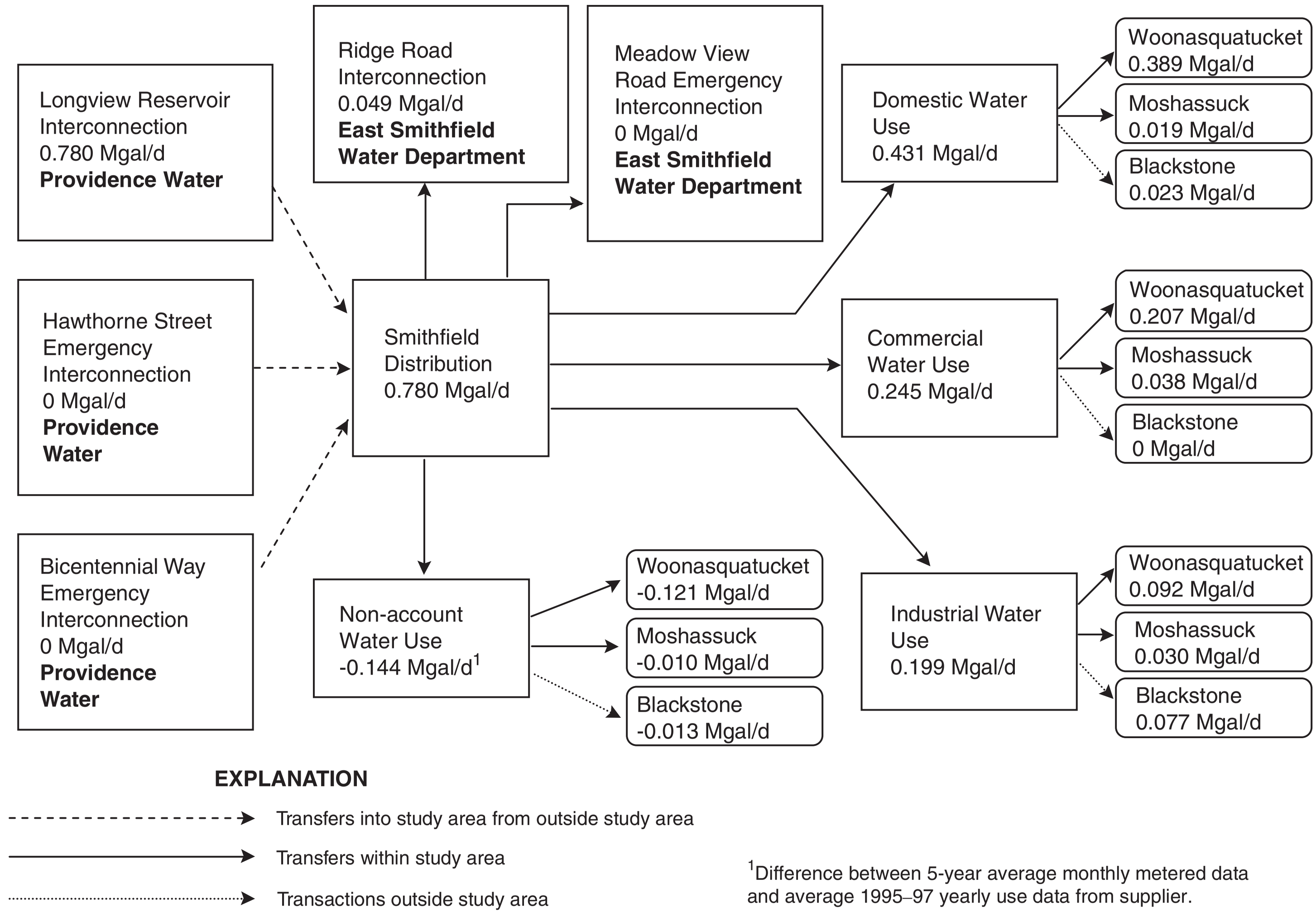


Figure 6. Greenville Water District system, north-central Rhode Island (Mgal/d, million gallons per day).



[1]Difference between 5-year average monthly metered data and average 1995–97 yearly use data from supplier.

Figure 7. Smithfield Water Supply Board system, north-central Rhode Island (Mgal/d, million gallons per day).

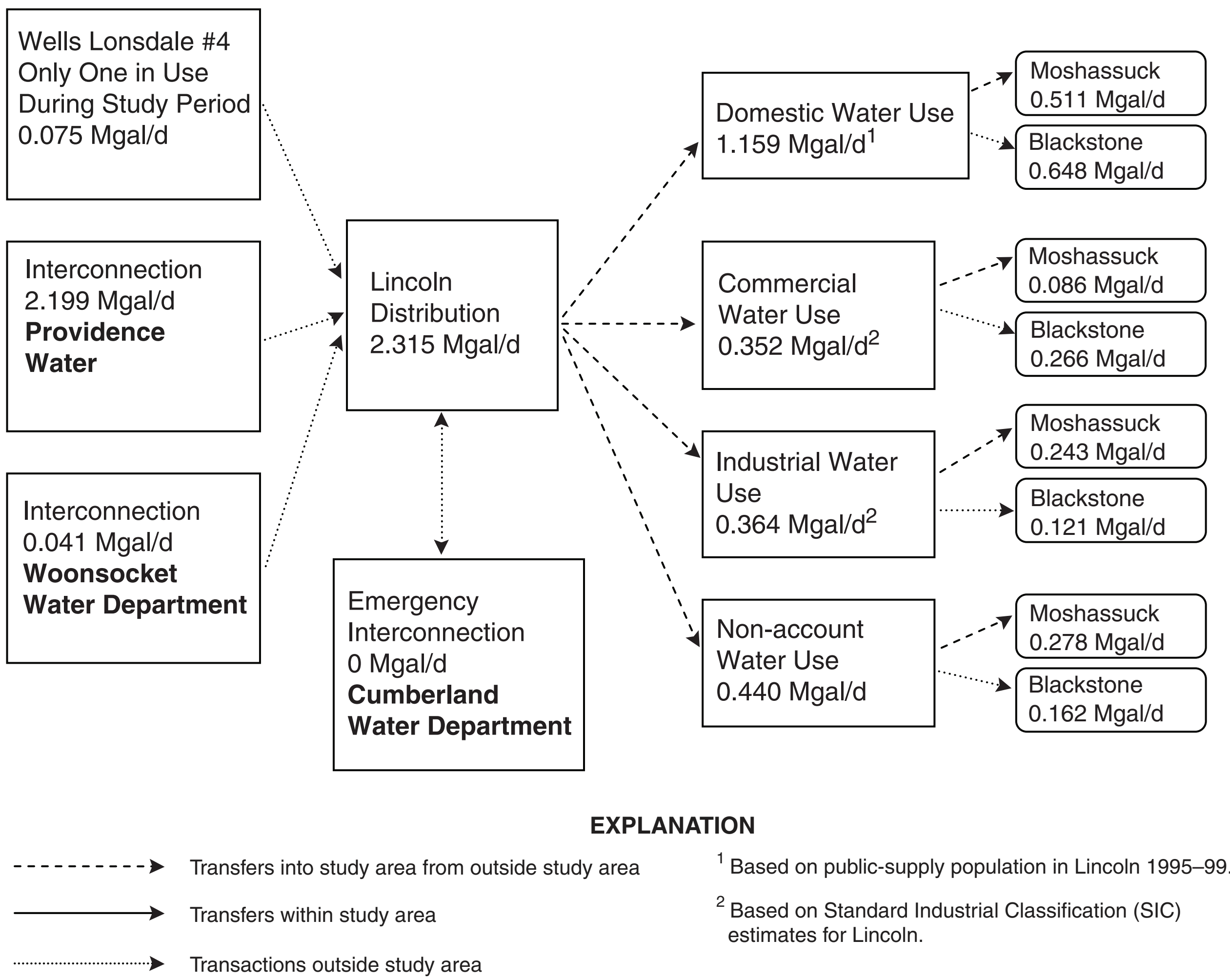
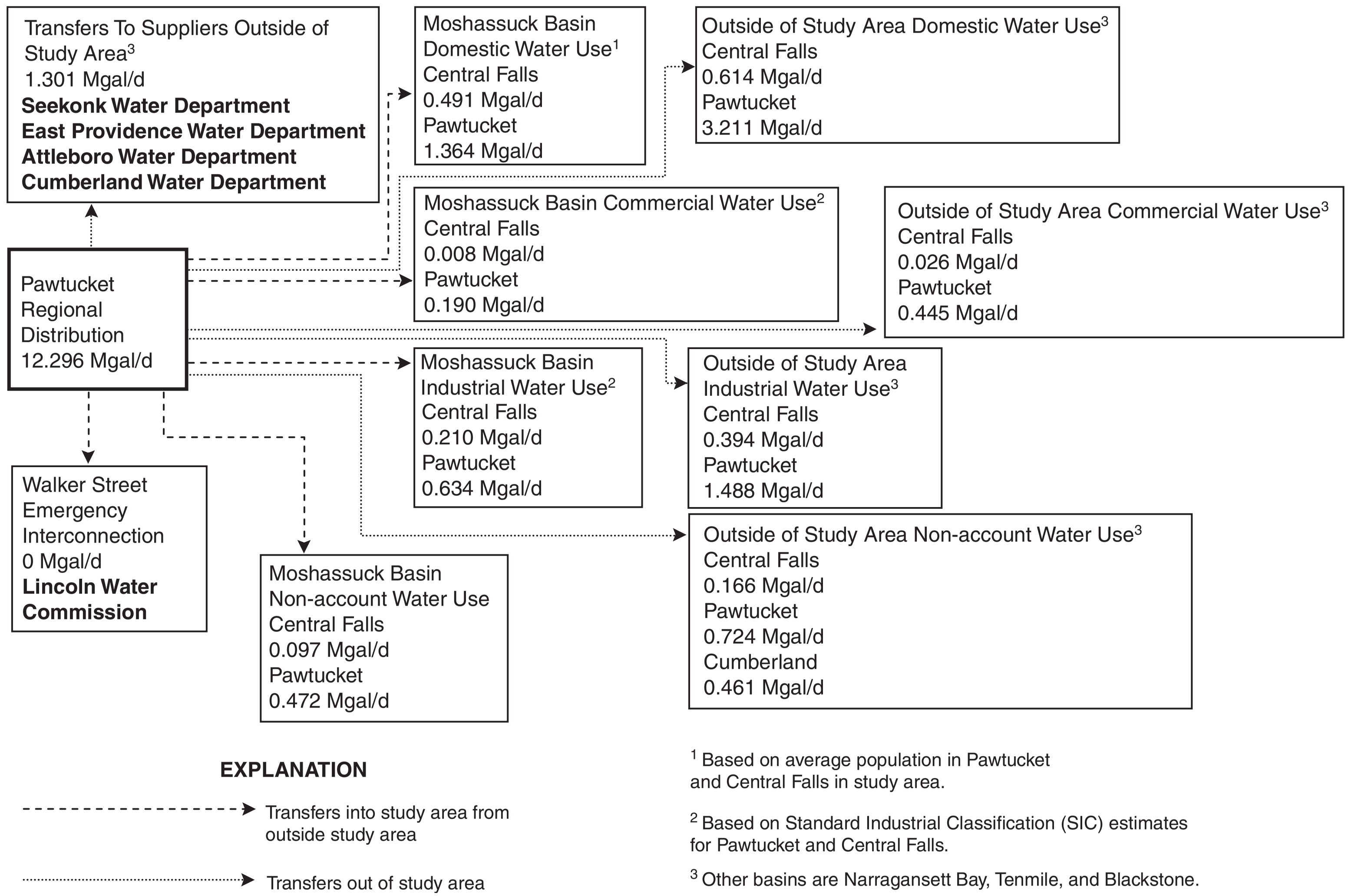


Figure 8. Lincoln Water District system, north-central Rhode Island (Mgal/d, million gallons per day).



[1] Based on average population in Pawtucket and Central Falls in study area.

[2] Based on Standard Industrial Classification (SIC) estimates for Pawtucket and Central Falls.

[3] Other basins are Narragansett Bay, Tenmile, and Blackstone.

Figure 9. Pawtucket Water Supply Board system, north-central Rhode Island (Mgal/d, million gallons per day).

Domestic Water Use

Domestic water use is the amount of water used by residential populations either served by public-water supplies or private wells; water supplies from private wells are known as self-supplied users. The domestic water-use category includes the public-water supply deliveries to residents within the political or hydrologic boundaries in the study area. Estimates of domestic withdrawals were based on the U.S. Department of Commerce (1990) Census coverage available through RIGIS. The coverage includes the 1990 populations that are self supplied. This coverage was then separated by basin. To obtain the populations served by public-water supplies, the self supplied populations were subtracted from the total population in the basins. To calculate the water use for this category, population estimates in Rhode Island were multiplied by the water-use coefficients, 71 gal/d/person for self-supplied domestic and 67 gal/d/person for public-supply domestic water use. These coefficients were based on the 1990 National Water-Use Compilation (Korzendorfer and Horn, 1995).

Public-Supply Use

Water suppliers provide information about populations served within towns rather than basins, so a GIS was used to estimate basin populations on public supply. The 1990 census blocks that have the domestic populations on private wells were merged with the basin coverage. The 1990 population that supplies its own water was subtracted from the total population for each basin. The ratio of the 1990 to 1995–99 populations was applied in each basin to calculate the populations on public supply and self-supply water by basin for each town (table 1). Because limited withdrawal data are available for the two minor public suppliers in the study area, the water-use coefficient was applied to populations served (table 7) by each minor supplier (Korzendorfer and Horn, 1995). The public-supply domestic water use in the Woonasquatucket River Basin ranged from 0.001 Mgal/d in North Smithfield to 3.350 Mgal/d in Providence. In the Moshassuck River Basin, the public-supply domestic use ranged from 0.038 Mgal/d in Smithfield to 1.997 Mgal/d in Providence (table 6).

Self-Supplied Use

Domestic self-supply water use was calculated by merging the basin coverages with the U.S. Census 1990 population coverages obtained through RIGIS. The 1995–99 self-supply population in each basin was estimated from the 1990 population and the 1995–99 ratio of growth within each basin. The self-supply domestic water use in the Woonasquatucket River Basin ranged from none in Cranston to 0.231 Mgal/d in Smithfield. In the Moshassuck River Basin, the self-supply domestic use ranged from 0.001 Mgal/d in North Providence and Pawtucket to 0.080 Mgal/d in Lincoln (table 6).

Commercial and Industrial Water Use

Limited data are available concerning commercial and industrial water use from public-water supply and self-supplied systems, because withdrawals and use for these water-use categories are not regulated in Rhode Island. Commercial and industrial water-use estimates were derived by dividing the total calculated water use for each town (table 8) by the basin area of each land-use type for the town. 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 regarding commercial and industrial use of public-supply water included metered and unmetered data. When the data were available, the public suppliers provided the delivery volumes and the number of service connections for commercial and industrial water users. In some cases, the suppliers reported the commercial and industrial users together; and in other cases, the information was not available. Government water use is water used by city and town facilities and government agencies, and it is accounted for within the commercial water-use category, according to the Standard Industrial Classification (SIC) codes. However, government water use is a separate use category in NEWUDS. Because some water-supply district service areas are within one or more basins, public-supply commercial and industrial water use were apportioned on the basis of percentage of each type of land-use area (table 4), within each basin. Land-use coverages from RIGIS were merged with the water-supply district, town, and basin coverages to calculate the percentage of commercial and industrial land use within the supply districts for towns served in the Woonasquatucket and Moshassuck River Basins. Public-supply commercial use in the Woonasquatucket River Basin ranged from none in Glocester and North Smithfield to 1.342 Mgal/d in Providence. In the Moshassuck River Basin public-supply commercial use ranged from 0.010 Mgal/d in Smithfield to 1.462 Mgal/d in Providence. In the Woonasquatucket River Basin, public-supply industrial water use ranged from none in Glocester and North Smithfield to 0.461 Mgal/d in Providence. In the Moshassuck River Basin, public-supply industrial use ranged from 0.010 Mgal/d in Smithfield to 0.634 Mgal/d in Pawtucket (table 6).

Self-Supplied Use

Commercial and industrial self-supply water use were calculated by using information obtained from industrial and commercial directories published by the Rhode Island Economic Development Corporation (Export/Import Directory, High Tech Industries in Rhode Island, and Major

Table 8. Estimated water use per 2-digit Standard Industrial Classification code by city or town in the Woonasquatucket and Moshassuck River Basins, north-central Rhode Island, 1995–99.

[IWR-MAIN, Institute for Water Resources, Municipal and Industrial Needs. Units for IWR-MAIN are gallons per day per person. Mgal/d, million gallons per day; <0.001, value not used in totals; --, not applicable]

Two-digit Standard Industrial Classification category and code	IWR-MAIN coefficient	Water use (Mgal/d)				
		Central Falls	Cranston	Glocester	Johnston	Lincoln
Mining [14]		--	--	--	--	--
Construction [15–17]	35	--	0.009	--	--	0.004
Industrial [20–39]						
Food [20]	469	--	.162	--	0.002	.047
Textile Mills [22]	315	0.291	.008	--	--	.061
Finished apparel [23]	13	--	--	--	--	.0004
Wood, lumber [24]	78	--	--	--	--	--
Furniture [25]	30	--	--	--	--	--
Paper Products [26]	863	.175	.237	--	--	--
Printing, Publishing [27]	42	--	.0001	--	.001	.0006
Chemical Products [28]	289	.004	.069	--	--	.026
Petroleum Refining [29]	1,045	--	--	--	--	--
Rubber [30]	119	--	.15	--	.025	.003
Leather [31]	148	--	.007	--	--	--
Stone, clay, glass, and concrete [32]	202	.101	.141	--	.101	--
Primary metals [33]	178	--	.012	--	.026	.089
Fabricated metal [34]	95	.013	.066	--	--	.067
Machinery [35]	58	.01	.029	0.0001	.0002	.010
Electrical equipment [36]	71	--	.035	--	.002	.005
Transportation equipment [37]	63	--	--	--	--	--
Instruments [38]	66	--	.039	--	.005	.007
Jewelry, precious metals [39]	36	.009	.040	--	.032	.044
Total Industrial [20–39]		0.603	0.995	0.0001	0.2002	0.360
Commercial [40–97]						
Transportation, communication, utilities [40–49]	51	--	0.019	--	0.006	0.019
Wholesale trade [50–51]	58	--	.034	--	--	--
Retail trade [52–59]	58	--	.290	--	.041	.007
Finance, insurance, real estate [60–67]	71	--	.008	--	.052	.039
Services [70–89]	106	0.034	.375	0.031	.247	.287
Public administration [91–97]	71	--	--	--	--	--
Total Commercial [40–97]		0.034	0.726	0.031	0.346	0.352

Employers in Rhode Island). Commercial and industrial water use were estimated for each town by identifying the number of employees for the industrial and commercial sectors for each SIC code and applying the Institute of Water Resources, Municipal and Industrial Needs (IWR-MAIN) water-use coefficient (in gal/d/person) for each town (table 8) as described in Horn (2000). The estimated commercial and industrial use of public water was subtracted from the total aggregate to obtain the estimated total use for these categories. The results for commercial and industrial water withdrawals and water use are listed in table 6. The total water use for each town was disaggregated by basin on the basis of the commercial and industrial land use for each town, respectively (table 2). Commercial use of self-supply water ranged from none in four towns in both basins to 0.019 Mgal/d in the Smithfield portion of the Woonasquatucket River Basin.

Table 8. Estimated water use per 2-digit Standard Industrial Classification code by city or town in the Woonasquatucket and Moshassuck River Basins, north-central Rhode Island, 1995–99.—Continued

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

Two-digit Standard Industrial Classification category and code	IWR-MAIN coefficient	Water use (Mgal/d)				
		North Providence	North Smithfield	Pawtucket	Providence	Smithfield
Mining [14]						
Construction [15–17]	35	--	--	0.005	0.072	0.004
Industrial [20–39]						
Food [20]	469	--	--	.210	.176	.077
Textile Mills [22]	315	--	--	.580	.058	--
Finished apparel [23]	13	--	--	.0003	.001	--
Wood, lumber [24]	78	--	--	--	--	--
Furniture [25]	30	--	--	.022	.003	.003
Paper Products [26]	863	--	--	.526	.582	--
Printing, Publishing [27]	42	--	0.0001	.025	.069	--
Chemical Products [28]	289	--	.007	.019	.019	--
Petroleum Refining [29]	1,045	--	--	--	--	--
Rubber [30]	119	0.009	.015	.158	.044	--
Leather [31]	148	--	--	--	.001	--
Stone, clay, glass, and concrete [32]	202	--	.071	.003	--	.006
Primary metals [33]	178	--	--	.283	.055	.011
Fabricated metal [34]	95	.010	--	.049	.125	.001
Machinery [35]	58	--	--	.015	.026	.005
Electrical equipment [36]	71	--	.009	.026	.048	.003
Transportation equipment [37]	63	--	--	--	.026	.002
Instruments [38]	66	.0001	.001	.098	.075	.032
Jewelry, precious metals [39]	36	.021	--	.107	.215	.019
Total Industrial [20-39]		0.0401	0.1031	2.121	1.523	0.159
Commercial [40–97]						
Transportation, communication, utilities [40–49]	51	0.0008	0.005	0.016	0.435	--
Wholesale trade [50–51]	58	--	.010	.003	.038	--
Retail trade [52–59]	58	.023	.016	.048	.122	0.030
Finance, insurance, real estate [60–67]	71	--	--	.048	.676	.076
Services [70-89]	106	.226	.052	.520	4.72	.142
Public administration [91–97]	71	--	--	--	--	--
Total Commercial [40–97]		0.2498	0.083	0.635	5.991	0.248

Smithfield was the only town in the Moshassuck River Basin that had self-supplied commercial water use, estimated to be 0.003 Mgal/d. Industrial self-supplied water use in the Woonasquatucket and Moshassuck River Basins ranged from none in four towns in the Woonasquatucket River Basin and the entire Moshassuck River Basin to 0.018 Mgal/d in the Smithfield portion of the Woonasquatucket River Basin.

There was one self-supplied user in the Woonasquatucket River Basin, in the category of power generation. This category is generally considered as a separate water-use category from industrial use. The study period average withdrawals were 0.022 Mgal/d. This withdrawal is accounted for separately from the industrial category, and is included in the withdrawals in the basin.

Table 9. Estimated consumptive water use by city or town and basin in the Woonasquatucket and Moshassuck River Basins, north-central 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	
Woonasquatucket Basin									
Cranston	0.010	--	<0.001	--	0.001	--	--	--	0.011
Glocester	.001	0.018	--	--	--	--	0.001	0.027	.047
Johnston	.112	.014	.009	0.002	.006	<0.001	.001	.001	.145
North Providence	.150	<.001	.010	--	.002	--	--	--	.162
North Smithfield	<.001	.008	--	<.001	--	<.001	--	.002	.010
Providence	.502	.001	.134	--	.046	--	.022	--	.705
Smithfield	.144	.035	.021	.002	.010	.002	.004	.003	.221
Basin total	0.919	0.076	0.174	0.004	0.065	0.002	0.028	0.033	1.301
Moshassuck Basin									
Central Falls	0.074	0.001	0.022	--	0.017	--	--	--	0.114
Lincoln	.077	.012	.009	--	.024	--	0.019	--	.141
North Providence	.165	<.001	.015	--	.002	--	.007	--	.189
Pawtucket	.205	<.001	.019	--	.063	--	--	--	.287
Providence	.300	<.001	.146	--	.029	--	--	--	.475
Smithfield	.006	.002	.001	<.001	.001	--	--	--	.010
Basin total	0.827	0.015	0.212	<0.001	0.136	--	0.026	--	1.216
Study Area Total									
Study area total	1.746	0.091	0.386	0.004	0.201	0.002	0.054	0.033	2.517

Agricultural Water Use

Agricultural water use (livestock, crop irrigation, and golf course irrigation) was calculated from information provided by the U.S. Department of Agriculture (USDA), NRCS, formerly the Soil Conservation Service (SCS), and the RIDEM Division of Agriculture. The estimated value was calculated for each town and then disaggregated into the basins. Livestock withdrawals and use were assumed to be 9 percent from surface water (streams and ponds) and 82 percent from ground water (wells) on the basis of previously estimated statewide livestock water-use figures from the USDA (1993). Withdrawals and use for irrigation (golf courses and crops) were assumed to be 81 percent from surface water and 13 percent from ground water, on the basis of previously estimated statewide irrigation water use from the USDA (1993). The remaining 9 percent of livestock use and 6 percent of irrigation use is assumed to come from public supply. Consumptive water use for agriculture was assumed to be 100 percent (table 9).

Livestock water requirements are calculated by multiplying water-use estimates for each type of livestock by the number of livestock (Laura Medalie, U.S. Geological Survey, written commun., 1995). Because the livestock and crop-irrigation data are reported in the 1997 Census of Agriculture at the county level, the estimates were disaggregated by town and then by basin on the basis of the number of farms in the town and the percentage of agricultural land use by town and by basin. The livestock water-use estimate represents a year-round usage.

It is estimated that 60 percent of livestock water use is consumptive and 40 percent is returned to ground water (Horn and others, 1994); however, this distinction was negligible for the study area. The livestock water use was 2.2 percent of the agricultural water use in the Woonasquatucket River Basin and 1 percent of the agricultural water use in the Moshassuck River Basin during the study period.

Crop and golf course irrigation were estimated by using a method derived by the USGS in Vermont and New Hampshire during previous water-use compilations (Laura Medalie, U.S. Geological Survey, written commun., 2000). It was assumed that 1 in/week/acre of water was needed to irrigate crop land, an average of 0.143 in/d/acre. The monthly deficiency of water was determined by subtracting the average monthly rainfall from the 0.143 in/day/acre needed, then multiplying the amount of water needed by the percentage of agricultural land-use area for each town in the county. The resulting value was subdivided into the irrigation water use for the Woonasquatucket and Moshassuck River Basins on the basis of land-use area (table 2). Yardages for the golf courses were collected from World Golf.com (2002) and GolfCourse.com, (2002). The coefficient of 0.0116 Mgal/d per 1,000 yards (Laura Medalie, U.S. Geological Survey, written commun., 2000) was applied to the golf courses for the towns in the Woonasquatucket and Moshassuck River Basins. This coefficient was comparable to the metered withdrawal data summarized for the 2000 water-use compilation for Massachusetts, which reported an average withdrawal rate of approximately 0.0117 Mgal/d per 1,000 yards. According to the SCS (1993), most irrigation is done during June, July, and August; therefore, it was assumed that crop and golf course irrigation water were used only during these months in the study area. A concurrent USGS study presently involves collecting data on crop and golf course irrigation; however, the data were unavailable for this study. Self-supply agricultural water use was estimated by town and disaggregated by basin. Estimated agricultural use was 0.061 Mgal/d in the Woonasquatucket River Basin and 0.026 Mgal/d in the Moshassuck River Basin.

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 surface water (usually rivers) and ground water. The self disposal and return flow in the Woonasquatucket River Basin was 3.127and 0.898 Mgal/d in the Moshassuck River Basin (table 10).

Site-Specific Return Flow

Small systems in Rhode Island that release water to the environment were identified through the RIDEM Rhode Island Pollutant Discharge Elimination System (RIPDES), and some system operators are required to report their discharges to RIDEM. Return-flow data were collected from RIDEM for these small systems in the Woonasquatucket and Moshassuck River Basins (table 11). Discharge pipes dispose of water used during industrial and commercial processes, but also include water condensation from air-conditioning systems. The total RIPDES discharges in the study area were 1.285 Mgal/d, of which 0.691 Mgal/d was disposed in the Woonasquatucket River Basin and 0.594 Mgal/d in the Moshassuck River Basin (table 11).

Monthly data were collected for wastewater-treatment facilities, including the Smithfield Sewer Authority Plant in Smithfield, the Bucklin Point WWTF in East Providence, the Fields Point WWTF in Providence, and the Woonsocket WWTF in Woonsocket (table 12), in or serving the towns in the Woonasquatucket and Moshassuck River Basins. The Smithfield Sewer Authority is the only one of these plants that discharges treated wastewater to the rivers in the study area. The average discharge for the study period to the Woonasquatucket River Basin from this plant was 1.676 Mgal/d. The rest of the publicly disposed water is transferred out of the study area to Narragansett Bay by the Narragansett Bay Commission (NBC) or to the Blackstone River Basin by the Woonsocket WWTF (table 12).

Aggregate Return Flow

Aggregate return flow was estimated for domestic, industrial, and commercial water use. Approximately 85 percent of the water used by domestic populations with septic systems was returned to ground water on the basis of the estimate that 15 percent of the water used was consumed (table 9) (Solley and others, 1998). Populations on public disposal were used to determine the self-disposed populations (table 1). To estimate the amount of self-disposed domestic water, the population (table 1) was multiplied by the water-use coefficient for self-disposed water use (71 gal/d/person), converted to million gallons per day, and multiplied by 85 percent (table 10). It is estimated that 90 percent of industrial and commercial return flow is disposed to ground water, and the other 10 percent is consumed (Horn, 2000).

Estimated public-disposed domestic return flows in the Woonasquatucket River Basin ranged from 0.001 Mgal/d in North Smithfield to 2.822 Mgal/d in Providence. In the Moshassuck River Basin these return flows ranged from 0.018 Mgal/d in Smithfield to 1.688 Mgal/d in Providence. Self-disposed domestic water in the Woonasquatucket River Basin ranged from no self disposal in Cranston to 0.327 Mgal/d in Smithfield, and in the Moshassuck River Basin from 0.006 Mgal/d in Central Falls to 0.227 Mgal/d in Lincoln.

Table 10. Estimated public- and self-disposed domestic, commercial, industrial, and metered return flow in the Woonasquatucket and Moshassuck River Basins, north-central 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 disposal (Mgal/d)		Estimated commercial disposal (Mgal/d)		Estimated industrial disposal (Mgal/d)		Metered return flow		Total self disposal and return flow (Mgal/d)
	Public	Self	Public	Self	Public	Self	RIPDES	Wastewater-treatment facilities	
Woonasquatucket Basin									
Cranston	0.059	--	0.001	--	0.008	--	--	--	--
Glocester	.003	0.101	--	--	--	--	--	--	0.101
Johnston	.539	.180	.079	0.016	.054	0.004	0.391	--	.591
North Providence	.837	.012	.088	--	.018	--	.300	--	.312
North Smithfield	.001	.047	--	.005	--	.004	--	--	.056
Providence	2.822	.031	1.208	--	.415	--	<.001	--	.031
Smithfield	.692	.327	.193	.017	.087	.016	--	1.676	2.036
Basin total	4.953	0.698	1.569	0.038	0.582	0.024	0.691	1.676	3.127
Moshassuck Basin									
Central Falls	0.416	0.006	0.202	--	0.157	--	--	--	0.006
Lincoln	.284	.227	.095	--	.219	--	0.537	--	.764
North Providence	.915	.020	.137	--	.018	--	--	--	.020
Pawtucket	1.150	.012	.171	--	.571	--	.057	--	.069
Providence	1.688	.013	1.316	--	.262	--	--	--	.013
Smithfield	.018	.023	.009	0.003	.009	--	--	--	.026
Basin total	4.471	0.301	1.930	0.003	1.236	--	0.594	--	0.898
Study Area Total									
Study area total	9.424	0.999	3.499	0.041	1.818	0.024	1.285	1.676	4.116

Estimated publicly disposed commercial return flows in the Woonasquatucket River Basin ranged from no public disposal in Glocester and North Smithfield to 1.208 Mgal/d in Providence. In the Moshassuck River Basin, these return flows ranged from 0.009 Mgal/d in Smithfield to 1.316 Mgal/d in Providence. Self-disposed commercial return flows in the Woonasquatucket River Basin ranged from none in several towns to 0.017 Mgal/d in Smithfield; and in the Moshassuck River Basin, Smithfield was the only town with commercial self disposal (0.003 Mgal/d).

Estimated public-disposed industrial return flows in the Woonasquatucket River Basin ranged from none in two towns to 0.415 Mgal/d in Providence; and in the Moshassuck River Basin, from 0.009 Mgal/d in Smithfield to 0.571 Mgal/d in Pawtucket. Self-disposed industrial return flow in the Woonasquatucket River Basin ranged from none in four towns to 0.016 Mgal/d in Smithfield. In the Moshassuck River Basin, there was no self-disposed industrial return flow.

Table 11. Return flows by basin for the Rhode Island Pollutant Discharge Elimination System sites in the Woonasquatucket and Moshassuck River Basins, north-central Rhode Island, 1995–99.

[**Reference Number:** The identifier for site on figure 3. SIC, Standard Identification Code; Mgal/d, million gallons per day; <.001, value not included in totals; --, not applicable]

Return flow site	Reference number	City/Town	Discharge permit number	Receiving water body	SIC code	Return flow 1995–99 (Mgal/d)
Woonasquatucket Basin						
Rexam Decorative Specialities International, Inc.	1	Johnston	RI0021491	Woonasquatucket	3999	0.391
Induplate, Inc.	2	North Providence	RI0021571	Woonasquatucket	3471	.035
Worcester Textile	3	North Providence	RI0020401	Woonasquatucket	2231	.265
ABC Realty Co.	4	Providence	RI0023019	Woonasquatucket	6531	<.001
Basin total						0.691
Moshassuck Basin						
Conklin Limestone	5	Lincoln	RI0021211	Moshassuck	1422	0.497
Technical Materials	6	Lincoln	RI0021423	--[1]	3356	.040
Pawtucket Power Associates	7	Pawtucket	RI0021741	Moshassuck	4911	.057
Basin total						0.594
Study Area Total						
Study area total						1.285

[1]Site likely discharges to ground water due to distance from stream.

Table 12. Return flow from wastewater-treatment facilities within and outside of the Woonasquatucket and Moshassuck River Basins, north-central Rhode Island, 1995–99.

[Mgal/d, Million gallons per day]

Wastewater-treatment facility	Discharge permit number	Receiving water body (subbasin or basin)	Average discharge 1995–99 (Mgal/d)
Return flow to the study area			
Smithfield Sewer Authority	RI0100251	Woonasquatucket River	1.676
Total			1.676
Return flow outside of the study area			
Narragansett Bay Commission Bucklin Point Facility	RI0100072	Seekonk River	23.916
Narragansett Bay Commission Fields Point Facility	RI0100315	Narragansett Bay	102.327
Woonsocket Wastewater-Treatment Facility	RI0100111	Blackstone River	8.860
Total			135.103

Interbasin Transfers

Wastewater was collected from towns and treated at the Bucklin Point, Fields Point, and Woonsocket WWTFs and was exported from the study area to Narragansett Bay and the Blackstone River Basin. Estimated populations on public-disposal systems (table 1) and estimated public-disposed industrial and commercial use from water districts were used to determine the exports as approximately 15.195 Mgal/d (table 13). The total wastewater discharge from the facilities to Narragansett Bay was 135.103 Mgal/d (table 12).

More than 96 percent of the water supply is imported to the study area from the Pawtuxet and Blackstone River Basins (tables 6, 13). The result was a gain of 17.564 Mgal/d in these basins. Much of this water is subsequently exported for treatment, and this export results in a loss of 14.741 Mgal/d. The total is a net gain of 2.823 Mgal/d because of the imports and exports of water. Within the balance of water withdrawals, water use, non-account water, consumptive use, and return flows, a percent error is included that is attributed to the summation of metered and estimated water-use components for each category. As an example, public-water supply withdrawals and return flows are metered, but the use by basin is estimated. Similarly, RIPDES disposals are metered but the withdrawal and use are estimated.

Table 13. Summary of estimated water withdrawals, imports, exports, use, non-account water use, consumptive use, and return flow in the Woonasquatucket and Moshassuck River Basins, north-central Rhode Island, 1995–99.

[**Non-account:** Loss of water through the system. **Consumptive use:** Basin export. **Net imports and exports:** Sum of the potable water and wastewater imports and exports and do not include non-account and consumptive water uses. AG, agricultural; COM, commercial; DOM, domestic; IND, industrial; +, potable distribution and wastewater collection imported to subbasin and basin; Mgal/d, million gallons per day; --, potable distribution and wastewater collection exported from subbasin and basin]

Basin	Water withdrawals, public and self (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)
			Use (DOM, COM, IND, AG)	Non-account (public use)		Surface water	Ground water		
Woonasquatucket	0.646	+5.669	9.149	2.834	1.301	2.367	0.760	-4.721	+0.948
Moshassuck	.102	+6.829	9.124	2.193	1.216	.554	.344	-7.010	+.181
Study area total	0.748	+12.498	18.273	5.027	2.517	2.921	1.104	-11.731	+0.767

Water Availability

During periods of little or no precipitation, streamflow is primarily ground-water discharge (base flow), and direct runoff is assumed to be negligible. The computerized PART method (Rutledge, 1993, 1998) was used to obtain ground-water discharge (base flow) to streams during periods of little or no precipitation during the summer. Water withdrawals are often higher during the summer, and precipitation and ground-water discharge may be lower than the long-term average. Therefore, in addition to calculating available water, ratios of water withdrawals to availability were calculated to determine how much of the available ground water is being 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 by using the water-availability flow scenarios at the 75th, 50th, and 25th percentiles for the subbasins, based on total water available from base-flow contributions from till and sand and gravel deposits in the subbasins.

Determining Ground-Water Discharge

Water availability during periods of little or no precipitation can be determined by using streamflow data collected at streamflow-gaging stations. Long-term data are available from the two streamflow-gaging stations in the study area; however, the characteristics of the basins upstream of the stations make them unacceptable for the methods utilized for determining base flow. As stated in the documentation for PART, regulation and diversion should be negligible (Rutledge, 1993, 1998). This assumption is not the case in the Woonasquatucket River Basin because some of the flow during low-flow periods is wastewater discharge from the Smithfield Sewage Treatment Plant. The Moshassuck station is less affected by diversions and withdrawals, but the urban nature of the basin causes a "flashy" hydrograph, characterized by rapid peaks concurrent with precipitation and rapid recessions. The method to determine water availability requires that all flow during recessions is from ground-water discharge. Because the stations described above are not acceptable for this application, an index station, the Branch River at Forestdale (01111500) (table 14) streamflow-gaging station (fig. 2) was used to calculate water availability for the study area. The Branch River station has operated continuously since January 1940; however, prior to 1957, the stream was heavily regulated by mills operating upstream of the station (Socolow and others, 2000). For this reason, the period between 1957 and 2000 was used in calculating availability (tables 15 and 16).

The PART program, a hydrograph-separation application, was used at the Branch River 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 criteria, and the base flow minus the Aquatic Base Flow (ABF) criteria.

Stratified sand and gravel deposits contribute most of the water to base flow, but till deposits also contribute a percentage of flow. Stratified deposits cover 32.8 percent of the surface area of the Woonasquatucket River Basin and 31.5 percent of the Moshassuck River Basin drainage areas. Also, stratified deposits cover 31.5 percent of the surface- water drainage area of the index gage. The similarity in the percentage of sand and gravel deposits supports the choice of the Branch River station as the index station for the Woonasquatucket River Basin and Moshassuck River Basin drainage areas. In addition, the Branch River station was used as the index station for availability calculations in the Blackstone report (Barlow, 2003), and the Blackstone River Basin borders the Moshassuck and Woonasquatucket River Basins, giving similar climatic conditions and surficial geology to the study area.

Table 14. U.S. Geological Survey stream-gaging stations and minimum streamflows pertinent to the Woonasquatucket and Moshassuck River Basins, north-central Rhode Island, study area.

[Station drainage areas are from Socolow and others (2001). Water years are from October 1 to September 30, are designated by the calendar year in which they end, and may vary from the period of record. USGS, U.S. Geological Survey; 7Q10, 7-day, 10-year flow; ABF, Aquatic Base Flow is the median of the monthly means; ft^3/s, cubic feet per second; Mgal/d, million gallons per day; mi^2, square mile]

USGS stream-gaging station number	Station name (water years)	Drainage area (mi^2)	Mean flow (Mgal/d)	Mean flow (ft^3/s)	Minimum Flows			
					7Q10 (Mgal/d)	7Q10 (ft^3/s)	ABF (Mgal/d)	ABF (ft^3/s)
01111500	Branch River at Forestdale, RI (1957–2001)	91.2	115	178	7.70	11.9	25.2	39.0
01114000	Moshassuck River at Providence, RI (1963–2001)	23.1	26.2	40.4	4.20	6.50	13.1	20.2
01114500	Woonasquatucket River at Centerdale, RI (1957–2001)	38.3	48.5	75.0	2.64	4.09	9.70	15.0

Because the index station is outside of the study area, the flow at the index station had to be corrected to reflect the physical characteristics of the study area more accurately. Regression equations were developed for five streamflow gaging stations in the Pawcatuck River Basin (P.J. Zarriello, U.S. Geological Survey, written commun., 2003) to calculate the percentages of base flow as a function of percent from stratified deposits and the percent from till, depending on the percent of area of the basin that is covered by these deposits. The stations in the Pawcatuck River Basin are Wood River near Arcadia (01117800), Chipuxet River at West Kingston (01117350), Usquepaug River near Usquepaug (01117420), Beaver River near Usquepaug (01117468), and Wood River at Hope Valley (01118000). The equation is $y = 0.7588x^{0.3156}$ for which r^2=0.8293, where y is the percentage of base flow from stratified sand and gravel deposits and x is the ratio of sand and gravel to till (fig. 10).

For the Branch River station the percentage of stratified deposits in the drainage area is 0.3147, and the ratio of sand and gravel to till is 0.4592. The regression equation indicates that the base-flow contribution from sand and gravel deposits at this station was 60 percent and the base-flow contribution from till deposits was 40 percent. The two contributions for June, July, August, and September were applied to the surficial deposits in the drainage area of the index station, and converted to a per-unit-area rate for the till and sand and gravel areas in the basin. The low-flow values calculated for the index station were multiplied by the areal percentages of sand and gravel and till in the study area basins to give estimates of the corresponding low flows for the basins in Mgal/d/mi^2.

Summer Water Availability and Ratios for Study Area

In the Woonasquatucket River Basin, the estimated water availability for the gross yield at the 50th percentile from sand and gravel deposits ranged from 8.31 Mgal/d in August to 18.00 Mgal/d in June, and from 4.63 Mgal/d in August to 10.0 Mgal/d in June for the contributions from till deposits (table 15). The gross yield water availability at the 50th percentile ranged from 12.94 Mgal/d in August to 28.0 Mgal/d in June, and for gross yield munus the 7Q10 criteria ranged from 8.41 Mgal/d in August to 23.49 Mgal/d in June (table 16). The average water withdrawals for the Woonasquatucket River Basin were 0.646 Mgal/d for the study period (table 13). The ratios for the gross-yield scenario at the 50th percentile ranged from 0.023 in June to 0.049 in August, and for gross yield minus 7Q10 low-flow criteria the ratios ranged from 0.028 in June to 0.077 in August (table 17). The gross water available minus the low flows for the study area basins for the summer months, and the ratio of the availability for the 50th percentile minus 7Q10 to withdrawals for August are shown in figure 11. This illustrates that the gross availability is less than the ABF in many cases, which results in no water available, and also no ratio. Discussion is therefore limited to gross yield and gross yield minus 7Q10.

Table 15. Summary of water availability from sand and gravel and till deposits for June, July, August, and September in the Woonasquatucket and Moshassuck River Basins, north-central Rhode Island, 1995–99.

[ABF, Aquatic Base Flow; 7Q10, 7-day, 10-year; Mgal/d, Million gallons per day; mi^2, square mile; --, available water is less than low flow]

Basin	Estimated gross yield for June (Mgal/d)			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									
Woonasquatucket River Basin	27.8	18.0	13.6	24.8	15.1	10.7	18.2	8.44	4.05
Moshassuck River Basin	12.4	8.0	6.07	11.1	6.73	4.77	8.15	3.77	1.81
Total estimated yields from sand and gravel deposits	40.2	26.0	19.7	35.9	21.8	15.5	26.4	12.2	5.86
Estimated Yields from Till Deposits									
Woonasquatucket River Basin	15.5	10.0	7.56	13.8	8.39	5.94	10.2	4.70	2.26
Moshassuck River Basin	7.36	4.76	3.60	6.59	3.99	2.83	4.83	2.24	1.07
Total estimated yields from till deposits	22.9	14.8	11.2	20.4	12.4	8.77	15.0	6.94	3.33
Total estimated yields	63.1	40.8	30.9	56.3	34.2	24.3	41.4	19.1	9.19

Basin	Estimated gross yield for July (Mgal/d)			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									
Woonasquatucket River Basin	13.1	10.0	6.57	10.2	7.14	3.66	3.61	0.52	--
Moshassuck River Basin	5.87	4.49	2.94	4.57	3.19	1.64	1.62	.23	--
Total estimated yields from sand and gravel deposits	19.0	14.5	9.51	14.8	10.3	5.30	5.23	0.75	--
Estimated Yields from Till Deposits									
Woonasquatucket River Basin	7.32	5.60	3.66	5.70	3.98	2.04	2.01	0.29	--
Moshassuck River Basin	3.48	2.66	1.74	2.71	1.89	.97	.96	.14	--
Total estimated yields from till deposits	10.8	8.26	5.40	8.41	5.87	3.01	2.97	0.43	--
Total estimated yields	29.8	22.8	14.9	23.2	16.2	8.31	8.20	1.18	--

Table 15. Summary of water availability from sand and gravel and till deposits for June, July, August, and September in the Woonasquatucket and Moshassuck River Basins, north-central Rhode Island, 1995–99.—Continued

[ABF, Aquatic Base Flow; 7Q10, 7-day, 10-year; Mgal/d, million gallons per day; mi^2, square mile; --, available water is less than low flow]

Basin	Estimated gross yield for August (Mgal/d)			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									
Woonasquatucket River Basin	11.2	8.31	5.02	8.30	5.40	2.11	1.68	--	--
Moshassuck River Basin	5.01	3.71	2.25	3.71	2.41	.94	.75	--	--
Total estimated yields from sand and gravel deposits	16.2	12.0	7.27	12.0	7.81	3.05	2.43	--	--
Estimated Yields from Till Deposits									
Woonasquatucket River Basin	6.24	4.63	2.80	4.62	3.01	1.18	0.94	--	--
Moshassuck River Basin	2.97	2.20	1.33	2.20	1.43	.56	.45	--	--
Total estimated yields from till deposits	9.21	6.83	4.13	6.82	4.44	1.74	1.39	--	--
Total estimated yields	25.4	18.8	11.4	18.8	12.2	4.79	3.82	--	--

Basin	Estimated gross yield for September (Mgal/d)			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									
Woonasquatucket River Basin	12.8	8.78	5.99	9.87	5.87	3.08	3.25	--	--
Moshassuck River Basin	5.71	3.93	2.68	4.41	2.63	1.38	1.45	--	--
Total estimated yields from sand and gravel deposits	18.5	12.7	8.67	14.3	8.50	4.46	4.70	--	--
Estimated Yields from Till Deposits									
Woonasquatucket River Basin	7.12	4.89	3.34	5.50	3.27	1.72	1.81	--	--
Moshassuck River Basin	3.39	2.33	1.59	2.62	1.56	.82	.86	--	--
Total estimated yields from till deposits	10.5	7.22	4.93	8.12	4.83	2.54	2.67	--	--
Total estimated yields	29.0	19.9	13.6	22.4	13.3	7.00	7.37	--	--

Table 16. Summary of gross water availability for June, July, August, and September in the Woonasquatucket and Moshassuck River Basins, north-central Rhode Island, 1995–99.

[7Q10, 7-day, 10-year; ABF, Aquatic Base Flow; Mgal/d, million gallons per day; --, available water is less than low flow]

Basin	Estimated gross yield for June (Mgal/d)			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 Gross Yields									
Woonasquatucket River Basin	43.3	28.0	21.16	38.6	23.49	16.64	28.4	13.14	6.31
Moshassuck River Basin	19.76	12.76	9.67	17.69	10.72	7.60	12.98	6.01	2.88
Total estimated yields	63.1	40.8	30.8	56.3	34.2	24.2	41.4	19.2	9.19

Basin	Estimated gross yield for July (Mgal/d)			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 Gross Yields									
Woonasquatucket River Basin	20.42	15.6	10.23	15.9	11.12	5.70	5.62	0.81	--
Moshassuck River Basin	9.35	7.15	4.68	7.28	5.08	2.61	2.58	.37	--
Total estimated yields	29.8	22.8	14.9	23.2	16.2	8.31	8.20	1.18	--

Table 16. Summary of gross water availability for June, July, August, and September in the Woonasquatucket and Moshassuck River Basins, north-central Rhode Island, 1995–99. —Continued

[7Q10, 7-day, 10-year; ABF, Aquatic Base Flow; Mgal/d, Million gallons per day; --, available water is less than low flow]

Basin	Estimated gross yield for August (Mgal/d)			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 Gross Yields									
Woonasquatucket River Basin	17.44	12.94	7.82	12.92	8.41	3.29	2.62	--	--
Moshassuck River Basin	7.98	5.91	3.58	5.91	3.84	1.5	1.2	--	--
Total estimated yields	25.4	18.8	11.4	18.8	12.2	4.79	3.82	--	--

Basin	Estimated gross yield for September (Mgal/d)			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 Gross Yields									
Woonasquatucket River Basin	19.92	13.67	9.33	15.37	9.14	4.8	5.06	--	--
Moshassuck River Basin	9.10	6.26	4.27	7.03	4.19	2.2	2.31	--	--
Total estimated yields	29.0	19.9	13.6	22.4	13.3	7.00	7.37	--	--

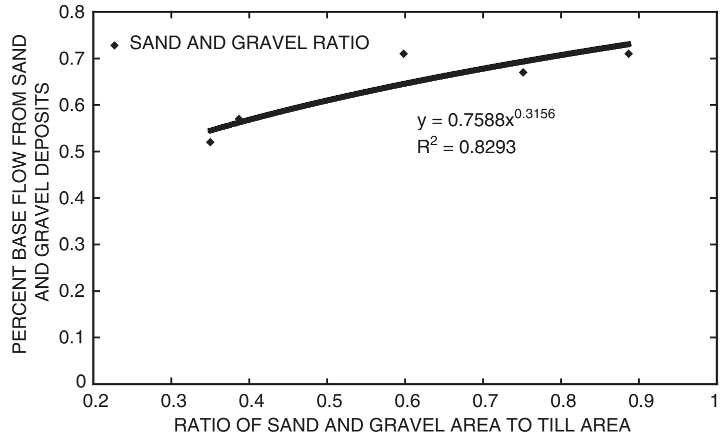


Figure 10. Percent base flow based on ratio of stratified deposits to till, Woonasquatucket and Moshassuck River Basins, north-central Rhode Island.

In the Moshassuck River Basin, the estimated water availability for the gross yield at the 50th percentile ranged from 3.71 Mgal/d in August to 8.0 Mgal/d in June for the contributions from sand and gravel deposits, and ranged from 2.20 Mgal/d in August to 4.76 Mgal/d in June for the contributions from till deposits (table 15). The water availability in the basin at the 50th percentile for the gross yield ranged from 5.91 Mgal/d in August to 12.76 Mgal/d in June, and for the gross yield minus the 7Q10 low-flow criteria ranged from 3.84 Mgal/d in August to 10.72 Mgal/d in June (table 16). The average water withdrawals for the Moshassuck River Basin were 0.102 Mgal/d for the study period (table 13). The results for the ratios for the gross yield scenario at the 50th percentile ranged from 0.008 in June to 0.017 in August, and for the gross yield minus the 7Q10 criteria the ratios ranged from 0.010 in June to 0.026 in August (table 17).

The ratios for both basins were the highest in July at the 50th percentile estimated gross yield minus ABF; where withdrawals are close to the available water. Ratios are not presented if the available water is less than the flow criteria. The ratios of withdrawals to the July gross yield at the 50th percentile minus ABF were 0.796 and 0.275 for the Woonasquatucket and for the Moshassuck Basins, respectively. In August and September, the water available in the stream at the 50th percentile was less than ABF; therefore, no positive ratio could be reported.

Water Budget

The basin water budget encompasses the hydrologic cycle, the water-use components, and inflow and outflow to the hydrologic system. The water-use components are summarized in table 13. For this report, a long-term water budget was calculated in which inflow equals outflow in the system. The change in storage from surface-water bodies and aquifers was considered to be negligible. Inflow to the basin includes precipitation, streamflow from upstream basins, ground-water inflow, and return flow (septic systems, RIPDES, and wastewater-treatment facilities). Outflow from the basin includes evapotranspiration, streamflow out of the basin, water withdrawals (public supplies and self-supplied domestic, commercial, industrial, and agricultural), and ground-water underflow. The water-budget components are summarized in table 18. The average precipitation at Woonsocket, RI was 47.97 in/yr, 1956–2000, and was 48.27 in/yr, 1964–2000. These periods of record were chosen to match the periods of record at the Woonasquatucket and Moshassuck River stations, and were converted to rates (2.28 Mgal/d/mi^2 and 2.30 Mgal/d/mi^2, respectively) and applied to the study-area drainage areas.

Table 17. Summary of ratios of water withdrawals to availability for June, July, August, and September in the Woonasquatucket and Moshassuck River Basins, north-central Rhode Island, 1995–99.

[ABF, Aquatic Base Flow; Mgal/d, million gallons per day; --, available water is less than low flow]

Basin	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
Woonasquatucket River Basin	0.015	0.023	0.030	0.017	0.028	0.039	0.023	0.049	0.102
Moshassuck River Basin	.005	.008	.010	.006	.010	.013	.008	.017	.035
Study area total	0.012	0.018	0.024	0.013	0.022	0.031	0.018	0.039	0.081

Basin	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
Woonasquatucket River Basin	0.032	0.041	0.063	0.040	0.058	0.113	0.115	0.796	--
Moshassuck River Basin	.011	.014	.022	.014	.020	.039	.040	.275	--
Study area total	0.025	0.033	0.050	0.032	0.046	0.090	0.091	0.632	--

Basin	Water withdrawals to water available for August (Mgal/d)			Water withdrawals to water available for August minus 7Q10 (Mgal/d)			Water withdrawals to water available for August minus ABF (Mgal/d)		
	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile
Woonasquatucket River Basin	0.037	0.049	0.082	0.050	0.077	0.196	0.247	--	--
Moshassuck River Basin	.013	.017	.028	.017	.026	.068	.085	--	--
Study area total	0.029	0.040	0.057	0.040	0.061	0.135	0.196	--	--

Basin	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)		
	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile	75th percentile	50th percentile	25th percentile
Woonasquatucket River Basin	0.032	0.047	0.069	0.042	0.071	0.135	0.128	--	--
Moshassuck River Basin	.011	.016	.024	.014	.024	.046	.044	--	--
Study area total	0.026	0.038	0.048	0.033	0.056	0.092	0.101	--	--

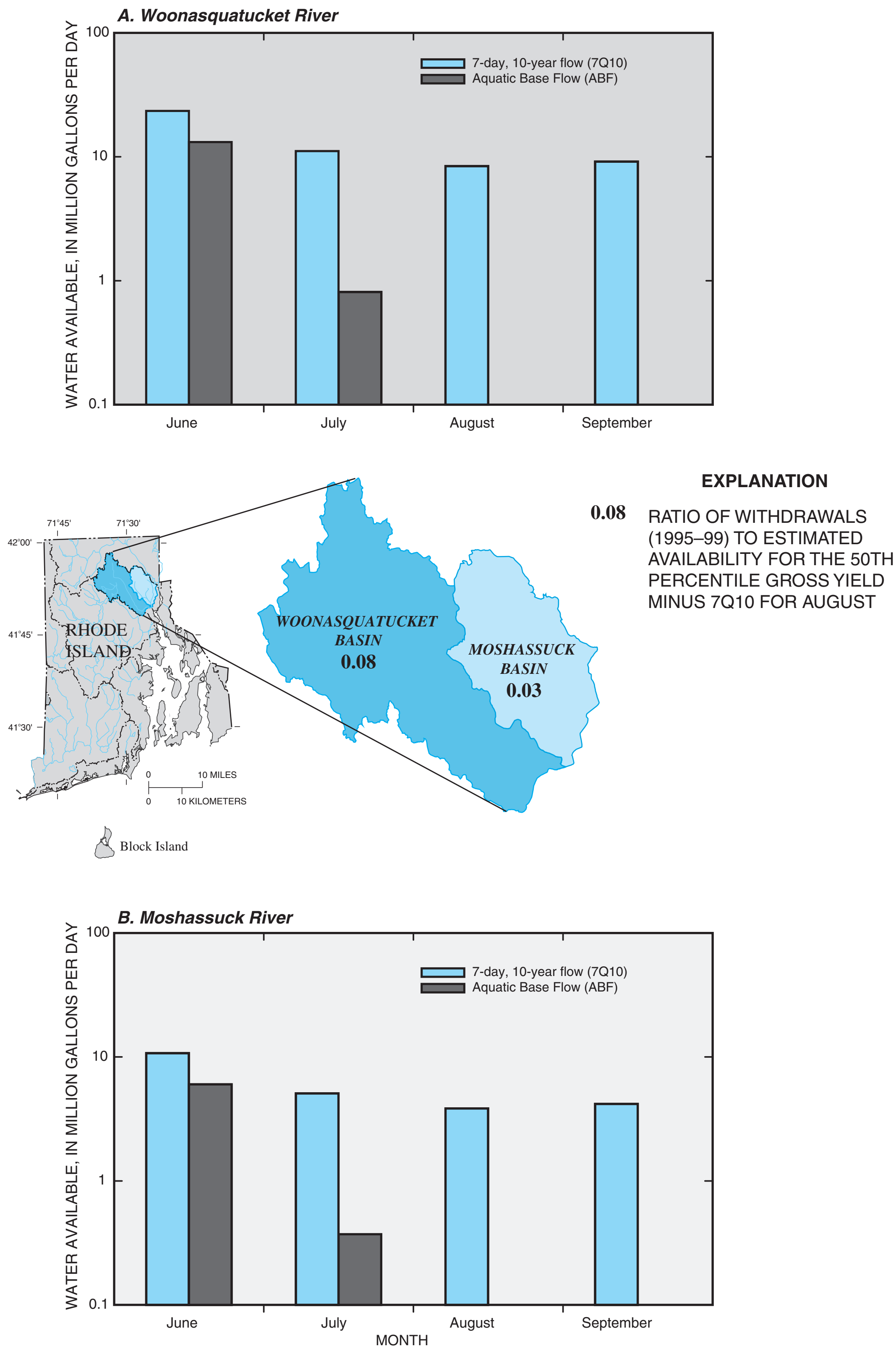


Figure 11. Ratio of withdrawals (1995–99) to estimated availability (1957–99) during August and graphs of gross yield minus Aquatic Base Flow and gross yield minus the 7-day, 10-year flow at the 50th percentile for June, July, and August for *A*, the Woonasquatucket River; and *B*, the Moshassuck River, north-central Rhode Island.

Table 18. Average hydrologic budget for the Woonasquatucket and Moshassuck River Basins study area, north-central Rhode Island.

[RIPDES, Rhode Island Pollution Discharge Elimination System. in/yr, inch per year; Mgal/d, million gallons per day; Mgal/d/mi², million gallons per day per square mile; mi², square mile; --, not applicable]

Water-budget component	Rate of flow (Mgal/d)		
	Woonasquatucket	Moshassuck	Total study area
Estimated inflow			
Precipitation (P_T)	[1]116.54	[2]54.72	171.26
Streamflow from upstream subbasins (SF_I)	--	--	--
Ground-water inflow (GW_I)	--	--	--
Return flow ($WWRF_I$)[3]	3.127	.898	4.025
Total inflow	119.667	55.618	175.285
Estimated outflow			
Evapotranspiration (ET)[4]	[5]51.949	[6]27.710	79.659
Streamflow (SF_O)[7]	67.072	27.806	94.878
Water withdrawals (W)[8]	.646	.102	.748
Ground-water underflow (GW_U)	--	--	--
Total outflow	119.667	55.618	175.285
Streamflow (SF_O) per square mile (Mgal/d/mi²)	1.315	1.168	1.268
Total drainage area at outlet (mi²)	51.0	23.8	74.8

[1]Based on average precipitation (47.97 in/yr) at Woonsocket, RI, 1956–2000.

[2]Based on average precipitation (48.27 in/yr) at Woonsocket, RI, 1964–2000.

[3]Return flow based on the total return flow from septic, RIPDES, and wastewater-treatment facilities, in the Woonasquatucket and Moshassuck River Basins, 1995–99.

[4]Evapotranspiration based on the difference between the average precipitation at Woonsocket, RI, and average monthly flow of the index stream-gaging station for the basin.

[5]Based on average monthly flow per unit area (1.266 Mgal/d/mi²) at the stream-gaging station Woonasquatucket River at Centerdale, RI, 1956–2000.

[6]Based on average monthly flow per unit area (1.135 Mgal/d/mi²) at the stream-gaging station Moshassuck River at Providence, RI, 1964–2000.

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

[8]Water withdrawal types include domestic, commercial, industrial, and agricultural users served by public- and self-water supply in the Woonasquatucket and Moshassuck River Basins, 1995–99.

Neither basin receives surface-water inflow from basins upstream. Ground-water inflow was not estimated for the study area because the information was unavailable. Return flow includes the average 1995–99 disposal of water from septic systems, RIPDES discharges, and wastewater-treatment facilities in the study area. Evapotranspiration was estimated on the basis of the difference between the long-term precipitation in the basin and the mean annual flow at the stream-gaging station located in each basin corrected to the total study area. The streamflow out of each basin was estimated by using the sum of the inflows minus the withdrawals minus evapotranspiration. Finally, ground-water underflow out of the basins was not estimated for the study area because the information was unavailable.

Total inflow in the Woonasquatucket River Basin was estimated as 119.667 Mgal/d, 97.4 percent of which was from precipitation and 2.6 percent was water return flow. The estimated outflow percentages from evapotranspiration, streamflow, and water withdrawals were 43.4, 56.1, and 0.5 percent, respectively. Total inflow in the Moshassuck River Basin was estimated at 55.618 Mgal/d, 98.4 percent of which was from precipitation and 1.6 percent was water return flow. The estimated outflows from evapotranspiration, streamflow, and water withdrawals were 50.0, 49.8, and 0.2 percent, respectively.

Summary

The U.S. Geological Survey, in cooperation with the Rhode Island Water Resources Board, began a series of water use and availability projects in 2000 to determine the relations between water use and the components of the hydrologic cycle (predominantly surface and ground water) during periods of little to no recharge. The Woonasquatucket and Moshassuck study area is currently supplied primarily from water imported from the Pawtuxet River Basin. Development of alternative sources within the basins would help to reduce reliance on these outside sources.

The Woonasquatucket River Basin (51.0 mi^2) and the Moshassuck River Basin (23.8 mi^2) are in central Rhode Island. To determine water use and availability, these basins were delineated on the basis of surface-water drainage areas instead of ground-water drainage areas. From 1995 through 1999, no major water suppliers in the basin withdrew water from these basins. The estimated water withdrawals from the two minor water suppliers during the study period were 0.010 Mgal/d and 0.007 Mgal/d, and both were in the Woonasquatucket River Basin. There were no minor suppliers in the Moshassuck River Basin. Because no metered data were available, the summer water withdrawals were assumed to be the same as the estimates for the rest of the year.

Self-supplied domestic, industrial, commercial, and agricultural withdrawals from the basin averaged 0.607 Mgal/d in the Woonasquatucket River Basin and 0.102 Mgal/d in the Moshassuck River Basin. Water use in the basin averaged 9.149 Mgal/d in the Woonasquatucket River Basin, and 9.124 Mgal/d in the Moshassuck River Basin. The average return flow was 3.127 Mgal/d in the Woonasquatucket River Basin, which included effluent from permitted facilities and self-disposed water users, and 0.898 Mgal/d in the Moshassuck River Basin.

The PART program, a computerized hydrograph-separation application, was used at a nearby index stream-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 low-flow criteria, and the base flow minus the Aquatic Base Flow criteria at the index station. The index station, the Branch River at Forestdale (01111500), was selected because of the similarity in the percentage of its sand and gravel deposits to those of the study area (30 percent) and its proximity to the study area. The base-flow contributions from till and sand and gravel deposits at the index station were computed for June, July, August, and September, and with the percentage of these surficial deposits at the index station, were used to convert to a flow per unit area at the station for the two types of surficial deposits and applied to the study-area basins. The scenarios were used to estimate the gross yield of base flow, and the yield minus two low-flow criteria, 7-day, 10-year and Aquatic Base flow. The base flows for the Branch River index station were lowest in August at the 75th, 50th, and 25th percentiles.

A ratio equal to total withdrawals divided by water availability was calculated. Water-availability scenarios, based on total water available from base-flow contributions from till and sand and gravel deposits in the basins at the 75th, 50th, and 25th percentiles were calculated. The ratios were the highest for the 50th percentile of the estimated gross yield minus Aquatic Base Flow, when withdrawals approach the rate of flow of the available water. Ratios were not presented if the available water was less than the low-flow criteria. The highest ratios, 0.796 for the Woonasquatucket and 0.275 for the Moshassuck occurred in July under the scenario in which the ABF was subtracted from the 50th percentile of base flow. Because the water available in the stream at the 50th percentile was less than ABF in August and September, there was no ratio to report.

A long-term hydrologic budget was calculated for the Woonasquatucket and Moshassuck River Basins to identify and assess the basins inflow and outflows. The water withdrawals and return flows used in the budget were from 1995 through 1999, and the hydrologic components were based on the periods of record for the stream-gaging stations, 1956–2000 for the Woonasquatucket River station and 1964–2000 for the Moshassuck River station. For the hydrologic budget, inflow was assumed to equal outflow. The calculated budget was about 120 Mgal/d in the Woonasquatucket River Basin and was about 55 Mgal/d in the Moshassuck River Basin. The estimated percentages of inflow from precipitation and wastewater return flow were 97.3 and 2.7 in the Woonasquatucket River Basin, and 98.7 and 1.3 in the Moshassuck River Basin, respectively. The estimated percentages of outflow in the Woonasquatucket River Basin from evapotranspiration, streamflow, and water withdrawals were 43.4, 56.1, and 0.5; and in the Moshassuck River Basin, they were 49.8, 50, and 0.2 percent, respectively.

Acknowledgments

Original water-use withdrawal and discharge data were collected from the public water-supply districts; the RIDEM Office of Water Resources; individual wastewater-discharge facilities; and the RIWRB. The authors thank the following individuals for assisting in the data-collection process: Peter LePage and Rich Blodgett, Providence Water Supply Board; Aaron Mello, RIDEM Office of Water Resources; Clay Commons, Rhode Island Department of Health, Office of Drinking Water Quality; and Dennis Ventetuolo and Tomas Smieszek, U.S. Geological Survey.

Selected References

Allen, W.B., 1953, Ground-water resources of Rhode Island, with a section on surface water resources, by Kinnison, H.B.: Rhode Island Water Resources Board Geological Bulletin 6, 170 p.

Archer, W.J., P.E., 1994, Lincoln Water Commission Water Management Plan, February 1994, variously paged.

Barlow, L.S., 2003, Estimated water use and availability in the Lower Blackstone River Basin, northern Rhode Island, and south central Massachusetts, 1995–99: U.S. Geological Survey Water-Resources Investigations Report 03-4190, 75 p.

Bierschenk, W.H., 1959, Ground-water resources of the Providence quadrangle: Rhode Island Water Resources Board Geological Bulletin 10, 104 p.

Butler, S.S., 1957, Engineering hydrology: Englewood Cliffs, NJ, Prentice-Hall, Inc., 356 p.

Church, P.E., Lyford, F.P., and Clifford, Scott, 2000, Distribution of selected volatile organic compunds determined with water-to-vapor diffusion samplers at the interface between ground water and surface water, Centredale Manor Site, North Providence, Rhode Island, September 1999: U.S. Geological Survey Open-File Report 00-276. 9 p.

Chute, N.E., 1949, Surficial geology of the Pawtucket quadrangle, Rhode Island–Massachusetts: U.S. Geological Survey Geologic Quadrangle 2, 1 pl., scale 1:31680.

Craft, P.A., Horn, M.A., and Medalie, Laura, 1995, Estimated withdrawals and use of freshwater in Rhode Island, 1990: U.S. Geological Survey Water-Resources Investigations Report 93-4150, 1 sheet.

GolfCourse.com, 2002, Find a course, accessed August 10, 2002, at http://www.golfcourse.com/.

Guthrie, R.C., and Stolgitis, J.A., 1977; Fisheries investigations and management in Rhode Island Lakes and Ponds: Rhode Island Department of Environmental Management Division of Fish and Wildlife Fisheries Report no. 3, 256 p.

Halberg, H.N., Konx, C.E., Pauszek, F.H, 1961, Water resources of the Providence area, Rhode Island U.S. Geological Survey Water-Supply Paper 1499-A, 50 p., 1 pl. scale 1:125,000.

Horn, M.A., and Craft, P.A., 1991, Plan for developing a water-use data program in Rhode Island: U.S. Geological Survey Water-Resources Investigations Report 90-4207, 26 p.

Horn, M.A., Craft, P.A., and Bratton, Lisa, 1994, Estimation of water withdrawal and distribution, water use and wastewater collection and return flow in Cumberland, Rhode Island, 1988: U.S. Geological Survey Water-Resources Investigations Report 93-4023, 54 p.

Horn, M.A., 2000, Method for estimating water use and interbasin transfers of freshwater and wastewater in an urbanized basin: U.S. Geological Survey Water-Resources Investigations Report 99-4287, 34 p.

Horn, M.A., 2003, User's manual for the New England water-use data system (NEWUDS): U.S. Geological Survey Open-File Report 01-328, 392 p.

Johnston, H.E., and Dickerman, D.C., 1974a, Availability of Ground water in the Blackstone River area, Rhode Island and Massachusetts: U.S. Geological Survey Water-Resources Investigations Report 4-74, 2 sheets, scale 1:24,000.

Johnston, H.E., and Dickerman, D.C., 1974b, Geologic and hydrologic data for the Blackstone River area, Rhode Island: U.S. Geological Survey Hydrologic Bulletin 7, 42 p., 1 pl., scale 1:24,000.

Kinnison, H.B.,1953, The ground water resources of Rhode Island, a reconnaissance: U.S. Geological Survey Geologic Bulletin 6, 170 p. 1 pl.

Kliever, J.D., 1996, Low-flow characteristics of selected streams in northern Rhode Island: U.S. Geological Survey Water-Resources Investigations Report 95-4299, 11 p.

Knox, C.E., and Nordenson, T.J., 1955, Average annual runoff and precipitation in the New England–New York area: U.S. Geological Survey Hydrologic Investigations Atlas HA-7 5 pls., scale 1:1,000,000.

Korzendorfer, B.A., and Horn, M.A., 1995, Estimated use of water in the New England States, 1990: U.S. Geological Survey Water-Resources Investigations Report 94-4252, 21 p.

Lang, S.M., 1961, Appraisal of the ground-water reservoir areas in Rhode Island: Rhode Island Water Resources Board Geological Bulletin, no. 11, 38 p.

Medalie, Laura, 1996, Wastewater collection and return flow in New England, 1990: U.S. Geological Survey Water-Resources Investigations Report 95-4144, 79 p.

Meyboom, P., 1961, Estimating ground-water recharge from stream hydrographs: Journal of Geophysical Research, v. 66, no. 4, p. 1203–1214.

National Oceanic and Atmospheric Administration, 2002, Normal daily mean temperature, degrees F, accessed September 2002, http://www.ncdc.noaa.gov/oa/climate/online/ccd/meantemp.html

Pare Engineering Corporation, 1998, Water Supply Management Plan for Smithfield Water Supply Board, variously paged.

Pawtucket Water Supply Board, 1998, Water Supply Management Plan, edited and updated November 1998, variously paged.

Pollock, S.J., 1960, Ground-water resources of the North Scituate quadrangle, Rhode Island: Water Resources Board Ground Water Map 12, 1 pl., scale 1:24,000.

Quinn, A.W., 1951, Bedrock geology of the North Scituate Quadrangle, Rhode Island: U.S. Geological Survey Geologic Quadrangle 13, 1 pl., scale 1:31,680.

Quinn, A.W., 1959, Bedrock geology of the Providence Quadrangle, Rhode Island: U.S. Geological Survey Geologic Quadrangle 118, 1 pl., scale 1:24,000.

Quinn, A.W., Ray, R.G., and Seymour, W.L., 1949, Bedrock geology of the Pawtucket Quadrangle, Rhode Island–Massachusetts: U.S. Geological Survey Geologic Quadrangle 1, 1 pl., scale 1:31,680.

Quinn, A.W., Ray, R.G., Seymour, W.L., Chute, N.E., and Allen, W.B., 1948, The geology and ground-water resources of the Pawtucket Quadrangle, Rhode Island: Rhode Island Industrial Commission Geologic Bulletin 3, 85 p., 3 pl., scale 1:31,680.

Rhode Island Geographic Information System, 1988, Glacial geology of Rhode Island from 1965 USGS classification and mapping, accessed April 2, 2002, at http://www.edc.uri.edu/rigis-spf/statewide/state.html#geology/.

Rhode Island Geographic Information System, 1991, U.S. Census 1990 population and housing information, accessed April 2, 2002, at http://www.edc.uri.edu/rigis-spf/statewide/state.html#demographic/.

Rhode Island Geographic Information System, 1995a, 1995 Land use coverage, accessed April 2, 2002, at http://www.edc.uri.edu/rigis-spf/statewide/state.html#landuse/.

Rhode Island Geographic Information System, 1995b, Water supply districts, accessed April 2, 2002, at http://www.edc.uri.edu/rigis-spf/statewide/state.html#utilities

Rhode Island Geographic Information System, 1997a, Community well coverage, accessed April 2, 2002, at http://www.edc.uri.edu/rigis-spf/statewide/state.html#hydrography/.

Rhode Island Geographic Information System, 1997b, Non-community well coverage, accessed April 2, 2002, at http://www.edc.uri.edu/rigis-spf/statewide/state.html#hydrography/.

Rhode Island Geographic Information System, 1999, Rhode Island point discharge elimination system point locations, accessed April 2002, at http://www.edc.uri.edu/rigis-spf/statewide/state.html#hazmat/.

Rhode Island Economic Development Corporation, 1999, High tech industries in Rhode Island, accessed October 20, 2000, at http://www.riedc.com/pdfpubs/99_High_Tech_Catal.pdf

Rhode Island Economic Development Corporation, 2000a, Export/import directory, accessed October 20, 2000, at http://www.riedc.com/pdfpubs/riexporters.pdf

Rhode Island Economic Development Corporation, 2000b, Major employers in Rhode Island, accessed October 20, 2000, at http://www.riedc.com/pdfpubs/Employers.pdf

Rhode Island Economic Development Corporation, 2001, City and town population estimates, accessed December 19, 2001, at http://www.riedc.com/mcds/rimcdrame.html

Rhode Island Statewide Planning, 2001, Population of Rhode Island by State, county, and city & town Rhode Island, 1990 & 2000, accessed September 2001, http://www.planning.ri.gov/census/pdf%20files/miscpdf/popcity.pdf

Robinson, C.S.,1961, Surficial geology of the North Scituate quadrangle, Rhode Island: U.S. Geological Survey Geologic Quadrangle 143, 1 pl., scale 1:24,000.

Richmond, G.M., 1952, Bedrock geology of the Georgiaville Quadrangle, Rhode Island: U.S. Geological Survey Geologic Quadrangle 16, 1 pl., scale 1:31,680.

Richmond, G.M. 1953, Surficial Geology of the Georgiaville Quadrangle, Rhode Island: U.S. Geological Survey Geologic Quadrangle 22, 1 pl., scale 1:31,680.

Richmond, G.M., and Allen, W.B., 1951, Geology and ground-water resources of the Georgiaville quadrangle, Rhode Island: Rhode Island Port and Industrial Commission Geological Bulletin 4, 75 p., 3 pls., scale 1:31,680.

Ries, K.G., 1990, Estimating runoff to Narragansett Bay: U.S. Geological Survey Water-Resources Investigations Report 89-4164, 44 p., 1 pl., scale 1:125,000.

Rutledge, A.T., 1993, Computer programs for describing the recession of ground-water discharge and for estimating mean ground-water recharge and discharge from stream-flow records: U.S. Geological Survey Water-Resources Investigations Report 93-4121, 45 p.

Rutledge, A.T., 1998, Computer programs for describing the recession of ground-water discharge and for estimating mean ground-water recharge and discharge from streamflow records—update: U.S. Geological Survey Water-Resources Investigations Report 98-4148, 43 p.

Smith, J.H., 1956, Surficial geology of the Providence quadrangle, Rhode Island: U.S. Geological Survey Geologic Quadrangle 84, 1 pl., scale 1:31,680.

Socolow, R.S., Zanca, J.L., Murino, Domenic, Jr., and Ramsbey, L.R., 2000, Water resources data—Massachusetts and Rhode Island, water year 1999: U.S. Geological Survey Water-Data Report MA-RI-99-1, 401 p.

Solley, W.B., Pierce, R.R., Perlman, H.A., 1998, Estimated water use in the United States in 1995: U.S. Geological Survey Circular 1200, 71 p.

Tessler, Steven, 2002, Data model and relational database design for the New England water-use data system (NEWUDS): U.S. Geological Survey Open-File Report 01-359, 164 p.

Trench, E.C.T., and Morrissey, D.J., 1985, Classification and delineation of recharge areas to the Blackstone and lower Blackstone–Moshassuck ground-water reservoirs in northeastern Rhode Island: Rhode Island Department of Environmental Management Recharge Area Report 1, 21p., 1 pl., scale 1:24,000.

U.S. Census Bureau, 2000, Census summary file 1, accessed April 2004, at http://factfinder.census.gov/servlet/GCTTable?_bm=y&-geo_id=04000US44&-_box_head_nbr=GCT-PH1&-ds_name=DEC_2000_SF1_U&-format=ST-2

U.S. Department of Agriculture, 1993, Estimation of water use by agricultural enterprises during calendar year 1988, Appendix: Soil Conservation Service, U.S. Department of Agriculture Cooperative River Basin Study # 4437, 66 p.

U.S. Department of Agriculture, 1999, Census of agriculture, Rhode Island State and County data: Geographic Area Series, v. 1, part 39, 197 p.

U.S. Department of Commerce, 1990, Census of housing: Washington D.C., Census Bureau, publication ch-2-23, 431 p.

Wild, E.C., and Nimiroski, M.T., 2004, Estimated water use and availability in the Pawcatuck Basin, southern Rhode Island and southeastern Connecticut, 1995–99: U.S. Geological Survey Scientific Investigations Report 2004-5020, 72 p.

Wiley J. Archer Water Systems Consulting Group, 1999, Water Supply System Management Plan Greenville Water District, September 1999, variously paged.

Wiley J. Archer Water Systems Consulting Group, 1999, Water Supply System Management Plan East Smithfield Water District, September 1999, variously paged.

WorldGolf.com, 2002, Golf courses in Rhode Island, accessed August 10, 2002, at http://www.worldgolf.com/courses/unitedstates/rigcs.html/.

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)

Aquatic Base Flow (ABF) Median flow during the month of August established by the U.S. Fish and Wildlife Service and considered adequate flow 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 stream-gaging station is at least 50 square miles" (U.S. Fish and Wildlife Service, 1981).

Base flow Streamflow from ground-water discharge.

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.

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 multi-family dwellings. Also called residential water use. The water may be obtained from a public water supply or may be self supplied.

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, and concrete; primary metal; fabricated metal; machinery; electrical equipment; transportation equipment; instruments; and jewelry, precious metals; where 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 on lands to assist in the growth of crops or pasture including 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.

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, general 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.

Non-account 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. Non-account water use comprises authorized and unauthorized water uses.

Outfall Refers to the outlet or structure through which effluent is finally discharged into the environment.

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.

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.

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 Institute of Water Resources-Municipal and Industrial Needs (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.

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.